Appendix D:
System Security Study

2022 IGP System Security Study

Prepared By: Hawaiian Electric Transmission Planning
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EXECUTIVE SUMMARY

To accomodate future transmission grid-scale generation interconnection and system load growth according to the Company Integrated Grid Planning ("IGP") resource plans, a study which consists of both steady state and dynamic stability analyses is performed for the Company's five island systems for selected near term and long term years considering forcasted system resource and load. The study identifies system transmission level grid needs to accommodate various future plans in accordance with transmission system planning criteria, which include wire solutions (transmission network expansion and renewable energy zone enablement to identified desired potential), portfolio alternatives (limiting locational capacity to reduce the necessary transmission upgrades), and dynamic stability needs (e.g., grid-forming BESS, grid-forming STATCOM). High level cost estimates for wire solution based grid needs are also provided in the study.

With these new resource plans and impending reductions of synchronous machines on the system, the Company is truly embarking on a future of uncertainty ripe with technical challenges. As these analyses are sensitive to attributes outside of the Company's full control, (e.g., resource type, location, size, capabilities, etc.), transmission needs will need to be modified as resources are planned and added to the system. In addition, the future will heavily rely on the capabilities of grid-forming resources, which are the current latest and greatest inverter-based technologies available. Such resources are not yet operational on the Hawaiian Electric system, vary in capabilities, and will continue to evolve as much R&D related to grid-forming resources are currently on-going.

For each island system, both IGP base load scenario resource plan and high load scenario resource plan are studied. In the high load scenario resource plan, only near-term years (i.e., before 2040) are studied. Study years were selected according to major grid-scale resource commissioned year and the IGP resource plans. In each selected year, system dispatches representing annual system peak load without DER generation are identified and analyzed in the steady state analyses to determine steady state grid needs, and a system dispatch representing daytime high load and high DER generation with a short list of high-risk contingencies are analyzed to identify system dynamic stability grid needs.

A summary of findings for each island system are listed below. **These study findings are sensitive to the future grid-scale resource interconnection locations and size, as well as system load growth and system DER growth.** Therefore, it is necessary to update study when grid scale resource procurement plans are identified and finalized. Detailed study results with recommended system upgrade for each studied year are also summarized the Appendix A of this report.

O'ahu Transmission System Grid Needs Summary

In the near term, it is possible that the O'ahu transmission system will not require transmission network expansion.[1] Beyond 2040, both the interconnection of grid-scale generation projects from REZ development and system load increase will require transmission network expansion.

[1] Transmission network expansion refers to upgrades (e.g., reconductoring, new transmission lines, new switching stations, etc.) to the transmission network required to address the increase in capacity required to support addition(s) of grid-scale

It is important to continue exploring the use of grid-scale BESS, energy efficiency, demand response programs, and DER to reduce loading in the urban core to avoid overloading 138 kV overhead and underground lines. Additionally, the west side of system already has major generation stations, and further grid-scale renewable resources from REZ development located on the west side of the island will cause generation congestion on the 138 kV system for a contingency that results in losing one or multiple transmission lines. Full development of the REZ on the north shore of the island will require significant transmission network expansion around the Wahiawa 138 kV substation, which is consistent with the 2021 REZ study report.

For system stability condition in future years the system stability performance is within the planning criteria for the base scenario resource plan, and is attributed to interconnecting large amounts of PV paired with BESS with grid-forming ("GFM") control. For the land constrainted scenario resouce plan, due to the limited amount of grid-scale resources, it is likely addtional grid-scale GFM resources will be needed (i.e., retrofit of existing renewable plants or new standalone energy storage) to maintain system stability within the Oʻahu transmission planning criteria. To maintain system stability within the planning criteria, the study recommends the minimum requirement of contingency reserve provided by available MW headroom from grid-scale GFM resource at anytime should be 70% of DER generation being produced. System stability performance is highly dependent on the performance of future GFM resources, and is strongly recommended to continue to procure resources with GFM capability, provide specific control recommendations during project interconnection requirement studies, and continue through work with industry and operational experience, to improve our planning and operational expertise in best utilizing the emerging GFM technology .

Maui Transmission System Grid Needs Summary

From the study results, it is likely the new renewable resource procurements, including Stage 3 procurements, requires additional transmission system capacity. The capacity needs will likely be met by a combination of reconductoring 69 kV lines and adding new 69 kV lines and substations, the specifics of which are highly dependent on the locations of future grid-scale projects interconnection. In addition to these 69 kV requirements, overloading of Maui 69/23 kV tie transformers is identified in multiple study scenarios. This can be mitigated by solutions such as reducing the transfer, by adding grid-scale generation or energy at Maui 23 kV systems, replacing 69/23 kV tie transformers or reducing the 23 kV system load, or by increasing the tie transfer capability.

The grid-scale resources identified in the base scenario resource plan provide the system stability in accordance with the planning criteria, providing s a minimum MW headroom from GFM resources is held as contingency reserve. This minimum is a reserve equal to at least 60% of DER generation being produced . The study does not identify any addtional needs to maintain system stability within the planning criteria for this portfolio.

Hawaiʻi Island Transmission System Grid Needs Summary

The cross-island tie L6200 line and west side L8100/8900 line has risk of overloading condition in both near-term year and long-term. The cross-island tie L6200 overloading particularly for base scenarios

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resources to the network. Transmission network expansions are different from renewable energy zone enablement, which are transmission resources (e.g., new transmission lines, new switching stations, etc.) required to connect new utility-scale resources to the existing transmission network.

with a significant imbalance of energy production between the East and West sides of the island. Overloads occurred for single contingencies conditions, particularly for base case generation scenarios with a large west to east flow. This overloading ccould be mitigated by either reconductoring of the L6200 line to 556 AAC or resource procurements to meet requirements of a balanced generation dispatch between west side and east side of the system. The overloading of the L8100/8900 line also occurred, particularly for base scenarios involving large flow of power from east side to west side of system when L6800 line is tripped, especially when there is significant generation interconnected at Keamuku substation.

The steady state analysis for the Hawai'i Island system also showed that imbalance of generation production between west and east side of island would cause a significant undervoltage issue on either southern or northern part of the system. This undervoltage issue will become much worse if there is no generation resource interconnected in south Hawai'i Island. All these identified issues are more severe in the high load scenario resouce plan. It is recommended to have grid-scale resource (capable of providing voltage support regardless of active power generation) in south Hawai'i Island if voltage regulation from the Tawhiri wind plant is unavailable.

The dynamic stability study results indicate that the future grid-scale generation procurement the GFM resources assumed in the resouce plan, can maintain system stability within the planning criteria.

Moloka'i and Lana'i System Grid Needs Summary

For the Moloka'i and Lana'i system, a system dynamic stability review with very low and zero synchronous machine generation online was performed. Theminimum performance criteria used in the analyses for these two island systems is maintaining system stability when the system has a three-phase to ground fault with zero fault impedance for 2 seconds duration, or when the system has a single phase to ground fault with 40 ohm fault impedance for 20 seconds duration.

The Moloka'i system study concluded that system has acceptable stability performance in the years from 2030 to 2050 when the system is powered by 100% GFM inverter based resources, but have out of synchronism issues for the existing diesel units before 2030 when the system still need rely on the existing diesel units.

For the Lana'i system in the scenario without the resort load, a simliar conclusion as Moloka'i is identified – system has acceptable stability performance once the system is solely supplied by the GFM inverter-based resources, during the years from 2030 to 2050, and system will have risk of existing unit out of synchronism issues for the existing diesel units before 2029 when system still need rely on the exisitng disel units. For the scenario with the resort load and large GFM inverter based resource (with 15.8 MW capacity), the system can survive both the 2 seconds duration three-phase to ground fault and the 20 seconds high impedance single phase to ground fault.

Contents

Appendix D: System Security Study .... **Error! Bookmark not defined.**

EXECUTIVE SUMMARY ii

1. Introduction 16

2. Studied System Resource Plans 18

2.1. Oʻahu Resource Plans.. 18

2.2. Maui Resource Plans 20

2.3. Hawaiʻi Island Resource Plans 21

2.4. Molokaʻi and Lanaʻi Resource Plans 22

3. Study Methodology.. 24

3.1. Past Studies 24

3.1.1 Hawaiian Electric Transmission Renewable Energy Zone (“REZ”) Study........................... 24

3.1.2 Hawaiian Electric Island-Wide PSCAD Studies (Stage 2 System Impact Study)................. 24

3.1.3 2021 System Stability Study.. 24

3.1.4 Waena BESS Stability Study 26

3.1.5 Hawaiʻi Island RFP Stage 3 Grid Needs Assessment 26

3.1.6 RFP Stage 3 injection capacity studies... 26

3.2. Important Assumptions and Scope Limitations.................................... 27

3.3. Modeling 27

3.4. Study Generation Dispatches... 29

3.5. Study Criteria... 30

4. Study Results.. 31

4.1. Oʻahu System Study Results.. 31

4.1.1 Steady state analyses.. 31

4.1.2 Dynamic Stability Study 64

4.2. Maui System Study Results 77

4.2.1 Steady state analyses.. 77

4.2.2 Dynamic stability study.. 107

4.3. Hawaiʻi Island System Study Results 112

4.3.1 Steady state analyses.. 112

4.3.2 Dynamic stability study.. 124

4.4. Molokaʻi and Lanaʻi Study Results... 130

4.4.1 Molokaʻi Study Results... 131

4.4.2 Lana’i Study Results 136
5. Technical Advisory Panel Feedbacks 145
A. Summary of Study Results 148
A.1 Oʻahu Study Results Summary 148
A.2 Maui Study Results Summary 166
A.3 Hawaiʻi Island Results Summary 183

List of Figures

Figure 1 High-level description of the studied resource plans 18
Figure 2 Oʻahu base scenario resource plan 19
Figure 3 Oʻahu land constrained scenario resource plan 19
Figure 4 Oʻahu high load scenario resource plan 19
Figure 5 Maui base scenario resource plan 20
Figure 6 Maui high load scenario resource plan 20
Figure 7 Hawaiʻi island base scenario resource plan 21
Figure 8 Hawaiʻi island high load scenario resource plan 21
Figure 9 Relative range of system stability contribution by resource type 26
Figure 10 Simplified Maui system single line diagram with future resources and REZ 29
Figure 11 High-Level Oʻahu map for assumed RFP Stage 3 project locations and REZ zone development by 2030 32
Figure 12 High-Level Oʻahu map for assumed generation projects’ locations by 2035 35
Figure 13 High-Level Oʻahu map for assumed generation projects’ locations by 2045 37
Figure 14 High-Level single line diagram for proposed transmission networks expansion, Oʻahu base scenario resource plan, year 2045 41
Figure 15 High-Level Oʻahu map with REZ development status by 2050 42
Figure 16 High-Level Oʻahu map, land constrained scenario resource plan, by 2030 46
Figure 17 High-Level Oʻahu map, land constrained scenario resource plan, by 2035 48
Figure 18 High-Level Oʻahu map, land constrained scenario resource plan, by 2045 50
Figure 19 Simplified single line diagram for proposed transmission networks expansion, Oʻahu land constrained scenario resource plan, by 2045 54
Figure 20 High-Level Oʻahu map, land constrained scenario resource plan, by 2050 55
Figure 21 High-Level Oʻahu map, high load scenario resource plan, by 2030 58
Figure 22 High-Level Oʻahu map, high load scenario resource plan, by 2030 61
Figure 23 Dynamic stability simulation results, O’ahu base scenario resource plan, year 2027, P3 planning event 66
Figure 24 Dynamic stability simulation results, O’ahu base scenario resource plan, year 2027, P3 planning event 67
Figure 25 Dynamic stability mitigation study results, O’ahu base scenario resource plan, year 2027, P3 planning event, with system re-dispatch 69
Figure 26 Dynamic stability study results, O’ahu base scenario resource plan, year 2035, P3 planning event 71

Figure 27 Dynamic stability study results, O’ahu land constrained scenario resource plan, year 2035, P3 planning event 73
Figure 28 Dynamic stability study results, O’ahu land constrained scenario resource plan, year 2035, P3 planning event, with one more GFM resource out-of-service 74
Figure 29 Dynamic stability study results, O’ahu land constrained scenario resource plan (GNA Stage 3), year 2030, P3 planning event 76
Figure 30 Comparison of system voltage recovery performance post fault clearing 77
Figure 31 High-Level Maui map for assumed RFP Stage 3 project locations by 2027 78
Figure 32 High-Level single line diagram for the two line interconnection RFP Stage 3 projects, Maui system base scenario resource planning, year 2027 79
Figure 33 High-Level single line diagram for proposed transmission networks expansion, Maui base scenario resource plan, year 2027 81
Figure 34 High-Level Maui map for assumed future grid-scale project interconnection locations by 2035 82
Figure 35 High-level single line diagram for the 43 MW line interconnection project, Maui base scenario resource planning, year 2035 83
Figure 36 Overloading on tie transformers and undervoltage in 23 kV networks when losing one 69 kV feed for the 23 kV networks 85
Figure 37 Proposed Maui transmission networks expansion, Maui base scenario resource plan, year 2035 86
Figure 38 High-Level Maui map for assumed future grid-scale project interconnection locations by 2040 87
Figure 39 Proposed Maui transmission networks expansion, Mau i base scenario resource plan, year 2040 89
Figure 40 High-Level Maui map for assumed future grid-scale project interconnection locations by 2045 90
Figure 41 High-Level single line diagram for a new substation REZ C.2, Maui base scenario resource plan, year 2045 90
Figure 42 Proposed Maui transmission networks expansion, Mau i base scenario resource plan, year 2045 93
Figure 43 High-Level Maui map for assumed future grid-scale project interconnection locations by 2050 94
Figure 44 High-Level single line diagram for a new substation REZ C.3, Maui base scenario resource plan, year 2050 95
Figure 45 High-Level Maui map for assumed RFP Stage 3 project locations by 2027 97
Figure 46 High-Level single line diagram for proposed transmission networks expansion, Maui high load scenario resource plan, year 2027 99
Figure 47 High-Level Maui map for assumed future grid-scale project interconnection locations by 2030, high load scenario resource plan 100
Figure 48 High-level single line diagram for the 17 MW line interconnection project, Maui high load scenario resource planning, year 2030 101
Figure 49 High-Level single line diagram for proposed 69 kV transmission networks expansion, Maui high load scenario resource plan, year 2030 103

Figure 50 High-Level Maui map for assumed future grid-scale project interconnection locations by 2035, high load scenario resource plan 104
Figure 51 Dynamic stability simulation results, Maui base scenario resource plan, year 2028, P3 planning event 108
Figure 52 Dynamic stability simulation results, Maui base scenario resource plan, year 2028, P3 planning event 109
Figure 53 Dynamic stability simulation results, Maui base scenario resource plan, year 2036, P3 planning event 110
Figure 54 Dynamic stability simulation results, Maui base scenario resource plan, year 2036, P3 planning event 111
Figure 55 High-Level Hawaiʻi island map with assumed future grid-scale project interconnection locations by 2032, base scenario resource plan 112
Figure 56 High-Level Hawaiʻi island map with assumed future grid-scale project interconnection locations by 2050, base scenario resource plan 116
Figure 57 High-Level Hawaiʻi island map with assumed future grid-scale project interconnection locations by 2032, high load scenario resource plan 119
Figure 58 High-Level Hawaiʻi island map with assumed future grid-scale project interconnection locations by 2036, high load scenario resource plan 122
Figure 59 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2026, base dispatch, P5 planning event 126
Figure 60 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2026, sensitivity dispatch, P3 planning event 127
Figure 61 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2032, base dispatch, P5 planning event 128
Figure 62 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2032, base dispatch, P3 planning event 129
Figure 63 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, three-phase close in fault 131
Figure 64 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, three-phase close in fault 132
Figure 65 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, single phase far end fault with high fault impedance 132
Figure 66 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, three-phase close in fault 133
Figure 67 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, three-phase far end fault 134
Figure 68 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, high impedance far end fault 134
Figure 69 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, three-phase close in fault 135
Figure 70 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, three-phase far end fault 135
Figure 71 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, high impedance far end fault 136

Figure 72 Dynamic stability simulation results, Lana'i base scenario resource plan, year 2029, three-phase close in fault 137
Figure 73 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, three-phase close in fault 137
Figure 74 Dynamic stability simulation results, Lana'i base scenario resource plan, year 2029, single phase far end fault with high fault impedance........ 138
Figure 75 Dynamic stability simulation results, Lana'i base scenario resource plan, year 2050, three-phase close in fault 138
Figure 76 Dynamic stability simulation results, Lana'i base scenario resource plan, year 2050, three-phase close in fault 139
Figure 77 Dynamic stability simulation results, Lana'i base scenario resource plan, year 2050, single phase far end fault with high fault impedance........ 139
Figure 78 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2029, three-phase close in fault 140
Figure 79 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2029, three-phase close in fault 141
Figure 80 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2029, single phase far end fault with high fault impedance........ 141
Figure 81 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2030, three-phase close in fault 142
Figure 82 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2030, three-phase close in fault 142
Figure 83 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2030, single phase far end fault with high fault impedance........ 143
Figure 84 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2050, three-phase close in fault 143
Figure 85 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2050, three-phase close in fault 144
Figure 86 Dynamic stability simulation results, Lana'i no resort scenario resource plan, year 2050, single phase far end fault with high fault impedance........ 144

List of Tables

Table 1 Molokaʻi System Base and High Load Scenario Resource Plans 22
Table 2 Lanaʻi System Base and High Load Scenario Resource Plans, and without Resort Load Resource Plan........ 22
Table 3 P4 DER Voltage Ride-Through and Trip Settings Included in the PSCAD Models........ 28
Table 4 P4 DER Frequency Ride-Through and Trip Settings Included in the PSCAD Models 28
Table 5 P4 DER Momentary Cessation Assumptions........ 28
Table 6 System Generation Dispatches Studied for Maui Base Scenario Resource Plan, Year 2035....... 30

Table 7 Oʻahu Grid-Scale Generation Project Development by 2030, after RFP Stage 2, Base Scenario Resource Plan 32
Table 8 Oʻahu Grid-Scale Generation Removal by 2030 32
Table 9 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2030 32
Table 10 Studied System Generation (MW) Dispatches, Oʻahu Base Scenario Resource Plan, Year 2030 33
Table 11 Oʻahu REZ Enablement Cost Estimate for REZ Development by 2030 34
Table 12 Oʻahu Grid-Scale Generation Project Development between 2031 and 2035, Base Scenario Resource Plan 35
Table 13 Oʻahu Grid-Scale Generation Removal between 2031 and 2035 35
Table 14 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2035 35
Table 15 Studied System Generation (MW) Dispatches, Oʻahu Base Scenario Resource Plan, Year 2035 36
Table 16 Oʻahu Grid-Scale Generation Project Development between 2036 and 2045, Base Scenario Resource Plan 37
Table 17 Oʻahu Grid-Scale Generation Removal between 2036 and 2045 38
Table 18 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2045 38
Table 19 Studied System Generation (MW) Dispatches, Oʻahu Base Scenario Resource Plan, Year 2045 38
Table 20 138 kV Line Overloading Summary, Oʻahu Base Scenario Resource Plan, Year 2045 39
Table 21 Transmission Networks Expansion and High-Level Cost Estimate, Oʻahu Base Scenario Resource Plan, Year 2045 40
Table 22 Oʻahu REZ Enablement Cost Estimate for REZ Development between 2036 and 2045 42
Table 23 Oʻahu Grid-Scale Generation Project Development between 2046 and 2050, Base Scenario Resource Plan 42
Table 24 Oʻahu Grid-Scale Generation Removal between 2046 and 2050 43
Table 25 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2050 43
Table 26 Studied System Generation (MW) Dispatches, Oʻahu Base Scenario Resource Plan, Year 2050 43
Table 27 138 kV Line Overloading Summary, Oʻahu Base Scenario Resource Plan, Year 2050 44
Table 28 Transmission Networks Expansion and High-Level Cost Estimate, Oʻahu Base Scenario Resource Plan, Year 2050 44
Table 29 Oʻahu REZ Enablement Cost Estimate for REZ Development between 2046 and 2050 45
Table 30 Oʻahu Grid-Scale Generation Project Development by 2030, after RFP Stage 2, Land Constrained Scenario Resource Plan 46
Table 31 Oʻahu Grid-Scale Generation Removal by 2030 46
Table 32 Oʻahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2030 46
Table 33 Studied System Generation (MW) Dispatches, Oʻahu Land Constrained Scenario Resource Plan, Year 2030 47

Table 34 O‘ahu Grid-Scale Generation Project Development by 2035, Land Constrained Scenario Resource Plan 48
Table 35 O‘ahu Grid-Scale Generation Removal by 2035 48
Table 36 O‘ahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2035 49
Table 37 Studied System Generation (MW) Dispatches, O‘ahu Land Constrained Scenario Resource Plan, Year 2035 49
Table 38 O‘ahu Grid-Scale Generation Project Development by 2045, Land Constrained Scenario Resource Plan 50
Table 39 O‘ahu Grid-Scale Generation Removal by 2045 50
Table 40 O‘ahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2045 51
Table 41 Studied System Generation (MW) Dispatches, O‘ahu Land Constrained Scenario Resource Plan, Year 2045 51
Table 42 138 kV Line Overloading Summary, O‘ahu Land Constrained Scenario Resource Plan, Year 2045 52
Table 43 Transmission Networks Expansion and High-Level Cost Estimate, O‘ahu Land Constrained Scenario Resource Plan, Year 2045 53
Table 44 Grid-Scale Generation Project Development by 2050, Land Constrained Scenario Resource Plan 55
Table 45 O‘ahu Grid-Scale Generation Removal by 2050 55
Table 46 O‘ahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2050 55
Table 47 Studied System Generation (MW) Dispatches, O‘ahu Land Constrained Scenario Resource Plan, Year 2050 55
Table 48 138 kV Line Overloading Summary, O‘ahu Land Constrained Scenario Resource Plan, Year 2050 56
Table 49 Transmission Networks Expansion and High-Level Cost Estimate, O‘ahu Land Constrained Scenario Resource Plan, Year 2050 57
Table 50 O‘ahu Grid-Scale Generation Project Development by 2030, High Load Scenario Resource Plan 58
Table 51 O‘ahu Grid-Scale Generation Removal by 2030 58
Table 52 O‘ahu System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030 58
Table 53 Studied System Generation (MW) Dispatches, O‘ahu High Load Scenario Resource Plan, Year 2030 59
Table 54 138 kV Line Overloading Summary, O‘ahu High Load Scenario Resource Plan, Year 2030 59
Table 55 138 kV Line Overloading Summary, O‘ahu High Load Scenario Resource Plan, Year 2030 60
Table 56 O‘ahu REZ Enablement Cost Estimate for REZ Development by 2030 61
Table 57 O‘ahu Grid-Scale Generation Project Development by 2035, High Load Scenario Resource Plan 61
Table 58 O‘ahu Grid-Scale Generation Removal by 2035 62
Table 59 O‘ahu System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030 62

Table 60 Studied System Generation (MW) Dispatches, Oʻahu High Load Scenario Resource Plan, Year 2035 62
Table 61 138 kV Line Overloading Summary, Oʻahu High Load Scenario Resource Plan, Year 2035..... 63
Table 62 138 kV Line Overloading Summary, Oʻahu High Load Scenario Resource Plan, Year 2035..... 64
Table 63 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Base Scenario Resource Plan, Year 2027 65
Table 64 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Base Scenario Resource Plan, Year 2027 68
Table 65 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Base Scenario Resource Plan, Year 2035 70
Table 66 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Land Constrained Scenario Resource Plan, Year 2035 72
Table 67 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu land constrained scenario resource plan (GNA Stage 3), year 2030 75
Table 68 Maui Grid-Scale Generation Project Development by 2027, after RFP Stage 2, Base Scenario Resource Plan..... 79
Table 69 Maui Grid-Scale Generation Removal by 2027..... 79
Table 70 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2027 79
Table 71 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 202780
Table 72 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2027 80
Table 73 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2027 80
Table 74 Maui Grid-Scale Generation Project Development between 2028 and 2035, Base Scenario Resource Plan..... 83
Table 75 Maui Grid-Scale Generation Removal between 2028 and 2035 83
Table 76 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2035 83
Table 77 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 203584
Table 78 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2035 84
Table 79 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2035 86
Table 80 Maui Grid-Scale Generation Project Development between 2036 and 2040, Base Scenario Resource Plan..... 87
Table 81 Maui Grid-Scale Generation Removal between 2028 and 2035 87
Table 82 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2040 88
Table 83 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 204088
Table 84 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2040 88
Table 85 Maui Grid-Scale Generation Project Development between 2041 and 2044, Base Scenario Resource Plan..... 90
Table 86 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2045 91
Table 87 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 204591

Table 88 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2045 91
Table 89 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2045 92
Table 90 REZ Enablement and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2045 93
Table 91 Maui Grid-Scale Generation Project Development between 2046 and 2050, Base Scenario Resource Plan........ 95
Table 92 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2050 95
Table 93 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 205095
Table 94 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2050 96
Table 95 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2050 96
Table 96 REZ Enablement and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2050 97
Table 97 Studied System Generation (MW) Dispatches, Maui High Load Scenario Resource Plan, Year 2027 98
Table 98 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2027 98
Table 99 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2027 99
Table 100 Maui Grid-Scale Generation Project Development between 2028 and 2030, High Load Scenario Resource Plan........ 101
Table 101 Maui System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030 101
Table 102 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2030 101
Table 103 List of Undervoltage Violation and Voltage Collapse, Maui High Load Scenario Resource Plan, Year 2030 102
Table 104 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2030 102
Table 105 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2030 103
Table 106 REZ Enablement and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2030 104
Table 107 Maui Grid-Scale Generation Project Development between 2030 and 2035, High Load Scenario Resource Plan........ 105
Table 108 Maui System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2035 105
Table 109 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2035 105
Table 110 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2035 105

Table 111 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2035 106
Table 112 REZ Enablement and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2035 107
Table 113 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, Maui Base Scenario Resource Plan, Year 2028 107
Table 114 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, Maui Base Scenario Resource Plan, Year 2036 109
Table 115 Hawaiʻi Island Grid-Scale Generation Project Development by 2032, after RFP Stage 2, Base Scenario Resource Plan 113
Table 116 Hawaiʻi Island Grid-Scale Generation Removal by 2032 113
Table 117 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2032 113
Table 118 Studied System Generation (MW) Dispatches, Hawaiʻi Island Base Scenario Resource Plan, Year 2032 113
Table 119 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2032 114
Table 120 List of Undervoltage Violations, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2032 114
Table 121 Hawaiʻi Island Grid-Scale Generation Project Development by 2050, Base Scenario Resource Plan 117
Table 122 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2032 117
Table 123 Studied System Generation (MW) Dispatches, Hawaiʻi Island Base Scenario Resource Plan, Year 2032 117
Table 124 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2050 118
Table 125 List of Undervoltage Violations, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2050 118
Table 126 Hawaiʻi Island Grid-Scale Generation Project Development by 2032, High Load Scenario Resource Plan 119
Table 127 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), High Scenario Resource Plan, Year 2032 120
Table 128 Studied System Generation (MW) Dispatches, Hawaiʻi Island Base Scenario Resource Plan, Year 2032 120
Table 129 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island High Load Scenario Resource Plan, Year 2032 120
Table 130 List of Undervoltage Violations, Hawaiʻi Island High Load Scenario Resource Plan, Year 2032 120
Table 131 Hawaiʻi Island Grid-Scale Generation Project Development by 2036, High Load Scenario Resource Plan 122
Table 132 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2036 123

Table 133 Studied System Generation (MW) Dispatches, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036 123
Table 134 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036 123
Table 135 List of Undervoltage Violations, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036 124
Table 136 System Generation Dispatches (Base Dispatch and Sensitivity Dispatch) for Daytime Peak Load High DER Generation Scenario, Hawai'i Island Base Scenario Resource Plan, Year 2026 125
Table 137 Hawai'i Island System Dynamic Stability Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2026 125
Table 138 System Generation Dispatches (Base Dispatch and Sensitivity Dispatch) for Daytime Peak Load High DER Generation Scenario, Hawai'i Island Base Scenario Resource Plan, Year 2032 127
Table 139 Hawai'i Island System Dynamic Stability Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032 128
Table 140 Hawai'i Island System Minimum GFM Requirement Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032, Base Dispatch 130
Table 141 Hawai'i Island System Minimum GFM Requirement Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032, Sensitivity Dispatch 130

1. INTRODUCTION

As part of Company's Integrated Grid Planning process, Transmission Planning Department commenced with the 2022 IGP system security study in November 2022, in which both steady state and dynamic stability analyses are conducted to identify the transmission system of Oʻahu, Maui and Hawaiʻi island and Molokaʻi and Lanaʻi system grid needs in order to accomodate the Company's various resource plans, including both future grid-scale generation interconnection and load increase, to achieve 100% decarbonize Company's all systems by 2045.

The studied resource plans include base scenario resource plans for all five island systems, high load scenario resource plans for all five island systems, and Oʻahu land constrained resource plan. For each island system, several study years are selected according to the resource plan. Steady state analyses, performed in PSS/E, is conducted for each selected year. Considering future advance grid technology developments' impact on grid dynamic stability, the dynamic stability analyses are only performed for the selected near-term years (i.e., before 2040) in PSCAD/EMTDC for high-risk system dispatches and high-risk contingencies.

Past studies conducted in recent years are used as important inputs for this study. The past studies are Hawaiian Electric Transmission Renewable Energy Zone ("REZ") Study[2], Hawaiian Electric Island-Wide PSCAD Studies (Stage 2 System Impact Study)[3], 2021 system stability studies[4], Hawai'i Island RFP Stage 3 grid needs assessment[5], and RFP Stage 3 injection study for O'ahu system, Maui system and Hawai'i Island[6]. From these past studies, general information regarding system available capacity for future generation interconnection is obtained. These past studies inform selection of the high-risk system dispatches and high-risk contingencies for the 2022 IGP system security study dynamic stability analyses.

This study assesses system capacity and stability needs. Based on these needs, traditional wire solutions and non-wire solutions for certain wire solutions are identified and provided to resource expansion and production simulation to determine grid needs cost.

[2] Available at https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/solution_evaluation_and_optimization/20211105_transmission_renewable_energy_zone_study.pdf

[3] Available at https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/stakeholder_technical/20210630_electranix_report.pdf

[4] See Dkt. No. 2018-0165, filed Feb. 13, 2023

[5] See Dkt. No. 2017-0352, filed July 15, 2021

[6] See Dkt. No. 2017-0352 - Hawaii Island injection study filed Nov. 2, 2022, Oahu and Maui injection studies filed Dec. 22, 2022, and Maui injection update filed March 16, 2023.

In this report, section 2 describes the studied resource plan, section 3 summarizes study methodology, and section 4 lists study results. In section 5, feedback from the Technical Advisory Panel, with Company's review, is provided.

2. STUDIED SYSTEM RESOURCE PLANS

From Company's resource planning study, different resource plans are provided for this study. A high-level description of the provided resource plans is shown in the Figure 1. For all five islands transmission systems, both base scenario resource plans and high load resource plans are studied; additionally, the land constrained resource plan is also studied for O'ahu transmission system. In every resource plan, grid-scale resource retirement, new resources (both grid-scale and DER) adding into system, as well as system load forecast are provided from the resource planning results and hourly production simulation profiles, from 2024 to 2050. The study is performed from the year of the RFP Stage 3 projects guaranteed commercial operation date ("GCOD") to 2050.

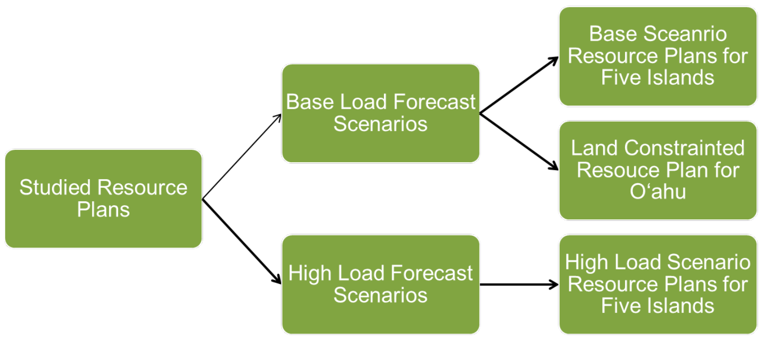


Figure 1 High-level description of the studied resource plans

2.1. O'ahu Resource Plans

Three O'ahu resource plans are analyzed in this study – O'ahu base scenario resource plan, O'ahu land constrained resource plan, and O'ahu high load resource plan. In the base resource plan, Renewable Energy Zone ("REZ") development is included. Hence, large amounts of grid-scale resource interconnection is described in the base resource plan. The land constrained resource plan has the same system load forecast as the base resource plan; however, grid-scale generation from the REZ development is reduced and replaced by the combination of more firm generation and DER generation from distribution side. Therefore, after RFP Stage 3 procurement, grid-scale generation interconnection described in the land constrained resource plan is less than that in the base resource plan. In the high load resource plan, higher system load forecast is constructed in the resource plan. And only near term years in this resource plan is analyzed in this study. All three resource plans are summarized in following figures. For the high load resource plan, only near-term years are selected for the study.

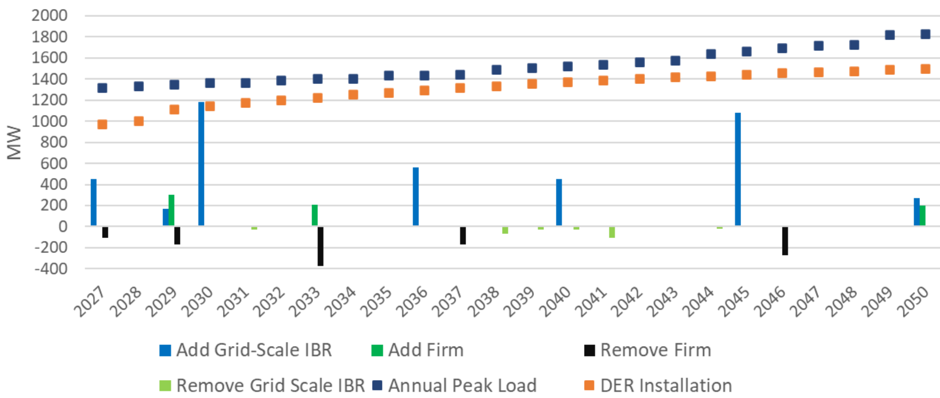


Figure 2 O'ahu base scenario resource plan

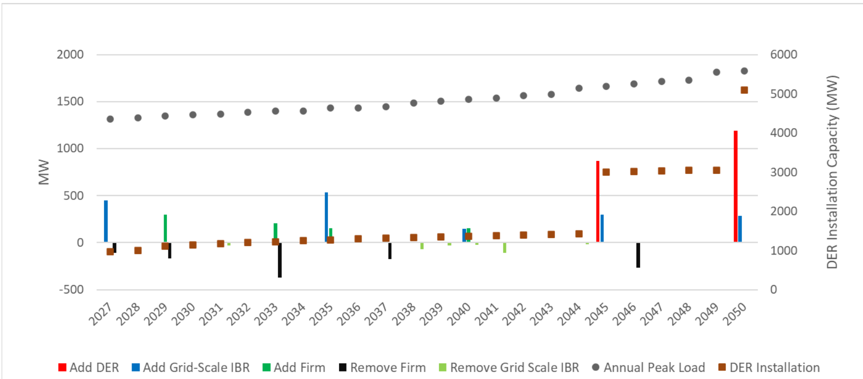


Figure 3 O'ahu land constrained scenario resource plan

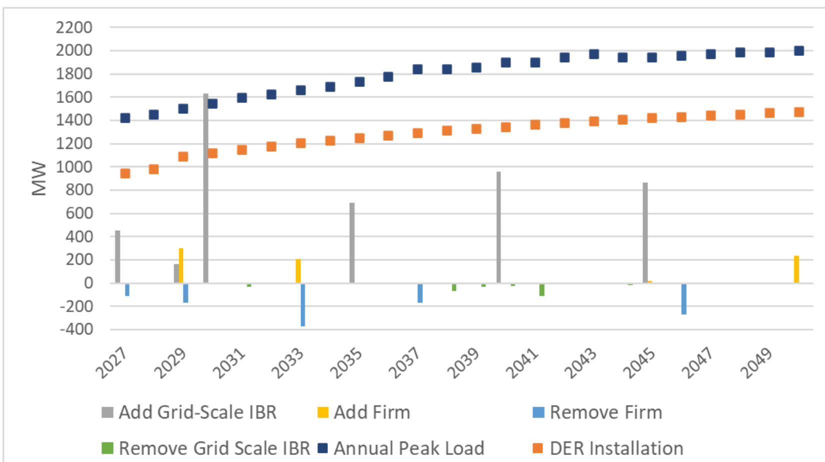


Figure 4 O'ahu high load scenario resource plan

Based on the grid-scale generation projects online time, the following years are selected for the study.

- O‘ahu system base scenario resource plan and land contrained scenario resource plan – 2030, 2035, 2046 and 2050.
- O‘ahu system high load scenario resource plan – 2030 and 2035.

2.2. Maui Resource Plans

Two Maui resource plans are analyzed in this study – Maui base scenario resource plan and high load scenario resource plan. Both resource plans have grid-scale generation interconnections for future years. The high load resource plan has faster system load increase than the base scenario resource plan. High level descriptions for the two studied resource plans are shown in follwing figures.

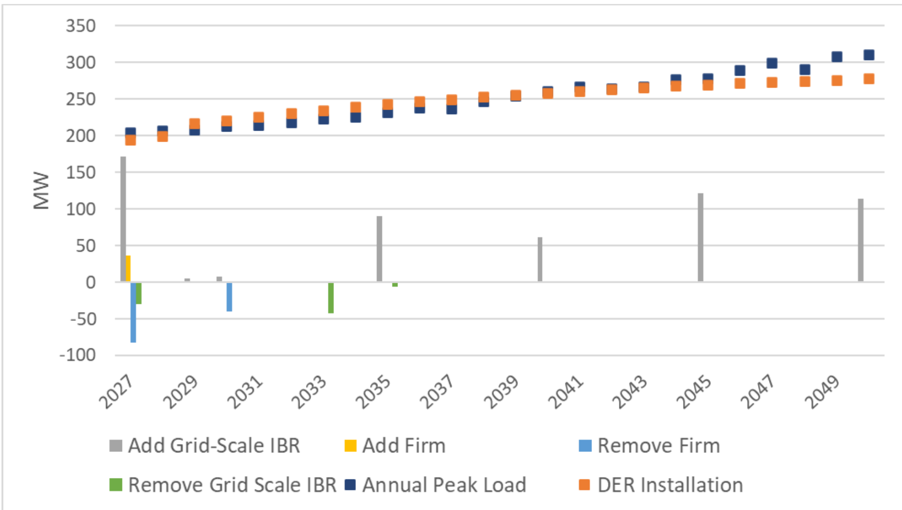


Figure 5 Maui base scenario resource plan

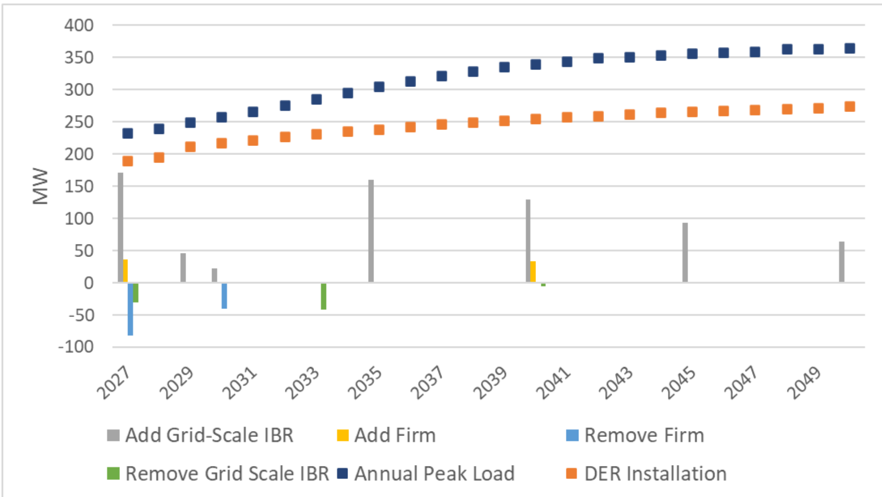


Figure 6 Maui high load scenario resource plan

Based on the grid-scale generation projects online time, following years are selected for the study.

- Maui system base scenario resource plan – 2027, 2035, 2041, 2045 and 2050.
- Maui system high load scenario resource plan – 2027, 2030 and 2035.

2.3. Hawai'i Island Resource Plans

Similiar as Maui system, two resource plans are analyzed for Hawai'i island system in this study – Hawai'i island base scenario resource plan and high load scenario resource plan. Both resource plans have grid-scale generation interconnections for future years. The high load resource plan has faster system load increase than the base scenario resource plan. High level descriptions for the two studied resource plans are shown in follwing figures.

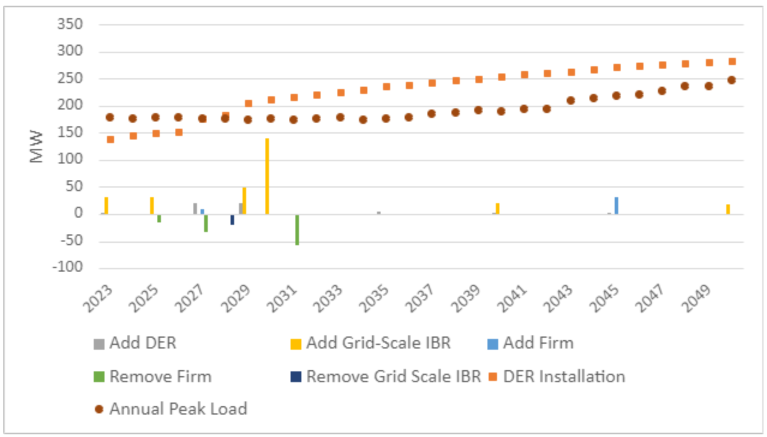


Figure 7 Hawai'i island base scenario resource plan

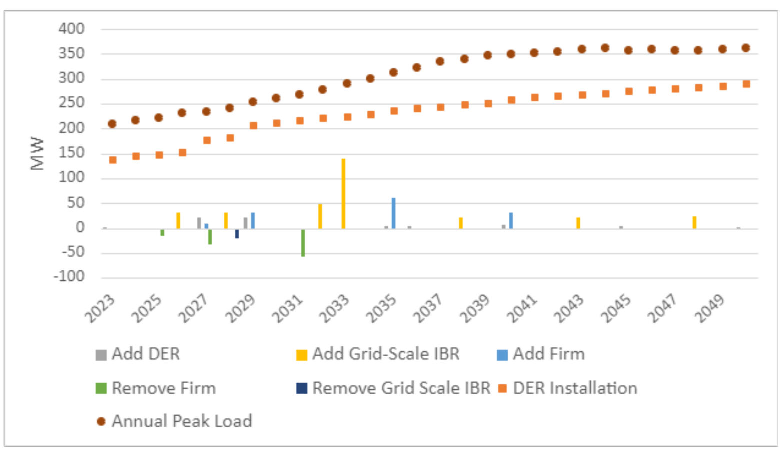


Figure 8 Hawai'i island high load scenario resource plan

Based on the grid-scale generaiton projects online time, following years are selecte for the study.

- Hawai'i island system base scenario resource plan – 2032 and 2050.
- Hawai'i island system high load scenario resource plan – 2032 and 2036.

2.4. Moloka'i and Lana'i Resource Plans

Moloka'i and Lana'i are much smaller systems for which Company which, due to the smaller size, follow different reliability criteria than the other islands. Grid-scale generation projects must be interconnected through the system 12 kV substation bus. Both base scenario resource plans and high load scenario resource plans are studied for these two systems. Addtionally, without resort load resource plan is also studied for the Lana'i system. The studied Moloka'i and Lana'i resource plans are described in the Table 1 .

Table 1 Moloka'i System Base and High Load Scenario Resource Plans

Year	Resource Added to System in Base/High Load Scenario Resource Plan
Pre-2029	CBRE Phase 1 – 0.25 MW PV CBRE Phase 2 – 2.75 MW 11 MWh PV-BESS
2029	0.4 MW/0.7 MWh SA BESS 3 MW/3MWh PV-BESS
2030	0.1 MW/0.3 MWh SA BESS 8.5 MW/29.7MWh PV-BESS
2035	0.1 MW/0.1 MWh SA BESS 2.3 MW/1.9 MWh PV-BESS
2040	0.1 MW/0.1 MWh SA BESS 1.1 MW/2.8 MWh PV-BESS
2045	0.1 MW/0.2 MWh SA BESS 2.6 MW/6.9 MWh PV-BESS
2050	0.1 MW/0.2 MWh SA BESS 1.2 MW/2.9 MWh PV-BESS

Table 2 Lana'i System Base and High Load Scenario Resource Plans, and without Resort Load Resource Plan

Year	With Resort Load Base/High Load Scenario Resource Plan	Without Resort Load Resource Plan
Pre-2029	RFP Phase 2 – 15.8 MW/63.2 MWh PV-BESS	No new resource
2029	0.6 MW/1.1 MWh SA BESS 0.3 MW/0.3MWh PV-BESS	0.7 MW/1.3 MWh SA BESS 3.9 MW/3.9 MWh PV-BESS
2030	4.9MW/4.9 MWh PV-BESS	6.4 MW/24.5 MWh PV-BESS
2035	0.3 MW/0.3 MWh PV-BESS	0.4 MW/1.4 MWh PV-BESS
2040	0.3 MW/0.3 MWh PV-BES	0.3 MW/0.9 MWh PV-BESS
2045	0.2 MW/0.3 MWh SA BESS 1.5 MW/1.5 MWh PV-BESS	0.1 MW/0.1 MWh SA BESS 1.1 MW/2 MWh PV-BESS
2050	0.1 MW/0.1 MWh SA BESS 0.9 MW/0.9 MWh PV-BESS	0 MW/0.2 MWh SA BESS 0.5 MW/1.1 MWh PV-BESS

Years that are selected in each scenario for the study are:

- Molokaʻi system base scenario resource plan – 2029, 2030 and 2050.
- Molokaʻi system high load scenario resource plan – 2029, 2030 and 2050
- Lanaʻi system base scenario resource plan – 2029 and 2050.
- Lanaʻi system high load scenario resource plan – 2029 and 2050
- Lanaʻi system No Resort scenario resource plan – 2029, 2030 and 2050

3. STUDY METHODOLOGY

3.1. Past Studies

In recent years, Transmission Planning Department has performed several studies that addressed both near term and long term plans. These studies provide important inputs to the the 2022 IGP System Security Study, such as system available injection capacity, system stability related high-risk generation dispatch and high-risk contingencies, and importance of grid-forming ("GFM") resource. A brief summary of the referenced past studies is provided in this subsection.

3.1.1 Hawaiian Electric Transmission Renewable Energy Zone ("REZ") Study

In November 2021, Company released the first version of transmission REZ study report. In this report, high level cost estimate for both REZ enablment (e.g., interconnection facilities) and transmission network expansions are identified, based on assumptions of resource procurement targets by 2040 and a fix rate of system load increase, for O‘ahu, Maui and Hawai‘i island systems. The cost per MW REZ enablement for each studied interconnection substation is used in the 2022 IGP System Security Study for the REZ enablment cost esitmate with new resource plan and system load forecast. Also, several transmission networks expansion solutions identified in the 2021 REZ study are used in the 2022 IGP System Security Study.

3.1.2 Hawaiian Electric Island-Wide PSCAD Studies (Stage 2 System Impact Study)

In June 2021, Company released a report regarding system-wide dynamic stability condition assessment for post RFP Stage 2 system conditions. This is the first island-wide system stabilty study performed in electromagnetic transient ("EMT") simulation enviroment via a tool called PSCAD/EMTDC for O‘ahu, Maui and Hawai‘i island system. The dynamic stability study was performed for a few selected generation dispatch with a list of high-risk contingency. The report summarizes system stability performance issue caused by the high penetration of inverter-based resource ("IBR") and distributed energy resources ("DER") and the displacement of synchronou machine-based resource after the RFP Stage 2 projects online. From the study, it is also recommended that Company should continue to require and implement GFM technology in all battery energy storage system ("BESS") devices for future projects and continue to perform EMT study to evaluate future system stability risks.

3.1.3 2021 System Stability Study

A more comprehensive system stability study for near-term years before the RFP Stage 3 projects online was conducted for all five islands from summer of 2021 to end of 2022. The study looked into more stability related topics than what was studied in the Stage 2 System Impact Study. Both PSS/E and PSCAD were used as simulation tool; however, as part of study results, it is confirmed that at current stage, PSS/E has great limitation to be used for performing dynamic stability study for systems with high IBR and DER penetration and for GFM resource modeling and simulation. Important study recommendations that are used in the 2022 IGP System Security Study are:

- Company should continue to require GFM control for generation paried with BESS component and procure enough GFM resource to make sure system stability performance within planning criteria.

- DER momentary cessation poses high risk to system stability. Daytime peak load high DER generation with low wind generation dispatch currently poses the highest risk on system stability. During the daytime, generation from customer-scale inverter-based DER may makeup the highest proportion of generation, and in the future, this could be also true during the evening. When there is a three-phase to ground fault that happens at the transmission system, before the fault get cleared, the voltage across the entire system can be very low (e.g., everywhere less than 0.2 pu) during the fault. This magnitude of voltage sag can cause DER to enter into momentary cessation mode (or trip offline). After the fault being cleared, which normally takes no more than 5 cycles after fault inception, system voltage would recover within continous operation range, which means most of system demand would also recover. However, depending on the inverter model, DER generation may not recover to pre-event level as fast as the system demand once it enters into momentary cessation mode. This slow DER generation recovery would take dozens of cycles, which would cause huge system wide generation load imbalance. Since system physical inertia is already low, the huge generation load imbalance can potentially cause very fast frequency decline, generation and load tripping, and even system blackout if frequency is not regulated back to acceptable range within a time limit. From a recent system event, DER momentary cessation is observed from distribution substation power quality meter fast recording data. The voltage sag caused by a fault is one of common causes for DER entering into momentary cessation mode. The momentary cessation exists in both legacy DER inverters and the latest inverters. More importantly, according to the IEEE 1547-2018 and Hawaii Rule14h Source Requirement Document, DER momentary cessation is allowed when system voltage below a certain threshold. Currently, according to the Rule 14h, this low voltage threshold for all the new inverters is no higher than 0.5 pu. For grid-scale inverters, we have been not allowing DER momentary cessation from RFP Stage 1 procurement. Currently, we are working with NREL, doing more inverter testings to better understanding inverter momentary cessation, and preliminary results indicate certain inverters do indeed enter momentary cessation or trip at low voltage levels (e.g., under 0.5 p.u.).
- Existing Oʻahu standalone solar grid-scale generation projects have fault ride-through issue, which cannot recovery pre-event active power generation within 1 second after clearing fault. According to the historical performance recording, these plants may take more than 20 seconds to recover 90% of the pre-event generation. It is recommend to manual trip these plants during the dynamic stability study simulation.
- O’ahu, Maui and Hawai’i Island high-risk contingency list is generated, which will be used for future dynamic stability studies.
- Substation interconnected GFM resource is critical for Molokaʻi and Lānaʻi system stability once the existing diesel units are retired.
- System critical clearing times (“CCT”) should be no longer than 24 cycles.

The study also concludes qualitive way to describe impacts from various resources on system stability performance, which is shown as Figure 9.

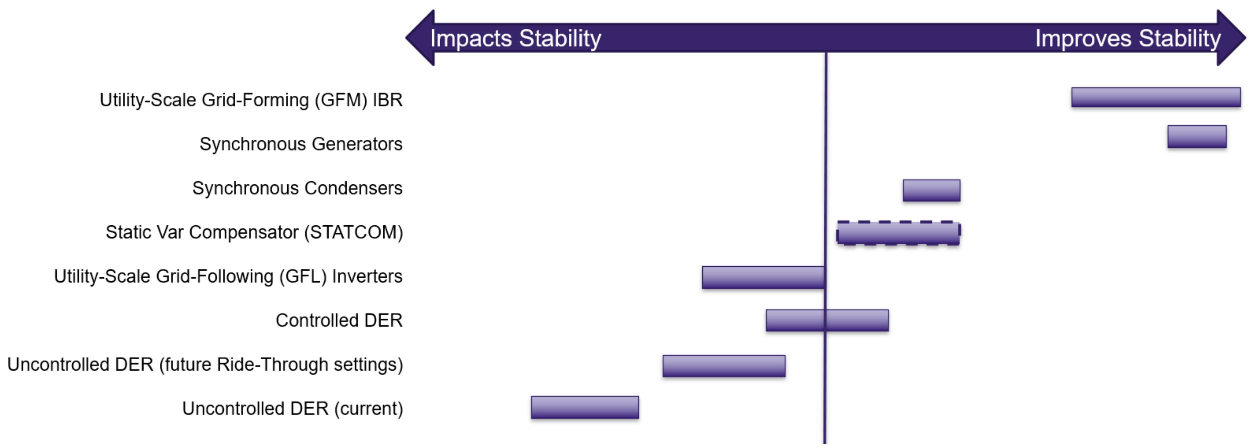


Figure 9 Relative range of system stability contribution by resource type

3.1.4 Waena BESS Stability Study

In 2022, per Commission's request, a dynamic stability study was conducted in PSCAD/EMTDC to evaluate impacts from various MW sizes of Waena BESS project on Maui system dynamic stability. The study results indicates that Maui system could have excessive under-frequency load shedding ("UFLS") or even system collapse if the RFP Stage 2 projects power purchase agreement ("PPA") or applications are not approved, or project withdrawal happens.

3.1.5 Hawaiʻi Island RFP Stage 3 Grid Needs Assessment

In July 2021, per Commission's request, a high-level grid needs assessment was performed for Hawaiʻi island system in order to allow existing system resource retirement and RFP Stage 3 resource interconnected into the Hawaiʻi island transmission system. From the high-level analysis based on the proposed RFP Stage 3 resource plans, the near-term steady-state concerns are identified as follows:

- Immediate voltage support needs in East Hawaiʻi island caused by removal of existing generating units.
- Potential voltage support needs in South Hawaii caused by the absence of nearby local generation and dynamic voltage regulation (i.e., Tawhiri/Apollo wind plant).
- Potential future thermal overloads in the Waikoloa area if additional future generation is connected near the area.

In addition to the needs identified in the system security assessment and the high-level steady-state analysis, system security study needs will need to be assessed after RFP Stage 3 projects are selected. Also, the RFP Stage 3 resources should be procured in strategic locations to maintain past levels of resource locational diversity and provide a balanced generation portfolio supplied from different areas of the island to avoid planning criteria violations such as voltage violations or potential cross-island line overloads.

3.1.6 RFP Stage 3 injection capacity studies

In 2022, an injection capacity study was performed for Oʻahu, Maui and Hawaiʻi island separately, which is part of Company's RFP Stage 3 activities. In the injection capacity studies, locations (i.e., transmission lines and substations) with available injection capacity are identified to help project bidders prepare their proposals. In the 2022 IGP System Security Study, it is assumed that future grid-scale generation procured in the near-term years take the location with available injection capacity first, and later years' generation interconnections rely on Company's transmission system expansion.

3.2. Important Assumptions and Scope Limitations

For future grid-scale generation interconnection, the study assumes current interconnection sites with avaiable grid capacity will be used first. Also, awarded projects that were withdrew from the RFP Stage 2 procurement are assumed to come back to system during the RFP Stage 3 procurement. Once all existing capacity is occupied, future interconnection sites will be selected based on the renewable potential, community feedback and cost of system upgrades. It is possible that actual project interconnections in future procurements are at different locations. Different interconnection locations can drive very different transmisson system ` capacity upgrade needs.

In each studied case, load is allocated in proportion to existing substation loads, aggregated at transmission substations, instead of using spatial load forecast. In reality, load may increase at different rates across the system.

To identify Company's transmission system needs for accommodating future grid-scale generation projects as well as system load per the load forecast, DER generation is not considered in the steady state analyses.

Dynamic stability study is senstive to advanced grid technology development. Therefore, only near term year scenarios (i.e., before 2040) are analyzed for system dynamic stability. New grid technology, on both generation side and customer load side, can possibly drive different grid needs regarding stability. Also, detailed control tunning for future grid-scale generation projects are not included in the scope of this study, which will be addressed by future generation projects' interconnection requirements study.

In this study systems with very high penetration of inverter-based resource ("IBR") and distributed energy resource ("DER") are studied. For example, in the Maui dynamic study, all studied scenarios represent 100% IBR and DER system scenarios. Currently, industry has very limited operational experience for a system with 100% IBR and DER. Both study scope and models used for the dynamic stability study have limitations. As such, there may be other stability risks that are unknown currently, and hence, not included in the current study, or represented in current models used for this study.

3.3. Modeling

In this study, PSS/E is used for steady state analyses which determines studied system networks expansion needs and steady state voltage regulation needs; PSCAD/EMTDC is used for dynamic stability analyses which determine system dynamic stability needs, such as minimum requirement of GFM resource in a system.

For the steady state analyses, all the PSS/E models which represent studied future year scenarios are developed based on 2021 benchmarked system power flow cases. Future system demand is modeled by scaling up load in a fixed rate across the system to match the forecast system total demand. Future system DER is modeled in a similar way. Future grid-scale generation projects are modeled in an aggregated way without a detailed modeling for in-plant feeders but one aggregated generation unit with a properly sized generator step-up transformer ("GSU").

The PSCAD/EMTDC models are built based on a model conversion process of converting a PSS/E model into a PSCAD/EMTDC model. This process is performed in a commercially available software called E-Tran. All the future PV paired with BESS generation projects are represented by the same inverter model which were provided by an inverter OEM and assumed to have GFM control. Because of the limited time frame of performing this study, sensitivity study of using different inverter models from different inverter OEM for future projects is not performed.

Model preparation and related assumptions are the same as what was used in the 2021 system stability study, with one addition – P4 type DER. Per Company's Customer Energy Resource team, for all DER inverters that are online later than October 1st, 2022, inverter ride-through capability should comply with Company's Utility Required Profile ("URP"). According to this rule, a new type of DER, P4 DER, is created to represent the DER that are online later than October 1st, 2022, for transmission planning study purpose. The P4 type DER ride-through and trip settings are listed in Table 3, Table 4, and Table 5.

Table 3 P4 DER Voltage Ride-Through and Trip Settings Included in the PSCAD Models

Remain Connected (p.u.)	Over-Voltage		Under-Voltage	
	Voltage (p.u.)	Delay (s)	Voltage (p.u.)	Delay (s)
0.1 < V > 1.1	V>1.1 V>1.2	13 0.16	V<0.88 V<0.1	21 2

Table 4 P4 DER Frequency Ride-Through and Trip Settings Included in the PSCAD Models

Remain Connected (Hz)	Over-Frequency		Under-Frequency	
	Frequency (Hz)	Delay (s)	Frequency (Hz)	Delay (s)
0.1 < V > 1.1	f>63 f>65	180 0.16	f<57 f<50	180 0.16

Table 5 P4 DER Momentary Cessation Assumptions

UV Block Limit (Vmc, p.u.)	UV Unblock Limit (Vmc, p.u.)	Recovery Delay (Δtsr, s)	Recovery Ramp Rate (during Δtrr, p.u./s)
0.5	0.5	0.033	2.2

In the dynamic stability study, system load is modeled as ZIP (i.e., constant impedance, constant current, constant power load or the combinations of them) load, but not complex type load with explicit modeling of motor load. This load modeling may have limitations of representing system votlage recovery dynamics during post-fault clearing stage.

3.4. Study Generation Dispatches

From the resource plans and production simulation results of the selected study years, various generation dispatches are generated for the study. Every selected generation dispatch represents a snapshot of system operated under certain degree of stress, which is used to identify if system has enough capacity or stability resources in the studied situation.

For steady state analysis, the way of creating study dispatch is demonstrated by using Maui system with addition and retirement of resource in 2035 according to the base scenario resource plan. A simplified system one-line diagram with REZ is shown in Figure 10. In the study for the 2035, system load, forecasted for 2036 as 237 MW, is used for the study.

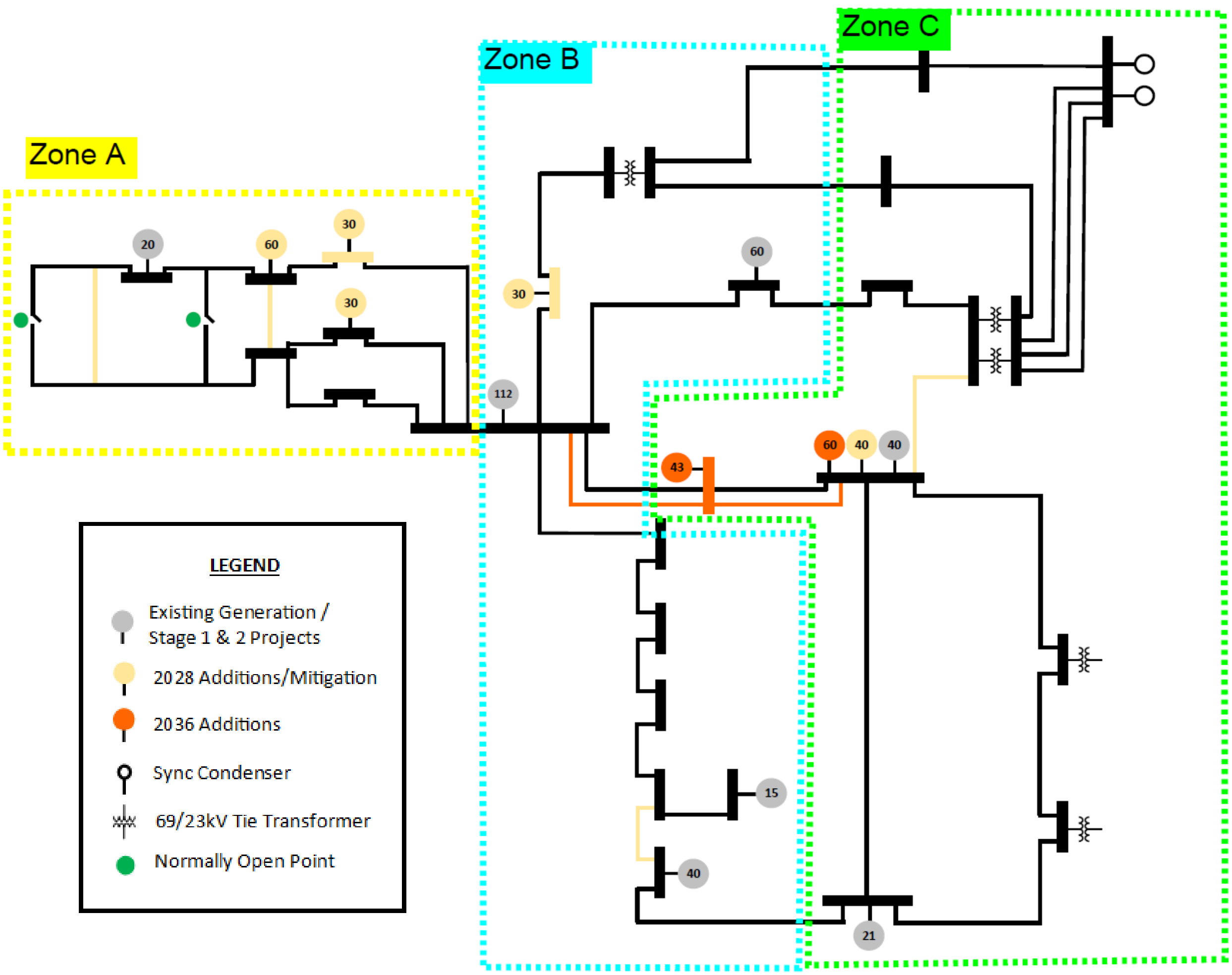


Figure 10 Simplified Maui system single line diagram with future resources and REZ

It can be found that system load can be supplied by generation from one REZ (i.e., Zone B), combination of two different zones (i.e., Zone A+B, Zone B+C and Zone A+C), or all three zones. Therefore, system generation dispatches are created to cover those combinations of zones for performing steady state analyses. The studied system generation dispatches for the 2035 of Maui base resource plan are summarized in Table 6. All studied system generation dispatches are listed in Section 4 study results.

Table 6 System Generation Dispatches Studied for Maui Base Scenario Resource Plan, Year 2035

Max Rating		Zone A	Zone B*	Zone C	Zone A+C	Zone B+C	All Zones
Zone A	140	140	0	0	118	0	77.5
Zone B	257	97.3	237.3	33.3	0	116.3	85.5
Zone C	204	0	0	204	119.3	121	74.3
Total Load	237.3	237.3	237.3	237.3	237.3	237.3	237.3

For dynamic stability study, since previous studies indicate daytime peak load high DER low wind generation dispatch poses the highest risk toward system stability and island wide PSCAD simulation is extremely time consuming, the study will only focus on a few selected scenarios of daytime peak load, high DER, with low wind generation dispatch. The process of identifying system load, DER generation and other grid-scale generation in this studied dispatch is the same as the process described in the 2021 system stability study report. All studied system generation dispatches for the dynamic stability study are described in Section 4 as well.

3.5. Study Criteria

Company's transmission planning criteria of O'ahu, Maui and Hawai'i island are used as primary study criteria. For Moloka'i and Lana'i systems, smaintaining system dynamic stability for a three-phase bolted fault with 2 seconds duration and for a single-phase to ground fault with 40 ohm fault impedance and 20 seconds duration is used as the criteria to evlaluate system dynamic stability condition.

4. STUDY RESULTS

In this section, both steady state analyses and dynamic stability analyses for each selected study year in each resource plan are presented. For the scenarios with planning criteria violation, mitigation solutions are also discussed.

4.1. Oʻahu System Study Results

4.1.1 Steady state analyses

Base scenario resource plan, year 2030

Study descriptions

According to the base scenario resource plan, by 2030, the Oʻahu system will have new generation from Stage 3 Oʻahu RFP procurement and initial REZ development. Specifically, there will be 450 MW renewable dispatch generation ("RDG") and 300 MW firm generation procured through the Stage 3 Oʻahu RFP activity, 510 MW RDG development from the REZ zone 1, 2 and 7, and 543 MW RDG development from the REZ zone 3, 4, 5 and 6. The grid-scale generation projects from the REZ development are assumed interconnected at various Oʻahu 138 kV substations and 46 kV substations, same as assumed in the 2021 REZ study. Specifically, REZ zone 1 interconnection location is Hoʻohana substation, REZ zone 2 interconnection location is Ewa Nui substation, REZ zone 3 interconnection location is Kahe substation, REZ zone 4 interconnection location is Waiau substation, REZ zone 5 interconnection location is Halawa substation, REZ zone 6 and 7 interconnection location is Koʻolau substation, and REZ zone 8 interconnection location is Wahiawa substation. The REZ development is expected to have both solar and wind generation. In this timeframe, it is also planned to remove 371 MW generation from Waiau power plant. High-level locations of the RFP Stage 3 projects assumed in the study and developed REZ zones are shown in Figure 11. The detailed system grid-scale resources changes are summarized in Table 7 and Table 8. By 2031, system annual peak load forecast is 1,364 MW, which is used for the study for this year. System resource summary and the forecasted system load is summarized in Table 9.

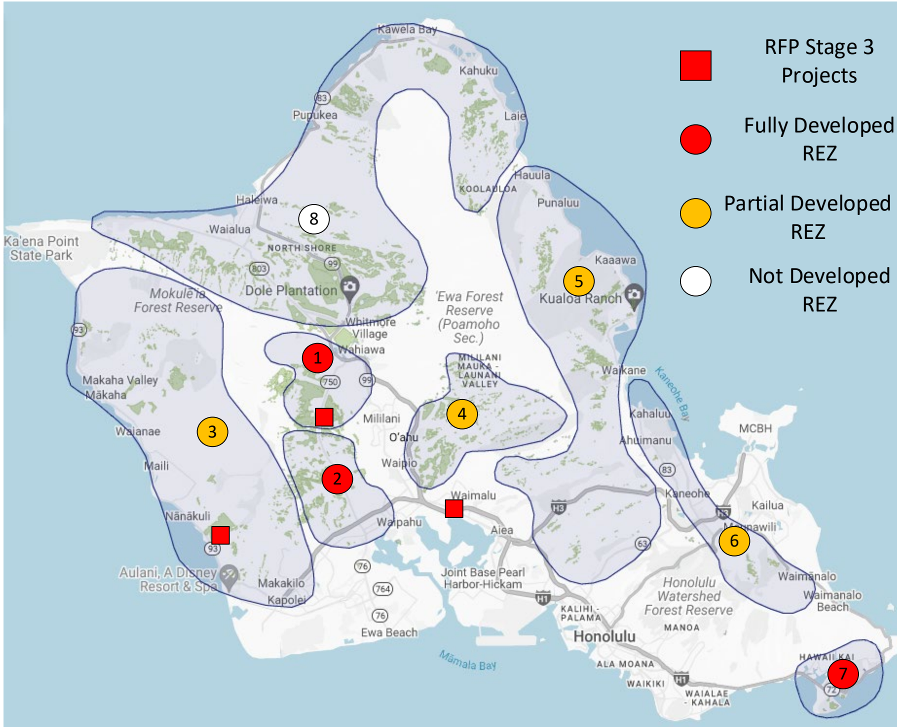


Figure 11 High-Level Oʻahu map for assumed RFP Stage 3 project locations and REZ zone development by 2030

Table 7 Oʻahu Grid-Scale Generation Project Development by 2030, after RFP Stage 2, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Oʻahu RFP	Renewable Dispatchable Generation	450	2027	Central Oʻahu, West Oʻahu
	Firm Generation	300	2029	Central Oʻahu
REZ Development	Renewable Dispatchable Generation	510	2030	Zone 1, 2, and 7
		543	2030	Zone 3, 4, 5 and 6
Other	Standalone BESS	84	2030	138/46 kV substations

Table 8 Oʻahu Grid-Scale Generation Removal by 2030

Removal	Generation Type	MW Capacity	Year	Location
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

Table 9 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2030

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	257	168	1,573	219	1,171	1,364

To evaluate O'ahu transmission system needs, various system dispatches are generated to stress the system during normal configuration and contingency configurations, which are listed in Table 10. For the 543 MW RDG development from the REZ zone 3, 4, 5 and 6, the study investigated two sensitivities: study case A and E in which all the 543 MW projects interconnected at west side of system, and study case D in which all the 543 MW projects interconnect at east side of system.

Table 10 Studied System Generation (MW) Dispatches, O'ahu Base Scenario Resource Plan, Year 2030

Region	Substation	Study Cases					
		A	B	C	Cm1a	D	E
West	HP, CIP	35	35	198	198	35	35
	CEIP	0	177	202	202	0	0
	Ewa Nui	324	336	336	256	0	0
	Kalaeloa	0	0	208	208	0	0
	Kahe	543	271	270	270	0	821
North	Hema/Akau	39	39	0	0	0	0
	Wahiawa	0	22	0	0	0	142
Central	Ho'ohana	232	232	0	80	276	0
	Mahi	120	120	0	0	120	0
	Waiau	5	66	150	150	300	366
East	Halawa	0	0	0	0	396	0
	Koolau	66	66	0	0	237	0
System Total Demand		1,364	1,364	1,364	1,364	1,364	1,364

Study results

Power flow simulations are performed for all the system generation dispatches, for system under normal configuration and contingency configurations (i.e., N-1 and N-2). The simulation results show that there is no voltage criteria violation, no 138 kV transmission line overloading in either system normal configuration or N-2 contingency configuration. However, overloading is identified on Ewa Nui-Waiau #1 & #2 138 kV lines during one N-1 contingency in study case C. The overloading is caused by too large an amount of generation dispatched from West region of system, which causes high level power flowing from the west region to Waiau substation via the Ewa Nui-Waiau #1 & #2 138 kV lines. When one of these two lines is out of service, the other line will have overloading condition.

Mitigation study – transmission networks expansion

The identified trasmission line overloading can be mitigated by reconductoring the Ewa Nui-Waiau #1 and #2 line as double bundle 795 AAC conductor. High level cost estimate to reconductor these two 138 kV lines is $161.4 million.

Mitigation study – portfolio alternatives

An alternative for the Ewa Nui – Waiau #1 and #2 line reconductor could be reducing REZ zone 2 interconnection MW size by 150 MW.

REZ Enablement

In the 2021 REZ study, REZ enablement cost estimate in term of $MM/MW is obtained for each REZ zones of Oʻahu. Based on these estimate, REZ enablement cost estimate by year 2030 is listed in Table 11. Since there is no detailed information regarding a breakdown of the 543 MW development from zone 3 to 6 for each zone, only a range of cost estimate is provided by assuming the 543 MW development come from the lower cost zones or higher cost zones.

Table 11 Oʻahu REZ Enablement Cost Estimate for REZ Development by 2030

REZ Zone	1	2	3	4	5	6	7
Cost ($MM) per MW	0.21	0.27	1.32	0.82	1.51	0.62	N/A
REZ Enablement ($MM)	24.6	87.6	448.4-819.9				N/A

Base scenario resource plan, year 2035

Study descriptions

In addition to previous system resource changes by 2030, by 2035, the Oʻahu system will have addition of 64 MW grid-scale standalone BESS and 509 MW offshore wind. There is no further development of REZ during this time frame. There will be 208 MW firm generation procured and interconnected at the Kalaeloa substation once the Kalaeloa power plant contract expires. High-level locations of the new grid-scale generation projects added into system between 2031 and 2035 assumed in the study are shown in Figure 12. The detailed system grid-scale resources changes are summarized in Table 12 and Table 13. By 2036, system annual peak load forecast is 1,432 MW, which is used for the study for this year. System resource summary and the forecasted system load is summarized in Table 14.

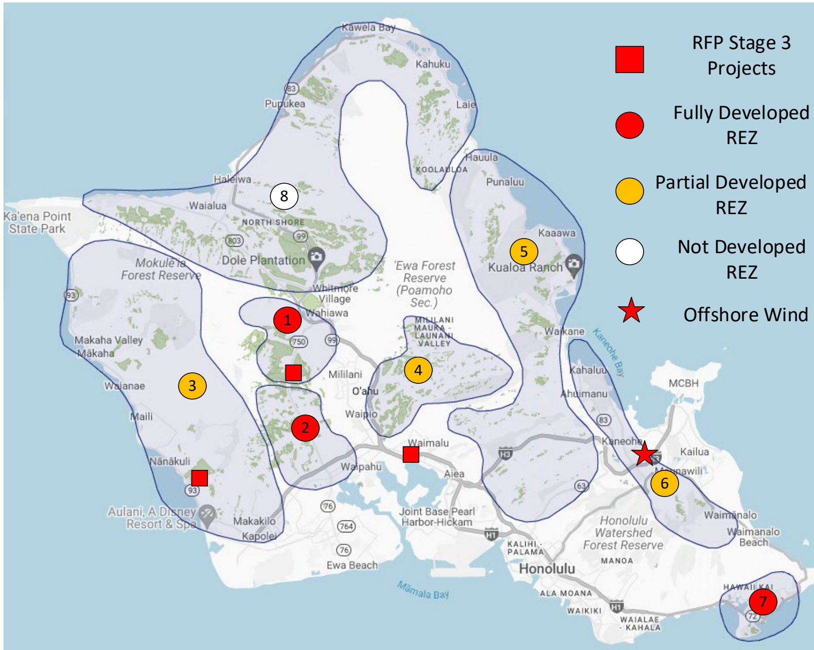


Figure 12 High-Level Oʻahu map for assumed generation projects' locations by 2035

Table 12 Oʻahu Grid-Scale Generation Project Development between 2031 and 2035, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Others	Firm Generation	208	2033	Kalaeloa Substation
	Standalone BESS	64	2035	138/46 kV substations
	Offshore wind	509	2035	Koʻolau 138 kV substation

Table 13 Oʻahu Grid-Scale Generation Removal between 2031 and 2035

Removal	Generation Type	MW Capacity	Year	Location
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustainable Energy Park	Solar	1	2032	Kahe 46 kV substation
Kalaeloa Solar	Solar	5	2032	KS substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

Table 14 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2035

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,297	257	509	157	1,573	282	1,295	1,432

Table 15 summarizes studied system generation dispatches for the 2035. It is worth noting that the conductor upgrade mitigation solution identified in the 2030 study is not included in the model for the study for 2035.

Table 15 Studied System Generation (MW) Dispatches, O'ahu Base Scenario Resource Plan, Year 2035

Region	Substation	Study Cases							
		A	B	C	Cm1	Cm1a	D	Dm1a	E
West	HP, CIP	35	35	198	198	198	35	35	35
West	CEIP	0	177	202	202	202	0	0	0
West	Ewa Nui	336	336	336	336	186	0	0	0
West	Kalaeloa	0	0	208	0	208	0	0	0
West	Kahe	543	339	396	396	396	0	0	845
North	Hema/Akau	39	39	0	0	0	0	0	0
North	Wahiawa	0	22	0	0	0	0	0	142
Central	Ho'ohana	257	232	0	0	120	0	10	0
Central	Mahi	120	120	0	0	0	0	0	44
Central	Waiau	36	66	92	300	92	255	255	366
East	Halawa	0	0	0	0	0	396	396	0
East	Koolau	66	66	0	0	30	746	736	0
System Total Demand		1,432	1,432	1,432	1,432	1,432	1,432	1,432	1,432

Study results

According to the power flow simulation results, overloading is identified for the Ewa Nui-Waiau #1 and #2 138 kV lines from the study case C when system is under N-1 contingency configuration, and high loading condition (96% of emergency rating) is identified for Koolau-Waiau #1 and #2 line, and Halawa-Koolau line from the study case D when system is under N-2 contingency configuration. It is worth noting that study case D represents a scenario that majority part of system load (79%) is supplied from REZ generation and offshore wind farm interconnected at east side of system. The identified high loading condition indicates the dispatched generation in east side is close to system transfer limit.

Mitigation study – transmission network expansion

Besides the reconductor of Ewa Nui-Waiau #1 and #2 circuits as identified in the 2030 study, there is no addtional transmission network expansion identified.

Mitigation study – portfolio alternatives

In addition to reducing REZ zone 2 interconnection MW size by 150 MW to avoid overloading the Ewa Nui-Waiau transmission lines, the REZ zone 6 or 7 interconnection size can be reduced by 10 MW to avoid high load conditions on the Koolau-Waiau #1 and #2 line, and Halawa-Koolau line.

REZ Enablement

There is no onshore REZ development between 2031 to 2035. However, the offshore wind development that requires interconnection facility is the 509 MW offshore wind, which requires expansion of the Koʻolau substation by adding 4 BAAH bay for the offshore wind interconnection. The cost estimate is $50.6 million.

Base scenario resource plan, year 2045

Study descriptions

In addition to previous system resource changes, by 2045, the Oʻahu system will finish developing the majority of REZ zone 1, 2, 3, 4, 5, 6 and 7, only 106 MW potential remaining undeveloped. Meanwhile, 452 MW solar potential of the REZ zone 8 will also be developed by 2045. System load is forecasted with significant growth, reaching 1,692 MW peak demand at 2046, which is used for the study. High level system map with REZ development is shown in Figure 13. The detailed system grid-scale resources changes are summarized in Table 16 and Table 17. System resource summary and the forecasted system load is summarized in Table 18.

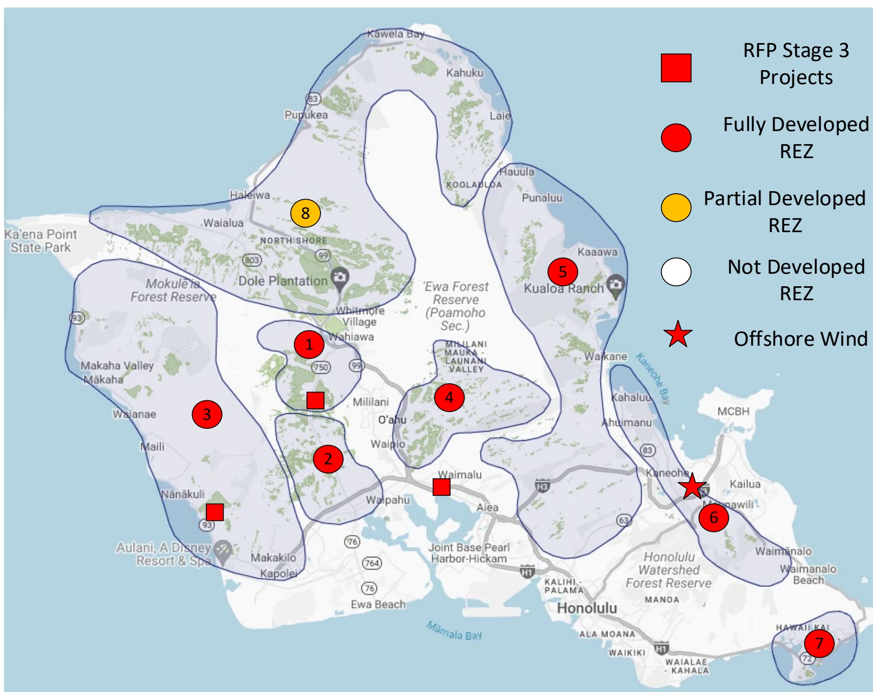


Figure 13 High-Level Oʻahu map for assumed generation projects' locations by 2045

Table 16 Oʻahu Grid-Scale Generation Project Development between 2036 and 2045, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Renewable Dispatchable Generation	521	2040	REZ zone 3, 4, 5, and 6
		504	2045	
		452	2045	REZ zone 8
Other	Standalone BESS	1	2040	Hoʻohana substation
		32	2045	Hoʻohana substation

Recovered Solar	Standalone Solar	168	2045	Waiver project locations
Recovered Wind	Wind	123	2045	Removed wind locations

Table 17 Oʻahu Grid-Scale Generation Removal between 2036 and 2045

Removal	Generation Type	MW Capacity	Year	Location
Kahe 3, 4	Fossil	172	2037	Kahe substation
Kawailoa Wind	Wind	69	2038	Wahiawa 46 kV
Waianae Solar	Solar	27.6	2039	Kahe 46 kV
Na Pua Makani Wind	Wind	24	2040	Koʻolau 46 kV
Waiver Clearway Projects	Solar/Wind	110	2041	Various 138 kV and 46 kV substations
West Loch Solar	Solar	20	2044	CEIP 46 kV

Table 18 Oʻahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2045

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,126	287	509	441	2,777	315	1,454	1,692

Table 19 summarizes studied system generation dispatch for the 2045. By comparing with previous study cases, a case (i.e., study case E) with much higher generation from Wahiawa substation (i.e., REZ zone 8) is considered in the study for 2045.

Table 19 Studied System Generation (MW) Dispatches, Oʻahu Base Scenario Resource Plan, Year 2045

Region	Substation	Study Cases						
		A	B	C	Cm1	Cm1a	D	E
West	HP, CIP	35	35	198	198	198	35	35
	CEIP	0	177	202	202	202	0	0
	Ewa Nui	324	336	336	336	226	0	0
	Kalaeloa	0	0	208	0	208	0	0
	Kahe	588	599	656	656	656	0	588
North	Hema/Akau	0	39	0	0	0	0	99
	Wahiawa	0	22	0	0	0	0	623
Central	Hoʻohana	120	232	0	0	110	3	0
	Mahi	0	120	0	0	0	0	0
	Waiau	331	66	92	300	92	300	347

East	Halawa	228	0	0	0	0	608	0
	Koolau	66	66	0	0	0	746	0
System Total Demand		1692	1692	1692	1692	1692	1692	1692

Study results

Significant 138 kV line overloading and high loading conditions is identified in both N-1 system contingency configurations and N-2 system contingency configurations from multiple study cases. A detailed summary of the conductor overloading and high loading is provided in Table 20. 138 kV line overloading is not identified in the normal system configuration study. Also, there is no steady state voltage planning criteria violation from the study results.

Table 20 138 kV Line Overloading Summary, Oʻahu Base Scenario Resource Plan, Year 2045

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	None		Makalapa-Airport	99
			Halawa-Iwilei	98
			Halawa-School	97
B	Halawa-Hoʻohana #1	101	Halawa-Hoʻohana #1	110
	Halawa-Hoʻohana #2	99	Halawa-Hoʻohana #2	107
	Ewa Nui-Waiau #1 and #2	98	Makalapa-Airport	98
			Halawa-Iwilei	97
			Halawa-School	96
C	Ewa Nui-Waiau #1 and #2	124	Halawa-Koʻolau	108
	Kahe-Hoʻohana #1 and #2	101	Koolau-Waiau #1 and #2	108
			Ewa Nui-Waiau #1 and #2	108
			Kahe-Hoʻohana #1 and #2	103
			Halawa-Hoʻohana #1 and #2	99
			Makalapa-Airport	98
			Halawa-Iwilei	97
			Halawa-School	96
Cm1	Ewa Nui-Waiau #1 and #2	99	Halawa-Koʻolau	108
	Makalapa-Waiau	97	Koolau-Waiau #1 and #2	108
			Makalapa-Airport	102
			Makalapa-Waiau	101
			Iwilei-Airport	99
			Halawa-Iwilei	97
			Halawa-School	97
D	None		Makalapa-Airport	99
			Halawa-Iwilei	98
			Halawa-School	97
E	Wahiawa-Waiau	150	Wahiawa-Waiau	131
	Kahe-Hema	149	Kahe-Hema	130
	Akau-Hema	136	Akau-Hema	118
	Wahiawa-Akau	122	Makalapa-Airport	109
	Makalapa-Waiau	104	Halawa-Koʻolau	108
			Koʻolau-Waiau #1 and #2	108

			Wahiawa-Akau	107
			Iwilei-Airport	106
			Makalapa-Waiau	105
			Halawa-Hoʻohana #1 and #2	103
			Kahe-Hoʻohana #1 and #2	97
			Halawa-Iwilei	96
			Halawa-School	96

Mitigation study – transmission networks expansion

Significant transmission networks expansion will be required in order to interconnect all the grid-scale generation projects and host the forecasted system load. The transmission networks expansion option 2 identified in the 2021 REZ study is adopted here as the mitigation solution for the overloading and high loading conditions listed in the study results, which is shown in Table 21. A high-level single line diagram which represents the proposed transmission networks expansion is shown in Figure 14.

Table 21 Transmission Networks Expansion and High-Level Cost Estimate, Oʻahu Base Scenario Resource Plan, Year 2045

No.	Transmission Line	Upgrade Type	Conductore Requirements	Cost Estimate ($MM)
1	Kahe-Akau-Hema-Wahiawa	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	314.1
2	Wahiawa-Kahe	New Line, 138 kV	Two circuits, with double-bundled 795 AAC	875.3
3	Wahiawa-Waiau	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	214.1
4	Wahiawa-Waiau	New Line, 138 kV	Two circuits, with double-bundled 795 AAC	962.8
5	Waiau-Makalapa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	72.3
6	Halawa-Koʻolau	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	172.1
7	Halawa-Koʻolau	New Line, 138 kV	One circuit, with 1590 AAC conductor	195.3
8	Koʻolau-Waiau #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	233
9	Koʻolau-Waiau #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	247.4
10	Makalapa-Airport #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	32.1
11	Halawa-School #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	92.8
12	Halawa-Iwilei #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	248.7

13	Airport-Iwilei #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	161.2

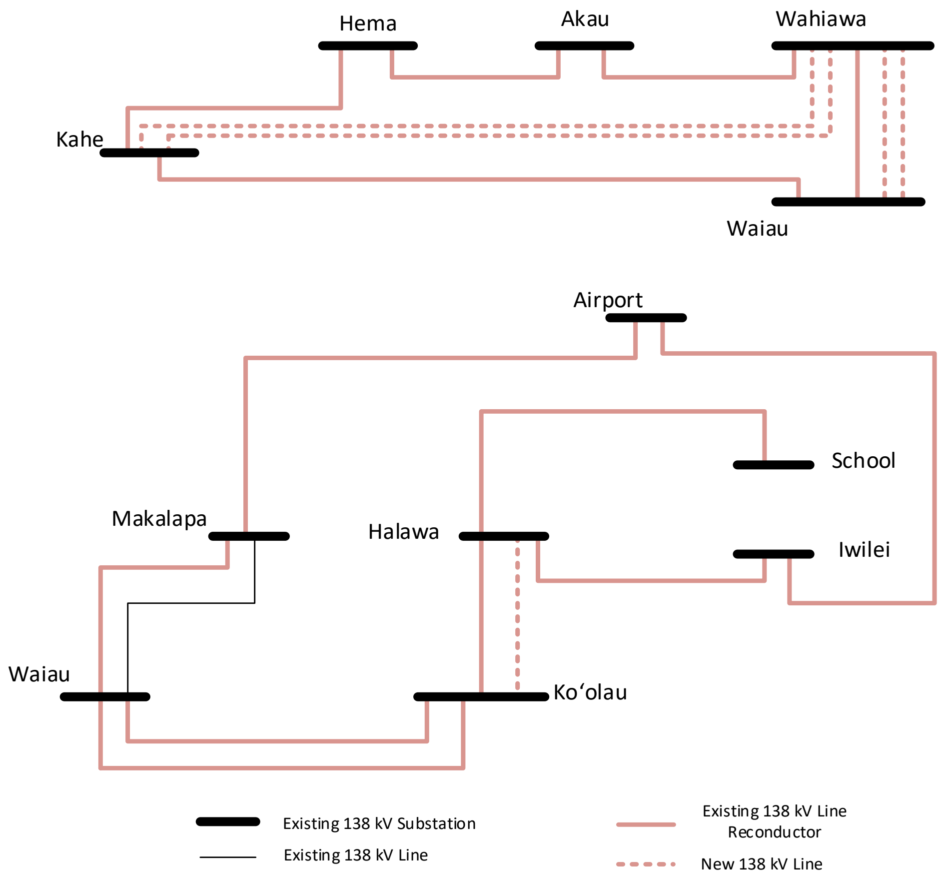


Figure 14 High-Level single line diagram for proposed transmission networks expansion, O'ahu base scenario resource plan, year 2045

Mitigation study – portfolio alternatives

Considering the degree of identified overloading conditions and scale of proposed transmission networks expansion, it is determined that there is no alternative to fully replace the proposed wire solution considering current electric grid technology developments and renewable procurement needs.

REZ Enablment

According to the REZ development MW target and the per MW cost estimate for REZ enablement identified in the 2021 REZ study, a high-level REZ enablment cost for REZ development between 2036 and 2045 is provided in Table 22.

Table 22 Oʻahu REZ Enablement Cost Estimate for REZ Development between 2036 and 2045

REZ Zone	3	4	5	6	8
Cost ($MM) per MW	1.32	0.82	1.51	0.62	1.25
REZ Enablement ($MM)	1084.6-1468.5				565.0

Base scenario resource plan, year 2050

Study descriptions

By 2050, 3,344 MW of all eight REZ zones will be fully developed. System load is forecasted with significant growth: 1,829 MW peak demand at 2050, which could possibly cause underground cable overloading for 138 kV underground cable among School Street, Iwilei and Archer 138 kV substations. All Kahe fossil generation units will be retired by 2050. Besides switching fossil fuel to biodiesel fuel for remaining firm units, 153 MW new firm units will be added to the Oʻahu system by 2050. A high-level system map with REZ development status is shown in Figure 15. The detailed system grid-scale resources changes are summarized in Table 23 and Table 24. System resource summary and the forecasted system load is summarized in Table 25.

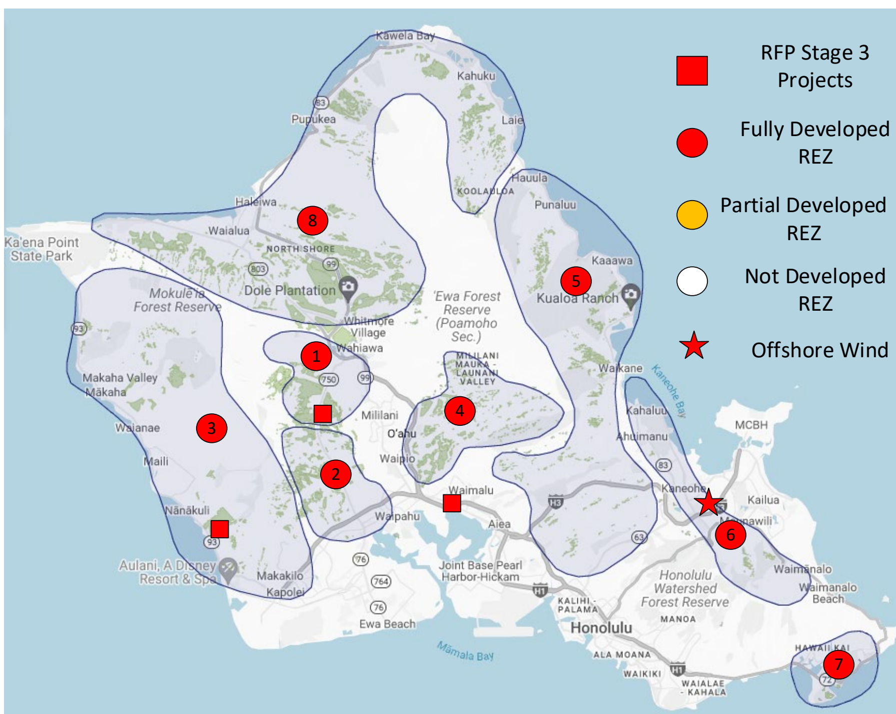


Figure 15 High-Level Oʻahu map with REZ development status by 2050

Table 23 Oʻahu Grid-Scale Generation Project Development between 2046 and 2050, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Renewable Dispatchable Generation	106	2050	REZ zone 3, 4, 5, and 6
		714	2050	REZ zone 8
Other	Standalone BESS	18	2050	138 kV Substation
Other	Firm Generation	153	2050	Kahe Substation

Table 24 O'ahu Grid-Scale Generation Removal between 2046 and 2050

Removal	Generation Type	MW Capacity	Year	Location
Kahe 5, 6	Fossil	270	2046	Kahe substation

Table 25 O'ahu System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2050

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,010	287	509	480	3,558	333	1,497	1,829

Table 26 summarizes studied system generation dispatch for the 2050. It is worth noting that all the transmission networks expansion identified in the 2045 study is included in the system model for the 2050 study.

Table 26 Studied System Generation (MW) Dispatches, O'ahu Base Scenario Resource Plan, Year 2050

		Study Cases							
Region	Substation	A	B	C	Cm1	Cm1a	D	E	Em1a
West	HP, CIP	35	35	198	198	198	35	35	35
	CEIP	0	177	202	202	202	0	0	0
	Ewa Nui	324	336	336	336	186	0	0	0
	Kalaeloa	0	0	208	0	208	0	0	0
	Kahe	588	736	793	793	793	0	358	358
North	Hema/Akau	0	39	0	0	0	0	99	99
	Wahiawa	0	22	0	0	0	0	1337	1117
Central	Ho'ohana	120	232	0	0	120	140	0	0
	Mahi	0	120	0	0	0	0	0	0
	Waiau	331	66	92	300	92	300	0	0
East	Halawa	218	0	0	0	0	608	0	220
	Koolau	213	66	0	0	30	746	0	0
System Total Demand		1,829	1829	1829	1829	1829	1829	1829	1829

Study results

After the transmission networks expansion proposed for 2045, transmission line high loading and overloading conditions are still identified from all study cases. A summary of identified high loading and overloading conditions are listed in Table 27. There is no steady state voltage violation identified from the study.

Table 27 138 kV Line Overloading Summary, Oʻahu Base Scenario Resource Plan, Year 2050

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	Archer-School	100	None	
	Archer-Iwilei	100		
B	Archer-School	99	Halawa-Hoʻohana #1	97
	Archer-Iwilei	99		
	Halawa-Hoʻohana	96		
C	Ewa Nui-Waiau #1 and #2	112	Kahe-Hoʻohana #1	101
	Archer-School	99	Kahe-Hoʻohana #2	100
	Archer-Iwilei	99		
	Kahe-Hoʻohana #1	97		
	Kahe-Hoʻohana #2	96		
Cm1	Archer-School	99	Makalapa-Waiau #1	97
	Archer-Iwilei	99	Makalapa-Airport	96
D	Archer-School	100	Halawa-Makalapa	99
	Archer-Iwilei	100		
E	Makalapa-Waiau #1	101	Wahiawa-Waiau #3	125
	Makalapa-waiau #2	99	Wahiawa-Waiau #2	114
	Archer-School	98	Wahiawa-Waiau #1	103
	Archer-Iwilei	98	Makalapa-Airport	102
			Makalapa-waiau #2	101
			Iwilei-Airport	99
Em1a	None		None	

Mitigation study – transmission networks expansion

Study results indicate the high loading and potential overloading on the 138 kV underground cables: Archer-Iwilei and Archer-School. As a wire solution, cable repalcement for these two underground line is recommended. Meanwhile, overloading and high loading conditions are also identified on Kahe-Hoʻohana #1 and #2 lines and Hoʻohana-Halawa #1 and #2 lines. The proposed transmission networks expansion is summarized in Table 28.

Table 28 Transmission Networks Expansion and High-Level Cost Estimate, Oʻahu Base Scenario Resource Plan, Year 2050

No.	Transmission Line	Upgrade Type	Conductore Requirements	Cost Estimate ($MM)
1	Kahe-Hoʻohana #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	174.4
2	Kahe-Hoʻohana #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	158.5
3	Hoʻohana-Halawa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	258.3
4	Hoʻohana-Halawa #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	272.6

5	Archer-School #1	Cable Replacement	2 cables per phase of 3000KCM CU XLPE	166.6
6	Archer Iwilei #1	Cable Replacement	2 cables per phase of 3000KCM CU XLPE	178.5

The results of the study case E, in which all REZ zone 8 capacity is dispatched, shows overloading on the new lines and reconductored lines that connect with Wahiawa substation. Wire-based solution is not identified for mitigating this overloading, instead, non-wire solution is identified, which will be discussed in next subsection.

Mitigation study – portfolio and non-wire solutions

To avoid overloading the transmission lines that connect with the Wahiawa substation, it is recommened to reduce interconnection size of REZ zone 8 by 220 MW. Also, to avoid the 138 kV underground cable Archer-Iwilei and Archer-School overloading, would require reduction of peak demand in areas supplied by Archer substation, Kewalo substation and Kamoku substation by 37 MW (assuming 0.95 inductive power factor).

REZ Enablement

The high-level cost estimate for the REZ enablement of the REZ development between 2046 and 2050 is summarized in Table 29.

Table 29 Oʻahu REZ Enablement Cost Estimate for REZ Development between 2046 and 2050

REZ Zone	3	4	5	6	8
Cost ($MM) per MW	1.32	0.82	1.51	0.62	1.25
REZ Enablement ($MM)	86.9-160.1				892.5

Land Constrained scenario resource plan, year 2030

Study descriptions

By 2030, the Oʻahu system will have all new generation from Stage 3 Oʻahu RFP procurement on transmission and sub-transmisison side. Specifically, there will be 450 MW renewable dispatch generation ("RDG") and 300 MW firm generation procured through the Stage 3 Oʻahu RFP activity, which is the same as this in the base scenario resource plan. Most of these new generation are expected to be interconnected at Oʻahu 138 kV system. In this time frame, it is also planned to remove 371 MW generation from Waiau power plant. There is no REZ development in the land constrained scenario resource plan. High-level system map with the new grid-scale generation projects coming online by 2030 is shown in Figure 16. The assumptions regarding RFP Stage 3 project interconnection locations are the same as what are used in the base scenario resource plan studies.

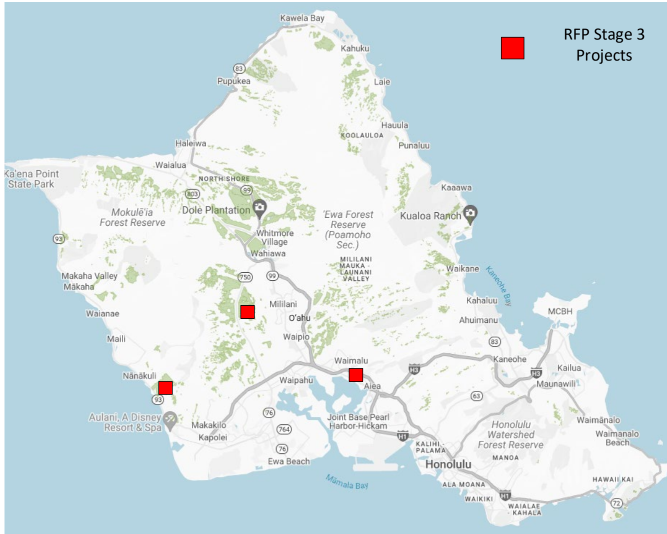


Figure 16 High-Level Oʻahu map, land constrained scenario resource plan, by 2030

The detailed system grid-scale resources changes are summarized in Table 30 and Table 31. By 2031, system annual peak load forecast is 1,364 MW, which is used for the study for this year. System resource summary and the forecasted system load is summarized in Table 32.

Table 30 Oʻahu Grid-Scale Generation Project Development by 2030, after RFP Stage 2, Land Constrained Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Oʻahu RFP	Renewable Dispatchable Generation	450	2027	Central Oʻahu, West Oʻahu
	Firm Generation	300	2029	Central Oʻahu

Table 31 Oʻahu Grid-Scale Generation Removal by 2030

Removal	Generation Type	MW Capacity	Year	Location
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

Table 32 Oʻahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2030

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	123	168	684	135	1,171	1,364

Table 33 summarizes studied system generation dispatches for the land constrained scenario resource plan in 2030.

Table 33 Studied System Generation (MW) Dispatches, Oʻahu Land Constrained Scenario Resource Plan, Year 2030

Region	Substation	Study Cases		
		A	B	F
West	HP, CIP	35	198	35
	CEIP	202	202	67
	Ewa Nui	12	12	12
	Kalaeloa	0	208	208
	Kahe	302.6	270	302
North	Hema/Akau	99.4	0	0
	Wahiawa	141	0	157
Central	Hoʻohana	112	54	112
	Mahi	120	120	120
	Waiau	316	300	351
East	Halawa	0	0	0
	Koolau	24	0	0
System Total Demand		1,364	1,364	1,364

Study results

Power flow simulation results for the three system generation dispatches show that there are no steady state voltage or transmission line loading planning criteria violations. Hence, there is no discussion regarding mitigation solutions.

Land Constrained scenario resource plan, year 2035

Study descriptions

In addtion to previous system resource changes by 2030, by 2035, the Oʻahu system will have 105 MW grid-scale standalone BESS and 400 MW offshore wind. 153 MW Firm resource will also be added to system by 2035. There will be 208 MW firm generation procured and interconnected at the Kalaeloa substation once the Kalaeloa power plant is removed. 30 MW wind recovered wind resource from the retired wind power plant will be added to system to meet the system demand as well. According to the forecast, system annual peak demand will reach 1,432 MW by 2036, which is used for the study. High-level system map with the addtion of the grid-scale resources is shown in Figure 17. The detailed system grid-scale resource changes are summarized in Table 34 and Table 35. System resource summary and the forecasted system load is summarized in Table 36.

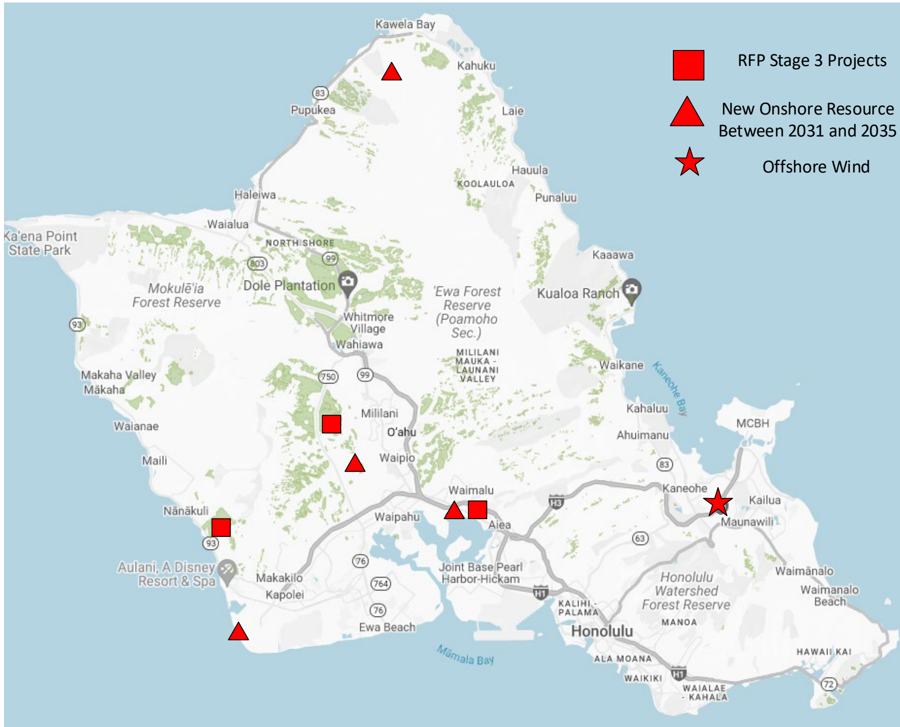


Figure 17 High-Level Oʻahu map, land constrained scenario resource plan, by 2035

Table 34 Oʻahu Grid-Scale Generation Project Development by 2035, Land Constrained Scenario Resource Plan

Generation Type	MW Capacity	GCOD	Location
Firm Generation	208	2033	Kalaeloa Substation
Firm Generation	153	2035	Waiau Power Plant
Standalone BESS	105	2035	138/46 kV substations
Offshore wind	400	2035	Koʻolau 138 kV substation

Table 35 Oʻahu Grid-Scale Generation Removal by 2035

Removal	Generation Type	MW Capacity	Year	Location
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustainable Energy Park	Solar	1	2032	Kahe substation
Kalaeloa Solar	Solar	5	2033	Kahe 46 kV substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

Table 36 O‘ahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2035

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,450	123	400	157	684	240	1,295	1,432

Table 37 summarizes the studied system generation dispatches for the land constrained scenario resource plan in 2035. New system generation dispatches are added to evaluate system resource changes.

Table 37 Studied System Generation (MW) Dispatches, O‘ahu Land Constrained Scenario Resource Plan, Year 2035

Region	Substation	Study Cases				
		A	B1	B2	C	F
West	HP, CIP	35	198	198	35	35
	CEIP	197	202	202	177	67
	Ewa Nui	12	12	117	12	12
	Kalaeloa	0	208	208	0	208
	Kahe	297	270	270	20	370
North	Hema/Akau	99	0	0	39	0
	Wahiawa	141	0	0	22	157
Central	Ho‘ohana	217	122	17	217	112
	Mahi	120	120	120	120	120
	Waiau	290	300	300	366	351
East	Halawa	0	0	0	0	0
	Koolau	24	0	0	424	0
DER		0	0	0	0	0
System Total Demand		1,432	1,432	1,432	1,432	1,432

Study results

Power flow simulation results for aforementioned system generation dispatches show that there are no steady state voltage or transmission line loading planning criteria violations. Hence, there is no discussion regarding mitigation solutions.

Land Constrained scenario resource plan, year 2046

Study descriptions

In addtion to previous system resource changes, by 2045, the O‘ahu system will add another 153 MW firm geneartion into the system. Also, 169 MW standalone solar and 93 MW wind development from retired solar and wind locations will be completed by 2045. 169 MW new Grid-scale standalone BESS will be interconnected to system from transmission substations. System load is forecasted with significant growth: 1,692 MW peak demand at 2046. 783 MW DER coupled with 1,567 MWh DER BESS will be added to the system to supply system load demand. A high-level map for Oʻahu system with addtion of grid-scale resource since 2036 is shown in Figure 18. The detailed system grid-scale resources changes are summarized in Table 38 and Table 39. System resource summary and the forecasted system load is summarized in Table 40.

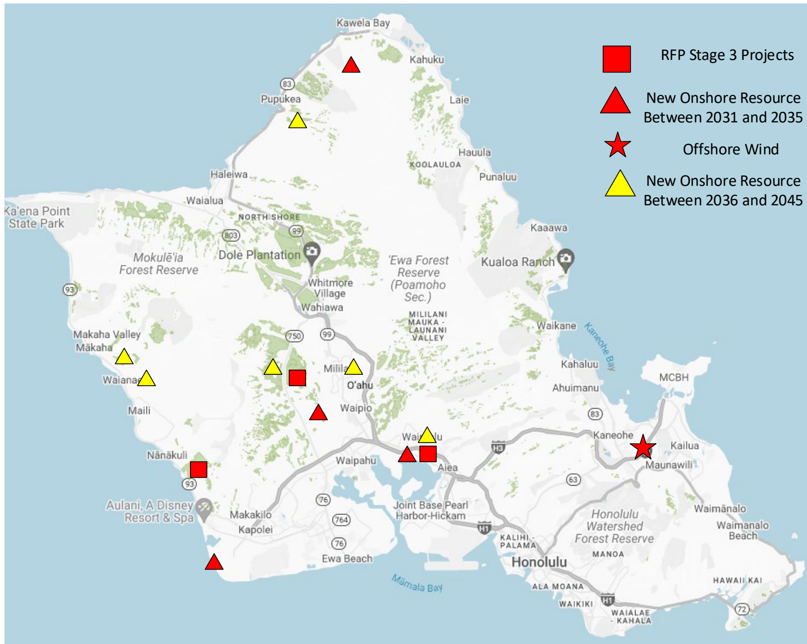


Figure 18 High-Level Oʻahu map, land constrained scenario resource plan, by 2045

Table 38 Oʻahu Grid-Scale Generation Project Development by 2045, Land Constrained Scenario Resource Plan

Generation Type	MW Capacity	GCOD	Location
Standalone BESS	14	2040	Hoʻohana substation
Firm Generation	153	2040	Waiau substation
Standalone Solar	39	2040	Waiver project locations
Wind	93	2040	Retired wind locations
Standalone BESS	145	2045	Hoʻohana substation
Standalone Solar	130	2045	Waiver project locations

Table 39 Oʻahu Grid-Scale Generation Removal by 2045

Removal	Generation Type	MW Capacity	Year	Location
Kahe 3, 4	Fossil	172	2037	Kahe substation
Kawailoa Wind	Wind	69	2038	Wahiawa 46 kV
Waianae Solar	Solar	27.6	2039	Kahe 46 kV
Na Pua Makani Wind	Wind	24	2040	Koʻolau 46 kV
Waiver Clearway Projects	Solar/Wind	104	2041	Various 138 kV and 46 kV substations
West Loch Solar	Solar	20	2044	CEIP 46 kV

Table 40 O'ahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2045

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,432	123	400	169	684	399	3,020	1,692

Table 41 summarizes studied system generation dispatches for the land constrained scenario resource plan in 2045. By assuming DER technology maturity, system level monitoring and control being ready, and Company has sufficient DER program, two study cases (i.e., D and E) are created to represent scenarios where the majority system load is supplied by DER on distribution side. For this case creation spacial forecast of DER adoption across system is not used, instead, a flat rate of DER adoption across the system is assumed. Also, neither 46 kV subtransmission circuits nor distribution circuits (25 kV, 12 kV and 4 kV) are modeled in the PSS/E models used for this study. So, it is likely that potential sub-transmission and distribution system capacity needs in the study case D and E are not captured.

Table 41 Studied System Generation (MW) Dispatches, O'ahu Land Constrained Scenario Resource Plan, Year 2045

Region	Substation	Study Cases						
		A	B1	B2	B2m1a	C	D	E
West	HP, CIP	35	198	198	198	35	35	35
	CEIP	202	202	202	202	177	0	0
	Ewa Nui	12	12	276	246	12	0	0
	Kalaeloa	0	208	208	208	0	0	0
	Kahe	302.6	328	328	358	121	0	0
North	Hema/Akau	99.4	0	0	0	39	0	0
	Wahiawa	171	0	0	0	22	0	0
Central	Ho'ohana	376	324	60	60	376	0	0
	Mahi	120	120	120	120	120	0	0
	Waiau	350	300	300	300	366	0	0
East	Halawa	0	0	0	0	0	0	0
	Koolau	24	0	0	0	424	0	400
DER		0	0	0	0	0	1,657	1,257
System Total Demand		1,692	1,692	1,692	1,692	1,692	1,692	1,692

Study results

High loading and overloading conditions on many 138 kV lines are observed in several study cases. A summary of the findings regarding transmission line high loading and overloading conditions are listed in Table 42. There is no voltage planning criteria violation identifed from the study.

Table 42 138 kV Line Overloading Summary, Oʻahu Land Constrained Scenario Resource Plan, Year 2045

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	Halawa-Hoʻohana #1	99	Halawa-Hoʻohana #1	111
	Halawa-Hoʻohana #2	96	Halawa-Hoʻohana #2	108
			Halawa-Koʻolau	105
			Koʻolau-Waiau #1 and #2	103
			Halawa-Iwilei	98
			Halawa-School	97
			Makalapa-Airport	98
B1	Halawa-Hoʻohana #1	104	Halawa-Koʻolau	112
	Halawa-Hoʻohana #2	101	Koʻolau-Waiau #1 and #2	109
	Halawa-Hoʻohana	96	Halawa-Hoʻohana #1	108
			Halawa-Hoʻohana #2	106
			Halawa-Iwilei	99
			Halawa-School	98
			Makalapa-Airport	99
B2	Ewa Nui-Waiau #1	98	Halawa-Koʻolau	112
	Ewa Nui-Waiau #2	97	Koʻolau-Waiau #1 and #2	109
	Makalapa-Waiau #1	99	Makalapa-Airport	105
			Makalapa-Waiau	104
			Iwilei-Airport	102
			Halawa-Iwilei	99
			Halawa-School	98
C	None		Halawa-Iwilei	99
			Makalapa-Airport	99
			Halawa-School	98
D	None		None	
E	None		None	

The reason of the high loading and overloading condition is generation congestion and system load increase. The results of study case A, B1 and B2 indicate that interconnecting future generation projects, including standalone BESS, in west side or west central part of system could cause generation congestion on transmission lines. Instead, interconnecting those project on east side of system would avoid certain transmission line overloading or high loading conditions.

Study results for case D and E also demonstrate that DER resources supplying system load would not cause transmission line overloading. However, for this case creation instead of using spatial DER adoption forecast a flat rate of DER adopton increase on top of existing DER adopton across system is used for modeling future years' DER generation. To fully demonstrate that adopting DER can avoid transmission networks expasion, more detailed study will be performed, and system level monitoring and control of DER will be required.

Mitigation study – transmission networks expansion

According to the study results, following transmission line upgrades summarized in Table 43 are proposed to mitigate the identified transmission line high load conditions or overloading conditions. A simplified single line diagram as Figure 19 shows the proposed line upgrade.

Table 43 Transmission Networks Expansion and High-Level Cost Estimate, O‘ahu Land Constrained Scenario Resource Plan, Year 2045

No.	Transmission Line	Upgrade Type	Conductore Requirements	Cost Estimate ($MM)
1	Waiau-Makalapa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	72.3
2	Halawa-Ko`olau	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	172.1
3	Halawa-Ko`olau	New Line, 138 kV	One circuit, with 1590 AAC conductor	178.3
4	Ko`olau-Waiau #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	233
5	Ko`olau-Waiau #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	247.4
6	Makalapa-Airport #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	32.1
7	Halawa-School #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	92.8
8	Halawa-Iwilei #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	248.7
9	Airport-Iwilei #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	161.2
10	Kahe-Ho‘ohana #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	150.5
11	Kahe-Ho‘ohana #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	136.7
12	Ho‘ohana-Halawa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	222.8
13	Ho‘ohana-Halawa #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	235.1

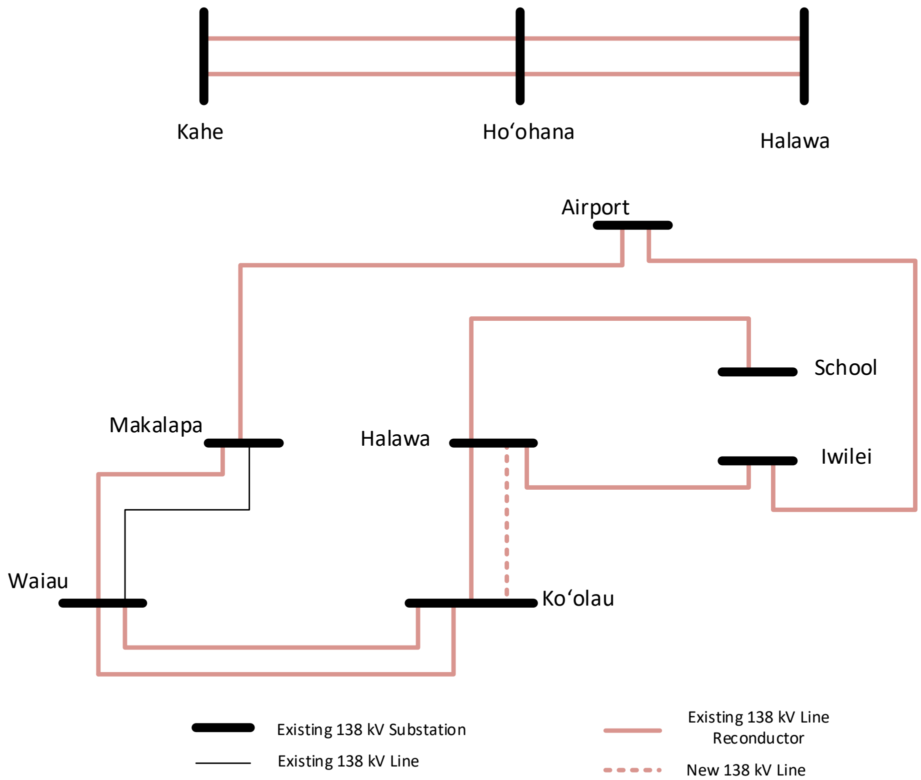


Figure 19 Simplified single line diagram for proposed transmission networks expansion, O'ahu land constrained scenario resource plan, by 2045

Mitigation study – non-wire alternatives

Considering the degree of identified overloading condition and scale of proposed transmission networks expansion, it is determined that there is no non-wire alternative to fully replace the proposed wire solution in current electric grid technology development condition.

Land Constrained scenario resource plan, year 2050

Study descriptions

From 2046 to 2050, the only grid-scale resource added to the O'ahu system as planned is a 119 MW/1,110 MWh grid-scale BESS. Kahe 5, 6, which will be the only remaining fossil generation at Kahe power plant by 2050, will be retired in 2050. It is also planned to add 1,017 MW DER, coupled with 2,033 MWh DER BESS into system distribution side. System peak load is forecasted to be 1,829 MW by 2050. A high-level map for O'ahu system with addtion of grid-scale resource is shown in Figure 20. The detailed system grid-scale resources changes are summarized in Table 44 and Table 45. System resource summary and the forecasted system load is summarized in Table 46.

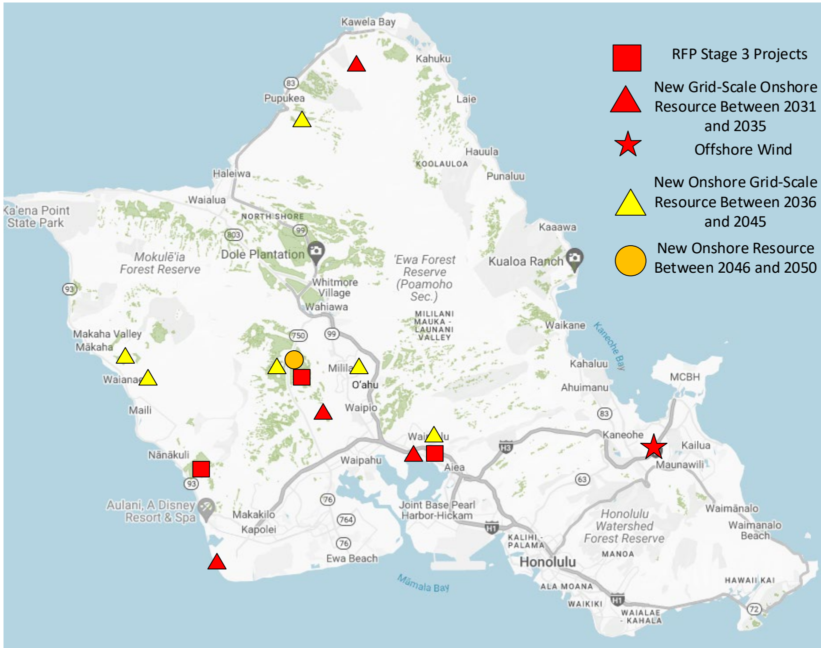


Figure 20 High-Level Oʻahu map, land constrained scenario resource plan, by 2050

Table 44 Grid-Scale Generation Project Development by 2050, Land Constrained Scenario Resource Plan

Generation Type	MW Capacity	GCOD	Location
Standalone BESS	119	2050	138 kV Substation

Table 45 Oʻahu Grid-Scale Generation Removal by 2050

Removal	Generation Type	MW Capacity	Year	Location
Kahe 5, 6	Fossil	270	2050	Kahe substation

Table 46 Oʻahu System Resource Summary and Forecasted Demand (MW), Land Constrained Scenario Resource Plan, Year 2050

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,163	123	400	169	684	519	5,097	1,829

Table 47 summarizes studied system generation dispatches for the land constrained scenario resource plan in 2050. All the transmission networks expansion identified in the 2045 study is included in the models for study cases listed in the Table 47.

Table 47 Studied System Generation (MW) Dispatches, Oʻahu Land Constrained Scenario Resource Plan, Year 2050

Region	Substation	Study Cases						
		A	B1	B2	B2m1a	C	D	E
West	HP, CIP	36	198	198	198	35	35	35

	CEIP	202	202	202	202	177	0	0
	Ewa Nui	12	12	396	206	12	0	0
	Kalaeloa	0	208	208	208	0	0	0
	Kahe	302.6	345	345	345	138	0	0
North	Hema/Akau	99.4	0	0	0	39	0	0
	Wahiawa	171	0	0	0	22	0	0
Central	Ho'ohana	496	444	60	250	496	0	0
	Mahi	120	120	120	120	120	0	0
	Waiau	366	300	300	300	366	0	0
East	Halawa	0	0	0	0	0	0	0
	Koolau	24	0	0	0	424	0	400
DER		0	0	0	0	0	1,794	1,394
System Total Demand		1,829	1,829	1,829	1,829	1,829	1,829	1,829

Study results

High loading and overloading conditions are still observed on a few 138 kV lines in several study cases. A summary of the findings regarding transmission line high loading and overloading conditions are listed in Table 48. There is no voltage planning criteria violation identifed from the study.

Table 48 138 kV Line Overloading Summary, O'ahu Land Constrained Scenario Resource Plan, Year 2050

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	Archer-School	100	Halawa-Ho'ohana #1	99
	Archer-Iwilei	100	Halawa-Ho'ohana #2	98
B1	Archer-School	100	Halawa-Ho'ohana #1	98
	Archer-Iwilei	100	Halawa-Ho'ohana #2	97
	CEIP-Ewa Nui	96		
B2	Ewa Nui -Waiau #1	114	Ewa Nui-Waiau #1	100
	Ewa Nui -Waiau #2	113	Ewa Nui-Waiau #2	99
	Archer-School	100	Makalapa-Waiau #1	97
	Archer-Iwilei	100	Makalapa-Waiau #2	96
B2m1a	Archer-School	100	None	
	Archer-Iwilei	100		
C	Archer-School	101	None	
	Archer-Iwilei	100		
D	None		None	
E	None		None	

High loading and overloading is identified on the 138 kV underground cable Archer-School and Archer-Iwilei in several study cases. This is due to the system load increase. Simliar to what is observed and recommended in the base scenario resource plan 2050 study, either cable replacement (2 cables per phase of 3000KCM CU XLPE) for these two lines or peak load reduction by 37 MW (assuming load power factor is inductive 0.95) will mitigate the overloading and high loading issues.

Regarding the overloading and high loading on the remaining 138 kV overhead lines, by comparing study case A, B1, B2 and B2m1a, it is observed that relocating part of new 138 kV standalone BESS from Ewa Nui substation or Hoʻohana substation to east side of system, such as Halawa substation or Koʻolau substation will mitigate those high loading or overloading issue.

Mitigation study – transmission networks expansion

To mitigate the high loading and overloading on the 138 kV underground cables, cable replacement is recommended as Table 49, which is the transmission networks expansion solution for the 2050 in land constrained resource plan.

Table 49 Transmission Networks Expansion and High-Level Cost Estimate, Oʻahu Land Constrained Scenario Resource Plan, Year 2050

No.	Transmission Line	Upgrade Type	Conductore Requirements	Cost Estimate ($MM)
1	Archer-School #1	Cable Replacement	2 cables per phase of 3000KCM CU XLPE	166.6
2	Archer Iwilei #1	Cable Replacement	2 cables per phase of 3000KCM CU XLPE	178.5

Mitigation study – non-wire alternatives

Simliar as what is recommended in the base scenario resource plan 2050 study, an alternative for the cable replacement mitigation listed in the Table 49, could be a reduction in peak demand in areas supplied by Archer substation, Kewalo substation and Kamoku substation by 37 MW (assuming 0.95 inductive power factor). Also, generation congestion is identified on the west side and west central part of the system, interconnecting the grid-scale standalone BESS project on the east side of system will mitigate the generation congestion issue if dispatched to reduce west side generation.

High load scenario resource plan, year 2030

Study descriptions

By 2030, the Oʻahu system will have new generation from Stage 3 Oʻahu RFP procurement and initial REZ development. Specifically, there will be 450 MW RDG and 300 MW firm generation procured through the Stage 3 Oʻahu RFP activity, 510 MW RDG development from the REZ zone 1, 2 and 7, and 1,225 MW RDG development from the REZ zone 3, 4, 5 and 6. Most of these new generation will be interconnected at Oʻahu 138 kV system. The REZ development is expected to have both solar and wind generation. In this time frame, it is also planned to add 60 MW standalone BESS into system and remove 371 MW generation from Waiau power plant. System peak load will reach 1,595 MW in 2031, according to the forecast. The high load scenario resource plan has much more aggresive grid-scale generation projects interconnection schedule than that in the base scenario resource plan and land constrained scenario resource plan.

A high-level map for Oʻahu system with addtion of grid-scale resource is shown in Figure 21. The detailed system grid-scale resources changes are summarized in Table 50 and Table 51. System resource summary and the forecasted system load is summarized in Table 52.

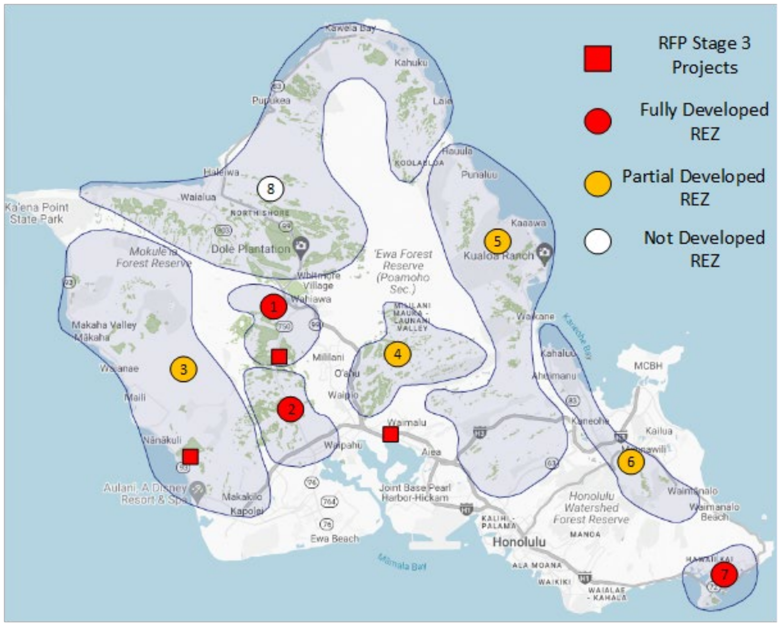


Figure 21 High-Level O'ahu map, high load scenario resource plan, by 2030

Table 50 O'ahu Grid-Scale Generation Project Development by 2030, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 O'ahu RFP	Renewable Dispatchable Generation	450	2027	Central O'ahu, West O'ahu
	Firm Generation	300	2029	Central O'ahu
REZ Development	Renewable Dispatchable Generation	510	2030	Zone 1, 2, and 7
		1,225	2030	Zone 3, 4, 5 and 6
Other	Standalone BESS	60	2030	138/46 kV Substations

Table 51 O'ahu Grid-Scale Generation Removal by 2030

Removal	Generation Type	MW Capacity	Year	Location
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

Table 52 O'ahu System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	123	168	2,419	195	1,147	1,595

Table 53 summarizes studied system generation dispatch for the 2030.

Table 53 Studied System Generation (MW) Dispatches, O'ahu High Load Scenario Resource Plan, Year 2030

Region	Substation	Study Cases					
		A	B	C	Cm1a	D	E
West	HP, CIP	35	35	198	198	35	35
	CEIP	0	177	202	202	0	0
	Ewa Nui	324	336	336	276	0	0
	Kalaeloa	0	0	208	208	0	0
	Kahe	588	502	351	351	0	845
North	Hema/Akau	0	39	0	0	0	0
	Wahiawa	0	22	0	0	0	142
Central	Ho'ohana	120	232	0	0	232	87
	Mahi	0	120	0	0	120	120
	Waiau	331	66	300	300	363	366
East	Halawa	131	0	0	0	608	0
	Koolau	66	66	0	60	237	0
System Total Demand		1,595	1,595	1,595	1,595	1,595	1,595

Study results

Transmission line high loading and overloading conditions are identified in serval study cases, which are simliar to the findings in the base scenario resource plan, however, in later years. A summary of the high loading and overloading results are listed in Table 54. There is no steady state voltage violation identified from the study.

Table 54 138 kV Line Overloading Summary, O'ahu High Load Scenario Resource Plan, Year 2030

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	None		None	
B	Halawa-Ho'ohana #1	96	Halawa-Ho'ohana #1	103
			Halawa-Ho'ohana #2	101
C	Ewa Nui-Waiau #1	102	Halawa-Ko'olau	105
	Ewa Nui-Waiau #2	101	Makalapa-Airport	104
	Makalapa-Waiau #1	98	Ko'olau-Waiau #1	102
			Ko'olau-Waiau #2	102
			Makalapa-Waiau #1	101
			Iwilei-Airport	100
D	None		None	
E	None		Halawa-Ko'olau	104

			Koʻolau-Waiau #1	102
			Koʻolau-Waiau #2	102
			Halawa-Hoʻohana #1	98
			Halawa-Hoʻohana #2	96

Mitigation study – transmission networks expansion

To mitigate high loading and overloading issue identified fromt the study, transmission networks expansion, including both reconductor and adding new circuit, are proposed as listed in Table 55.

Table 55 138 kV Line Overloading Summary, Oʻahu High Load Scenario Resource Plan, Year 2030

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line	Upgrade Type	Conductor Requirements	
Waiau-Makalapa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	46.4
Halawa-Ko`olau	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	110.5
Halawa-Ko`olau	New Line, 138 kV	One circuit, with 1590 AAC conductor	114.4
Ko`olau-Waiau #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	149.6
Ko`olau-Waiau #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	158.8
Kahe-Hoʻohana #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	96.6
Kahe-Hoʻohana #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	87.7
Hoʻohana-Halawa #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	143
Hoʻohana-Halawa #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	150.9
Ewa Nui – Waiau #1	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	80.5
Ewa Nui – Waiau #2	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	80.9

Mitigation study – portfolio alternatives

Same as previous study results, a non-wire alternative for deferring the reconductor of Ewa Nui-Waiau #1 and #2 reconductoring is to reduce interconnection MW size at Ewa Nui substation of future generation projects from REZ zone 2 development by 150 MW.

REZ Enablement

Based on the REZ enablement cost estimate for each MW generation in all REZ zones, a REZ enablement cost estimate for REZ project interconnection by year 2030 is listed in Table 56. Since there is no detailed inforamtion regarding a breakdown of the 1,225 MW development from zone 3 to 6 for each zone, only a range of cost estimate is provided by assuming the 1,225 MW development come from the lower cost zones or higher cost zones.

Table 56 Oʻahu REZ Enablement Cost Estimate for REZ Development by 2030

REZ Zone	1	2	3	4	5	6	7
Cost ($MM) per MW	0.21	0.27	1.32	0.82	1.51	0.62	N/A
REZ Enablement ($MM)	24.6	87.6	1,378.8-1,718.0				N/A

High load scenario resource plan, year 2035

Study descriptions

In addtion to previous system resource changes by 2030, by 2035, the Oʻahu system will have 95 MW grid-scale standalone BESS and 600 MW offshore wind. There is no further development of REZ between 2031 and 2035. There will be 208 MW firm generation interconnected at the Kalaeloa substation. By 2035, the BESS MWh of the PV/BESS projects developed in REZ zones in 2030 will be increased as well. According to the forecast, system annual peak load will reach 1,776 MW by 2036. A high-level map for Oʻahu system with addtion of grid-scale resource is shown in Figure 22. The detailed system grid-scale resources changes are summarized in Table 50 and Table 51. System resource summary and the forecasted system load is summarized in Table 52.

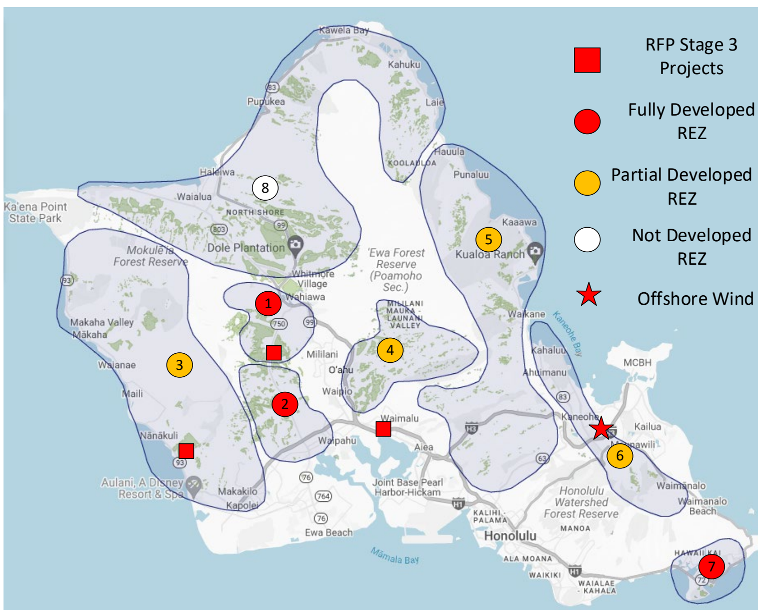


Figure 22 High-Level Oʻahu map, high load scenario resource plan, by 2030

Table 57 Oʻahu Grid-Scale Generation Project Development by 2035, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Others	Firm Generation	208	2033	Kalaeloa Substation
	Standalone BESS	95	2035	138/46 kV substations
	Offshore wind	600	2035	Koʻolau 138 kV substation

Table 58 O'ahu Grid-Scale Generation Removal by 2035

Removal	Generation Type	MW Capacity	Year	Location
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustainable Energy Park	Solar	1	2032	Kahe substation
Kalaeloa Solar	Solar	5	2032	KS substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

Table 59 O'ahu System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,297	93	600	157	2,419	290	1,271	1,776

Table 60 summarizes studied system generation dispatch for the 2035. Study case D represents a scenario in which the 600 MW offshore wind is dispatched, and majority of system load is supplied by the east side generation. Also, it is worth noting that the transmission network expansion in the 2030 study is included in the model for this 2035 study.

Table 60 Studied System Generation (MW) Dispatches, O'ahu High Load Scenario Resource Plan, Year 2035

Region	Substation	Study Cases						
		A	B	C	Cm1	Cm1a	D	E
West	HP, CIP	35	35	198	198	198	35	35
	CEIP	0	177	202	202	202	0	36
	Ewa Nui	324	336	336	336	306	0	0
	Kalaeloa	0	0	208	0	208	0	0
	Kahe	588	683	551	551	551	0	845
North	Hema/Akau	0	39	0	0	0	0	0
	Wahiawa	0	22	0	0	0	0	142
Central	Ho'ohana	120	232	0	0	0	0	232
	Mahi	0	120	0	0	0	0	120
	Waiau	331	66	281	489	281	296	366
East	Halawa	305	0	0	0	0	608	0
	Koolau	73	66	0	0	30	837	0
System Total Demand		1,776	1,776	1,776	1,776	1,776	1,776	1,776

Study results

Significant transmission line high loading and overloading conditions are identified from the study results, which are summarized in Table 61. The high loaded and overloaded transmission lines indicate both generation congestion and high system loading issue. More importantly, the study results also indicates that when system load reach closing to 1.8 GW magnitude, system generation dispatch should maintain certain balance between east, central and west of system, or large amount of power transfer from one side to another side of system would cause trasmission line overloading. Study does not identify any steady state voltage planning criteria violation.

Table 61 138 kV Line Overloading Summary, Oʻahu High Load Scenario Resource Plan, Year 2035

Study Case	N-1 Contingency		N-2 Contingency	
	Overloading/High loading Line	Max. Loading (%)	Overloading/High loading Line	Max. Loading (%)
A	Archer-School	97	Makalapa-Airport	105
	Archer-Iwilei	97	Halawa-Iwilei	103
			Halawa-School	103
			Iwilei-Airport	101
B	Ewa Nui-Waiau #1 and #2	101	Makalapa-Airport	104
	Archer-School	96	Halawa-Iwilei	102
	Archer-Iwilei	96	Halawa-School	102
			Iwilei-Airport	100
			Waiau-Mahi	97
C	Ewa Nui-Waiau #1	112	Makalapa-Airport	108
	Ewa Nui-Waiau #2	111	Halawa-Iwilei	103
	Archer-School	96	Halawa-School	102
	Archer-Iwilei	96	Iwilei-Airport	103
			Ewa Nui-Waiau #1	96
			Ewa Nui-Waiau #2	96
Cm1	Archer-School	96	Makalapa-Airport	114
	Archer-Iwilei	96	Halawa-Iwilei	103
			Halawa-School	102
			Iwilei-Airport	111
			Makalapa-Waiau	97
D	Archer-School	97	Makalapa-Airport	104
	Archer-Iwilei	97	Halawa-Iwilei	103
			Halawa-School	102
			Iwilei-Airport	101
E	Archer-School	96	Makalapa-Airport	103
			Halawa-Iwilei	102
			Halawa-School	101
			Iwilei-Airport	99
			Waiau-Mahi	96

Mitigation study – transmission networks expansion

To mitigate high loading and overloading issue identified fromt the study, transmission networks expansion, including both reconductor and adding new circuit, are proposed as listed in Table 62.

Table 62 138 kV Line Overloading Summary, Oʻahu High Load Scenario Resource Plan, Year 2035

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line	Upgrade Type	Conductor Requirements	
Makalapa-Airport	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	23.9
Halawa-School	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	69.1
Halawa-Iwilei	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	185
Airport-Iwilei	Re-conductor	One circuit, re-conductor to double-bundled 795 AAC	119.9

For the high loading condition on Archer-Iwilei and Archer-School lines, it is recommend to keep monitoring on the two lines, and prepare solutions to reduce peak load on the related substations (i.e., Archer, Kewalo and Kamoku) to avoid these two underground cable having overloading issue.

Mitigation study – portfolio and/or non-wire alternatives

Due to the magnitude of overloading conditions, identification of portfolio change or non-wire alternative of the proposed mitigation solution in Table 62 is not pursued in this study. The non-wire alternative can be re-evaluated when more detailed information regaridng system is obtained, such as detailed load forecast and future generation interconnection locations.

REZ Enablement

There is no REZ development between 2021 and 2035. The cost for interconnecting 600 MW offshore wind at Koʻolau substation is $50.6 million, without the cost of transmisison networks expansion, which was estimated in the 2021 REZ study.

4.1.2 Dynamic Stability Study

The O’ahu system in near-term years 2027 and 2035 for both the base scenario resource plan and land constrained resource plan are selected for performing dynamic stability study to evaluate system dynamic stability performance. Considering the O’ahu system has similar grid-scale generation resources by the RFP Stage 3 GCOD in both plans, only the base scenario resource plan is studied for 2027. Both resource plans are studied for the 2035.

System generation dispatch for daytime peak load with high DER generation, which poses the highest risk to the system stability according to the past studies, is modeled for the dynamic stability study, with simulations of a high-risk contingency. The high-risk contingencies for O’ahu system are 1) P3 planning event - the largest GFM resource is out-of-service, and a three-phase fault happens at gen-tie of another grid-scale GFM resource resulting in the loss of the GFM resource, and 2) P5 planning event - delayed fault clearing of a three-phase fault on a transmission line close to load center.

Base scenario resource plan, year 2027

Study descriptions and study results

According to the resource plan, a system generation dispatch that represents daytime peak load with high DER generation scenario is created (as Table 63) and modeled in PSCAD/EMTDC.

Table 63 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Base Scenario Resource Plan, Year 2027

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
H-Power	35	2.8	68.5
Waiver Standalone PV	117	17.2	168
Stage 1 PV/BESS (GFL)	101		140
KES (GFM)	0	27	135
Stage 2 PV/BESS (GFM)	69		94
Stage 3 PV/BESS (GFM)	273		450
Wind	0	0	123
DER	670	53	1,004
System Load (MW)	1,265		
GFM MW Headroom (Excluding KES)/DER Generation	0.3		

PSCAD simulations with a total simulation time of 25 seconds are performed with three-phase to ground faults applied at 10 seconds. For the simulated P3 planning event, it is assumed that the KES is out of service before the fault happens. Simulation results for the P3 planning event are shown in Figure 23 and for the P5 planning event are shown in Figure 24.

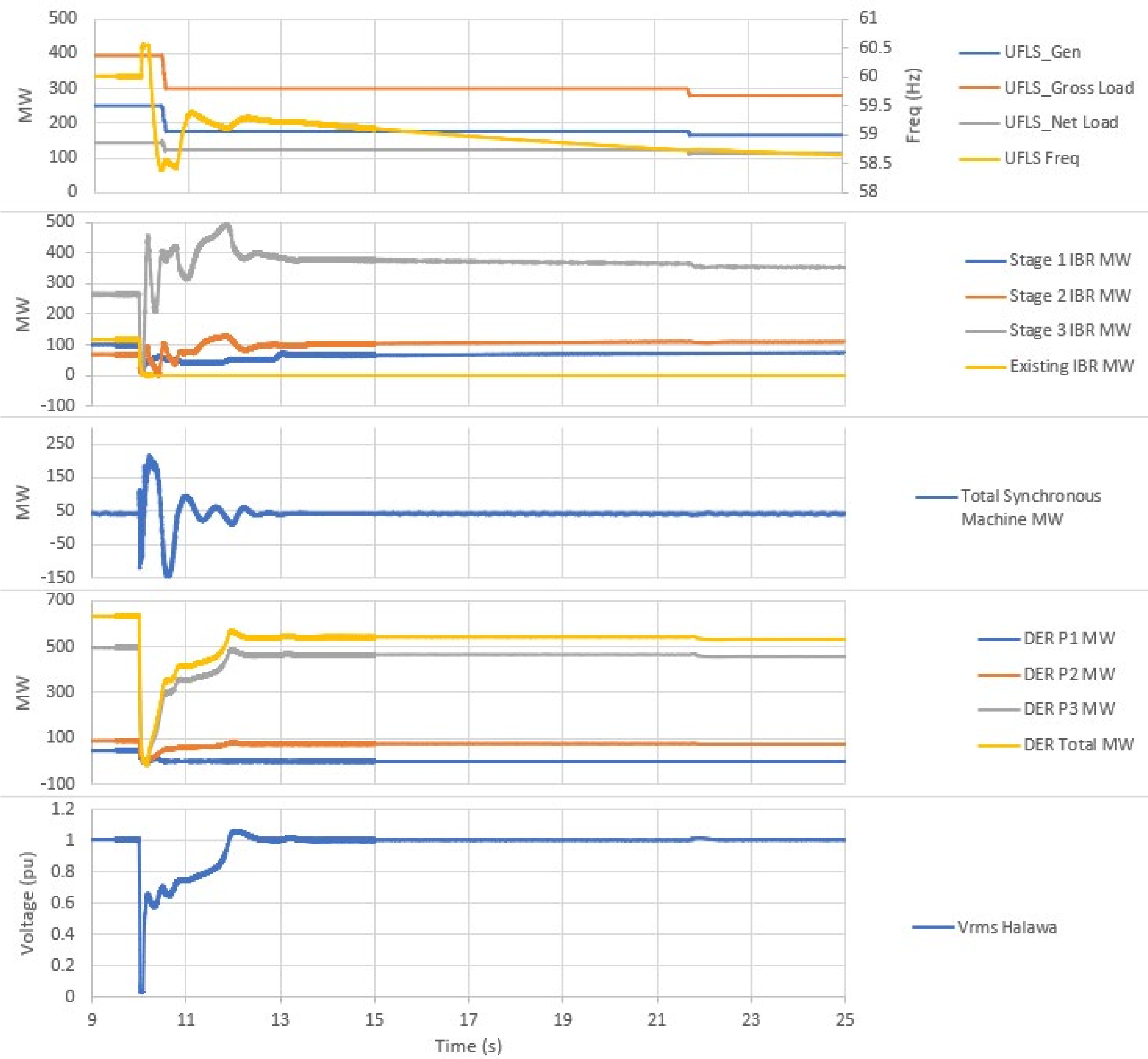


Figure 23 Dynamic stability simulation results, O'ahu base scenario resource plan, year 2027, P3 planning event

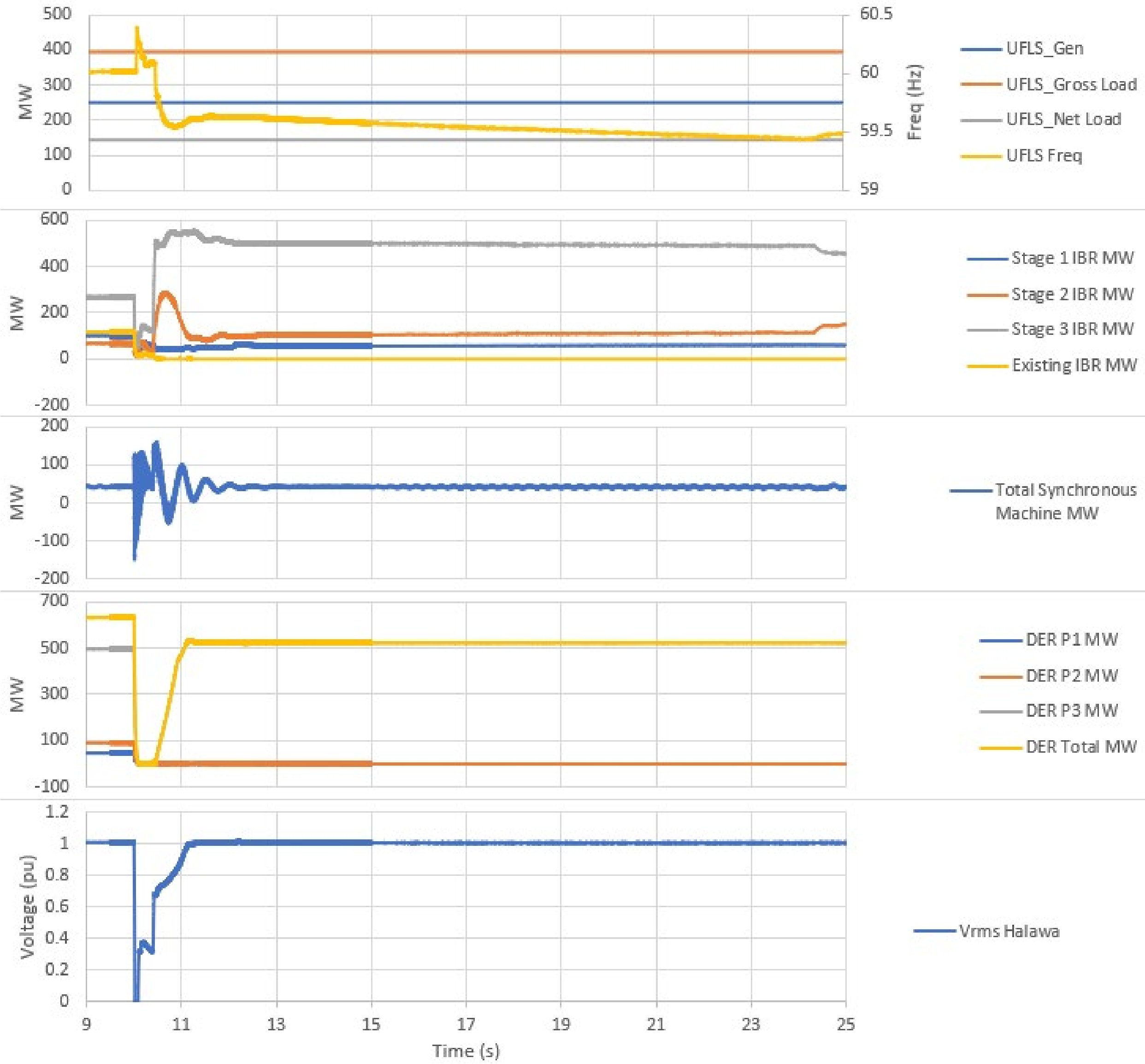


Figure 24 Dynamic stability simulation results, O'ahu base scenario resource plan, year 2027, P3 planning event

The PSCAD simulation results indicate two stages of UFLS in the P3 planning event, which is a severe planning criteria violation. Acceptable dynamic stability performance is observed in the P5 planning event. In the P3 planning event, frequency nadir reaches below 58.5 Hz; however, in the P5 planning event, frequency nadir still maintains above 59.5 Hz, which indicate sufficient stability margin during the event. The results comparison between the studied P3 planning event and the studied P5 planning event indicates the P3 planning event poses higher stability risk to the O'ahu system.

According to the past studies, maintaining available contingency reserve in the form of MW headroom (i.e., contract MW capacity minus dispatched MW generation) on GFM resources is critical for maintaining system stability and avoiding excessive UFLS. To mitigate the planning criteria violation identified from the P3 planning event, system generation is re-dispatched by turning on more synchronous machine-based generation and reducing the dispatch of the Stage 2 and 3 project GFM generation to ensure contingency reserve from GFM resources. The re-dispatched system generation dispatch is shown in Table 64. After the re-dispatch, system available MW headroom from GFM resource (excluding KES) over DER generation increase to 0.5 from the previous 0.3. The P3 planning event results with this updated system generation dispatch. Simulation results are shown in Figure 25. For GFM provided from paired energy resources, operational interfaces to support management of contingency reserve may be require additional consideration over that considered in the present requirements. The simulation results indicate that after the system generation re-dispatch (i.e., dispatching more synchronous machine generation to provide contingency reserve from GFM resources), system stability can be maintained within planning criteria. However, system frequency nadir is still below 59 Hz (the triggering point of the first stage of the instantanous UFLS is 58.9 Hz), which indicates very limited stability margin of the system during the simulated system event.

It is worth noting that even though the minimum contingency reserve has been defined as a ratio of available MW headroom from GFM resources over DER generation, to achieve the desired ratio required more synchronous machine-based resources be online in order create the reserve headroom on GFM, assuming the available GFM IBR in the resource plans. Therefore, the results represent the response of the increased GFM contingency reserve and required online synchronous machine-based resources which also provide effective contribution toward maintaining system stability. It is possible that adding more GFM resource into the resource plans may provide the needed system stability without requiring operation of synchronous machines; this could be confirmed through additional study.

Table 64 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Base Scenario Resource Plan, Year 2027

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
H-Power, KPLP	168	13	277
Waiver Standalone PV	117	17	168
Stage 1 PV/BESS (GFL)	101		140
KES (GFM)	0	17	135
Stage 2 PV/BESS (GFM)	0		94
Stage 3 PV/BESS (GFM)	209		450
Wind	0	0	123
DER	670	53	1,004
System Load (MW)	1,265		
GFM MW Headroom (Excluding KES)/DER Generation	0.5		

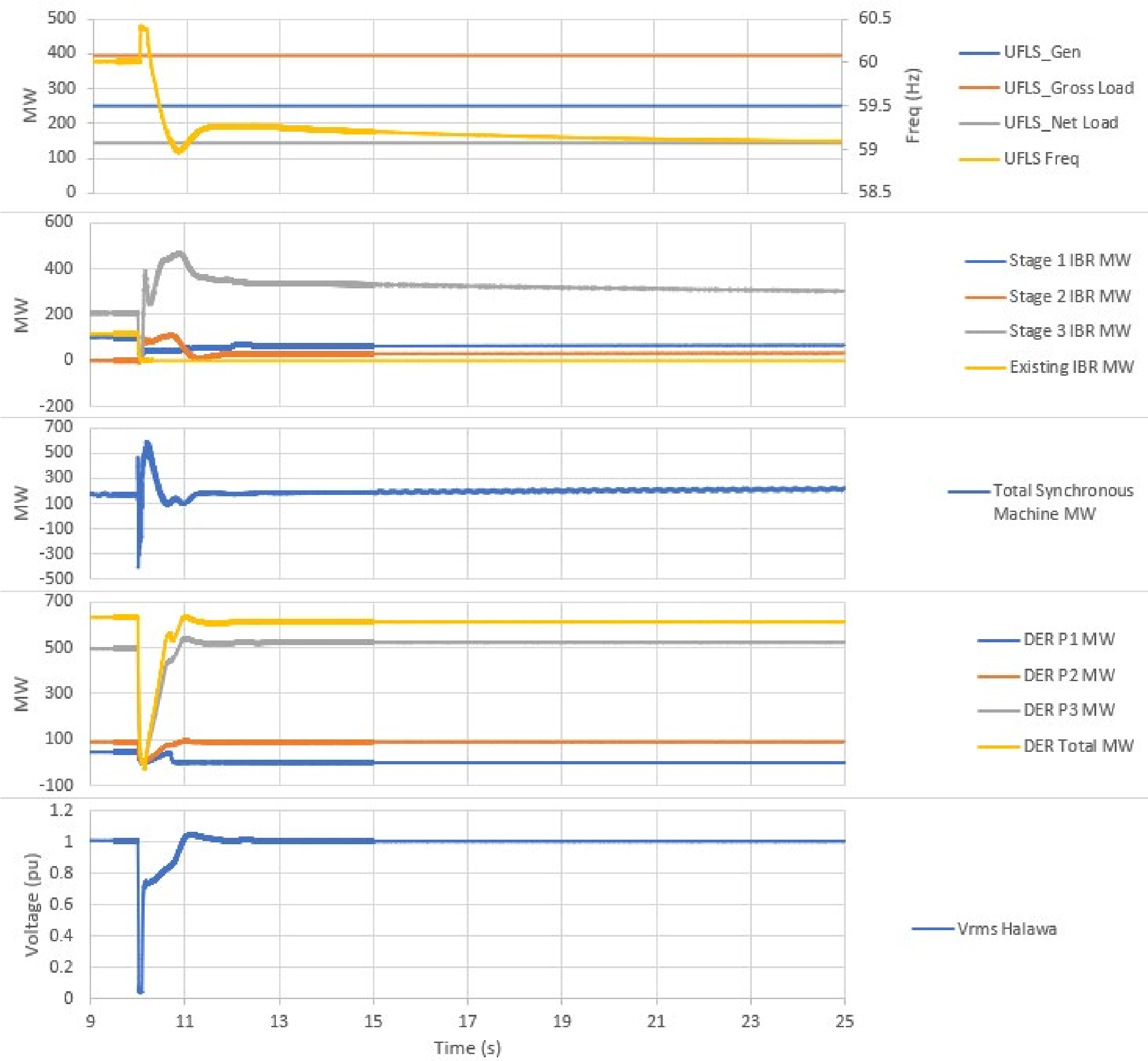


Figure 25 Dynamic stability mitigation study results, O'ahu base scenario resource plan, year 2027, P3 planning event, with system re-dispatch

Base scenario resource plan, year 2035

Study descriptions and study results

According to the resource plan, a system generation dispatch that represents daytime peak load with high DER generation scenario for 2035 is created (as Table 65) and modeled in PSCAD/EMTDC. In this dispatch, due to the REZ development and new grid-scale standalone BESS interconnected to the system, the O'ahu system has much more grid-forming resources than in 2027. The ratio of available MW headroom from GFM resources (exclude KES) over DER generation reaches 1.65. The P3 planning event is simulated in this system model, and results are shown in Figure 26.

Table 65 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O’ahu Base Scenario Resource Plan, Year 2035

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
H-Power	47	3	68.5
Waiver Standalone PV	117	10	168
Stage 1 PV/BESS (GFL)	19		140
KES (GFM)	0	13	135
Stage 2 PV/BESS (GFM)	13		94
Stage 3 PV/BESS (GFM)	167		450
REZ	148	11	1,053
New Standalone BESS (GFM)	0	0	147
Wind	0	0	123 + 400
DER	858	63	1,295
System Load (MW)	1,369		
GFM MW Headroom (Excluding KES)/DER Generation	1.65		

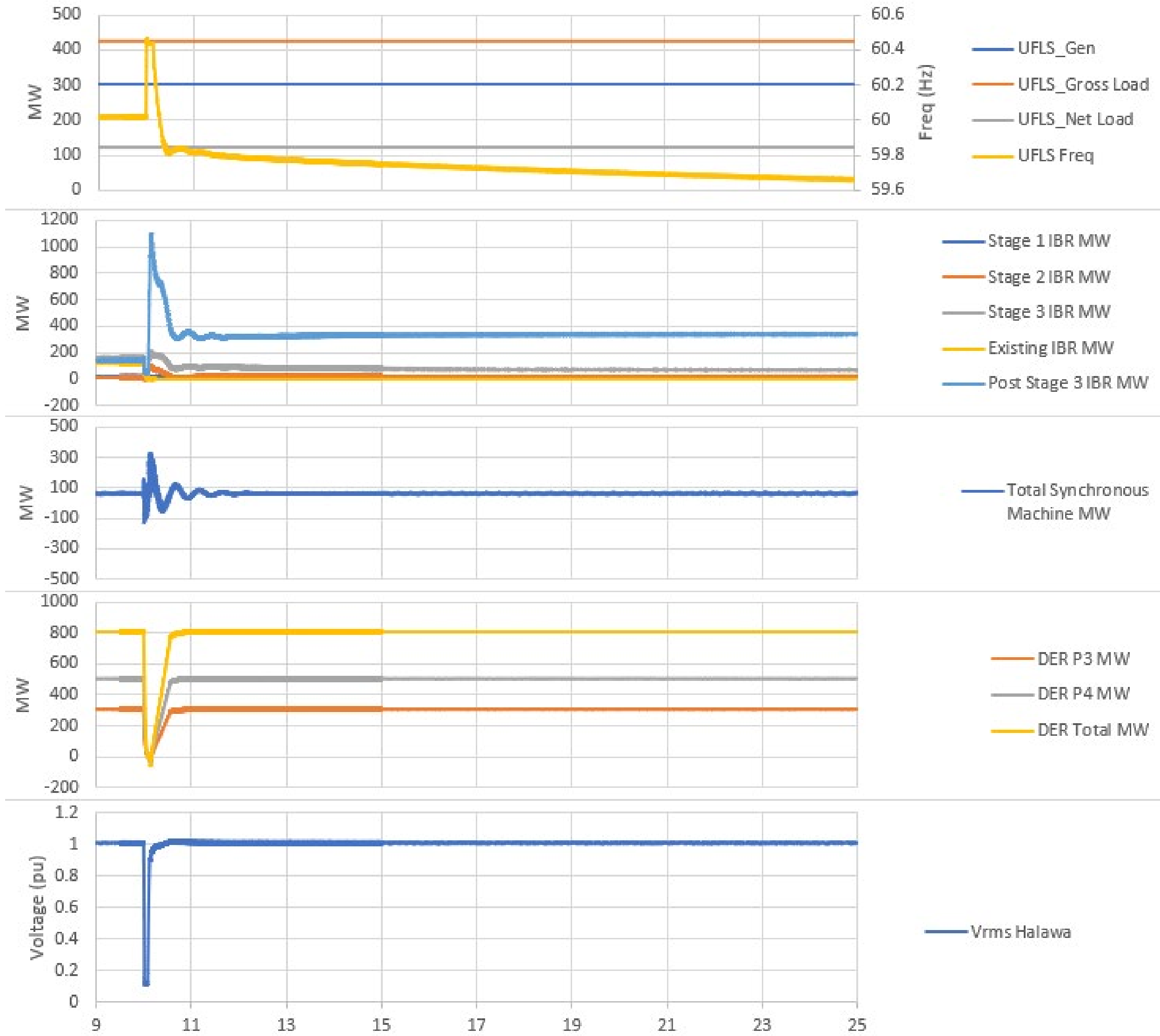


Figure 26 Dynamic stability study results, O'ahu base scenario resource plan, year 2035, P3 planning event

Simulation results indicate that the O'ahu system stability performance is within planning criteria limit and has sufficient stability margin.

Land constrained scenario resource plan, year 2035

Study descriptions and study results

In the land constrained scenario resource plan, it is assumed that the REZ development will not happen. Instead, after the RFP Stage 3 GCOD, grid-scale resources will be only offshore wind and standalone BESS. Since at the time of performing this study, offshore wind GFM technology is not commercially available, it is assumed that the offshore wind will not provide GFM type stability response in the study scope. According to the resource plan, a system generation dispatch that represents daytime peak load with high DER generation scenario for 2035 is created (as Table 66) and modeled in PSCAD/EMTDC. The P3 planning event is simulated in this system model, and results are shown in Figure 27.

Table 66 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu Land Constrained Scenario Resource Plan, Year 2035

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
H-Power	68	5	68.5
Waiver Standalone PV	117	14	168
Stage 1 PV/BESS (GFL)	79		140
KES (GFM)	0	22	135
Stage 2 PV/BESS (GFM)	52		94
Stage 3 PV/BESS (GFM)	243		450
New Standalone BESS (GFM)	0	0	147
Wind	0	0	123 + 509
DER	810	59	1,295
System Load (MW)	1,369		
GFM MW Headroom (Excluding KES)/DER Generation	0.44		

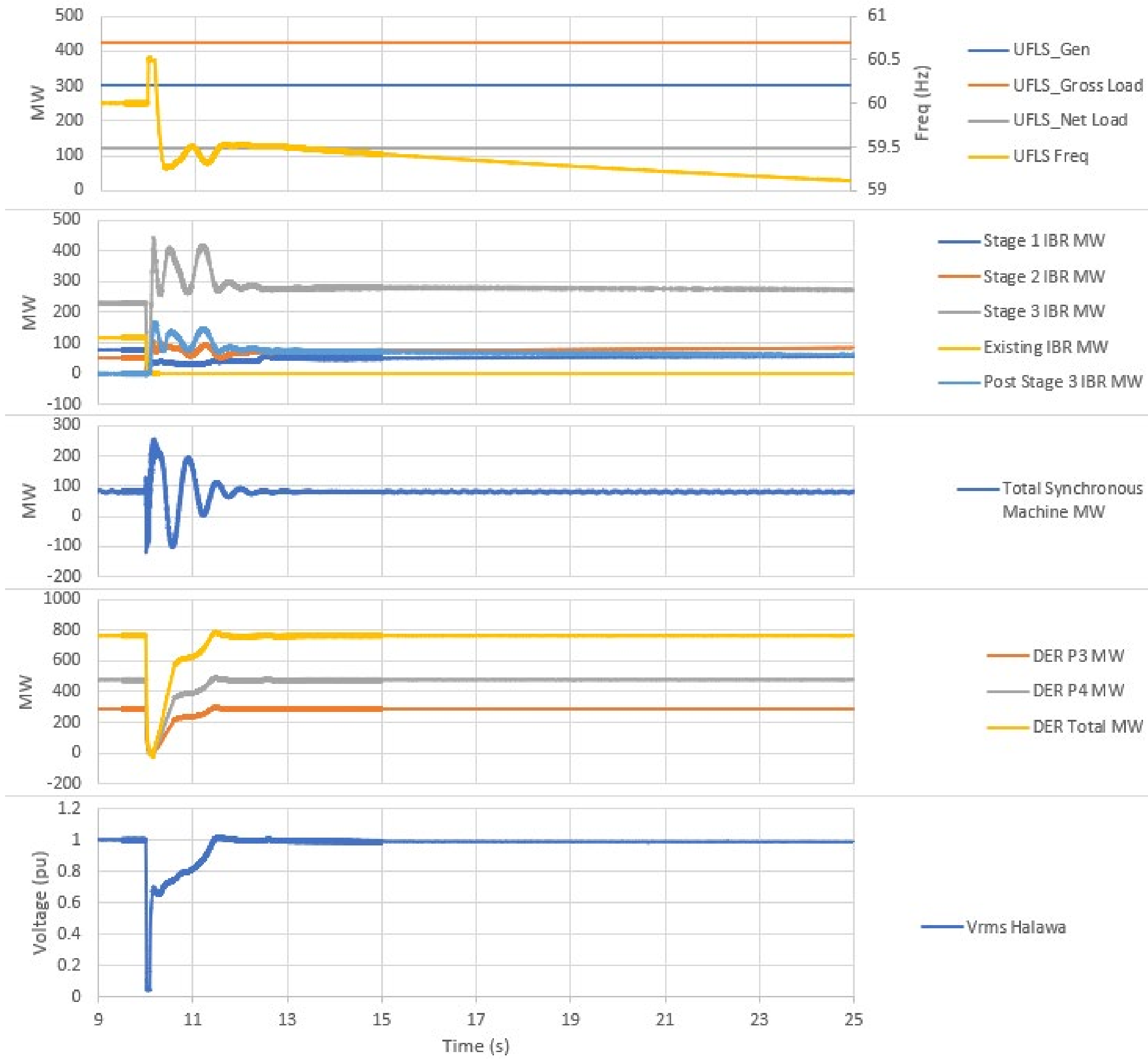


Figure 27 Dynamic stability study results, O'ahu land constrained scenario resource plan, year 2035, P3 planning event

UFLS is not identified from the 25 seconds simulation results, which means system stability performance stays within the planning criteria. However, a trend of decling frequency is observed. This trend is caused by the faded virtual inertia response from the online GFM resources which reaches their steady state generation limit. Considering the trend of the frequency, without adding more active power generation to the grid, the frequency my trigger the kicker block or the first block of UFLS if the simulation time is longer than 25 seconds.

To better understand the stability margin of the study case for the year 2035 in the land constrained scenario resource plan, the same P3 planning event is simulated with one more GFM resource offline due to maintenance prior to the system event. In this case, the ratio of available MW headroom from GFM resources over DER generation reduces to 0.36 from 0.44. Simulation results are shown in Figure 28.

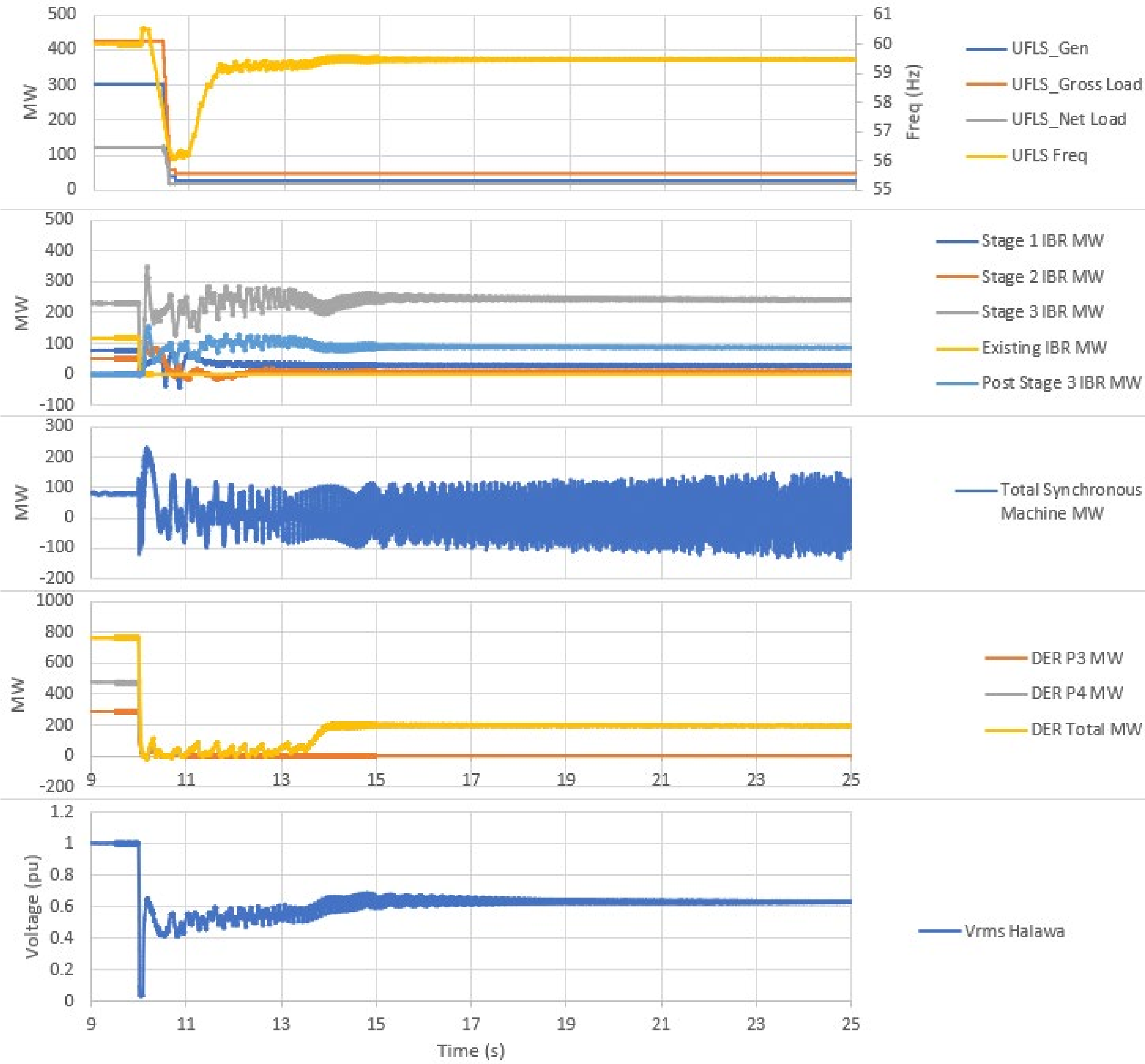


Figure 28 Dynamic stability study results, O'ahu land constrained scenario resource plan, year 2035, P3 planning event, with one more GFM resource out-of-service

For the examined case, system collapse was observed. These results indicate that even though for a regular P3 planning event the system does not have any UFLS load shedding (as Figure 27), the system would not survive the same fault with one more GFM resource pre-event outage. Therefore, system stability margin is limited and a higher ratio of available MW headroom from GFM resource over DER generation is required.

During the Stage 3 Quick Stability Study, a PSCAD simulation was performed for system generation dispatch with daytime peak load high DER generation in 2030 with a P3 planning event. The system generation dispatch is created according to an outdated land constrained scenario resource plan which has more grid-scale standalone BESS resources and achieve 0.7 of avaiable MW headroom from GFM resource over DER generation. This can be observed by comparing the system generation dispatch (in Table 67) studied in the Stage 3 Quick Stability Study and the dispatched studied in the current 2022

IGP system security study (shwon in Table 66). The simulation results obtained in the Stage 3 Quick Stability Study are shown in Figure 29, which indicates system stability performance within planning criteria and sufficient stability margin.

Table 67 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, O'ahu land constrained scenario resource plan (GNA Stage 3), year 2030

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
H-Power, New Firm (assumed as LM6000 unit)	102	8	211
Waiver Standalone PV	117	10	168
Stage 1 PV/BESS (GFL)	11		140
KES (GFM)	0	20	135
Stage 2 PV/BESS (GFM)	0		94
Stage 3 PV/BESS (GFM)	262		450
New Standalone BESS (GFM)	0	0	321
Wind	15	1	123 + 509
DER	770	60	1,030
System Load (MW)	1,279		
GFM MW Headroom (Excluding KES)/DER Generation	0.7		

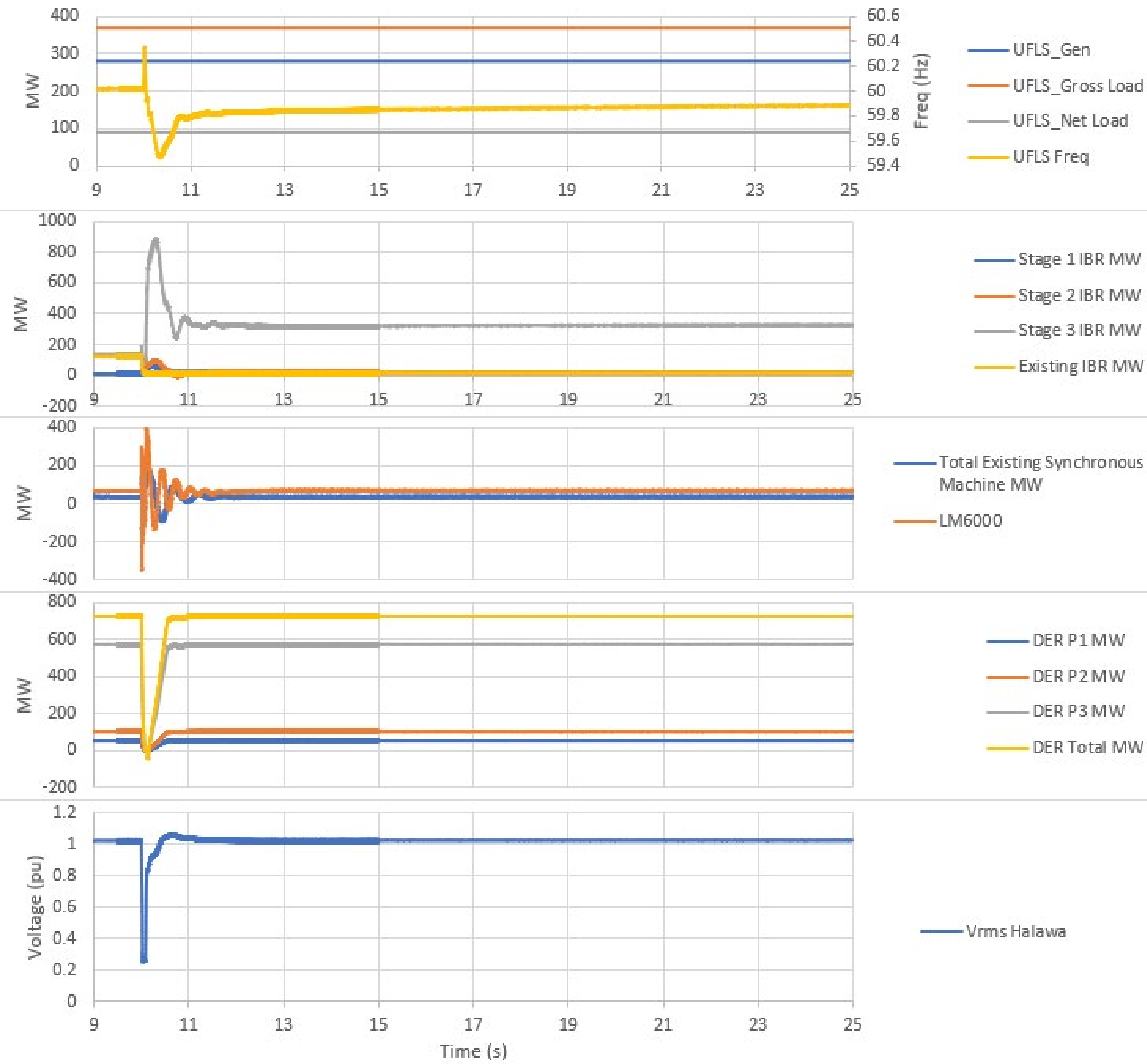


Figure 29 Dynamic stability study results, O'ahu land constrained scenario resource plan (GNA Stage 3), year 2030, P3 planning event

In addition to short term frequency stability, the systems voltage recovery performance post fault clearing is also analyzed by comparing the rms voltage at the Halawa bus from all forementioned simulation cases for the P3 planning event. Generally, with faster voltage recovery, generation resources can recover to pre-disturbance generation levels faster and the system has better stability performance as well as a lower chance of having fault induced delayed voltage recovery ("FIDVR"). The comparison is shown in Figure 30, which illustrates different system voltage recovery performance under different amount of available grid forming resources. With more available GFM resources (i.e., higher the ratio of available MW headroom from GFM resource over DER generation), system voltage recovery is faster. The fewer GFM resource, voltage recovery is slower. Once the recovery time is beyond a certain limit, system will have high risk of not being able to recover voltage post fault clearing, which means system collapse. Based on this observation, and past studies, it is recommended that at any time for O'ahu system the ratio of available MW headroom from GFM resources over DER generation should be no lower than 0.7.

It is important to point out that in addtion of fast active power injection, using GFM resouces to provide fast reactive current support during systme fault and post-fault clearing stage will be more and more important when more synchronous generation resouces are displaced by grid-scale IBR and DER resouces. This is not only for O‘ahu system, but applicable for all five island systems. With further studies, the detailed reactive current injection requirement will be added into the GFM functions and capability requirement in future generation resouce procurement.

This study assumes that the GFM resources have adequate energy (MWh) to support and ride through the examined contingencies. Additionally, because of existing limitations in the "state of the art" of EMT modeling of IBR the DC energy source representation is idealized for the GFM resources. To provide adequate dynamic support the GFM resources should be operated to maintain adequate energy (MWh) to respond to system events.

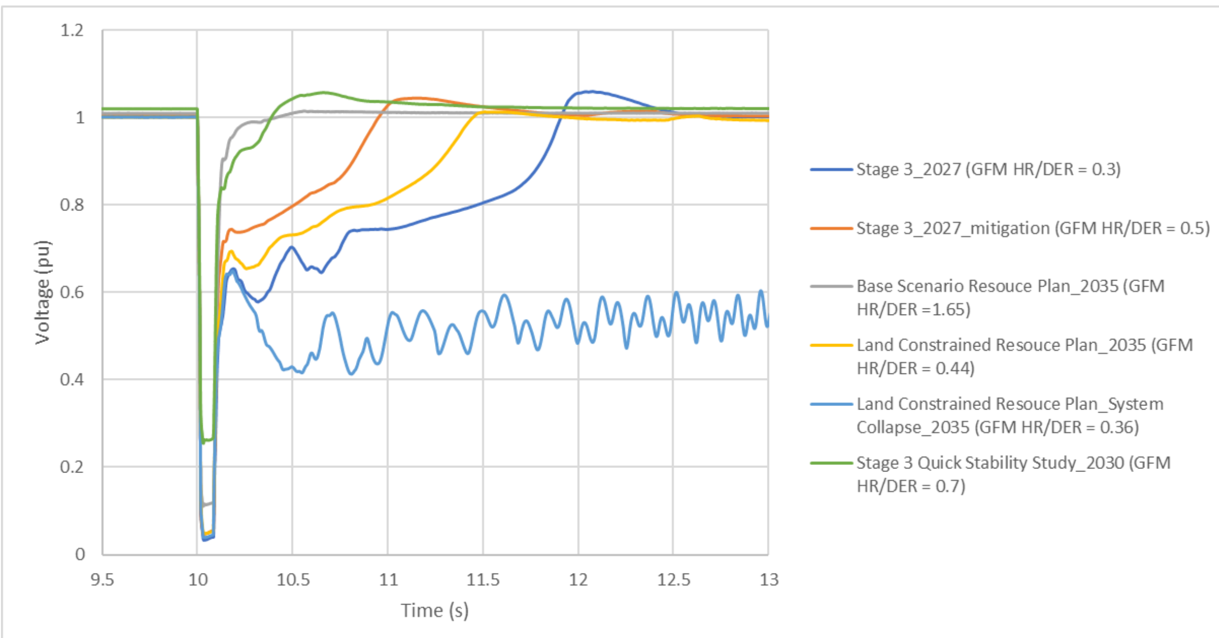


Figure 30 Comparison of system voltage recovery performance post fault clearing

4.2. Maui System Study Results

4.2.1 Steady state analyses

Base scenario resource plan, year 2027

Study descriptions

By 2027, the Maui system will have new generation from Stage 3 RFP procurement which will be 171 MW RDG and 36 MW firm generation, interconnected to Maui 69 kV system. Meanwhile, by 2027, the Maui system will finish Waena switchyard construction, Kahului Power Plant ("KPP") retirement and conversion of KPP K3 and K4 units to synchronous condensers, and Maalaea Power Plant (“MPP”) unit 10-13 retirement. The system peak load is forecasted to reach 207 MW by 2028. High-level locations of the RFP Stage 3 projects assumed in the study and planned REZ zones are shown in Figure 31. It is assumed in the study that the RFP Stage 3 projects will be interconnect at Lahainaluna substation (60 MW), MPP-Waiinu line (30 MW via a new substation STG 3.1), MPP-Lahainaluna line (30 MW via a new substation STG 3.2), KWP 1 substation (30 MW) and Kealahou substation (21 MW). The 60 MW line interconnection generation is shown in a high-level one line diagram as Figure 32. The 36 MW firm generation is assumed to be interconnected at Waena switchyard. The detailed system grid-scale resources changes are summarized in Table 68 and Table 69. By 2028, system annual peak load forecast is 207 MW, which is used for the study for this year. System resource summary and the forecasted system load is summarized in Table 70.

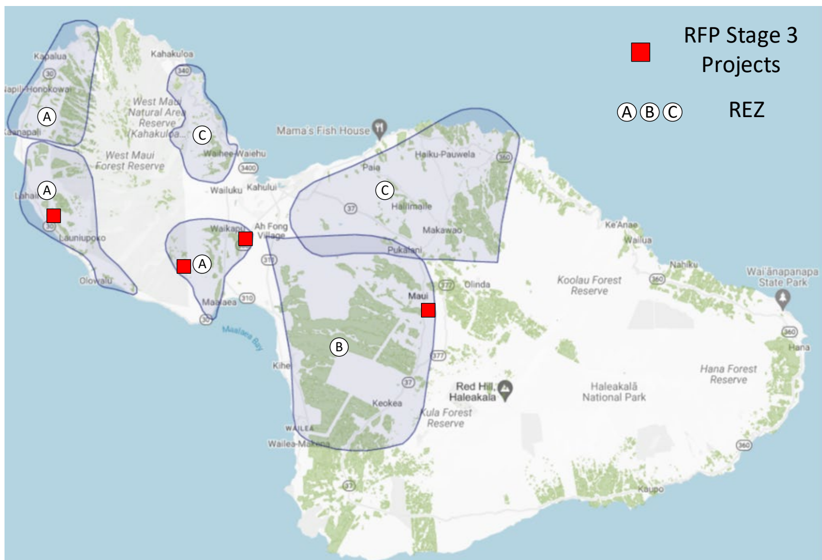


Figure 31 High-Level Maui map for assumed RFP Stage 3 project locations by 2027

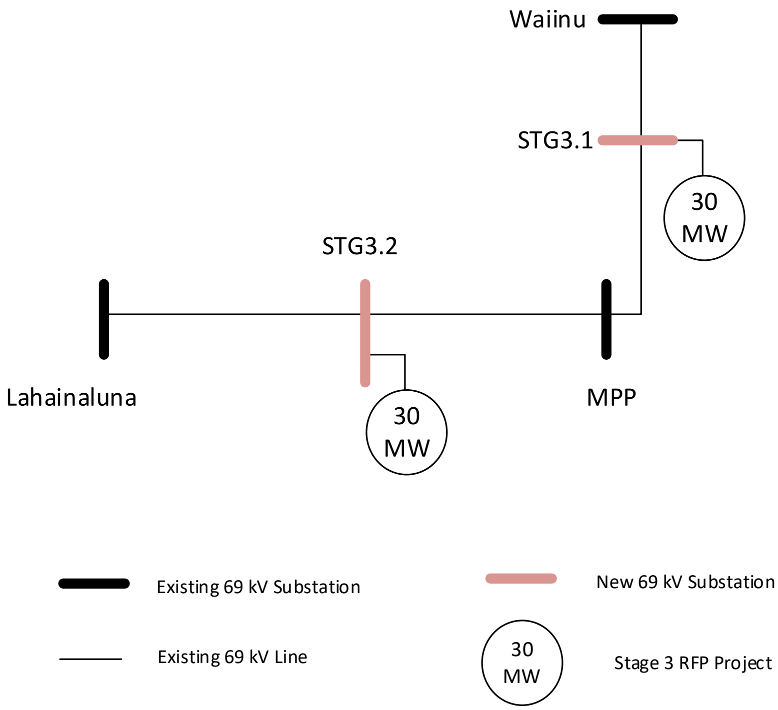


Figure 32 High-Level single line diagram for the two line interconnection RFP Stage 3 projects, Maui system base scenario resource planning, year 2027

Table 68 Maui Grid-Scale Generation Project Development by 2027, after RFP Stage 2, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Maui RFP	Renewable Dispatchable Generation	171	2027	West Maui, Central Maui and South Maui
	Firm Generation	36	2027	Central Maui

Table 69 Maui Grid-Scale Generation Removal by 2027

Removal	Generation Type	MW Capacity	Year	Location
Kaheawa Wind Power 1	Wind Generation	30	2027	KWP 1 substation
Kahului 1-4	Fossil Generation	32.5	2027	Kahului Power Plant
Maalaea 10-13	Fossil Generation	49.4	2027	Maalaea Power Plant

Table 70 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2027

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
197.5	42	296	40	170.7	207

Table 71 summarizes studied system generation dispatches for the 2027. The studied dispatches represent all possible combinations of differnt REZ zones supplying Maui system load.

Table 71 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2027

Aggregated Generation Capacity Rating (MW)		Zone A	Zone B*	Zone C*	Zone A+C	All Zones
Zone A	161	161	0	0	160	70
Zone B	313.5	46	207	106	0	70
Zone C	101	0	0	101	101	67
Total Load	207	207	207	207	207	207

*Studied variation of dispatches in the zone

Study results

Power flow simulations are performed for all stuided system generation dispatches with normal system configuration and N-1 contingency configurations. From the study results for system with normal configuration, there are no steady state voltage planning criteria violations or transmission element loading violations. For the system with N-1 contingency configurations, transmission line overloadng is identified, which is shown as percentage of conductor emergency rating. Steady state voltages are within planning criteria acceptable limits. A brief summary of identified overloading results are listed in Table 72.

Table 72 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2027

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Overloading Element	Max. Loading (%)	Overloading Element	Max. Loading(%)
Zone A	None		Lahaina-Lahainaluna 69kV Line	126
Zone B_1	None		None	
Zone B_2	None		None	
Zone C_1	None		None	
Zone C_2	None		Wailea-Auwahi 69kV Line	102
Zone A+C	None		None	
All Zones	None		None	

Mitigation study – transmission networks expansion

To mitigate the transmission line overloading conditions listed above, reconductoring of the overloading transmisison lines is proposed. The interconnecting 60 MW at the Lahainaluna substation in west Maui would also result in a Single Point of Failure MW value of 60 MW occurring when the MPP-Lahaina line is out of service. To solve this issue, it is propsed to add a normally closed circuit breaker at Mahinahina Substation to connect the west Maui Lahainaluna-Mauka and Lahainaluna-Makai two radial lines as a normal closed loop. A list of transmission networks expansion proposed for Maui system is listed in Table 73. A high-level one line diagram in Figure 33 demonstrates the proposed transmission networks expansion.

Table 73 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2027

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line	Upgrade Type	Conductor Requirements	
Lahaina-Lahainaluna	Re-conductor	One circuit, re-conductor to 556 AAC	2.5

Waena-Kanaha	Re-conductor	One circuit, re-conductor to 556 AAC	6.1
Wailea-Auwahi	Re-conductor	One circuit, re-conductor to 556 AAC	1.8
Mahinahina Substation	Expand West network	Install one 69kV circuit breaker	2.7

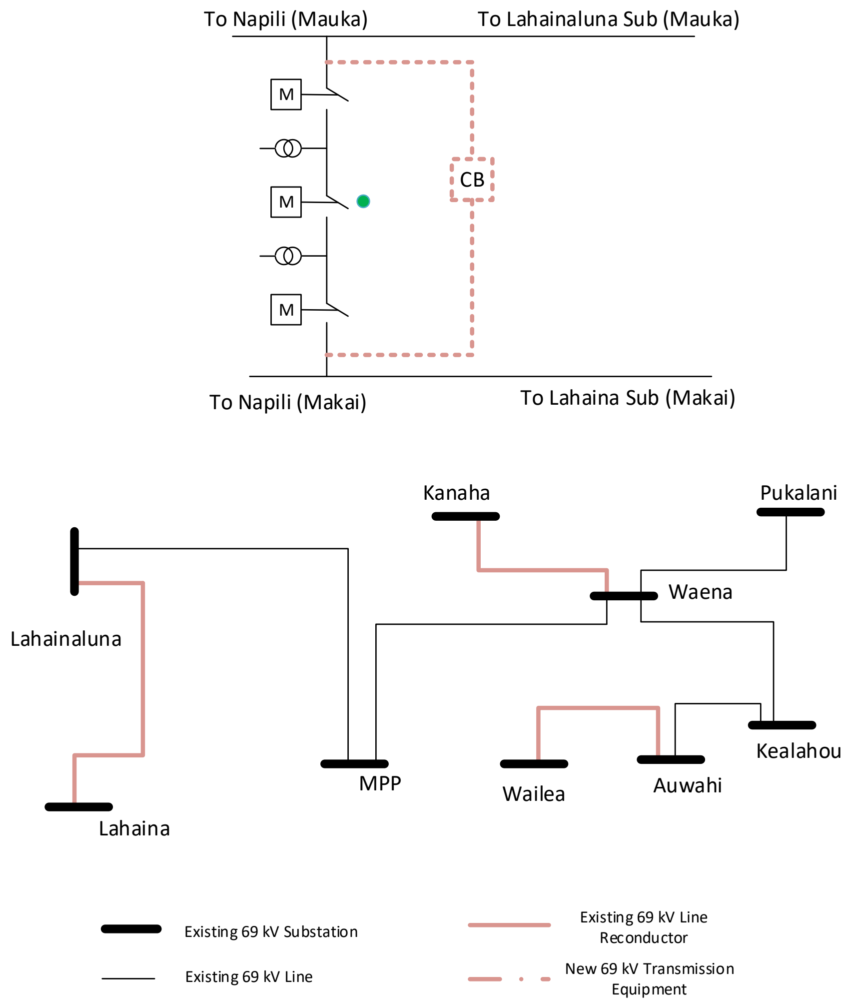


Figure 33 High-Level single line diagram for proposed transmission networks expansion, Maui base scenario resource plan, year 2027

Mitigation study – portfolio alternatives and non-wire solutions.

The transmission line Lahiana-Lahainaluna reconductoring work could be avoided by reducing MW interconnection total at the west Maui side (at Lahainaluna substation, KWP 1 substation, Lahainaluna-MPP line interconnection) by 24 MW. Waena-Kanaha and Wailea-Auwahi reconductor can be avoided by reducing the interconnection total at Waena switchyard and Kealahou substation by 18 MW. Reducing MW interconnections in these locations would require additional procurements somewhere else in the system, which, depending on size and location, might also require new or upgraded transmission. There is no non-wire alternative solution for deferring adding a circuit breaker in the Mahinahina substation to close west Maui loop.

REZ enablment

There is no REZ development by 2027, hence, there is no REZ enablement cost estimate.

Base scenario resource plan, year 2035

Study descriptions

In addtion to previous system resource changes by 2027, the Maui system resource plan provides 66 MW grid-scale onshore wind generation and 37 MW PV/BESS generation as addtional generation interconnected at Maui transmission system by 2035. This new generation will be developed in the Maui REZ zone C. Also, it is planned that the MPP unit 1 to 9 will be removed by 2030 and wind power generation KWP 2 and Auwahi will be retired by 2033. The system annual peak load is forecasted to reach 235 MW by 2036. A high-level Maui system map with locations of the RFP Stage 3 projects assumed in the study and developed REZ zones by 2035 is shown in Figure 34. In the total 103 MW new grid-scale generation project from the REZ zone C development, it is assumed that 60 MW generation will be interconnected at Waena switchyard, and the remaining 43 MW will be interconnected at a new substation REZ C.1 on the Waena-MPP line, which is shown as Figure 35.

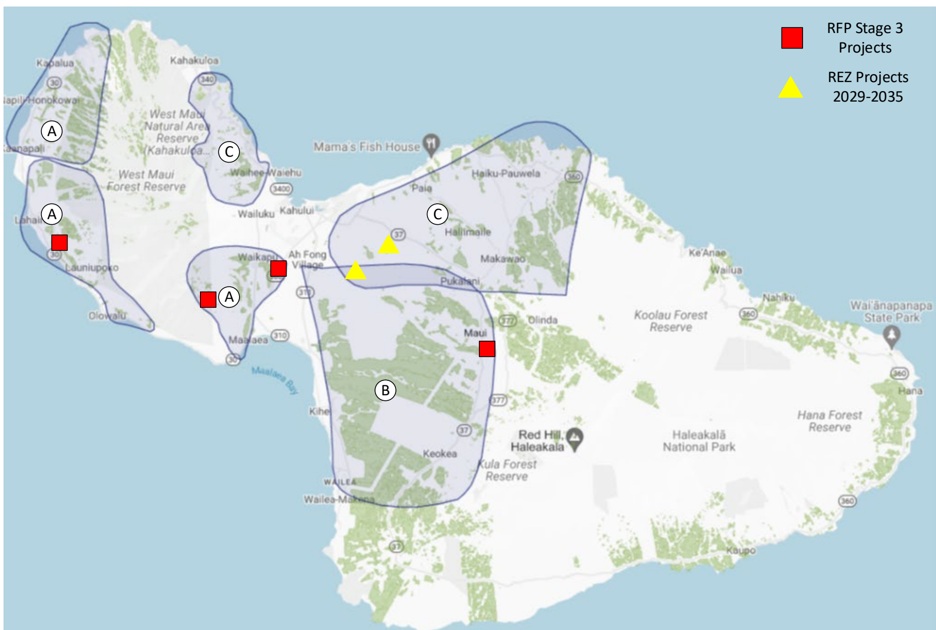


Figure 34 High-Level Maui map for assumed future grid-scale project interconnection locations by 2035

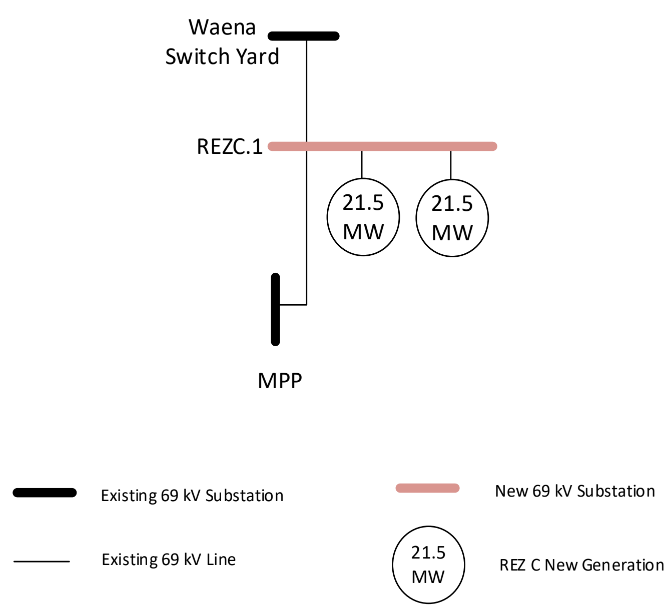


Figure 35 High-level single line diagram for the 43 MW line interconnection project, Maui base scenario resource planning, year 2035

The detailed system grid-scale resources changes are summarized in Table 74 and Table 75. System resource summary and the forecasted system load is summarized in Table 76.

Table 74 Maui Grid-Scale Generation Project Development between 2028 and 2035, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	5	2029	REZ Zone C
	Onshore Wind Generation	8	2030	REZ Zone C
	Onshore Wind Generation	53	2035	REZ Zone C
	Solar/BESS	37	2035	REZ Zone C

Table 75 Maui Grid-Scale Generation Removal between 2028 and 2035

Removal	Generation Type	MW Capacity	Year	Location
Maalaea Power Plant Units 1-9	Fossil	40.5	2030	MPP
Kaheawa Wind Power 2	Onshore Wind Generation	21	2033	KWP 2 Substation
Auwahi Wind	Onshore Wind Generation	21	2033	Auwahi Substation

Table 76 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2035

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	66	333	40	202	237

Table 77 summarizes studied system generation dispatches for the 2035. It is worth noting that the transmission networks expansion requirement identified in the 2027 study is assumed to be implemented before 2027 to mitigate the transmission line overloading issues.

Table 77 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2035

Aggregated Generation Capacity Rating (MW)		Zone A	Zone B	Zone C	Zone A+C	Zone B+C	All Zones
Zone A	140	140	0	0	118	0	77.5
Zone B	257	97	237	33	0	116	85.5
Zone C	204	0	0	204	119	121	74
Total Load	237	237	237	237	237	237	237

Study results

Power flow simulations are performed for all the system generation dispatches, for normal configuration and N-1 contingency configurations. Simulation results show that there is no transmission equipment overloading issue or steady state voltage planning criteria violation for the system with normal configuration. However, both transmission equipment overloading and undervoltage violations are identified for N-1 contingency configurations. In Table 78, a summary of overloading results is listed. There are three 69/23 kV tie transformers currently supplying the Maui system 23 kV networks. For the contingencies of losing one 69 kV feed for the tie transformers, the remaining two tie transformers have an overloading issue when they need supply all the 23 kV networks load. Additionally, this condition results in voltages outside planning criteria limits. An example shown in Figure 36 illustrates the tie transformer overloading issue and the undervoltage issue.

Table 78 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2035

Generation Dispatch	N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)
Zone A	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	112
Zone B	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	112
Zone C	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	111
Zone A+C	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	108
Zone B+C	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	109
All Zones	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	109

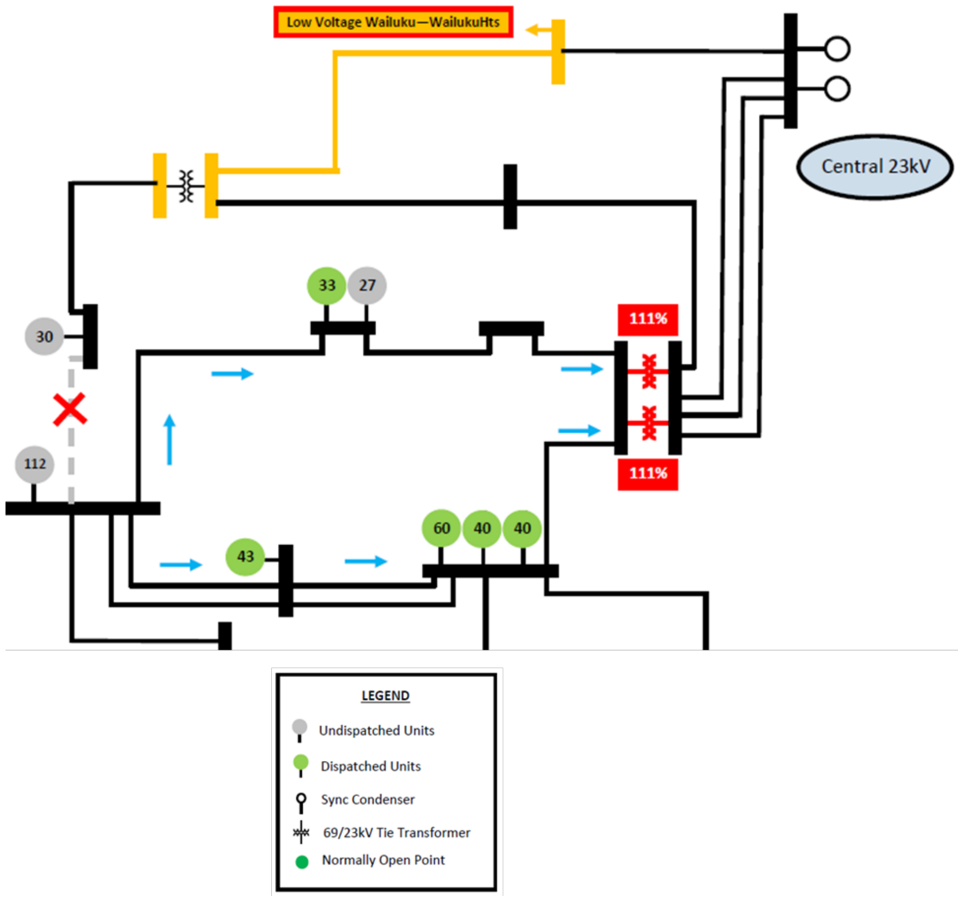


Figure 36 Overloading on tie transformers and undervoltage in 23 kV networks when losing one 69 kV feed for the 23 kV networks

Mitigation study – transmission networks expansion

To mitigate the tie transformers' overloading issue and the 23 kV networks undervoltage issue, it is proposed to add another 69 kV line between MPP and STG 3.1 substation, and from STG 3.1 to Waiinu substation. It is worth noting that there are other options to mitigate the tie transformers' overloading issue and the 23 kV networks undervoltage issue, such as replacing the tie transformers or adding generation in the 23 kV networks. Adding this new line can remove losing the 69 kV feed for the 23 kV networks from the N-1 contingency list and allow for increased future grid-scale generation interconnecting to the Maui transmission system via the STG 3.1 substation.

It is also proposed that a new line is added between Waena switchyard and MPP as well as adding a new substation, REZ C.1, interconnecting both lines between the Waena switchyard and MPP. This new substation also can be used for future grid-scale generation interconnection in the REZ development.

All aforementioned mitigation solutions are illustrated in Figure 37. Cost estimate for the proposed solution is listed in Table 79.

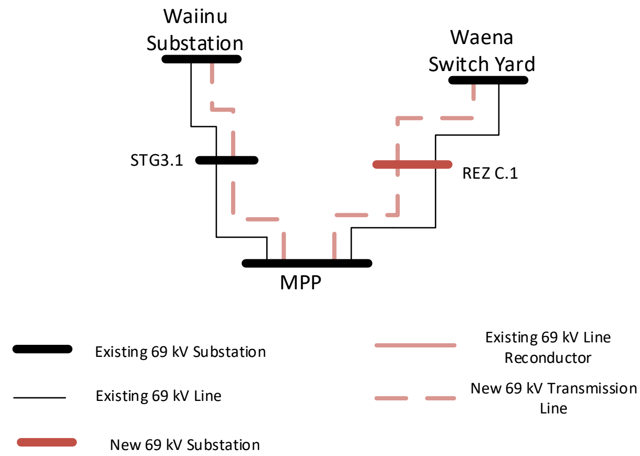


Figure 37 Proposed Maui transmission networks expansion, Maui base scenario resource plan, year 2035

Table 79 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2035

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
MPP – REZC.1 Sub – Waena	New Transmission Line	One circuit, 556 AAC	25.0
MPP Substation	New Transmission Line	Install One 69kV circuit breaker	2.9
REZ C.1 Substation	New Substation	Adding 3 BAAH Bays less 2 breakers	27.7
1 BAAH Bay in Waena	Adding 1 BAAH Bay	Adding 1 BAAH bay less 1 breaker	6.7
MPP – STG3.1 – Waiinu	New Transmission Line	One circuit, 336 AAC	18.4
MPP Substation	New Transmission Line	Install One 69kV circuit breaker	2.9
STG3.1 Substation	Adding 1 BAAH Bay	Adding 1 BAAH Bay	9.6
Waiinu Substation	New Transmission Line	Install One 69kV circuit breaker	2.9

Mitigation study – portfolio or non-wires solutions

Considering that the proposed portfolio additions are critical to meet the transformation goals, and the new lines and substations are critical to reliably interconnect these future grid-scale generation projects, there were no portfolio or non-wire alternatives identified in this study.

REZ Enablement

According to the resource plan, total 103 MW grid-scale generation from REZ zone C development will be interconnected to the Maui transmission system by 2035. It is assumed that 43 MW will be interconnected at the new substation REZ C.1, and remaining 60 MW will be interconnected at the

Waena switchyard. The 60 MW Waena switchyard interconnection enablement cost is $13.5 million. The estimate to allow 43MW interconnection at the new substation REZ C.1 cost estimate is $5.8 million. So, the total REZ enablement cost estimate is $19.3 million.

Base scenario resource plan, year 2040

Study descriptions

In 2040, another 61 MW REZ zone C development will be completed. It is assumed that 61 MW will be interconnected at Waena switchyard. Meanwhile, there will be retirement of existing 5.7 MW distribution interconnected PV. System annual peak demand is forecasted to reach 266 MW in 2041. A high-level Maui system map with locations of the future grid-scale project interconnection locations by 2040 are shown in Figure 38.

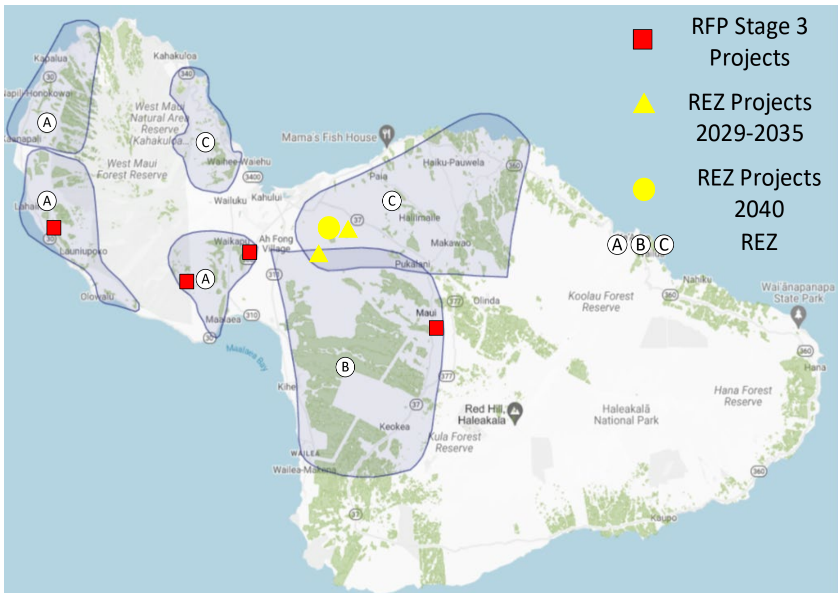


Figure 38 High-Level Maui map for assumed future grid-scale project interconnection locations by 2040

The detailed system grid-scale resources changes are summarized in Table 80 and Table 81. System resource summary and the forecasted system load is summarized in Table 82.

Table 80 Maui Grid-Scale Generation Project Development between 2036 and 2040, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	18	2040	REZ Zone C
	PV/BESS Generation	43	2040	REZ Zone C

Table 81 Maui Grid-Scale Generation Removal between 2028 and 2035

Removal	Generation Type	MW Capacity	Year	Location
Distribution Interconnected PV	Solar	5.7	2040	12 kV Distribution System

Table 82 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2040

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	84	376	40	218	266

Table 83 summarizes studied system generation dispatches for 2040. The transmission networks expansion requirement identified in the 2035 study is assumed to be implemented before 2035 to mitigate the transmission line overloading issues. Therefore, all the networks expansion listed in the Table 79 are included in the 2040 study models.

Table 83 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2040

Aggregated Generation Capacity Rating (MW)		Zone A	Zone B	Zone C	Zone A+C	Zone B+C	Zone A+B	All Zones
Zone A	140	140	0	0	134	0	140	85
Zone B	257	126	257	1	0	130	126	88
Zone C	265	0	9	265	132	136	0	93
Total Load	266	266	266	266	266	266	266	266

Study results

Results of power flow simulations for all the studied dispatches for system with both normal configuration and N-1 contingency configurations show undervoltage violation on Pukalani-Hana 23 kV circuit for both normal and N-1 contingency configurations and 69 kV transmission line overloading and high loading condition when system is with N-1 contingency configurations. The worst undervoltage violation is 0.75 p.u. during normal conditions and 0.67 p.u. during N-1 contingency. The undervoltage issue is caused by load growth on the Pukalani-Haiku 23 kV line. A summary of the 69 kV line overloading is provided in Table 84.

Table 84 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2040

Generation Dispatch	N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)
Zone A	Kealahou-Kamaole 69kV Line	97
Zone B	None	
Zone C	MPP-REZC.1 Ckt 1 or Ckt 2 69kV Line	114
Zone A+C	Kealahou-Kamaole 69kV Line	96
Zone B+C	None	
Zone A+B	None	
All Zones	None	

Mitigation study – transmission networks expansion

To mitigate the identified undervoltage issue, it is proposed to add one 3.6 Mvar (at 69 kV) capacitor bank at Keanae substation and another 3.6 Mvar (at 69 kV) capacitor bank at Kailua substaton. To mitigate the transmission line overloading issue, it is recommend to add one 69 kV line from MPP to the Waena switchyard via the REZ C.1 substation, which is shown in Figure 39. The high leve cost estimate for adding this new line is $51.9 million.

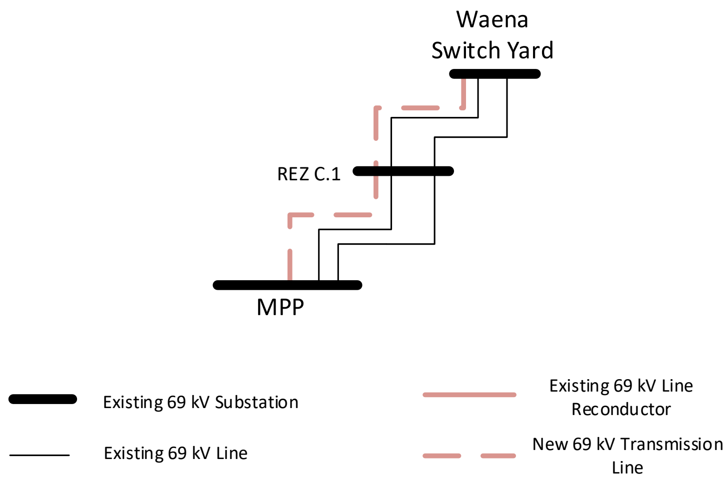


Figure 39 Proposed Maui transmission networks expansion, Mau i base scenario resource plan, year 2040

Mitigation study – portfolio mitigation

To defer the addtion of the new line from MPP to the Waena switchyard, would require 48 MW interconnection size reduction at the Waena switchyard. The needs for additional infrastructure for alternate resources would depend on the location(s).

REZ Enablement

According to the resource plan, total 61 MW grid-scale generation from REZ zone C development will be interconnected to the Waena switchyard. The 61 MW Waena switchyard interconnection enablement cost is $15.6 million.

Base scenario resource plan, year 2045

Study descriptions

Between 2041 and 2045, 66 MW PV/BESS generation and 41 MW onshore wind generation will be developed in REZ zone C; 15 MW PV/BESS generation will be developed in REZ zone B. Also, all the remaining fossil units will switch to biodiesel. The system annual peak demand is forecasted to reach 289 MW in 2046. A high-level Maui system map with locations of the future grid-scale project interconnection locations by 2045 are shown in Figure 40. Assumptions of future grid-scale generation interconnection locations are:

- Auwahi substation – 15 MW (REZ zone B)
- STG3.1 – 30 MW (REZ zone C)
- Kanaha substation (23 kV) – 30 MW (REZ zone C)
- New switching station, REZ C.2 (see Figure 41), on Waena-Kealahou line – 47 MW (REZ zone C)

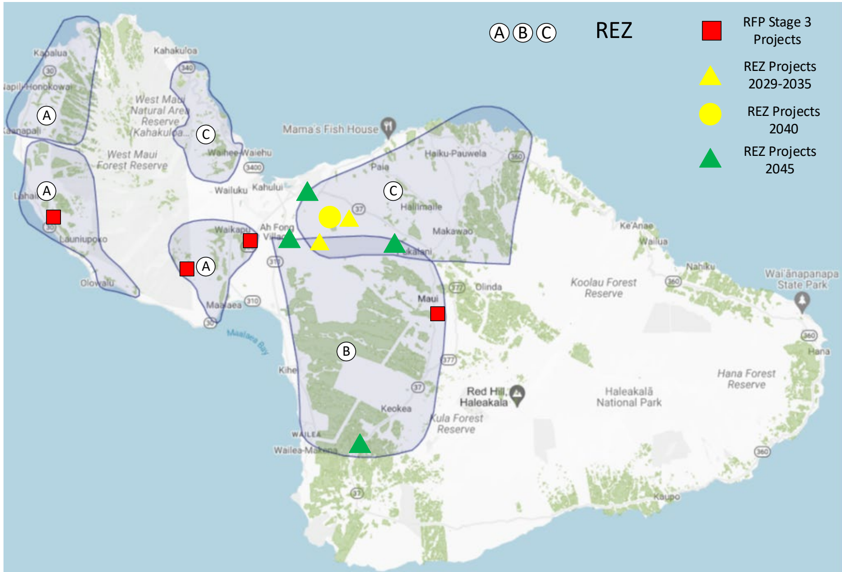


Figure 40 High-Level Maui map for assumed future grid-scale project interconnection locations by 2045

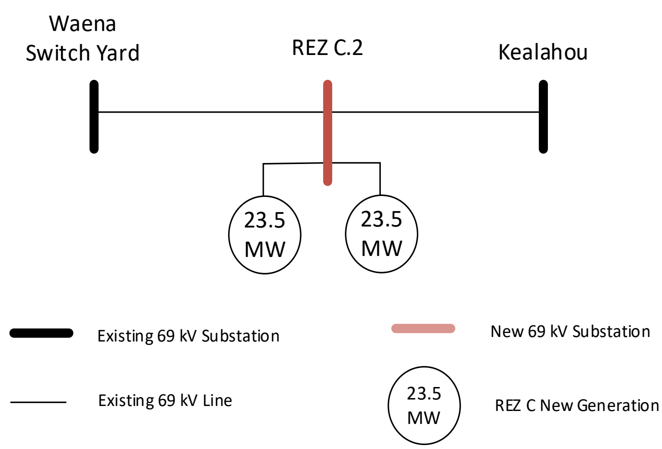


Figure 41 High-Level single line diagram for a new substation REZ C.2, Maui base scenario resource plan, year 2045

The detailed system grid-scale resources changes are summarized in Table 85 and Table 68. System resource summary and the forecasted system load is summarized in Table 86.

Table 85 Maui Grid-Scale Generation Project Development between 2041 and 2044, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	PV/BESS Generation	15	2045	REZ Zone B
	PV/BESS Generation	66	2045	REZ Zone C
	Onshore Wind Generation	41	2045	REZ Zone C

Table 86 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2045

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	125	457	40	229	289

Table 87 summarizes studied system generation dispatches for the 2045. It is worth noting that all the networks expansion identified in the 2040 study are included in the 2045 study models.

Table 87 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2045

Aggregated Generation Capacity Rating (MW)		Zone A	Zone B	Zone C	Zone A+C	Zone B+C	Zone A+B	All Zones
Zone A	140	140	0	0	140	0	140	93
Zone B	272	149	272	0	0	135	149	105
Zone C	372	0	17	289	149	139	0	91
Total Load	289	289	289	289	289	289	289	289

Study results

Power flow simulation results indicate 69 kV line overloading issue in all the studied system generation dispatch cases when system is with N-1 contingency configurations, which is shown in Table 88. These violations are caused by both system load increase and generation congestion. Voltage planning criteria violation is not identified in the study.

Table 88 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2045

Generation Dispatch	N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)
Zone A	Kealahou-Kamaole 69kV Line	102
Zone B	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	101
Zone C	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	101
Zone A+C	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	103
Zone B+C	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	101
Zone A+B	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	103
All Zones	MPP-Kaonoulu and Kaonoulu-Kihei 69kV Lines	103

Mitigation study – transmission networks expansion

To address the identified overloading issue, a set of mitigation solutions, including reconductor, adding new 69 kV line and substations are proposed. The proposed solutions are listed in Table 89 with high-level cost estimate and shown in Figure 42. The adding of new substatino REZ C.2 on the Waena-Kealahou line and REZ B.1 on south Maui provide benefit for the grid-scale generation projects interconnection between 2046 and 2050.

Table 89 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2045

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
Kamaole – Kealahou	Re-conductor	One circuit, re-conductor to 556 AAC	17.4
Waena – REZ C.2 – Kealahou	Add New Circuit	One circuit, 556 AAC	21.4
REZC.2 (Waena-Kealahou) Sub	New Substation	Adding 3 BAAH bays less 2 breakers	37.6
Waena Substation	Add new circuit	Install one 69kV circuit breaker	3.9
Kealahou Substation	Add new circuit	Add 1 BAAH bay less 1 breaker	9.9
New Substation REZ B.1	Adding a new 69 kV substation between Kihei substation and Wailea substation. • Add new substation (REZB.1) between Kihei Sub 35 and Wailea Sub 25 with (3) BAAH less 3 breaker.		32.5
MPP - REZ B.1	Adding New Circuit	One circuit, 556 AAC	42.0

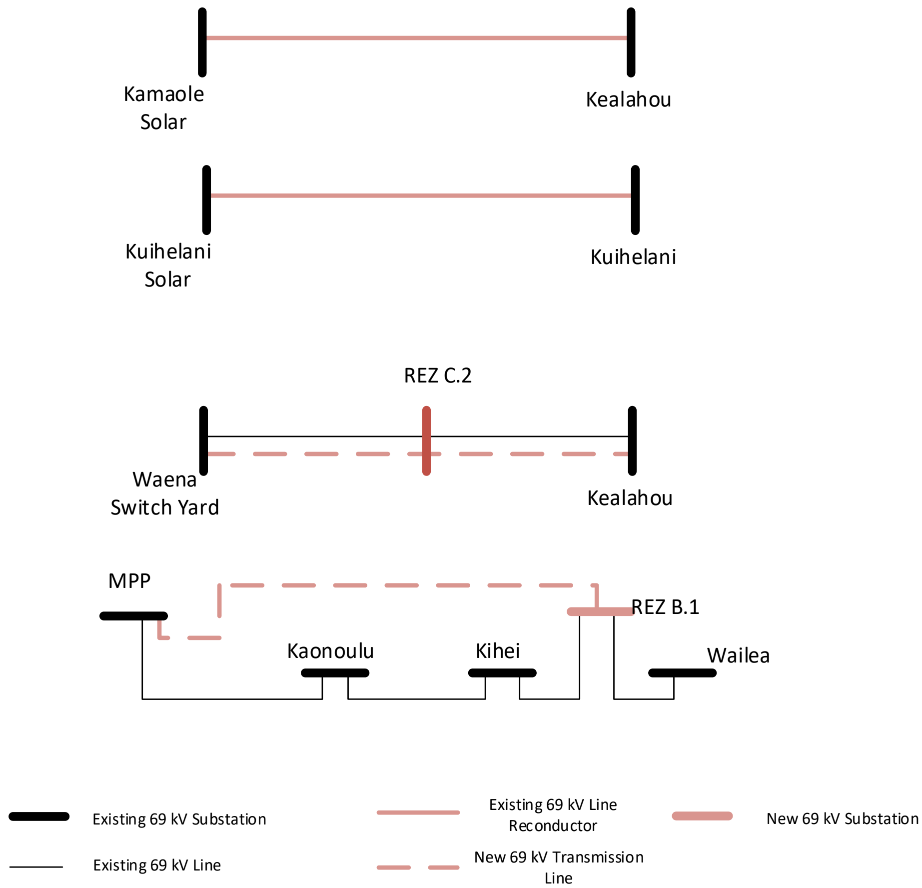


Figure 42 Proposed Maui transmission networks expansion, Mau i base scenario resource plan, year 2045

Mitigation study – alternative resource portfolio

The Kamaole-Kealahou line reconductoring. can be deferred by reducing south Maui generation interconnection size by 7 MW.

REZ Enablement

According to the resource plan, 15 MW generation from REZ zone B and 107 MW generation from REZ zone C will be interconnected to the Maui system between 2041 and 2045. It is assumed in the study that the total 122 MW generation will be interconnected at Auwahi substation (15 MW), STG 3.1 substation (30 MW), Kahana substation (23 kV, 30 MW), and the new substation REZ C.2 (47 MW). The high-level cost estimate for these REZ enablement is listed in Table 90.

Table 90 REZ Enablement and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2045

Enablement Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
Kanaha Substation	REZC development	Install one 23kV breaker	3.8
STG 3.1 POI (MPP-Waiinu) Sub	REZC development	Install one 69kV breaker	3.9
REZC.2 (Waena-Kealahou) Sub	REZC development	Install two 69kV breakers	7.8

Base scenario resource plan, year 2050

Study descriptions

In 2050, 57 MW PV/BESS generation will be developed in REZ zone C and another 57 MW PV/BESS generation will be developed in REZ zone B. System annual peak demand is forecasted to reach 310 MW in 2050. A high-level Maui system map with locations of the future grid-scale project interconnection locations by 2050 are shown in Figure 43.

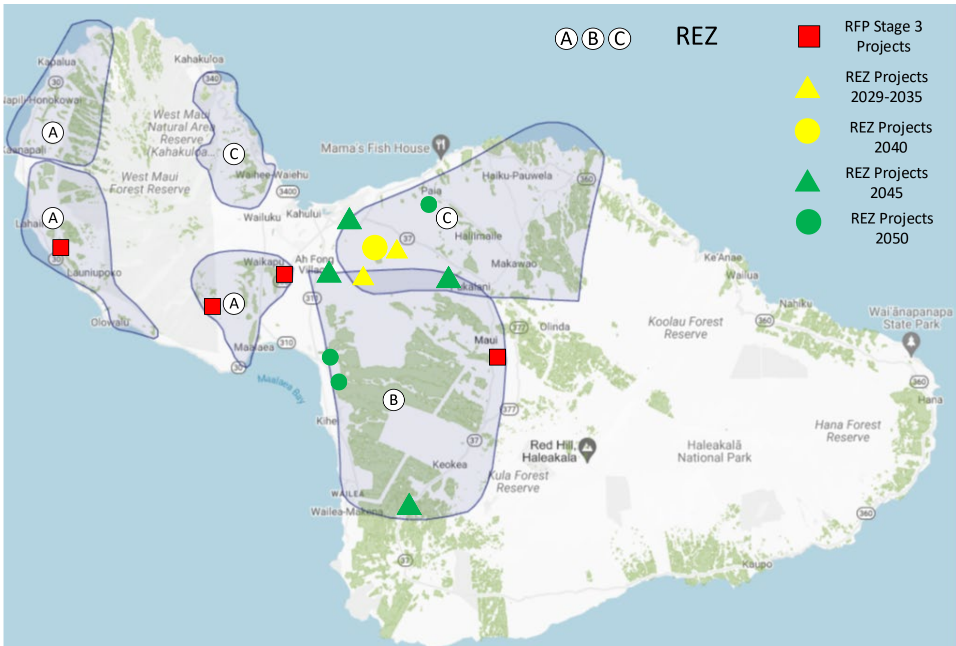


Figure 43 High-Level Maui map for assumed future grid-scale project interconnection locations by 2050

Interconnection locations for the total 114 MW grid-scale interconnection are assumed as following:

- REZ B.1 Substation – 51 MW (REZ zone B)
- Auwahi Substation – 7 MW (REZ zone B)
- REZ C.2 (Waena-Kealahou) Substation - 13MW (REZ zone C)
- New switching station, REZ C.3 (shown in Figure 44), on Waena-Pukalani line – 44 MW (REZ zone C)

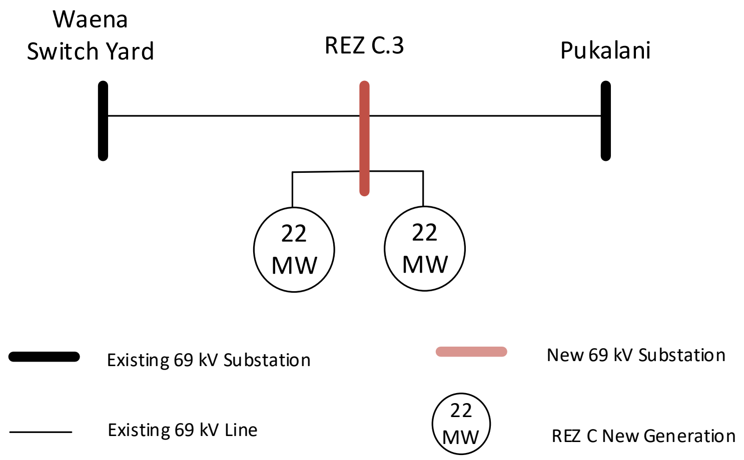


Figure 44 High-Level single line diagram for a new substation REZ C.3, Maui base scenario resource plan, year 2050

The detailed system grid-scale resources changes are summarized in Table 91 and Table 68. System resource summary and the forecasted system load is summarized in Table 92.

Table 91 Maui Grid-Scale Generation Project Development between 2046 and 2050, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	PV/BESS Generation	57	2050	REZ Zone B
	PV/BESS Generation	57	2050	REZ Zone C

Table 92 Maui System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2050

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	125	571	40	240	310

Table 93 summarizes studied system generation dispatches for the 2050. It is worth noting that all the networks expansion identified in the 2045 study are included in the 2050 study models.

Table 93 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2050

Aggregated Generation Capacity Rating (MW)		Zone A	Zone B	Zone C	Zone A+C	Zone B+C	Zone A+B	All Zones
Zone A	140	140	0	0	140	0	140	96
Zone B	329	170	310	0	0	152	170	113
Zone C	429	0	0	310	170	158	0	101
Total Load	310	310	310	310	310	310	310	310

Study results

Undervoltage violation is not observed from the power flow simulations for all the system generation dispatches, with either system normal configuration or N-1 contingency configurations. Transmission line overloading is not observed, either. The only planning criteria violation observed is overloading on

62/23 kV tie transformers during N-1 system contingency configurations. A summary of observed overloading is listed in Table 94.

Table 94 List of Overloaded Transmission Elements, Maui Base Scenario Resource Plan, Year 2050

Generation Dispatch	N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)
Zone A	None	
Zone B	69/23 kV Tie transformer	96
Zone C	None	
Zone A+C	69/23 kV Tie transformer	97
Zone B+C	69/23 kV Tie transformer	100
Zone A+B	69/23 kV Tie transformer	97
All Zones	69/23 kV Tie transformer	96

Mitigation study – transmission networks expansion

To mitigate the potential overloading on the tie-transformers, it is recommend to replace the two units of tie transformer in Kanaha substations with higher emergency rating, at least 24 MVA forced air rating. To mitigate transmission line overloading, adding the second 69 kV line between the Waena switchyard and the Pukalani substation via the REZ C.3 is proposed. The proposed mitigation solution is summarized in Table 95, with high-level cost estimate.

Table 95 Transmission Networks Expansion and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2050

Enablement Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
Waena – REZC.3 – Pukalani	Add New Circuit	One circuit, 336 AAC	31.2
Waena Substation	Add New Circuit	Install one 69kV circuit breaker	4.5
Pukalani Substation	Add New Circuit	Rebuild Sub—add 2 BAAH bays less one breaker	25.5
REZC.3 (Waena-Pukalani) Sub	New Substation	Add 3 BAAH bays less 2 breakers	46.9
Transformer	Transformer Upgrade Description		
New 69/23 kV Tie Transformer	Upgrade both Kahana Tie Transformers with FA rating of at least 24 MVA		15.0

Mitigation solution – non-wire alternatives

Non-wire alternatives are identified for deferring the tie-transformers upgrade. To bring down the tie transformer loading limit no higher than 95% of emergency loading during N-1 contingency configurations, 4 MW peak load reduction is required.

REZ Enablement

According to the resource plan, 57 MW generation from REZ zone B and another 57 MW generation from REZ zone C will be interconnected to the Maui system between by 2050. It is assumed in the study that the total 114 MW generation will be interconnected at Auwahi substation (7 MW), REZ B.1 substation (51 MW), REZ C.2 (13 MW), and the new substation REZ C.3 (44 MW). The high-level cost estimate for these REZ enablement is listed in Table 96.

Table 96 REZ Enablement and High-Level Cost Estimate, Maui Base Scenario Resource Plan, Year 2050

Enablement Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
REZB.1 (Kihei-Wailea) Sub	REZB development	Install two 69kV circuit breakers	9.0
REZC.3 (Waena-Pukalani) Sub	REZC development	Install two 69kV circuit breakers	9.0

High load scenario resource plan, year 2027

Study descriptions

By 2027, the Maui system will have new generation from Stage 3 RFP procurement which will be 171 MW RDG PV/BESS and 36 MW firm generation, interconnection at at Maui 69 kV system. Meanwhile, the Maui system will finish Waena switchyard construction, KPP retirement and conversion of KPP K3 and K4 units to synchronous condensers, and MPP unit 10-13 retirement. The system peak load is forecasted to reach 239 MW by 2028. A high-level locations of the RFP Stage 3 projects assumed in the study and developed REZ zones are shown in Figure 45. The assumptions regarding locations of the RFP Stage 3 projects are the same as what are used in the base scenario resource plan study. System grid-scale resource change in this high loare scenario resource plan by 2027 is the same as what is shown in the base scenario resource plan (i.e., Table 68 and Table 69). There are two differences, by comparing the 2027 base scenario resource plan and 2027 high load scenario resoiuce plan: 1) System peak load becomes 239 MW, instead of 207 MW in the base scenario resource plan, and 2) DER adoption forecast is 194 MW, instead of 170.7 MW in the base scenario resource plan.

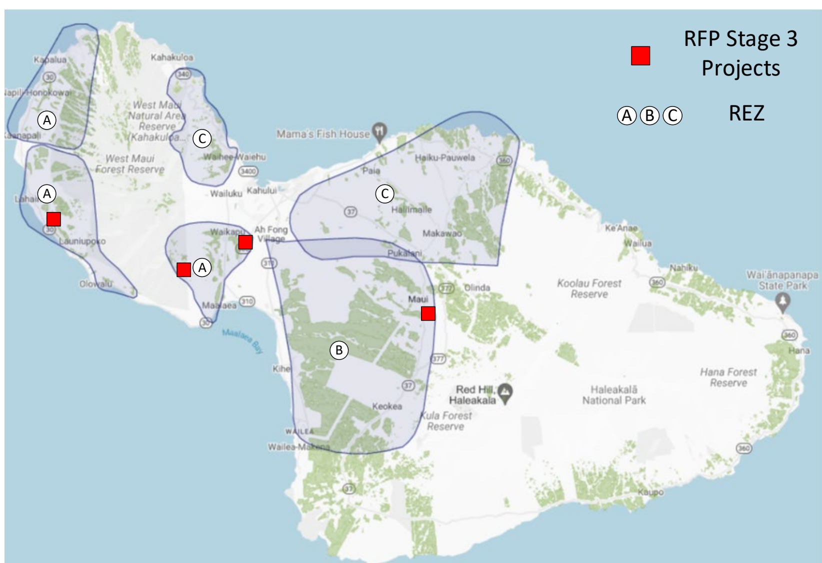


Figure 45 High-Level Maui map for assumed RFP Stage 3 project locations by 2027

Table 97 summarizes studied system generation dispatches for the 2027.

Table 97 Studied System Generation (MW) Dispatches, Maui High Load Scenario Resource Plan, Year 2027

Aggregated Generation Capacity Rating (MW)		Zone A*	Zone B_1	Zone B_2	Zone A+C	Zone B+C	All Zones
Zone A	161	161	0	55	138	0	70
Zone B	313.5	78	239	184	0	138	70
Zone C	101	0	0	0	101	101	67
Total Load	239	239	239	239	239	239	239

*Studied variation of dipatch zone

Study results

Power flow simulation results indicate that 1) 69 kV lines experience high loading condition during normal configuration for one generation dispatch, 2) overloading conditions are identified on 69 kV lines and 69/23 kV tie transformers when system is under N-1 contingency configurations, and 3) voltage planning criteria violations are observed, with worst undervoltage issues at 0.75-0.76 p.u.. Summary of transmission element overloading is listed in Table 98.

Table 98 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2027

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Overloading Element	Max Loading (%)	Overloading Element	Max. Loading(%)
Zone A_1	KuihelaniSolar-Kuihelani 69kV Line	97	KuihelaniSolar-Kuihelani 69kV Line	117
Zone A_2	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110
Zone B_1	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110
Zone B_2	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110
Zone A+C	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110
Zone B+C	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110
All Zones	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	110

Mitigation study – transmission networks expansion

To mitigate the transmission line overloading conditions, reconductoring of the overloading transmisison lines are proposed. Besides fixing the transmission line overloading issue, simimilar to what is proposed in the base scenario resource plan, closing west Maui loops is proposed for the high load scenario resource plan. A list of transmission networks expansion proposed for Maui system is listed in Table 99. A high-level one line diagram in Figure 46 demonstrates the proposed transmission networks expansion.

Table 99 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2027

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line	Upgrade Type	Conductor Requirements	
Mahinahina Substation	Expand West network	Install one 69kV circuit breaker	2.7
Lahaina-Lahainaluna	Re-conductor	One circuit, re-conductor to 556 AAC	2.5
MPP – Waiinu #2	New Transmission Line	One circuit, 336 AAC	13.6
1 BAAH Bay in STG3.1	Adding 1 BAAH Bay	Adding 1 BAAH Bay	7.8
Waiinu Substation	New Transmission Line	Install One 69kV circuit breaker	2.4
MPP Substation	New Transmission Line	Install One 69kV circuit breaker	2.4

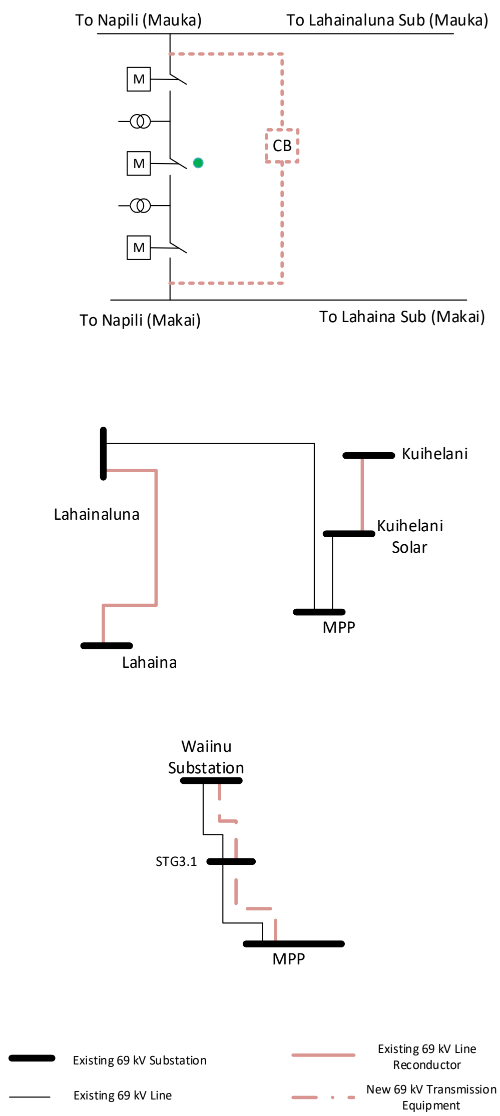


Figure 46 High-Level single line diagram for proposed transmission networks expansion, Maui high load scenario resource plan, year 2027

REZ enablment

There is no REZ development by 2027, hence, there is no REZ enablement cost estimate.

High load scenario resource plan, year 2030

Study descriptions

By 2030, the Maui system will have 69 MW grid-scale renewable generation from REZ zone C development. Also, it is planned that MPP unit 1 to 9 will be removed by 2030. The system annual peak load is forecasted to reach 266 MW by 2031. A high-level Maui system map with locations of all the future grid-scale generation projects by 2030 are shown in Figure 47. In total 69 MW of new grid-scale generation project from the REZ zone C development, it is assumed that 52 MW generation will be interconnected at the Waena switchyard, and the remaining 17 MW will be interconnected at a new substation REZ C.1 on the Waena-MPP line, which is shown as Figure 48.

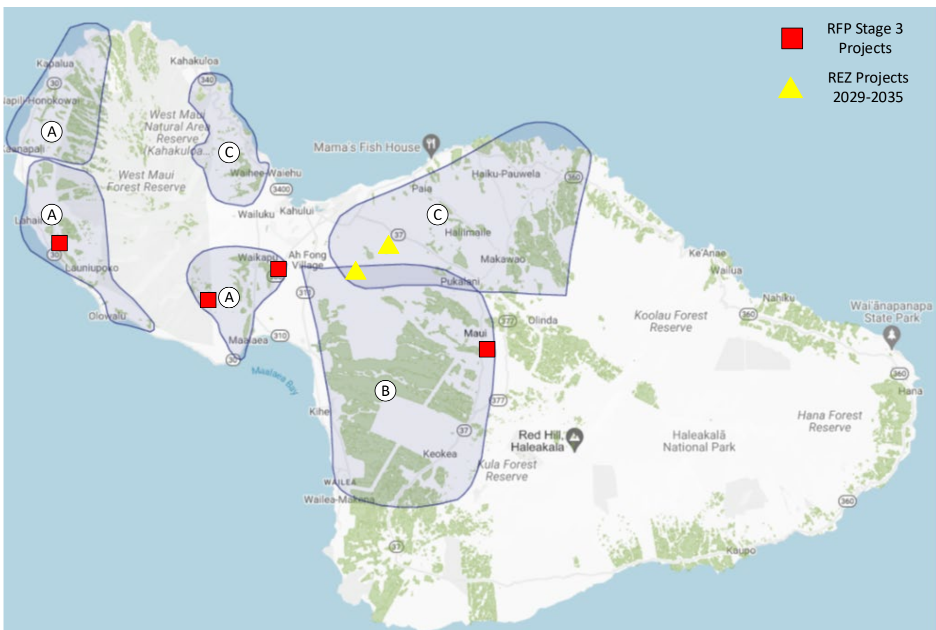


Figure 47 High-Level Maui map for assumed future grid-scale project interconnection locations by 2030, high load scenario resource plan

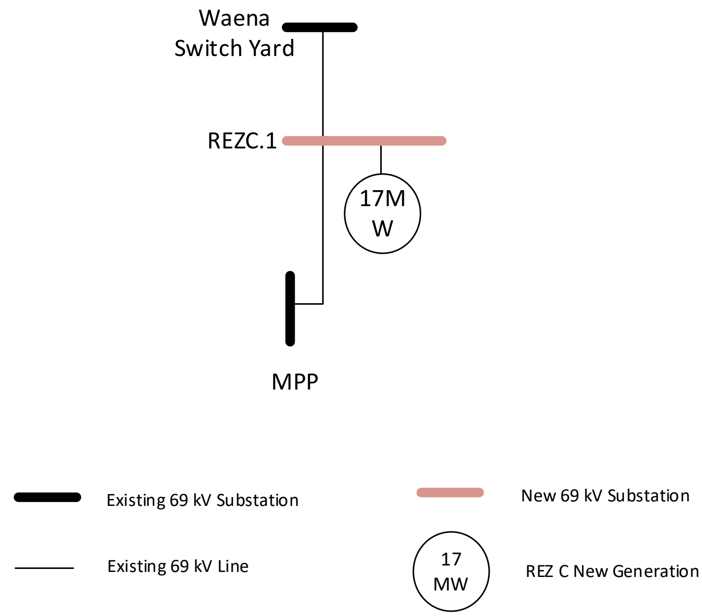


Figure 48 High-level single line diagram for the 17 MW line interconnection project, Maui high load scenario resource planning, year 2030

The detailed system grid-scale resources changes are summarized in Table 100. System resource summary and the forecasted system load is summarized in Table 101. Regarding system grid-scale resource retirement, both base scenario resource plan and high load scenario resource plan have the same resource retirment schedule.

Table 100 Maui Grid-Scale Generation Project Development between 2028 and 2030, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	6	2029	REZ Zone C
	Onshore Wind Generation	46	2030	REZ Zone C
	Solar/BESS	17	2030	REZ Zone C

Table 101 Maui System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2030

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	94	313	40	217	266

Table 102 summarizes studied system generation dispatches for the 2030.

Table 102 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2030

Aggregated Generation Capacity Rating (MW)		Zone A+B*	Zone B_1	Zone B_2	Zone B+C*	Zone A+C	All Zones
Zone A	140	140	0	124	0	134	88
Zone B	257	126	257	142	97	0	88

Zone C	170	0	9	0	170	132	90
Total Load	266	266	266	266	266	266	266

*Studied variation of dipatch zone

Study results

Power flow analyses are performed for the above system generation dispatches. Analyses results indicate transmission element overloading happen in both normal and N-1 contingency configurations. Undervoltage violation and voltage collapse (i.e., power flow simulation does not converge) are identified during N-1 contingency configurations. A summary of undervoltage violations,voltage collapse issues, and transmission element overloading issues identified from the analyses are shown in Table 103 and Table 104.

Table 103 List of Undervoltage Violation and Voltage Collapse, Maui High Load Scenario Resource Plan, Year 2030

Generation Dispatch	N-1 Contingency Configuration	
	Low Voltage Element	Lowest Voltage (p.u.)
Zone A+B_1	Haiku Substation	0.83
Zone A+B_2	Haiku Substation	0.83
Zone B_1	Haiku Substation	0.84
Zone B_2	Haiku Substation	0.83
Zone B+C_1	Haiku Substation	0.86
Zone B+C_2	Haiku Substation	0.85
Zone A+C	Haiku Substation	0.83
All Zones	HHaiku Substation	0.85

Table 104 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2030

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)	Overloading Element	Max. Loading(%)
Zone A+B_1	KuihelaniSolar-Kuihelani 69kV Line	105	KuihelaniSolar-Kuihelani 69kV Line	126
Zone A+B_2	None	None	None	None
Zone B_1	None	None	None	None
Zone B_2	None	None	MPP-KuihelaniSolar 69kV Line	121
Zone B+C_1	None	None	Waena-Kanaha 69kV Line	127
Zone B+C_2	Wailea-Auwahi 69kV Line	97	Waena-Kanaha 69kV Line	160
Zone A+C	None	None	None	None
All Zones	None	None	None	None

Mitigation study – transmission networks expansion

By adding one more 69 kV circuit between MPP and Waena switchyard, via the new substation REZ C.1, multiple 69 kV line overloading issues (i.e., MPP-REZC, MPP-Kuihelani Solar, KuihelaniSolar-Kuihelani, Waena-Kanaha, Wailea-Auwahi) are mitigated. Also, by converting Pukalani-Haiku 23 kV line to a 69 kV line and adding a capacitor bank at Kailu substation and Keanae substation, undervoltage and potential voltage collapse issue on the Pukalani-Haiku-Hana 23 kV line, as well as the Pukalani 69/23 kV transformer overloading will be mitigated. A summary of the proposed transmission networks expansion, with high-level cost estimate are listed in Table 105, with a simplified single line diagram shown in Figure 49.

Table 105 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2030

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line	Upgrade Type	Conductor Requirements	
MPP – Waena #2	New Transmission Line	One circuit, 556 AAC	21.6
REZ C.1 (MPP-Waena) Substation	Adding 3 BAAH Bay	Adding 3 BAAH Bays less 2 breakers	23.7
MPP Substation	New Transmission Line	Install one 69kV circuit breaker	2.5
Waena Substation	New Transmission Line	Install one 69kV circuit breaker	5.8
Converting Pukalani-Haiku line to 69 kV line; converting Makawao, Kauhikoa, Haiku substations to 69/12 kV substations; converting Kamole Weir, H'poko substaions 85, 86 and 87 to 69/23 kV substation; adding a tie transformer 12/16/20 MVA at Haiku substation; remove Pukalani 69/23 kV tie transformer; reconductor Pukalani-Haiku as 556 AAC			86.2
Add cap bank (1.2MVAR or greater) at Kailua substation and Keanae substation.			0.3

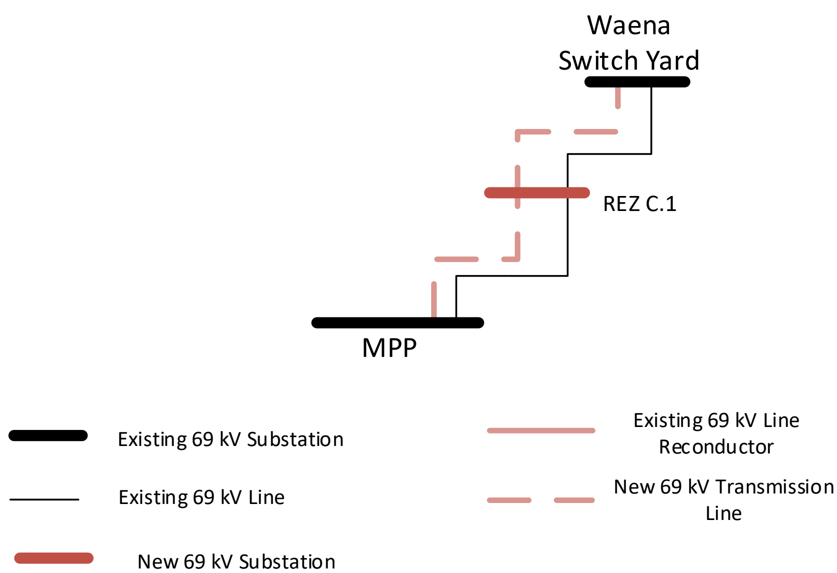


Figure 49 High-Level single line diagram for proposed 69 kV transmission networks expansion, Maui high load scenario resource plan, year 2030

REZ enablment

For the 2030 REZ development, 69 MW generation will be developed from REZ zone C and interconnected with Maui's 69 kV system. It is assumed that 52 MW will be interconnected at Waena switch yard, and 17 MW will be interconnected at a new substation REZ C.1 as shown in Figure 48. According to the REZ enablement cost identified in the 2021 REZ study, the estimate of REZ enablement for the 52 MW interconnection at the Waena switch yard is $45.8 million. A high-level cost estimate for the REZ enablement is listed in Table 106.

Table 106 REZ Enablement and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2030

Enablement Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
REZ C.1 (MPP-Waena)	REZC development	Install one 69kV circuit breaker	2.5
Waena Substation	REZC development	Add 2 BAAH bays less 2 breakers	11.6

High load scenario resource plan, year 2035

Study descriptions

In 2035, another 159 MW REZ zone C development will be completed. It is assumed that 38 MW generation will be interconnected at Waena switchyard, 60MW generation interconnected at REZC.1, 30MW generation interconnected at STG3.1 and 30MW generation interconnected at Kanaha Substation on the 23kV bus. In addition, system will have existing 42 MW wind contract expires. The system annual peak demand is forecasted to reach 313 MW in 2036. A high-level Maui system map with locations of all the future grid-scale generation projects by 2035 are shown in Figure 50.

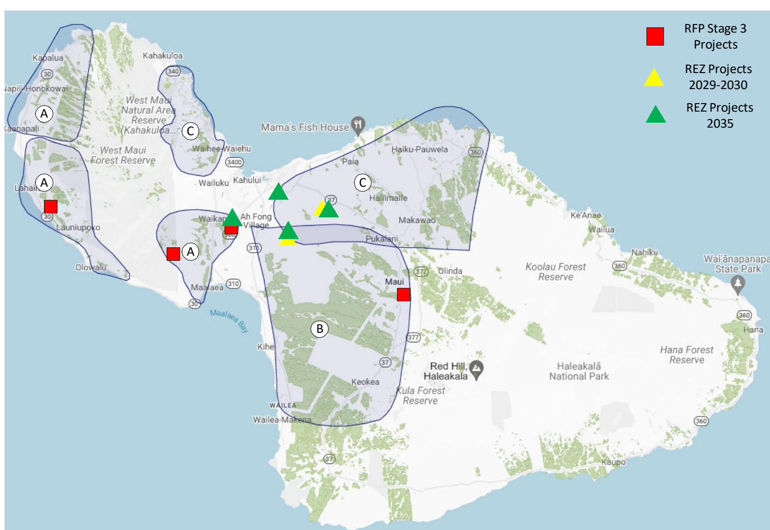


Figure 50 High-Level Maui map for assumed future grid-scale project interconnection locations by 2035, high load scenario resource plan

The detailed system grid-scale resources changes are summarized in Table 107. System resource summary and the forecasted system load is summarized in Table 101.

Table 107 Maui Grid-Scale Generation Project Development between 2030 and 2035, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	76	2035	REZ Zone C
	PV/BESS Generation	84	2035	REZ Zone C

Table 108 Maui System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2035

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	127	396	40	242	313

Table 109 summarizes studied system generation dispatches for the 2035. It is worth pointing out that the transmission networks expansion requirements identified in previous years are all assumed to be implmented per the schedule, and are all considered as availble in the models for the 2035 analyses.

Table 109 Studied System Generation (MW) Dispatches, Maui Base Scenario Resource Plan, Year 2035

Aggregated Generation Capacity Rating (MW)		Zone A+B*	Zone B	Zone C	Zone B+C*	Zone A+C	All Zones
Zone A	140	140	0	0	0	140	104
Zone B	257	173	257	0	155	0	104
Zone C	330	0	56	313	158	173	105
Total Load	313	313	313	313	313	313	313

*Studied variation of dipatch zone

Study results

According to the power flow analyses performed for all the studied system generation dispatches, high loading on 69/23 kV tie transformers and 69 kV line are observed in normal configuration, and 69 kV line and 69/23 kV tie transformer overloading are observed during system N-1 contingency configurations. A summary of transmission elements with high loading and overloading conditions is provided in Table 110.

Table 110 List of Overloaded Transmission Elements, Maui High Load Scenario Resource Plan, Year 2035

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Overloading Element	Max. Loading(%)	Overloading Element	Max. Loading(%)
Zone A+B_1	KuihelaniSolar-Kuihelani 69kV Line	98%	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	100%
Zone A+B_2	Waiinu 69/23kV Tie Tsf	98%	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	97%
Zone A+B_3	KuihelaniSolar-Kuihelani 69kV Line	104%	KuihelaniSolar-Kuihelani 69kV Line	102%
Zone B	None	None	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	103%
Zone C	None	None	MPP-REZC Ckt 1 or Ckt 2	114%

Zone B+C_1	None	None	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	105%
Zone B+C_2	None	None	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	103%
Zone B+C_3	None	None	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	110%
Zone A+C	None	None	Kanaha 69/23kV Tie Tsf 1 or Tie Tsf 2	104%
All Zones	None	None	Kanaha 69/23kV Tie Tsf 1 and Tie Tsf 2	96%

Mitigation study – transmission networks expansion

To mitigate the overloading and undervoltage issues identified from the study, following networks expansion is proposed. It is worth noting that adding a new line between Waena switchyard and MPP through REZ C.1 provides potential of interconnecting future grid-scale generation project at the REZ C.1 substaiton. High-level cost estimate is also provided along with the description of the proposed networks expansion.

Table 111 Transmission Networks Expansion and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2035

Networks Expansion Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Conductor Requirements	
Kamaole Solar – Kealahou	Reconductor	One circuits, 556 AAC	12.9
Kuihelani Solar- Kuihelani	Reconductor	One circuits, 556 AAC	2.7
MPP – Waena #3	Adding New Circuit	One circuits, 556 AAC	29.3
REZ C.1 (MPP-Waena)	Adding 1 BAAH Bay	Adding 1 BAAH Bay	9.6
MPP Substation	Adding New Circuit	Install One 69kV circuit breaker	2.9
Waena Substation	Adding New Circuit	Install One 69kV circuit breaker	2.9
Increase 1.2 Mvar cap bank to 3.6 Mvar cap bank at Keanae substation to mitigate undervoltage issue.			0.2
Increase 1.2 Mvar cap bank to 3.6 Mvar cap bank at Kailua substation to mitigate undervoltage issue.			0.2

REZ enablement

For the total 159 MW grid-scale generation interconnection from the development of REZ zone C, it is assumed that 38 MW generation will be interconnected at Waena switchyard, 60MW generation interconnected at REZC.1, 30MW generation interconnected at STG3.1 and 30MW generation interconnected at Kanaha Substation on the 23kV bus. The REZ enablment and high-level cost estiamte is listed in Table 112.

Table 112 REZ Enablement and High-Level Cost Estimate, Maui High Load Scenario Resource Plan, Year 2035

Enablement Descriptions			Cost Estimate (Million Dollars)
Transmission Line/Substation	Upgrade Type	Upgrade Requirements	
Waena Substation	REZC development	Add 2 BAAH bays less 2 breakers	13.5
REZC.1 (MPP-Waena)	REZC development	Install one 69kV circuit breaker	2.9
STG3.1 (MPP-Waiinu)	REZC development	Install one 69kV circuit breaker	2.9
Kanaha Substation	REZC development	Install one 23kV circuit breaker	2.8

4.2.2 Dynamic stability study

The Maui system in near-term years 2028 and 2036 for the base scenario resource plan are selected for performing dynamic stability study to evaluate system dynamic stability performance. Similar to the steady state analyses, the following assumptions are used in the Maui dynamic stability study:

- KPP K3 an K4 units are converted to synchronous condensers in the study.
- Puunene substation is removed, and the tie transformer #2 in Kanaha substation is in service.
- Stage 1 projects (Kuihelani Solar and Paeahu Solar, both in GFL model) are in service.
- Stage 2 projects (Kanaha Solar, Kamaole Solar, and Waena BESS, all in GFM model) are in service.

The system generation dispatch for daytime peak load with high DER generation, which poses the highest risk to the system stability according to the past studies, is modeled for the dynamic stability study, with simulations of high-risk contingencies. The high-risk contingencies for Maui system is 1) P3 planning event - the largest GFM resource is out-of-service due to maintenance, and a three-phase fault happens at gen-tie of another grid-scale GFM resource and results in the loss of this gen-tie, and 2) P5 planning event - delayed fault clearing (24 cycles) of a three-phase fault on a 69 kV transmission line that cause the whole system experience low voltage condition during the fault.

Base scenario resource plan, year 2028

Study descriptions and study results

According to the resource plan, a system generation dispatch that represents daytime peak load with high DER generation scenario in 2028 is created (as Table 113) and modeled in PSCAD/EMTDC. In this dispatch there is no synchronous machine-based generation dispatched.

Table 113 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, Maui Base Scenario Resource Plan, Year 2028

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
Existing Standalone PV	5.3	2.9	5.7
Existing Wind	2.2	1.2	42
Stage 1 PV/BESS (GFL)	30	16.4	75
Stage 2 PV/BESS (GFM)	10	10.4	50
Waena BESS (GFM)	0		40
Stage 3 PV/BESS (GFM)	9		171
DER	126.2	69.0	198.6

System Load (MW)	183
GFM MW Headroom /DER Generation	2

PSCAD simulations with a total simulation time of 25 seconds are performed with three-phase to ground faults applied at 10 seconds. For the simulated P3 planning event, it is assumed that the Waena BESS one POI is out of service before the fault occurs. Simulation results for the P3 planning event are shown in Figure 51 and for the P5 planning event are shown in Figure 52.

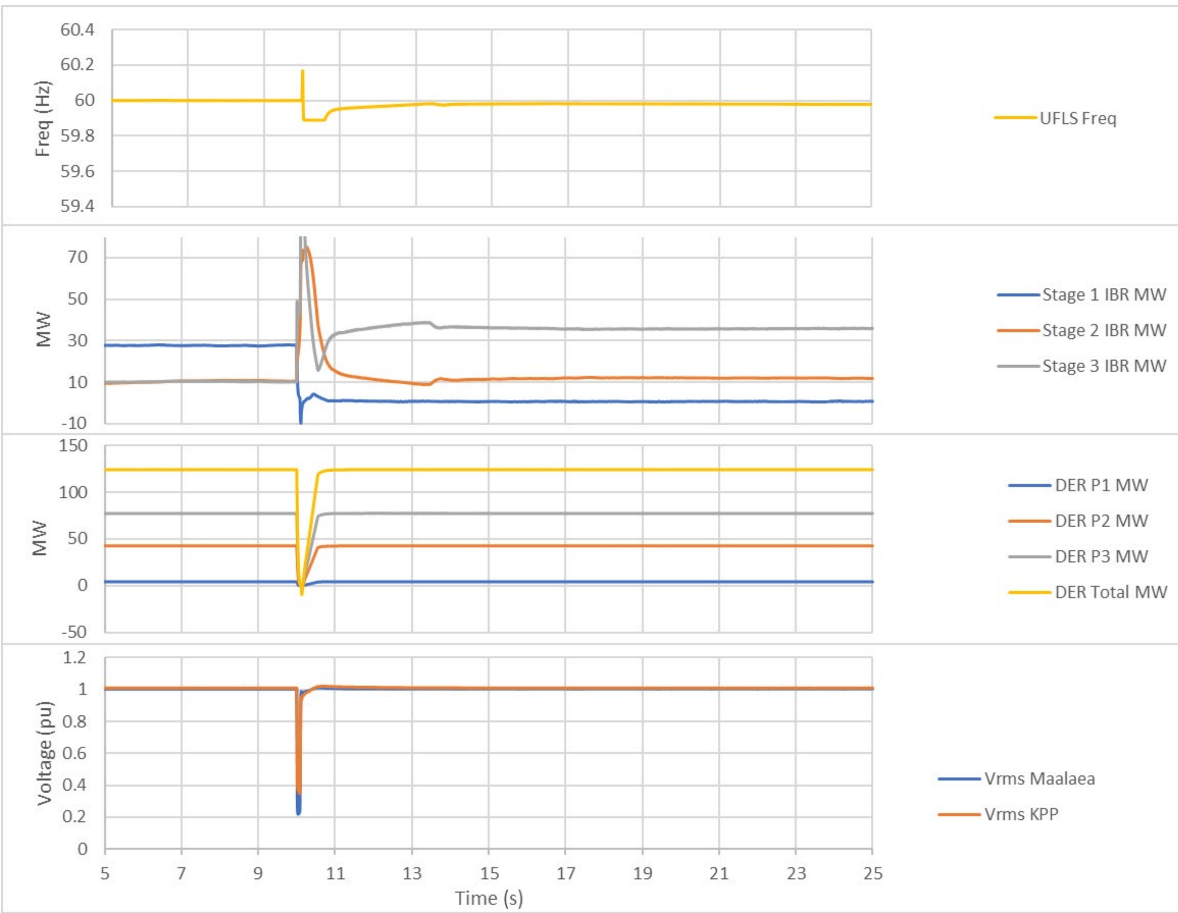


Figure 51 Dynamic stability simulation results, Maui base scenario resource plan, year 2028, P3 planning event

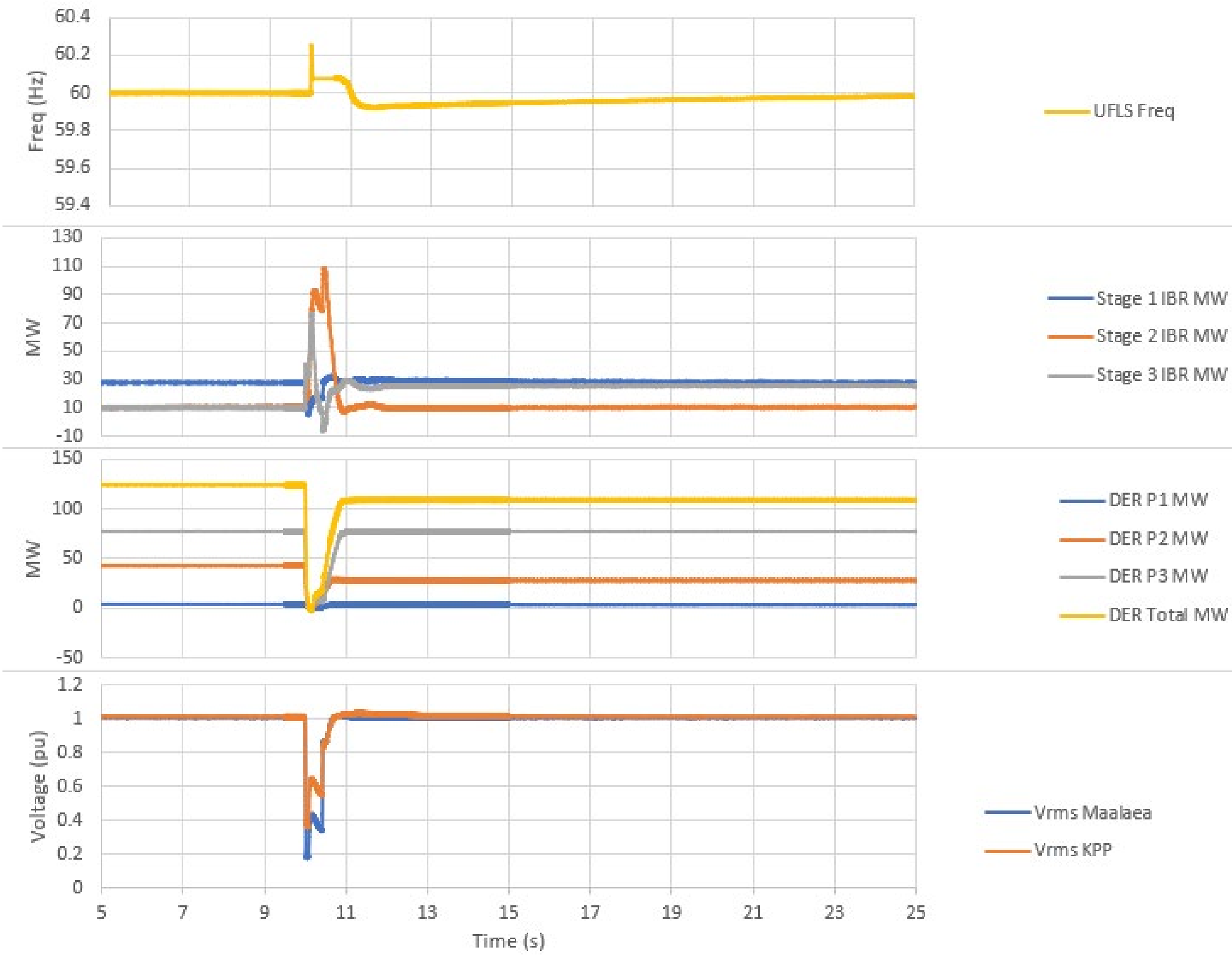


Figure 52 Dynamic stability simulation results, Maui base scenario resource plan, year 2028, P3 planning event

From above simulation results, UFLS is not identified, and system frequency nadir is well above the first block of UFLS trigger limit, 59 Hz. According to the Maui transmission planning criteria for the P3 planning event 20% of system net load UFLS is the acceptable limit and for the P5 planning event 15% of system net load UFLS is the acceptable limit.

Base scenario resource plan, year 2036

Study descriptions and study results

According to the resource plan, a system generation dispatch that represents daytime peak load with high DER generation scenario in 2036 is created (as Table 114) and modeled in PSCAD/EMTDC. It is worth noting that in this dispatch there is no synchronous machine-based generation dispatched.

Table 114 System Generation Dispatch for Daytime Peak Load High DER Generation Scenario, Maui Base Scenario Resource Plan, Year 2036

Generation Station	Dispatched (MW)	Gen/System Load (%)	Capacity (MW)
Existing Standalone PV	5.3	2.5	5.7
Existing Wind	2.2	1.1	42
Stage 1 PV/BESS (GFL)	0	0	75
Stage 2 PV/BESS (GFM)	10	9.2	60
Waena BESS (GFM)	0		40

Stage 3 PV/BESS (GFM)	9		171
REZ Wind	0	0	60
REZ PV/BESS (GFM)	30	14.5	43
DER	151.8	73.3	246
System Load (MW)	207		
GFM MW Headroom /DER Generation	1.7		

PSCAD simulations with a total simulation time of 25 seconds are performed with three-phase to ground faults applied at 10 seconds. For the simulated P3 planning event, it is assumed that the Waena BESS one POI is out of service before the fault occurs. In this P3 event, another GFM resource with 30 MW generation is tripped. Simulation results for the P3 planning event are shown in Figure 53 and for the P5 planning event are shown in Figure 54.

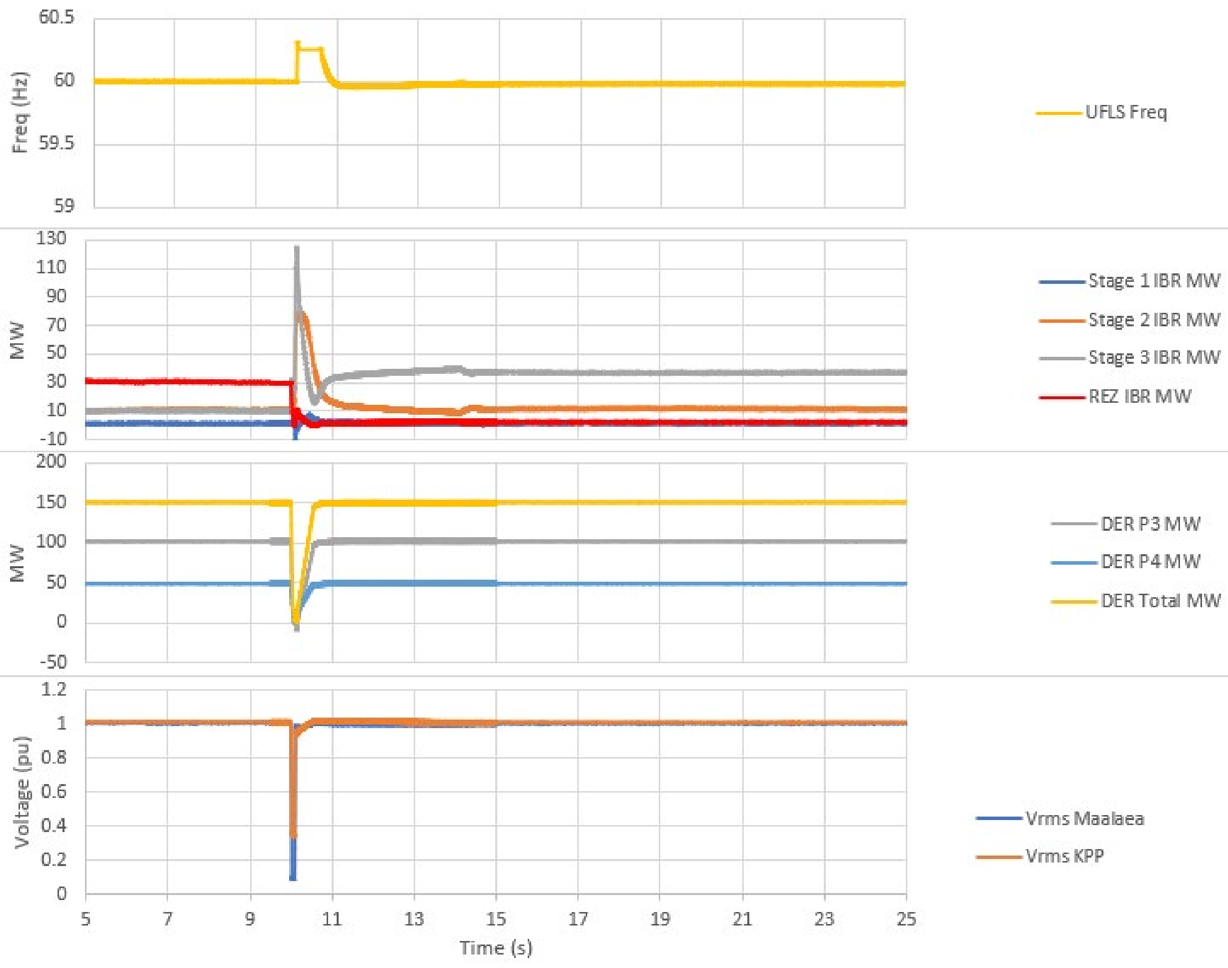


Figure 53 Dynamic stability simulation results, Maui base scenario resource plan, year 2036, P3 planning event

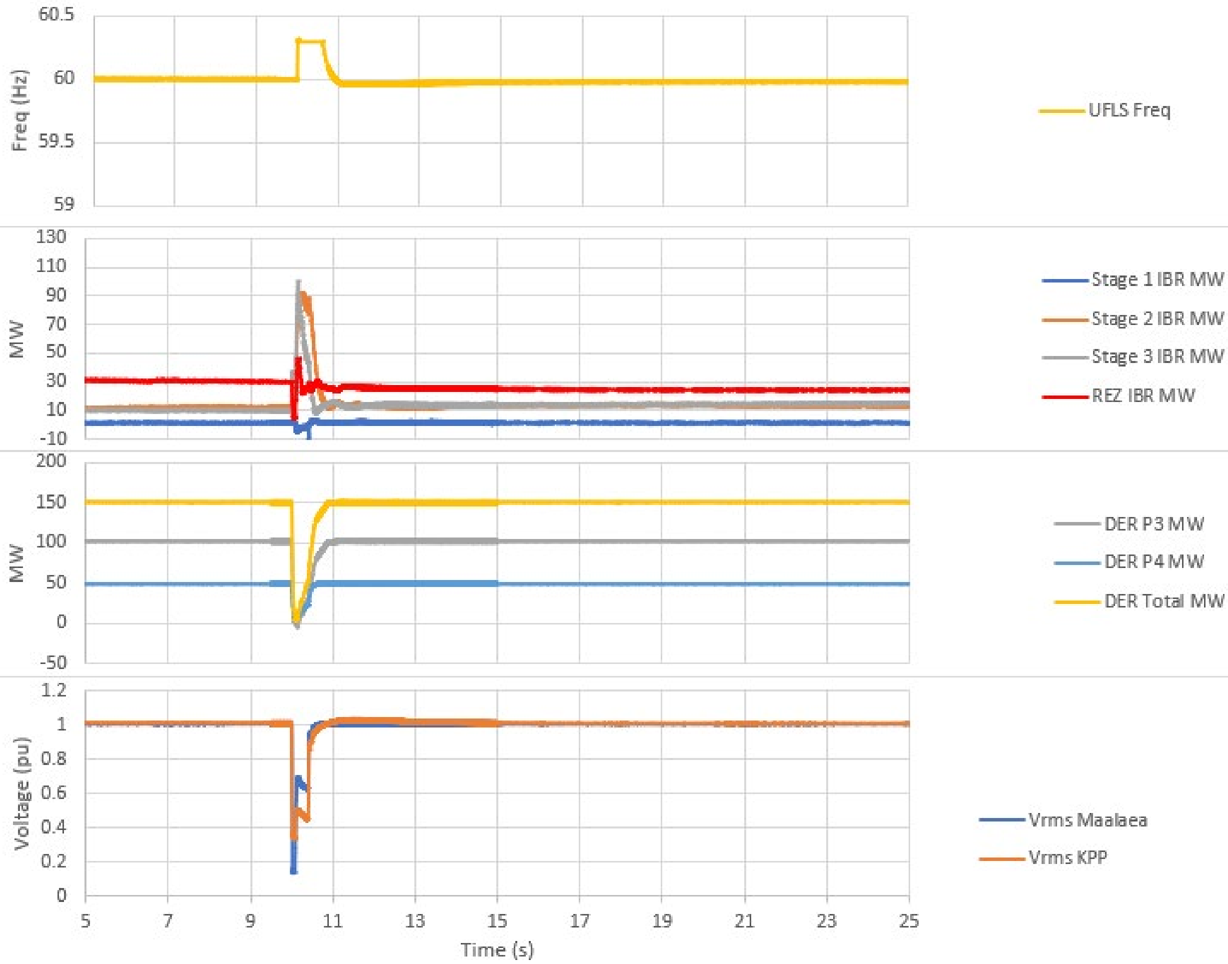


Figure 54 Dynamic stability simulation results, Maui base scenario resource plan, year 2036, P3 planning event

From above simulation results, UFLS is not identified, and system frequency nadir is well above the first block of UFLS trigger limit, 59 Hz. It can be concluded that system has sufficient GFM resource to maintain system stability within planning criteria.

Currently, industry has very limited operational experience for a system with 100% inverter-based resource. Though planning criteria violation is not observed from the PSCAD study, both study scope and models used for the study have limitations. And there may be other stability risks that are unknown currently, and hence not included in the current study, or represented in current models.

To identify the minimum capacity requirement of GFM resource procurement in RFP Stage 3 and REZ development to maintain Maui system stability within the planning criteria, the P3 and P5 planning events are simulated considering reduction of GFM resource in the studied 2028 and 2026 scenarios, until excessive UFLS is observed from the simulations. From the study, it is observed that for the year 2028, Maui system would require at least 90 MW contract capacity GFM resource. This include both Stage 2 and Stage 3 projects. For the year 2036, the Maui system would need at least 140 MW contract capacity of GFM resource. For the minimum requirement of the ratio of available MW headroom of GFM resource over DER generation, Maui system will need maintain this ratio as 0.6. It is worth noting that MWh energy and a realistic DC side model is not included in the dynamic stability study, and sufficient MWh energy in the battery side of GFM resource should always be available for the GFM resource contingency reserve.

4.3. Hawai'i Island System Study Results

4.3.1 Steady state analyses

Base scenario resource plan, year 2032

Study descriptions

By 2030, the Hawai'i system will have new generation from Stage 3 RFP procurement and REZ development, which will be 48 MW wind generation of REZ development by 2029 and 140 MW Stage 3 RFP PV/BESS generation by 2030. All of them will be interconnected at the Hawai'i island 69 kV system. Also, three existing generation plants will be removed by 2031: the 34 MW Hill 5 and 6 will be removed by 2028; the 21 MW Tawhiri wind generation PPA is expected to expire by 2028; and the 58 MW Hamakua Energy Partners ("HEP") contract is expected to expire by 2031. The system peak load is forecasted to reach 214 MW by 2032. A high-level map with locations of the grid-scale generation projects assumed in the study by 2032 is shown in Figure 55. For the 48 MW onshore wind generation from REZ zone A development, it is assumed that interconnection of the project is at the Keamuku substation. For the 140 MW RFP Stage 3 generation projects, it is assumed the generation interconnection locations are Puueo (30 MW), Kanoelehua (30 MW), Ouli (20 MW), Poopoomino (30 MW), and Keamuku (30 MW).

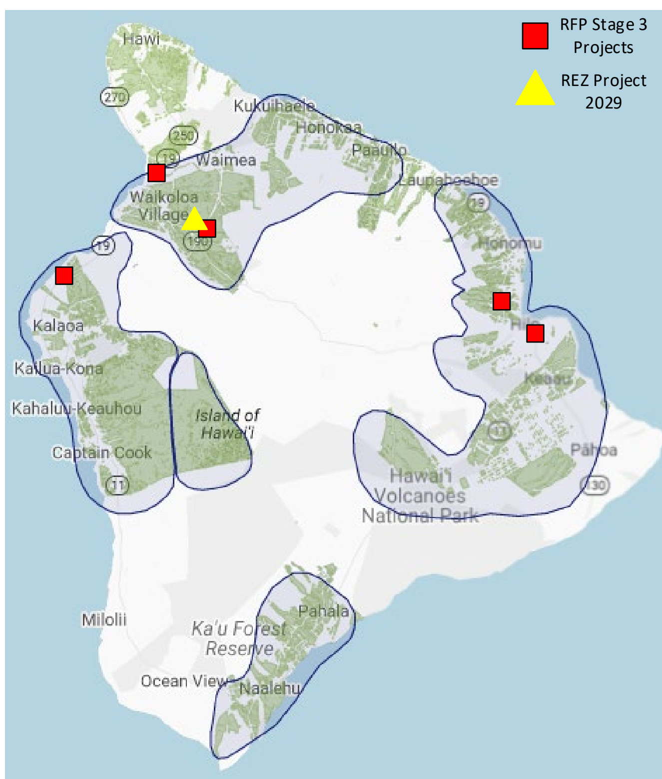


Figure 55 High-Level Hawai'i island map with assumed future grid-scale project interconnection locations by 2032, base scenario resource plan

The detailed system grid-scale resources changes are summarized in Table 115 and Table 116. After the retirement of HEP and Tawhiri wind generation, by assuming no new generation added in north and south of system, or no contract renew, there will not be any grid-scale generation on south or northeast side of the Hawaiʻi island system. The system resource summary and the forecasted system load is summarized in Table 117.

Table 115 Hawaiʻi Island Grid-Scale Generation Project Development by 2032, after RFP Stage 2, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Wind Generation	48	2029	West Hawaiʻi island
Stage 3 Hawaiʻi Island RFP	Solar/BESS Generation	140	2030	West and east side of Hawaiʻi island

Table 116 Hawaiʻi Island Grid-Scale Generation Removal by 2032

Removal	Generation Type	MW Capacity	Year	Location
Hill 5, 6	Fossil Generation	34	2027	Kanoelehua substation
Tawhiri Generation	Wind Generation	21	2028	Kamaoa substation
HEP	Fossil Generation	49.4	2031	Haina substation

Table 117 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2032

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
85.8	58.5	46	200	16.6	174	214

To evaluate 69 kV transmission system adequacy to host both grid-scale generation interconnection and the forecasted load according to the resource plan, various system generation dispatches are created for the study, which is shown in Table 118.

Table 118 Studied System Generation (MW) Dispatches, Hawaiʻi Island Base Scenario Resource Plan, Year 2032

Area	Max Capability	System Generation Dispatches							
		Max West 1	Max West 2	Max West 3	West Gen Only	Max East 1	Max East 2	East Gen Only	Max PV/BESS
North	n.a.	0	0	0	0	0	0	0	0
West	264	214	214	146	146	71	119	0	140
East	143	0	0	69	0	143	95	143	74
South	n.a.	0	0	0	0	0	0	0	0
Total	407	214	214	214	146	214	214	143	214

Study results

Power flow simlations are performed for all studed system generation dispatches with system normal configuration and N-1 contingency configurations. From the simulation results, transmission line overloading is identified from several system generation dispatches with system N-1 contingency configurations; undervoltage planning criteria violations are identified when system is under both normal configuration and N-1 contingency configurations. A summary of transmission line overloading is provided in Table 119, and a summary of undervoltage planning criteria violation is listed in Table 120. Max West 1 and 2 have 8 contingencies each that have non-divergent issues that do not solve and most likely result in voltage collapse cases.

Table 119 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2032

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	High Loading/Overloading Element	Max. Loading(%)	High Loading/Overloading Element	Max. Loading(%)
Max West 1	None	None	L6200	147
Max West 2	None	None	L6200	148
Max West 3	None	None	None	None
West Gen Only	None	None	None	None
Max East 1	None	None	L8900	97
Max East 2	None	None	L8900	99
East Gen Only	None	None	L6200	98
Max PV/BESS	None	None	None	None

Table 120 List of Undervoltage Violations, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2032

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Minimum Voltage (pu)	Substation	Minimum Voltage (pu)	Substation
Max West 1	None	None	0.266	Keauhou
Max West 2	None	None	0.240	Keauhou
Max West 3	None	None	0.810	Keauhou
West Gen Only	None	None	0.923	Keauhou
Max East 1	None	None	0.829	Keauhou
Max East 2	None	None	0.816	Keauhou
East Gen Only	None	None	0.900	Keauhou
Max PV/BESS	None	None	0.803	Keauhou

Mitigation study – transmission networks expansion

To mitigate the overloading issue on the L6200, a minimum requirement of reconductor is replacing the L6200 line from Keamuku substation to Kaumana substation by 556 AAC conductor. To mitigate the high loading condition on the L890 line, from Keamuku substation to Waikoloa distribution substation, the reconductor requirement is also to replace the line by 556 AAC conductor. A high-level cost estimate for the L6200 reconductor is $89.2 million, and for L8900 is $10.9 million.

Though the high loading and overloading conditon on the L6200 and L8900 is fixed by the reconductor, the undervoltage issues still exist, which cannot be mitigated by the reconductor. The undervoltage issue is mainly caused by the resource retirement in the south and north/east side of the Hawaiʻi island system.

Dependent on the system total load and the east side generation resources chosen to meet this minimum requirement, the east may require 20 MVAR of additional reactive power capability to resolve potential north/east voltage violations. At the peak load with 20 MW generation on east side of island, the following options are viable for mitigating north/east undervoltage violations:

- All 3 units of PGV online
- Puna CT3 online with 2.8 MVAR additional reactive capability required at Kanoelehua or Puueo substations
- Stage 3 Kanoelehua with 20 MVAR additional reactive capability required at Kanoelehua
- Stage 3 Kanoelehua & Puueo (split output) with 20 MVAR additional reactive capability required between the two locations. The Additional reactive capability at Kanoelehua and Puueo are in addition to the assumed capability of the Stage 3 resources at that location

To mitigate undervoltage violation identifed on south side of system, it is recommend to have a resource interconnected at Keauhou substation with at least 10.4 Mvar capability or at Kamaoa substation with 13.7 Mvar or 13.3 MW capability. The reactive power capability can be replaced by active power capability, or the combination of reactive power and active power capability.

Mitigation study – portfolio options

From the power flow analyses for various system generation dispatches, it can be concluded that:

- Overloading on the L6200 line will occur with higher levels of generation dispached on west side of system pre-contingency, and large volumn of cross island power flow through it during post contingency. This cross island power flow from west to east side of the system if generation resources are located to balance production in East and West Hawaii. It is also observed that system load is below 174 MW, the overloading on the L6200 is unlikely to happen.
- Reconductoring the L6200 line does not mitigate the undervotlage issue on north/east side and south side of the system. Generation resources and reactive power resources will be required on the east and south side of the system. Procuring resources on both the East and South side is required for the voltage constraint, which also improves the L6200 overload.

Therefore, reconductoring the L6200 is required for unconstrained use of resources identified in the portfolio. The resource acquisition would need to procure MW generation on the east side of Hawaii Island, at the levels needed to avoid overloading the L6200 line for single contingencies. The minimum requirement of MW generation on the east side of the system was calculated by following equation:

East side minimum generation (MW) = $\frac{System\ total\ load - 174}{214-174} \cdot 20$

The L8900 line high loading condition is caused by high production from the east side and Keamuku substation. By shifting of generation on further west side of system (e.g., Keahole, Poopoomino, Ouli), the overloading on the L8900 can be avoided.

The planning study did not consider beyond N-1 conditions, however, the reconductoring and procuring resources distributed around the island’s transmission system, will improve resilience, in addition to removing dispatch constraints on the present base resource portfolio that otherwise would be necessary.

REZ Enablement

The interconnection of 48 MW wind generation from REZ development is assumed at the Keamuku substation. The estimated REZ enablement cost for the 48 MW offshore wind interconnection at the Keamuku substation is $37.8 million.

Base scenario resource plan, year 2050

Study descriptions

In addition to previous system resource changes by 2031, the Hawai‘i island system will have 2 MW standalone BESS and 3 MW Solar/BESS from the REZ development by 2035. It is assumed that both interconnection will be in distribution circuits by considering their MW size. In 2040, there will be another 20 MW Solar/BESS generation developed from REZ. In 2045, all fossil generation will have fuel switch to biodisel. In the same year, there will be 30 MW geothermal generation and 2 MW standalone BESS interconnected to the system. By 2050, an additional 14 MW Solar/BESS and 2 MW onshore wind generation will be developed from REZ. The system annual peak load is forecasted to reach 295 MW by 2050. A high-level map with locations of the grid-scale generation projects assumed in the study by 2050 is shown in Figure 56. For the 20 MW PV/BESS generation from REZ zone A development by 2040, it is assumed that interconnection of the project is at the Pepeekeo substation. For the 30 MW geothermal generation project, it is assumed the generation interconnection is at Haina substation. For the 17 MW PV/BESS project, it is assumed the generation interconnection is at Kaumana substation.

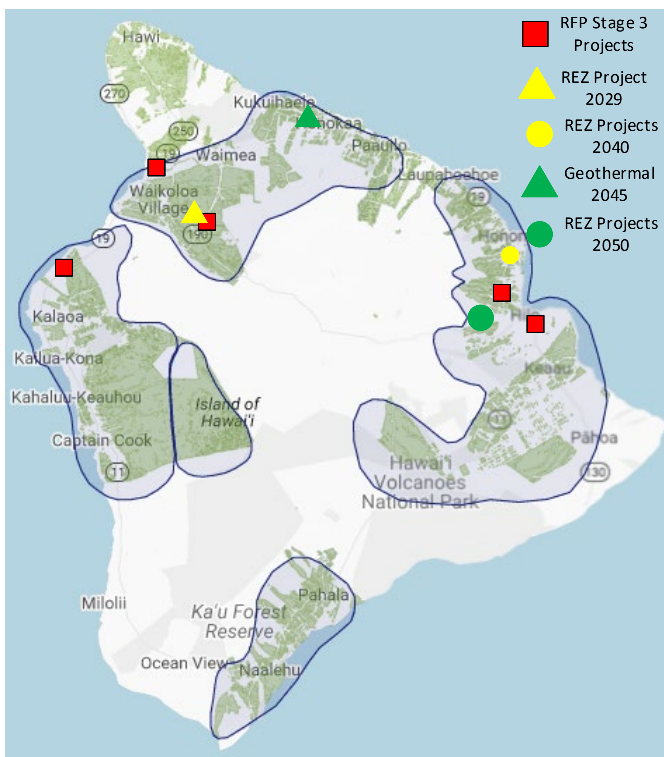


Figure 56 High-Level Hawai‘i island map with assumed future grid-scale project interconnection locations by 2050, base scenario resource plan

The detailed system grid-scale resource changes are summarized in Table 121. The system resource summary and the forecasted system load is summarized in Table 122.

Table 121 Hawai'i Island Grid-Scale Generation Project Development by 2050, Base Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Solar/BESS	3	2035	REZ, distribution interconnected
Other	Standalone BESS	2	2035	Distribution interconnected
REZ Development	Solar/BESS	20	2040	REZ, east side of Hawai'i island
Other	Geothermal	30	2045	North side of Hawai'i island
REZ Development	Solar/BESS	14	2050	REZ, east side of Hawai'i island
	Onshore wind	2	2050	

Table 122 Hawai'i Island System Resource Summary and Forecasted Demand (MW), Base Scenario Resource Plan, Year 2032

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
85.8	60.5	76	237	16.6	243	295

To evaluate 69 kV transmission system adequacy to host both grid-scale generation interconnection and the forecasted load according to the resource plan, various system generation dispatches are created for the study, which is shown in Table 123.

Table 123 Studied System Generation (MW) Dispatches, Hawai'i Island Base Scenario Resource Plan, Year 2032

Area	Max Capability	System Generation Dispatches			
		Max West	Max East	East Gen Only	Max PV Paird
North	30	30	30	0	6
West	264	264	86	0	192
East	180	0	180	180	97
South	n.a.	0	0	0	0
Total	474	294	294	294	294

Study Results

Similiar to what is observed in the base scenario resource plan year 2032 study, transmission line overloading, undervoltage violation and voltage collapse are also observed from the power flow analyses performed for the system generation dispatches. A summary of transmission line overloading condition is provided in Table 124. A summary of undervoltage planning criteria violation and voltage collapse is listed in Table 125. Max East case has 1 non-divergent issue, Max PV/BESS has 2 non-divergent issues, and Max West has 2 non-divergent issues. These cases with non-divergent issues have contingencies that do not solve and most likely result in voltage collapse.

Table 124 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2050

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	High Loading/Overloading Element	Max. Loading(%)	High Loading/Overloading Element	Max. Loading(%)
Max West	None	None	L6200	137
Max East	None	None	L8900	127
East Gen Only	None	None	L8600	128
Max PV/BESS	None	None	L8600	122

Table 125 List of Undervoltage Violations, Hawaiʻi Island Base Load Scenario Resource Plan, Year 2050

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Minimum Voltage (pu)	Substation	Minimum Voltage (pu)	Substation
Max West	0.848	PGV	0.161	Keauhou
Max East	None	None	0.414	Keauhou
East Gen Only	None	None	0.891	Keauhou
Max PV/BESS	None	None	0.235	Keauhou

Mitigation study – transmission networks expansion

Reconductoring L6200 and L8900 to 556 AAC is recommended to mitigate overloading issues. The estimated cost for reconductoring L6200 is $89.2 million, and the estimated cost for reconductoring L8900 is $10.9 million. To mitigate undervoltage violations on the north side of the system, it is recommended to dispatch an East unit (e.g., PGV, etc.) at 5 MW or higher.

To mitigate undervoltage violation on south and southwest side of the system, it is recommend to have a resource interconnected at Kamaoa with 22.5 MW generation capacity.

REZ Enablement

It is assumed that the geothermal generation in service in 2045 will be interconnected at Haina substation, and the REZ generation will be interconnected at Pepeekeo substation (20 MW) in 2040 and Kaumana substation (17 MW) in 2050.

High level cost estimate for the 20 MW interconnection REZ enablement at the Pepeekeo substation is $24.5 million, and for the 17 MW interconnection REZ enablement at the Kaumana substation is $27.9 million.

High load scenario resource plan, year 2032

Study descriptions

According to the resource plan, by 2030, the Hawaiʻi system will have new generation from Stage 3 RFP procurement, REZ development and a new geothermal generation plant, which will be 48 MW wind generation of REZ development and 30 MW geothermal generation by 2029 and 140 MW Stage 3 RFP

PV/BESS IBR generation by 2030. All of these new generation will be interconnected at Hawai'i island 69 kV system. Meanwhile, three generation plants will be removed by 2031: the 34 MW Hill 5 and 6 will be removed by 2028; the 21 MW Tawhiri wind generation will be removed by 2028; the 58 MW Hamakua Energy Partners ("HEP") will be removed from system by 2031. Accoridng to the forecast, system peak load will reach 280 MW by 2032. A high-level map with locations of the grid-scale generation projects assumed in the study by 2032 is shown in Figure 57. For the 48 MW onshore wind generation from REZ zone A development and the 140 MW generation projects from the RFP Stage 3 procurement, the assumptions regarding the generation interconnection locations are the same as what is used in the base scenario resource plan. For the 30 MW geothermal generation project, it is assumed that it will be interconnected at Haina substation.

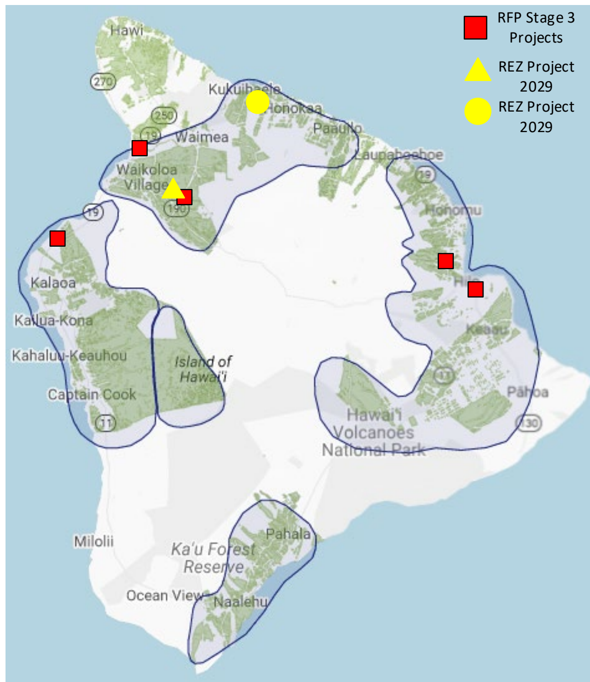


Figure 57 High-Level Hawai'i island map with assumed future grid-scale project interconnection locations by 2032, high load scenario resource plan

The detailed system grid-scale resources changes are summarized in Table 126. The system resource summary and the forecasted system load is summarized in Table 127. System resource retirement schedule in the high load scenario resource plan is the same as that in the base scenario resource plan.

Table 126 Hawai'i Island Grid-Scale Generation Project Development by 2032, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Wind Generation	48	2029	West Hawai'i island
Other	Geothermal Generation	30	2029	North of Hawai'i island
Stage 3 Hawai'i Island RFP	Solar/BESS Generation	140	2030	West and east side of Hawai'i island

Table 127 Hawai'i Island System Resource Summary and Forecasted Demand (MW), High Scenario Resource Plan, Year 2032

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
85.8	58.5	76	200	16.6	174	280

To evaluate 69 kV transmission system adequacy to host both grid-scale generation interconnection and the forecasted load according to the resource plan, various system generation dispatches are created for the study, which is shown in Table 128.

Table 128 Studied System Generation (MW) Dispatches, Hawai'i Island Base Scenario Resource Plan, Year 2032

Area	Max Capability	System Generation Dispatches			
		Max West	Max East	Max North/East	Max PV Paird
North	30	16	30	30	21
West	264	264	107	107	199
East	142	0	143	143	60
South	n.a.	0	0	0	0
Total	437	280	280	280	280

Study results

Significant transmission line overloading, undervoltage planning criteria violations and voltage collapse issues are identified from power flow analyses performed for all the studied system generation dispatches. A summary of transmission line overloading conditions are provided in Table 129. Asummary of undervoltage planning criteria violation and voltage collapse are listed in Table 130. Max East case has 1 non-divergent issue, Max PV/BESS has 1 non-divergent issue, and Max West has 18 non-divergent issues. These cases with non-divergent issues have contingencies that do not solve and most likely result in voltage collapse and show 0 PU minimum voltage.

Table 129 List of High Loading and Overloaded Transmission Lines, Hawai'i Island High Load Scenario Resource Plan, Year 2032

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	High Loading/Overloading Element	Max. Loading(%)	High Loading/Overloading Element	Max. Loading(%)
Max West	L8600	95	L6200	126
Max East	None	None	L8900	121
Max North/East	None	None	L8600	100
Max PV/BESS	None	None	L8600	99

Table 130 List of Undervoltage Violations, Hawai'i Island High Load Scenario Resource Plan, Year 2032

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Minimum Voltage (pu)	Substation	Minimum Voltage (pu)	Substation
Max West	0.787	PGV	0.645	PGV
Max East	None	None	0.771	Panaewa

Max North/East	None	None	0.835	Panaewa
Max PV/BESS	None	None	0.815	PGV

Mitigation study – transmission networks expansion

Reconductoring to 556 AAC for the L8100 line is recommended to mitigate the overloading on the L8100 line. The estimated cost for reconductoring L8100 is $10.9 million. Regarding the L6200 line overloading, it is recommended to defer the reconductor to further year by requiring minimum generation dispatch on the east side of the system.

Simliar as discussed in the base scenario resource plan study, generation resource and reactive power resource is required to mitigate the overvoltage and voltage collapse issues. Depending on the system total load and the East side generation resources chosen to meet this minimum requirement, the East may require 28 MVAR of additional reactive power capability to resolve potential North/East voltage violations. 14 MVAR at Kanoelehua and 14 MVAR at Puueo are recommended to be installed (in addition to the assumed capability of Stage 3 resources at that location).

To mitigate undervoltage violation identifed on south side of system, it is recommend to have a resource interconnected at Kamaoa substation with at least 24 MW generation capability, with var capability independent of active power generation. If a minimum MW is required this may require some resource to ensure it is available if the resource is variable, or define the requirement in terms of MVAR.

Mitigation study – Portfolio alternative

Reconductoring L6200 line to 556 AAC is required to accommodate the base portfolio without dispatch constraints. A minimum generation requirement on the east side of the system can be described as:

East side minimum generation (MW) = $\frac{System\ total\ load - 174}{214 - 174} \cdot 20$

If the system total load is lower than 178 MW, there is no mimimum MW requirement of generation dispatched on east side of the system.

REZ Enablement

The interconnection of 48 MW wind generation from REZ development is assumed at the Keamuku substation. The estimated REZ enablement cost for the 48 MW offshore wind interconnection at the Keamuku substation is $37.8 million.

High load scenario resource plan, year 2036

Study descriptions

In addtion to previous system resource changes, by 2035 the Hawaiʻi island system will have another 30 MW geothermal generation, 30 MW firm generation and 22 MW solar/BESS generation from REZ development. Accoriding to the forecast, system annual peak load will be reached at 323 MW by 2036. A high-level map with locations of the grid-scale generation projects assumed in the study by 2032 is shown in Figure 58. For the 22 MW PV/BESS generation from REZ zone A development, it is assumed to be interconnected at Pepeekeo substation; for the 30 MW firm generation, it is assumed to be interconnected at the Kanoelehua substation; and for the second 30 MW geothermal generation project, it is assumed to be interconnected at the Haina substation. The detailed system grid-scale resources changes are summarized in Table 131. The system resource summary and the forecasted system load is summarized in Table 132. System resource retirement schedule in the high load scenario resource plan is the same as that in the base scenario resource plan.

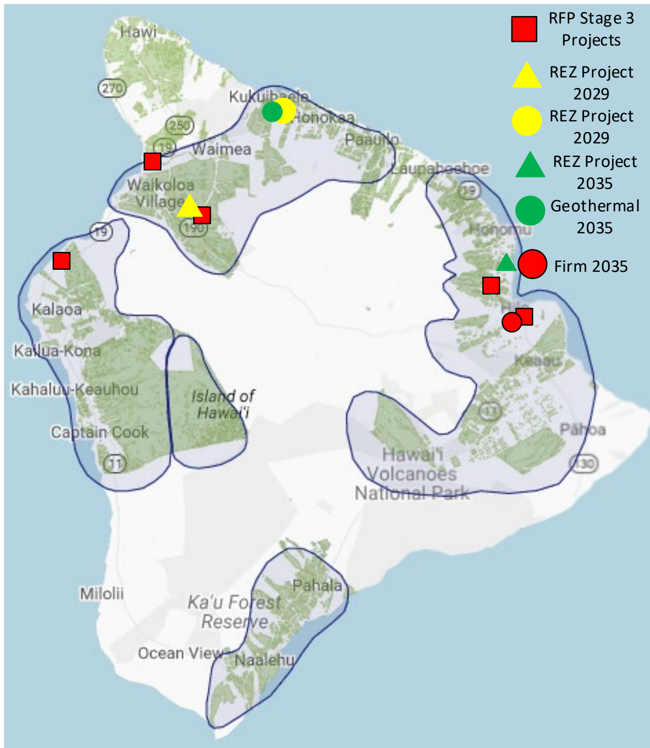


Figure 58 High-Level Hawai'i island map with assumed future grid-scale project interconnection locations by 2036, high load scenario resource plan

Table 131 Hawai'i Island Grid-Scale Generation Project Development by 2036, High Load Scenario Resource Plan

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Solar/BESS	22	2035	East side of Hawai'i island system
Other	Geothermal	30	2035	North side of Hawai'i island system
Other	Firm	30	2045	East side of Hawai'i island system

Table 132 Hawaiʻi Island System Resource Summary and Forecasted Demand (MW), High Load Scenario Resource Plan, Year 2036

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
115.8	58.5	106	220	16.6	230	323

To evaluate 69 kV transmission system adequacy to host both grid-scale generation interconnection and the forecasted load according to the resource plan, various system generation dispatches are created for the study, which is shown in Table 133.

Table 133 Studied System Generation (MW) Dispatches, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036

Area	Max Capability	System Generation Dispatches			
		Max West	Max East 1	Max East 2	Max Renewable
North	30	58	60	60	21
West	264	264	69	119	199
East	195	3	195	145	0
South	n.a.	0	0	0	0
Total	519	325	325	325	220

Study results

Power flow analyses are performed for all the system generation dispaches, when the Hawaiʻi island system is with normal configuration and when the system is with N-1 contingency configuration. Analysis results indicate significant trasmission line overloading on the cross-island line L6200 and undervoltage violation with voltage collapse potential, which is simliar as what is observed in the high load scenario resource plan year 2032 study. Additonally, overloading on the L8600 is also identified. This is due to the generation retirement, as well as load growth on the south side of the system. A summary of transmission line overloading condition is provided in Table 134. A summary of undervoltage planning criteria violation and voltage collapse is listed in Table 135. Max East 1 case has 4 non-divergent issue, Max East 2 has 3 non-divergent issues, Max Renewable has 4 non-divergent issues, and Max West has 20 non-divergent issues. These cases with non-divergent issues have contingencies that do not solve and most likely result in voltage collapse and show 0 PU minimum voltage.

Table 134 List of High Loading and Overloaded Transmission Lines, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	High Loading/Overloading Element	Max. Loading(%)	High Loading/Overloading Element	Max. Loading(%)
Max West	L8600	100	L8600	118
Max East 1	None	None	L8900	167
Max East 2	None	None	L8900	131
Max Renewable	None	None	L8900	123

Table 135 List of Undervoltage Violations, Hawaiʻi Island High Load Scenario Resource Plan, Year 2036

Generation Dispatch	Normal Configuration		N-1 Contingency Configuration	
	Minimum Voltage (pu)	Substation	Minimum Voltage (pu)	Substation
Max West	None	None	0.658	Kilauea
Max East	None	None	0.256	Keauhou
Max East 2	None	None	0.316	Keauhou
Max Renewable	None	None	0.815	Capt Cook

Mitigation study – transmission networks expansion

To mitigate the transmission line overloading issues, reconductor of L6200 line to 556 AAC and L8600 line to 336 AAC is proposed. The estimated cost for reconductoring the L6200 is $89.2 million, and the estimated cost for reconductoring the L8600 is $32.3 million.

To mitigate undervoltage violations on the north side of the system, it is recommended to dispatch an East unit (e.g., PGV, etc.) at 14 MW or higher.

To mitigate undervoltage violation on south and southwest side of the system, , it is recommended to have a resource interconnected at Kamaoa with at least 24 MW active power generation capacity and 7.5 Mvar reactive power capability.

To mitigate undervoltage violations on the west side of the system during dispatches with high east generation, it is recommended to dispatch Keahole at 10 MW or higher.

REZ Enablement

Between 2033 and 2036, there is 20 MW PV/BESS generation project from the REZ zone A development, which is assumed to be interconnected at the Pepeekeo substation. The estimated cost for the REZ enablement in Pepeekeo substation is $24.5 million.

4.3.2 Dynamic stability study

The Hawai'i Island system in near-term years 2026 and 2032 of base scenario resource plan are selected for performing dynamic stability study to evaluate system dynamic stability performance. Similar to the O'ahu and Maui studies, the Hawai'i Island system dynamic stability study is performed in PSCAD/EMTDC for the high-risk system generation dispatch, which is also the daytime peak load with high DER generation, with a short list of high-risk system contingency.

The Hawai'i Island system high-risk contingency consists of a contingency for each category of planning events from P1 to P5. Also, due to the system topology and interconnection of existing grid-scale generations, for each selected year, dynamic stability study is performed for a base dispatch, in which most synchronous machine-based generation is dispatched from east side of the system, and a sensitivity dispatch, in which most of synchronous machine-based generation is dispatched from west side of the system.

Base scenario resource plan, year 2026

Study descriptions and study results

According to the resource plan, in 2026, there is no additional grid-scale generation resource interconnected to the system beyond RFP Stage 1 projects. So, the study of 2026 benchmarks system dynamic stability performance. A base system generation dispatch and a sensitivity system generation dispatch, both representing daytime peak load with high DER generation scenario in 2026 with different system topology, are created (as Table 136) and modeled in PSCAD/EMTDC. In these two dispatches, there is no GFM IBR resources in the system. Study results are summarized in Table 137. From the simulation results, it can be concluded that the Hawai'i Island system does not have sufficient resource to maintain system stability within planning criteria for the selected dispatch scenarios before the RFP Stage 3 projects interconnected online.

Table 136 System Generation Dispatches (Base Dispatch and Sensitivity Dispatch) for Daytime Peak Load High DER Generation Scenario, Hawai'i Island Base Scenario Resource Plan, Year 2026

Generation Station	Capacity (MW)	Base Dispatch (MW)	Sensitivity Dispatch (MW)
PGV	38	38	0
Keahole DTCC	52	0	38
Hill 5&6	34	13	13
Hydro Generation	17	5	5
Wind Generation	31	5	5
Stage 1 PV/BESS (GFL)	60	36	36
DER	143	103	103
System Load (MW)		200	200

Table 137 Hawai'i Island System Dynamic Stability Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2026

Planning Event	2026 Base Dispatch						2026 Sensitivity Dispatch					
	UFLS (MW)	DER Trip (MW)	Freq. Nadir (Hz)	UFLS Blocks Shed	Planning Criteria Violation?	Notes	UFLS (MW)	DER Trip (MW)	Freq. Nadir (Hz)	UFLS Blocks Shed	Planning Criteria Violation?	Notes
P1/P3	6	5	58.8	B1	Yes	1	32	41	58.5	B1-3	Yes	1,2
P2	57	47	58.1	B1-4	Yes	1,2	57	47	58.0	B1-4	Yes	1,2
P4	0	8	59.3	None	No	3	0	1	59.5	None	No	3
P5	32	31	58.2	B1-3	Yes	1	57	46	58	B1-4	Yes	1

Note:
1. UFLS caused by DER momentary cessation during transmission fault voltages.
2. Legacy DER trip due to overfrequency overshoot caused by excessive UFLS.
3. Small synchronous machine power oscillations caused by unbalanced tripping of DER

Detailed simulation results for selected planning events (a P5 event for base dispatch and a P3 event for sensitivity dispatch) are shown in Figure 59 and Figure 60.

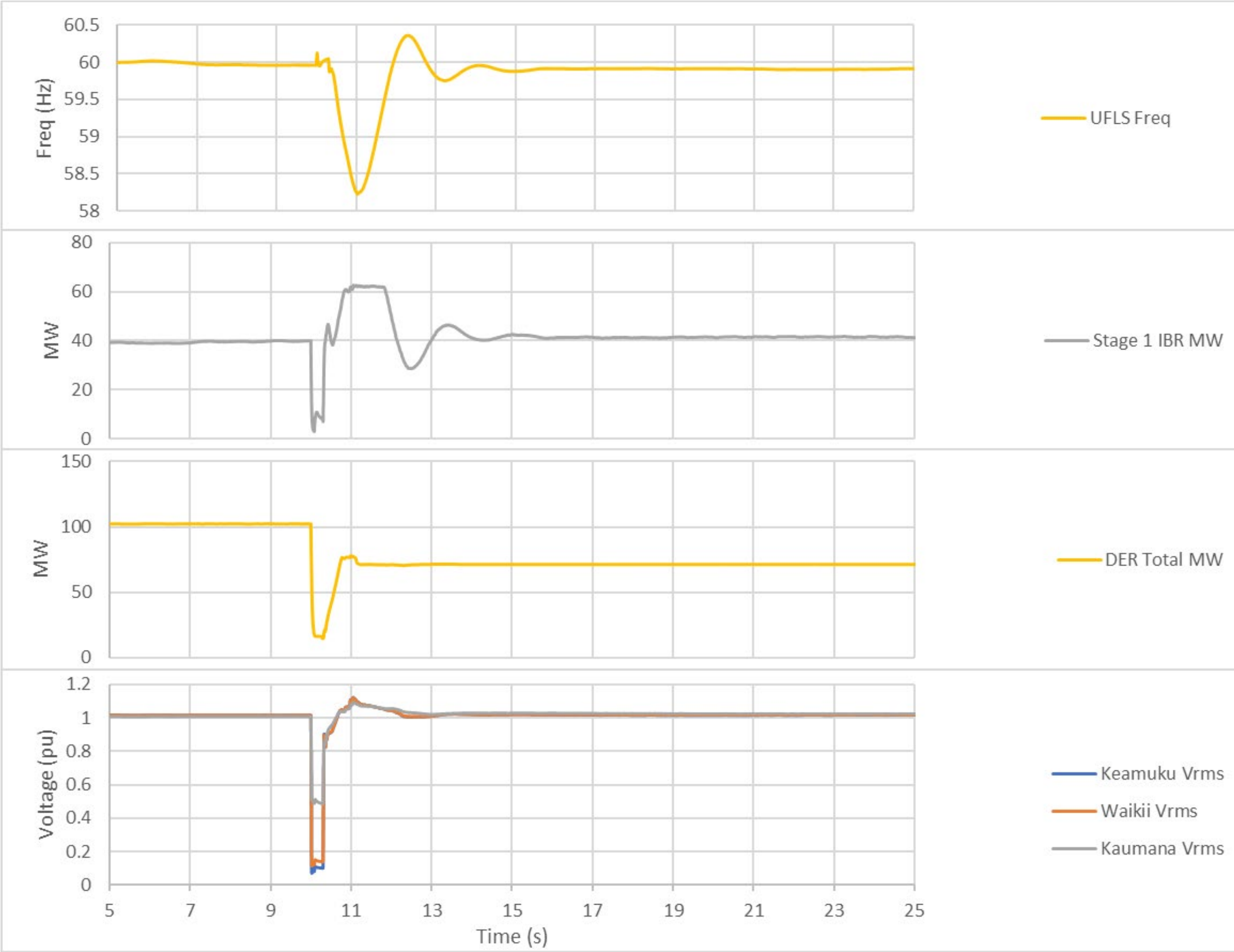


Figure 59 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2026, base dispatch, P5 planning event

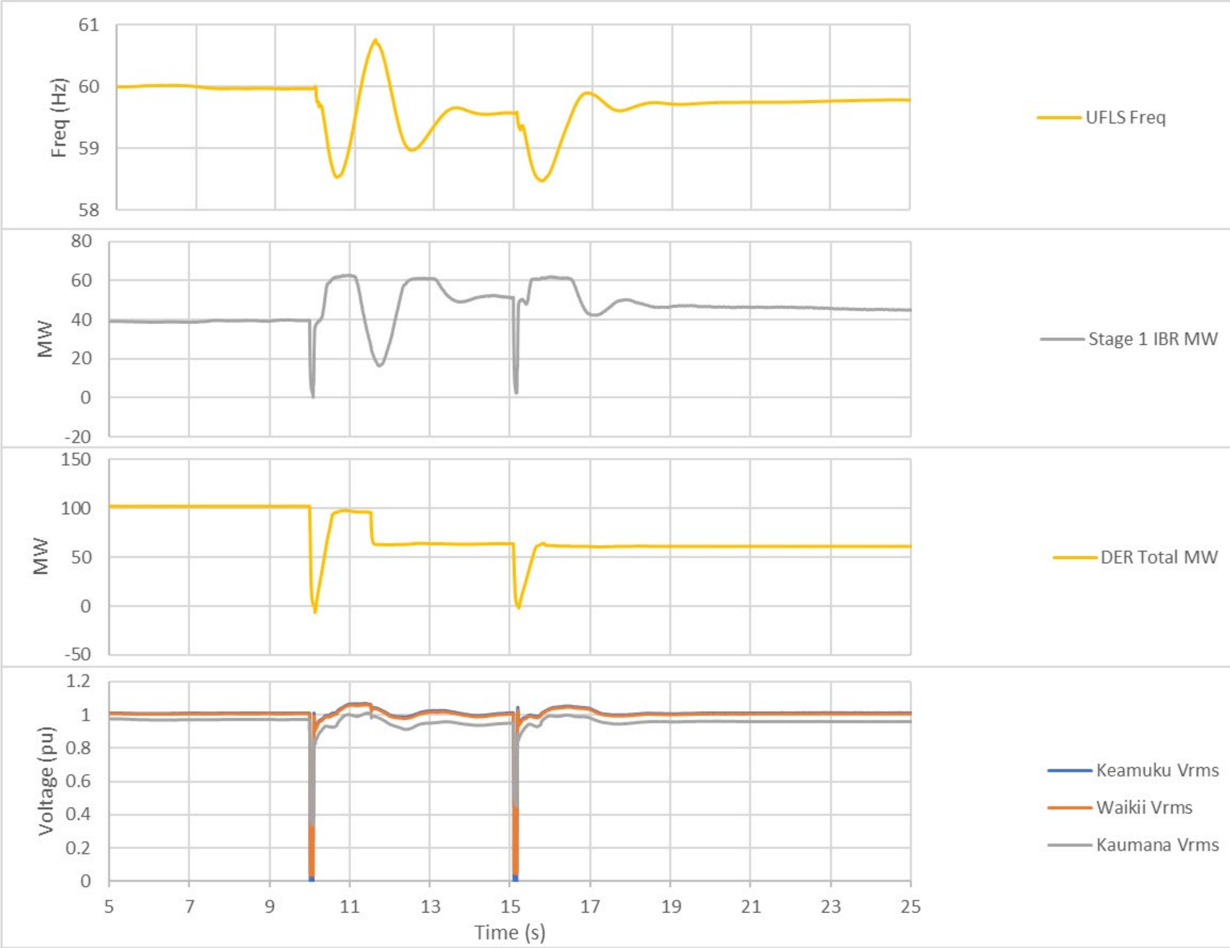


Figure 60 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2026, sensitivity dispatch, P3 planning event

Base scenario resource plan, year 2032

Study descriptions and study results

According to the resource plan, a base system generation dispatch and sensitivity system generation dispatch, both representing daytime peak load with high DER generation scenario in 2032 with RFP Stage 3 projects, are created (as Table 138) and modeled in PSCAD/EMTDC.

Table 138 System Generation Dispatches (Base Dispatch and Sensitivity Dispatch) for Daytime Peak Load High DER Generation Scenario, Hawai'i Island Base Scenario Resource Plan, Year 2032

Generation Station	Capacity (MW)	Base Dispatch (MW)	Sensitivity Dispatch (MW)
PGV	46	20	0
Keahole STCC	26	0	20
Hydro Generation	17	4	4
Wind Generation	59	0	0
Stage 1 PV/BESS (GFL)	60	20	20
Stage 3 PV/BESS (GFM)	140	28	28
DER	214	134	134
System Load (MW)		206	206
GFM Available MW Headroom/DER Generation		0.84	0.84

PSCAD simulation results are summarized in Table 139. After adding the 140 MW GFM resource from the RFP Stage 3 procurement, planning criteria violation is not identified, and according to the frequency nadirs of all simulated system events, the Hawai'i Island system has sufficient stability margin. From the simulations, sustained oscillations in real power are also observed in the Stage 3 IBR responses and synchronous machine responses. This may come from the untuned models which are used for representing the RFP stage 3 projects. Detailed simulation results for selected planning events (a P5 event for base dispatch and a P3 event for sensitivity dispatch) are shown in Figure 59 and Figure 60.

Table 139 Hawai'i Island System Dynamic Stability Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032

Planning Event	2032 Base Dispatch						2032 Sensitivity Dispatch					
	UFLS (MW)	DER Trip (MW)	Freq. Nadir (Hz)	UFLS Blocks Shed	Planning Criteria Violation?	Notes	UFLS (MW)	DER Trip (MW)	Freq. Nadir (Hz)	UFLS Blocks Shed	Planning Criteria Violation?	Notes
P1/P3	0	0	59.6	None	No		0	0	59.2	None	No	
P2	0	0	59.6	None	No	1	0	0	59.2	None	No	1
P4	0	0	59.8	None	No	1	0	0	59.8	None	No	1
P5	0	0	59.6	None	No		0	0	59.6	None	No	1
Note: 1. Steady state real power oscillations in RFP Stage 3 projects and synchronous machines.												

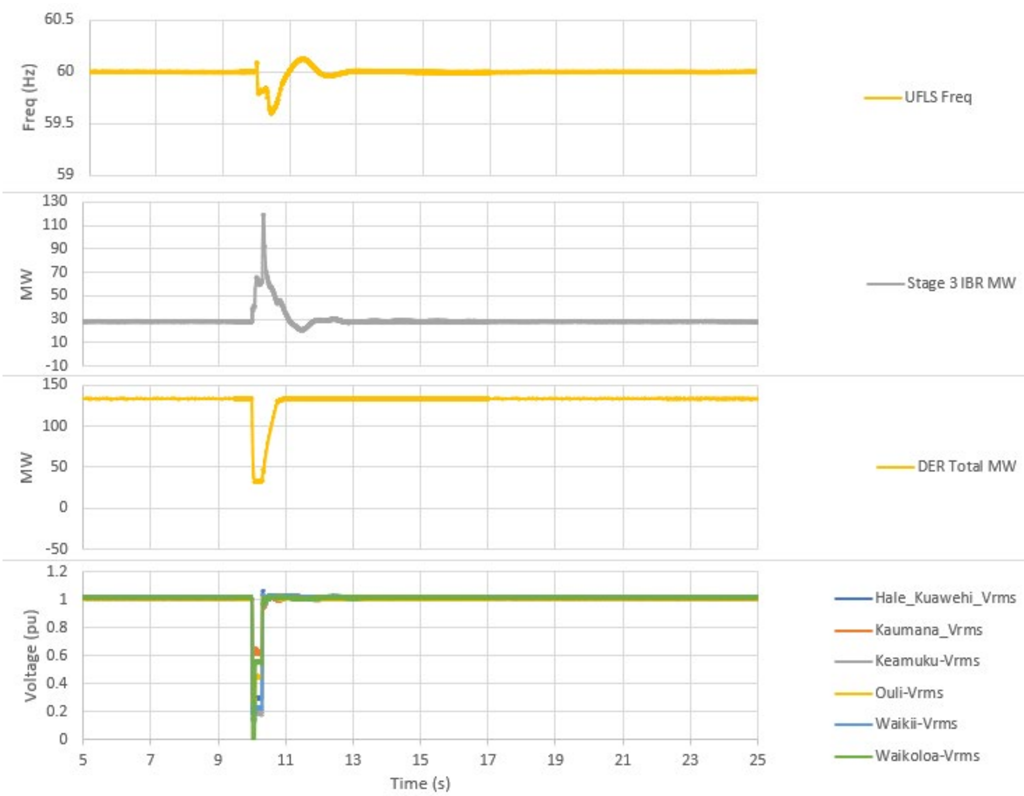


Figure 61 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2032, base dispatch, P5 planning event

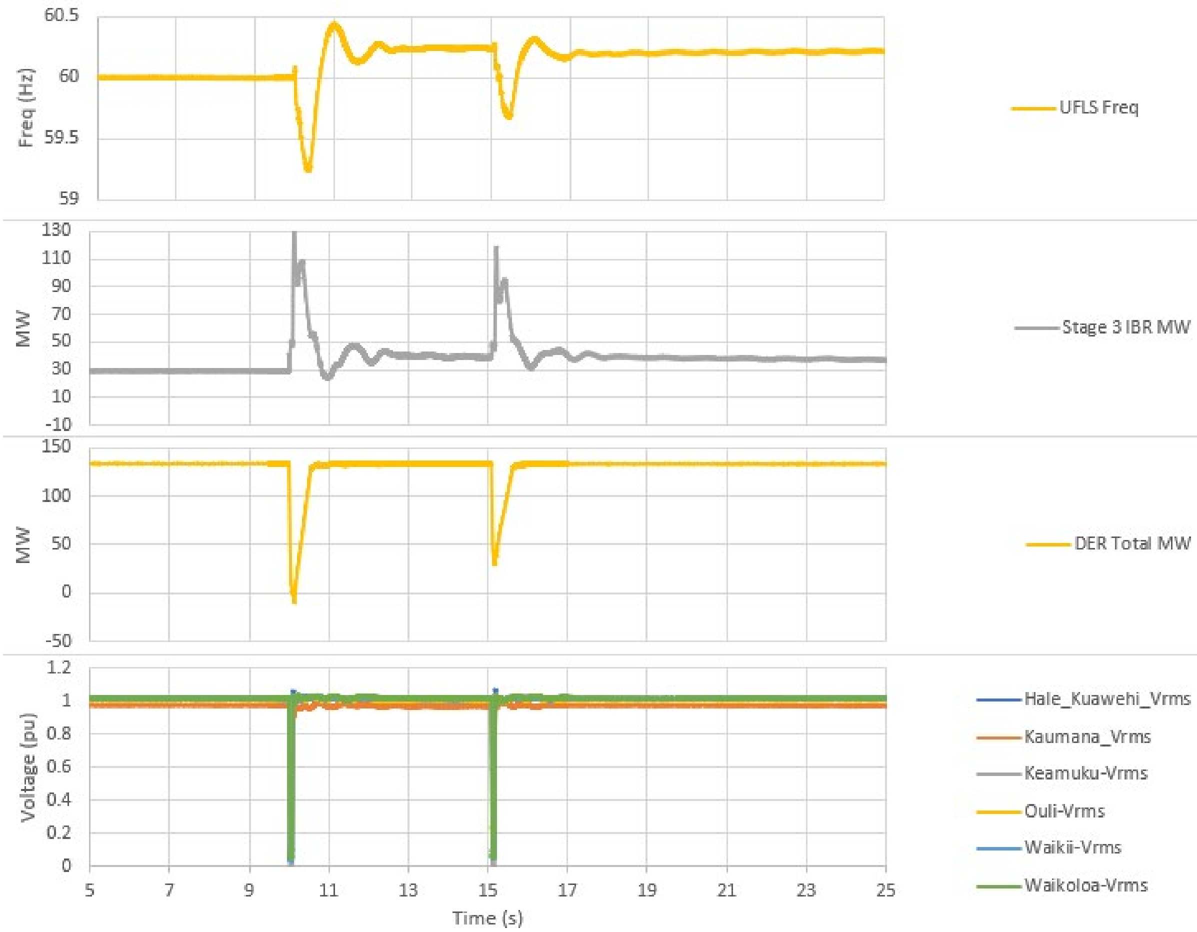


Figure 62 Dynamic stability simulation results, Hawai'i Island base scenario resource plan, year 2032, base dispatch, P3 planning event

Further study is also performed to identify minimum requirement regarding GFM resource procurement in order to maintain the Hawai'i Island dynamic stability within planning criteria, by step reducing the size of future GFM resource and creating different combinations of east side interconnection size and west side interconnection size. This study is performed for both base dispatch (i.e., major synchronous generation dispatched on east side) and sensitivity dispatch (i.e., major synchronous generation dispatched on west side), with the same high-risk contingency list. Study results for the base dispatch and sensitivity dispatch are summarized as following tables. From the study, it can be concluded that the minimum GFM requirements are dependent on system available GFM resource and synchronous generation and it is important to have a balanced interconnection of grid-scale GFM resources between east and west side of Hawai'i Island system. By 2032, the minimum requirement for Hawai'i Island system may be between 60MW – 110MW of GFM capacity on the system, and the ratio of available MW headroom from GFM resource to DER generation should be roughly 0.24 to 0.61 depending on system dispatch. All these requirements are based on the model performance used in the study to represent future GFM generation, and hence these requirements will be updated according to the future procured resource performance.

Table 140 Hawai'i Island System Minimum GFM Requirement Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032, Base Dispatch

MW Size of GFM Resource		Total GFM MW Size	GFM Headroom/ DER Generation	Contingency			
West side	East side			1	2	3	4
80	60	140	0.84	No Identified Issues	Steady-state oscillations	Steady-state oscillations	Steady-state oscillations
80	0	80	0.39	**No Identified Issues**	**Steady-state oscillations**	**No Identified Issues**	**No Identified Issues**
30	30	60	0.24	**No Identified Issues**	**Steady-state oscillations**	**Steady-state oscillations**	**No Identified Issues**
50	0	50	0.16	UFLS observed	UFLS observed	No Identified Issues	No Identified Issues
30	0	30	0.01	UFLS observed	UFLS observed	No Identified Issues	UFLS observed

Table 141 Hawai'i Island System Minimum GFM Requirement Study Results Summary, Hawai'i Island Base Scenario Resource Plan, Year 2032, Sensitivity Dispatch

MW Size of GFM Resource		Total GFM MW Size	GFM Headroom/ DER Generation	Contingency			
West side	East side			1	2	3	4
80	60	140	0.84	No Identified Issues	Steady-state oscillations	Steady-state oscillations	Steady-state oscillations
60	50	110	0.61	**No Identified Issues**	**Steady-state oscillations**	**No Identified Issues**	**Steady-state oscillations**
20	60	80	0.39	UFLS observed	UFLS observed Steady-state oscillations	No Identified Issues	No Identified Issues
20	30	50	0.16	UFLS observed	UFLS observed	No Identified Issues	No Identified Issues
0	30	30	0.01	UFLS observed	UFLS observed	No Identified Issues	UFLS observed

4.4. Molokaʻi and Lānaʻi Study Results

Both Moloka'i and Lānaʻi are much smaller systems by comparing with the remaining three island systems. Neither the Moloka'i nor the Lānaʻi system has a transmission planning criterion since there is no transmission system there. In the scope of this study, only dynamic stability of the Moloka'i and Lānaʻi system based on the resource plan is reviewed. The criteria used for this study is that the two systems can survive a primary circuit (12 kV or 33 kV) three-phase bolted fault with 2 seconds duration and single phase to ground high impedance fault with 40 Ohm fault impedance with 20 seconds duration. For each selected year for the study, for both the three-phase fault and the single line to ground fault, both close in fault, which is the fault applied at the beginning of the circuit, and far end fault, which is the fault applied at the end of a circuit, are simulated. All simulations are performed in PSCAD/EMTDC. The years that are selected for the study are:

- Molokaʻi system base scenario resource plan – 2029, 2030 and 2050.
- Molokaʻi system high load scenario resource plan – 2029, 2030 and 2050
- Lanaʻi system base scenario resource plan – 2029 and 2050.
- Lanaʻi system high load scenario resource plan – 2029 and 2050
- Lanaʻi system No Resort scenario resource plan – 2029, 2030 and 2050

4.4.1 Molokaʻi Study Results

Base scenario resource plan, year 2029

Daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load is 5.4 MW, supplied by DER (1 MW), existing diesel unit (D8, generating 2 MW), and centralized IBR (5.75 MW GFM BESS capacity and 6 MW PV generation capacity). Simulation results for a three-phase close in fault are shown in Figure 63, and for a three-phase far end fault is shown in Figure 64. From the close in fault results, it can be observed that system can survive the 2 seconds duration fault by successfully recovering system voltage and frequency; however, system may have diesel unit out of synchronism during the far end three-phase fault. In both cases, the GFM IBR resources demonstrate stability of ride-through the fault.

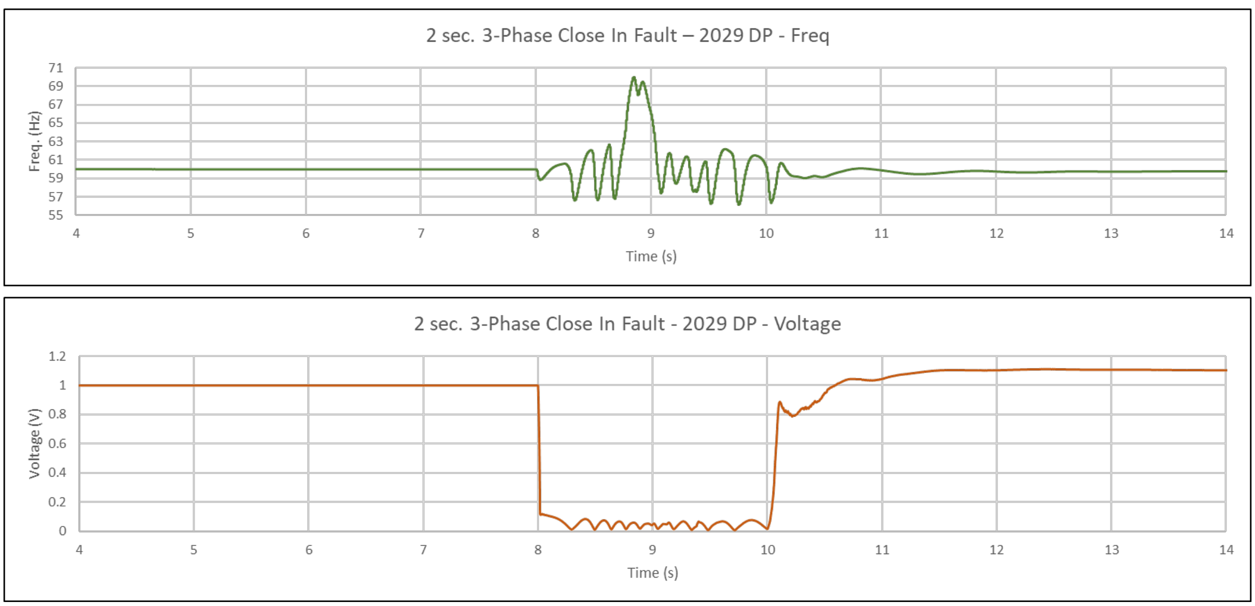


Figure 63 Dynamic stability simulation results, Molokaʻi base scenario resource plan, year 2029, three-phase close in fault

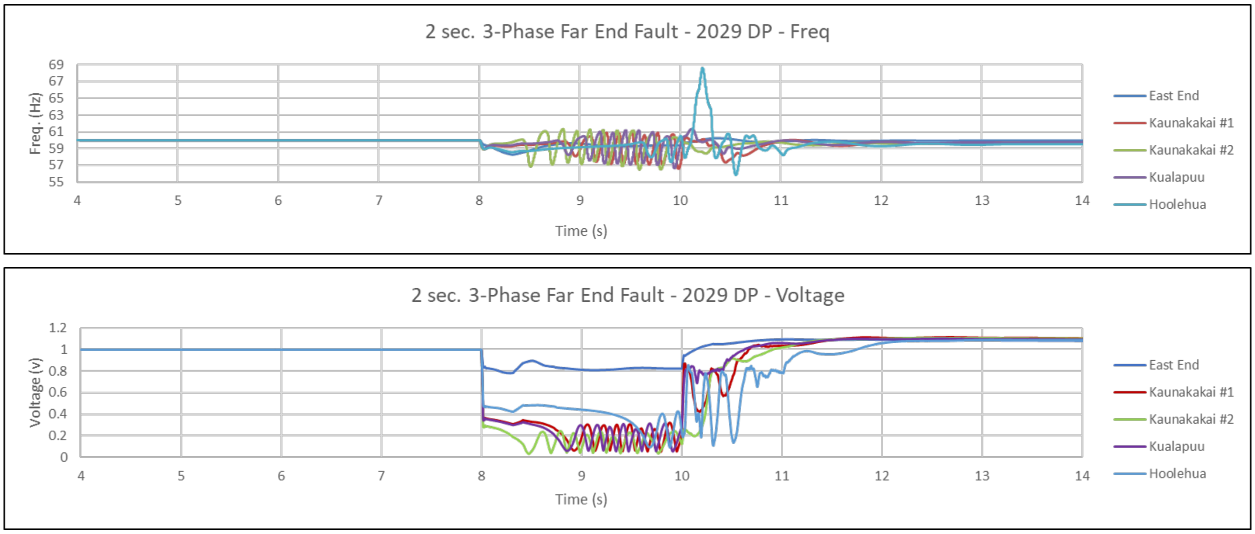


Figure 64 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, three-phase close in fault

For the single phase to ground high impedance fault, a case with a far end high impedance single phase to ground is shown in Figure 65. From the simulation, it can be found that Moloka'i Palaau substation could experience voltage dip down to 0.5 p.u., and system frequency could swing between 56 Hz to 64 Hz. Once again, the diesel unit become out of synchronism 3 seconds after the fault inception, which causes system frequency reach 64 Hz. After fault clearing, the system voltage and frequency can recover within acceptable limits. It is worth noting that in the current system, there is no out of synchronism protection for the diesel unit. Once system has enough GFM resource to pick up load supplied by the synchronous machine pre-event, system protection should be configured to let the synchronous machine trip, in order to reduce disturbance in the system.

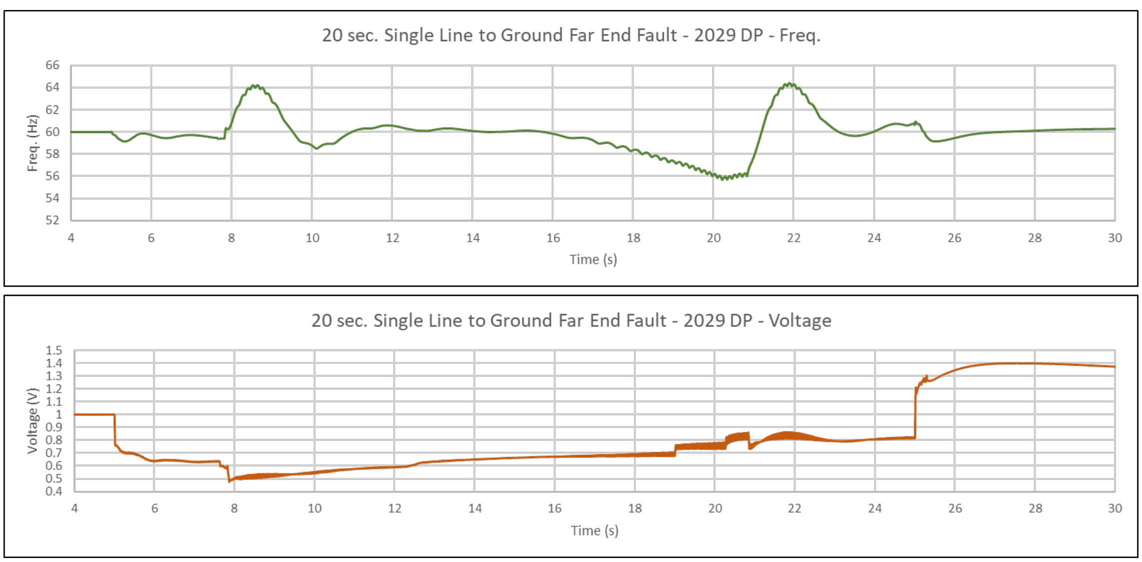


Figure 65 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, single phase far end fault with high fault impedance

Base scenario resource plan, year 2030

Daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load is 5.4 MW, supplied by DER (1 MW), existing diesel unit (D8, generating 1.1 MW), and centralized IBR (14.25 MW GFM BESS capacity, and 14.5 MW PV generation capacity). Simulation results of system voltage and frequency for a close in three-phase bolted fault with 2 seconds duration are shown in Figure 66, and for a far end three-phase fault are shown in Figure 67. The simulation results indicate system can maintain stable during the fault and after fault clearing. The large capacity of GFM resource can quickly recovery system voltage and frequency after the fault clearing. Simulation results for a far end high impedance single line to ground fault are shown in Figure 68 which indicates the same conclusion that system has sufficient stability to survive the 20 seconds duration high impedance fault.

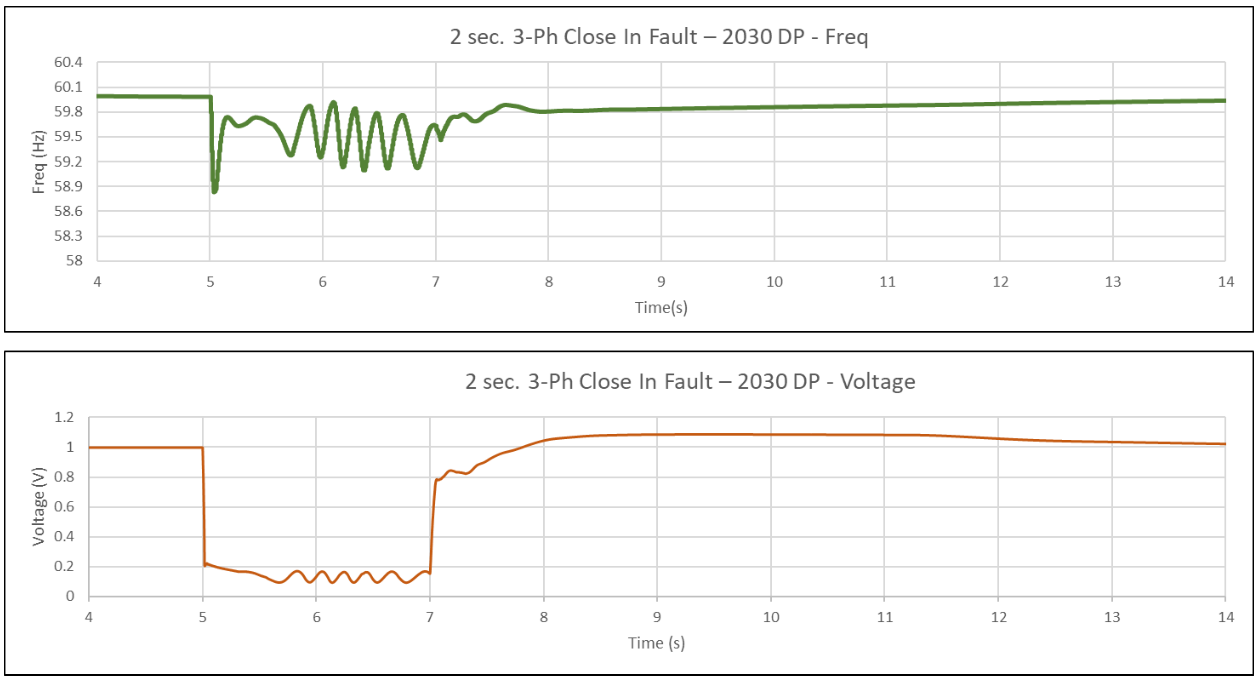


Figure 66 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, three-phase close in fault

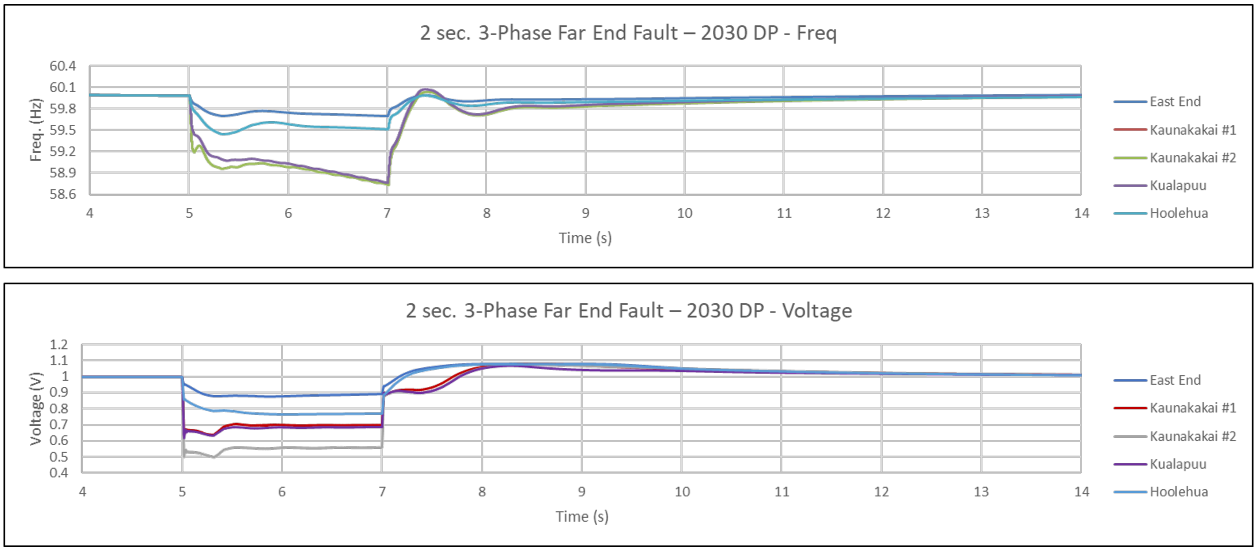


Figure 67 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, three-phase far end fault

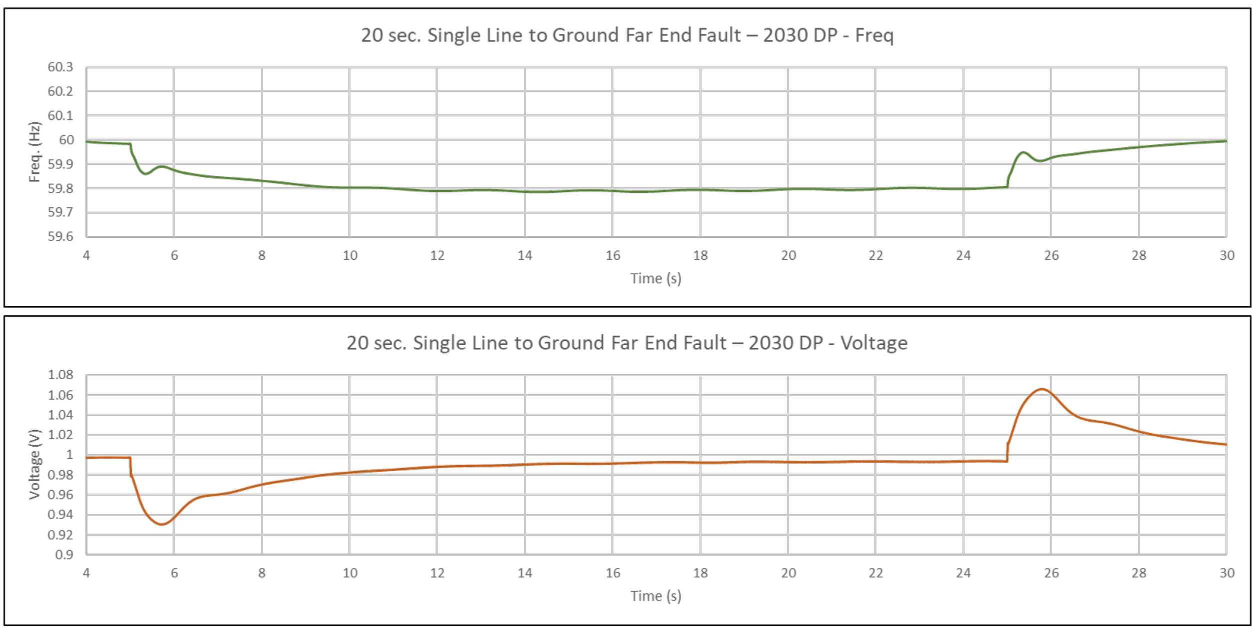


Figure 68 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2030, high impedance far end fault

Base scenario resource plan, year 2050

For the 2050 case, system evening peak load no DER no diesel unit generation dispatch is created for the study. In this scenario, all of the system load, which is 6.29 MW, is supplied by the centralized GFM BESS resources (with 21.5 MW capacity). Same three-phase faults and the far end high impedance single line to ground fault are studied. The simulation results indicate that the system can survive both the three-phase fault and the high impedance single line to ground fault. Simulation results are shown in Figure 69, Figure 70, and Figure 71.

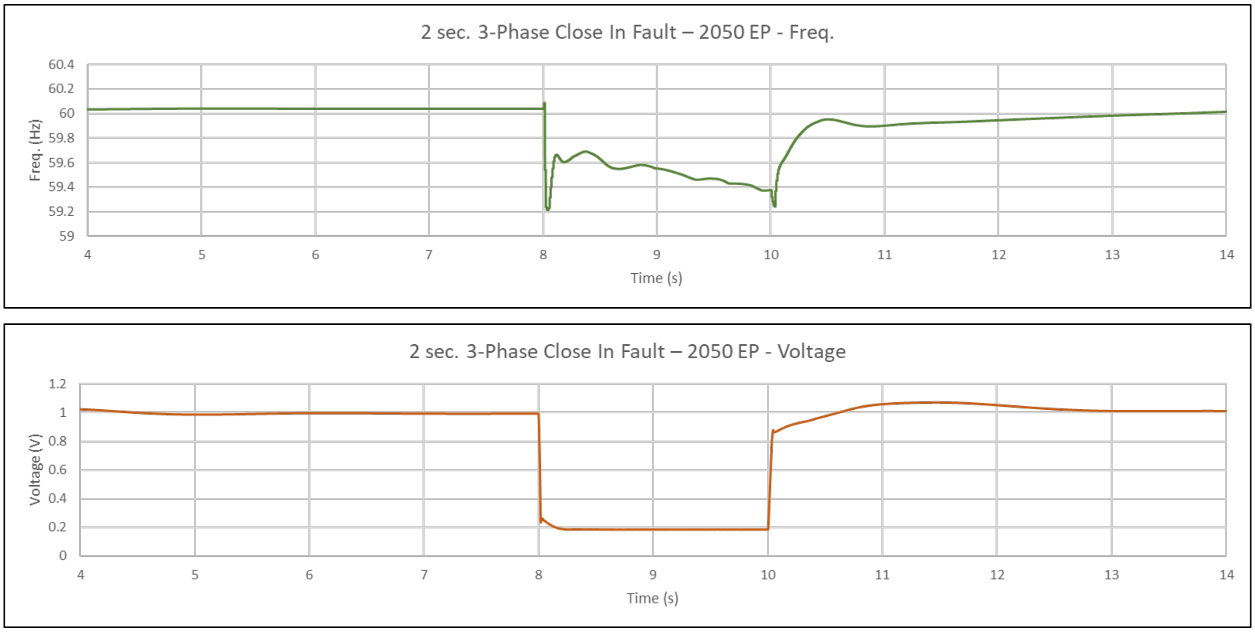


Figure 69 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, three-phase close in fault

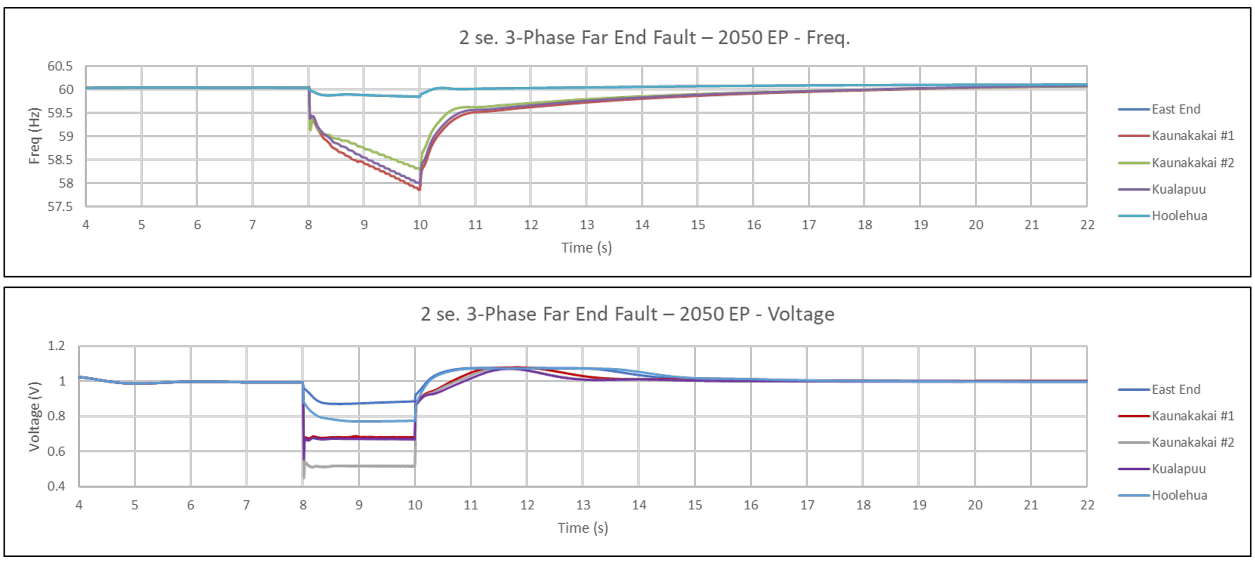
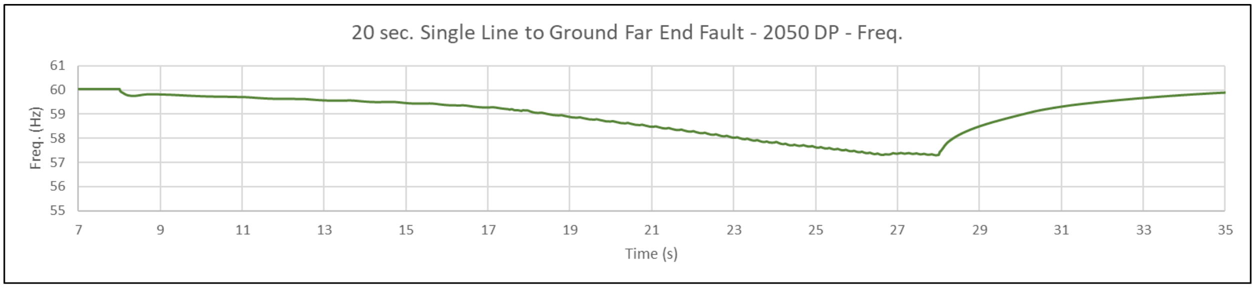


Figure 70 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, three-phase far end fault



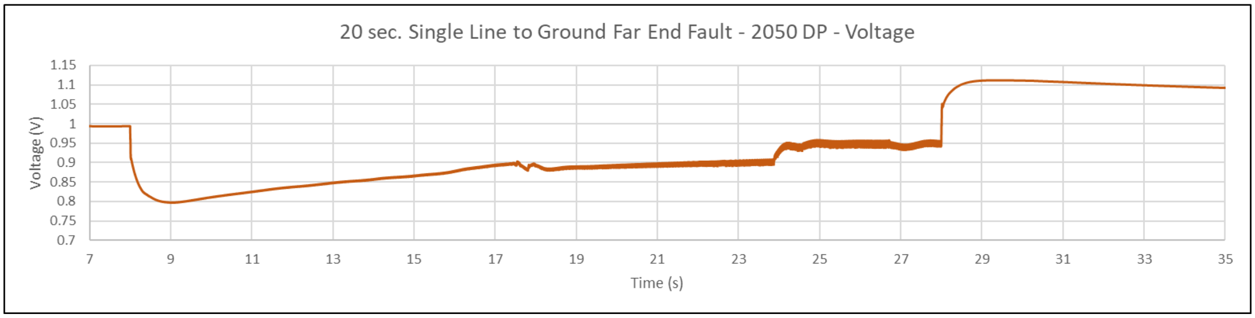


Figure 71 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2050, high impedance far end fault

In summary, it is found from the studies that sufficient centralized GFM resource interconnected at the Palaau substation can maintain system stability (i.e., surviving the 2 second three-phase bolted fault and the 20 seconds high impedance single line to ground fault) without need of the existing diesel unit. The existing diesel unit is likely to be out of synchronism during the fault, which could cause the system to experience large voltage or frequency swing. It is recommended that once system has sufficient GFM resource (from 2030), out-of-step protection should be installed for the existing diesel unit to make sure the machine can be tripped during the fault to avoid system voltage and frequency swing and equipment damage. This conclusion and recommendations are very similar as what is concluded in the 2021 System Stability Study.

High load scenario resource plan study

The Moloka'i system high load scenario resource plan is the same as the base scenario resource plan, but with different load forecast. According to the high load scenario resource plan, the Moloka'i system load is normally 1-2 MW higher than the same year load forecast in the base scenario resource plan. Exact same generation dispatches are studied for the same selected years (2029, 2030 and 2050), with the same fault events. Simulation results indicate the same conclusion as what is found for the base resource scenario that GFM resource in 2030 and further years is sufficient to maintain system stability, and out-of-step protection should be installed for the existing diesel units to avoid system voltage and frequency swing caused by the diesel units out of synchronism.

4.4.2 Lāna'i Study Results

Base scenario resource plan, year 2029

Daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load is 5.9 MW, supplied by DER (0.33 MW), existing diesel unit (D8, generating 0.5 MW), centralized IBR (16.1 MW GFM BESS capacity, and 16.1 MW PV generation capacity). Simulation results for a three-phase close in fault are shown in Figure 72, and for a three-phase far end fault is shown in Figure 73. From the close in fault results, it can be observed that system can survive the 2 seconds duration fault by successfully recovering system voltage and frequency. In both cases, the GFM IBR resources demonstrate stability and the ability to ride-through the fault.

Figure 72 Dynamic stability simulation results, Lāna'i base scenario resource plan, year 2029, three-phase close in fault

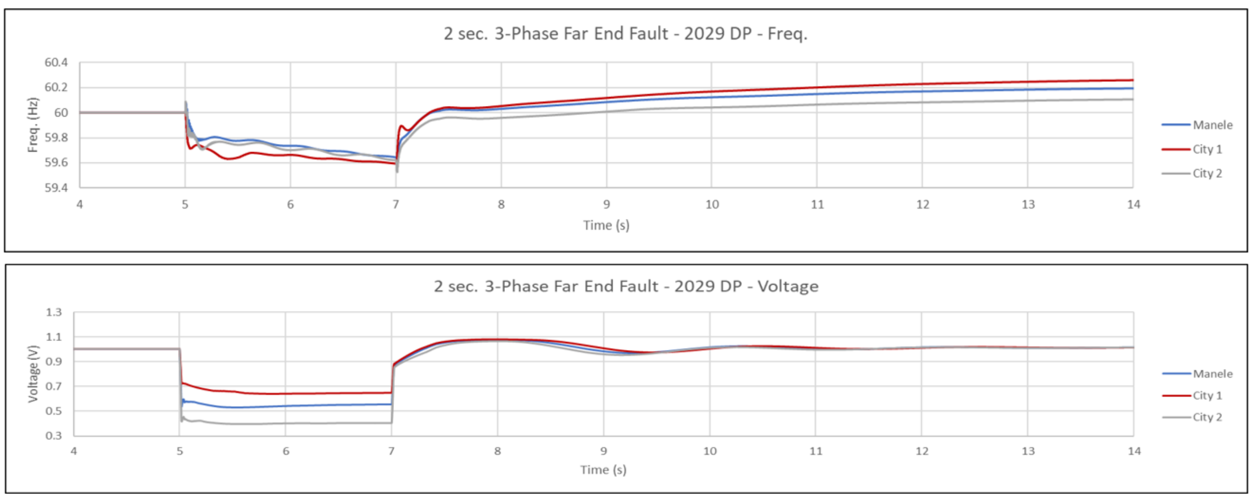


Figure 73 Dynamic stability simulation results, Moloka'i base scenario resource plan, year 2029, three-phase close in fault

Figure 74 shows the simulation results of system voltage and frequency for a far end high impedance single phase to ground fault scenario. From the simulation, it can be found that the Miki Basin substation voltage could experience voltage dip down to 0.75 p.u., and system frequency could be maintained between 59.5 Hz and 60 Hz. System can immediately recover voltage and frequency after clearing the fault. The system stability performance is well within acceptable range.

Figure 74 Dynamic stability simulation results, Lānaʻi base scenario resource plan, year 2029, single phase far end fault with high fault impedance

Base scenario resource plan, year 2050

Daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load is 5.83 MW, supplied by DER (0.34 MW), existing diesel unit (D8, generating 2 MW), centralized IBR (24.8 MW GFM BESS capacity, and 24.8 MW PV generation capacity). The same fault scenarios as studied in the 2029 case are also simulated in the study for the 2050 case. Simulation results indicate that the 24.8 MW GFM resource is sufficient to maintain system stability during both the three-phase fault and the high impedance single phase fault. The simulation results are shown in Figure 75, Figure 76, and Figure 77.

Figure 75 Dynamic stability simulation results, Lānaʻi base scenario resource plan, year 2050, three-phase close in fault

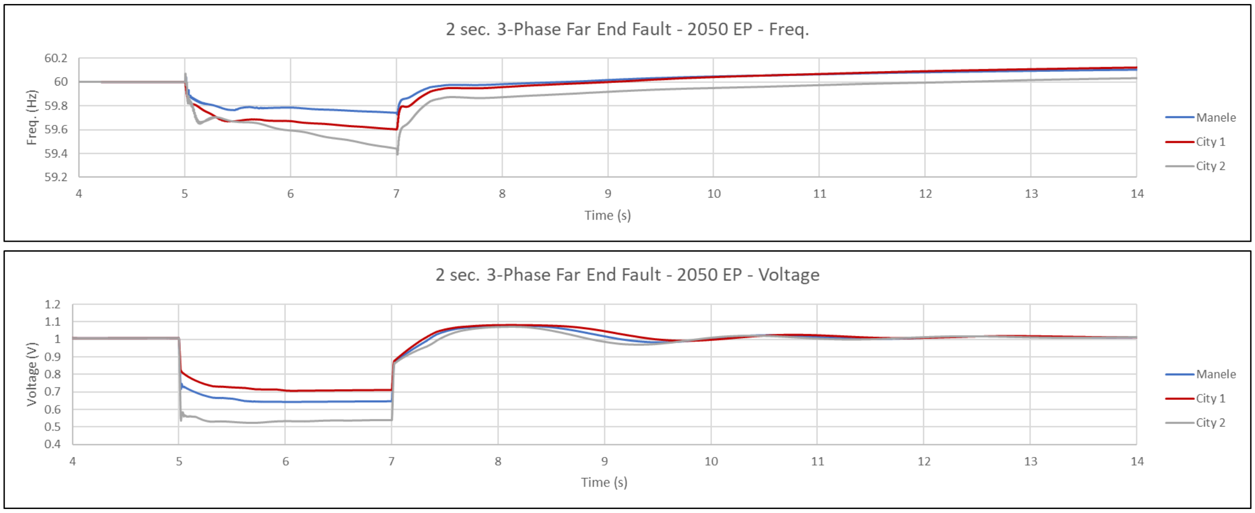


Figure 76 Dynamic stability simulation results, Lāna'i base scenario resource plan, year 2050, three-phase close in fault

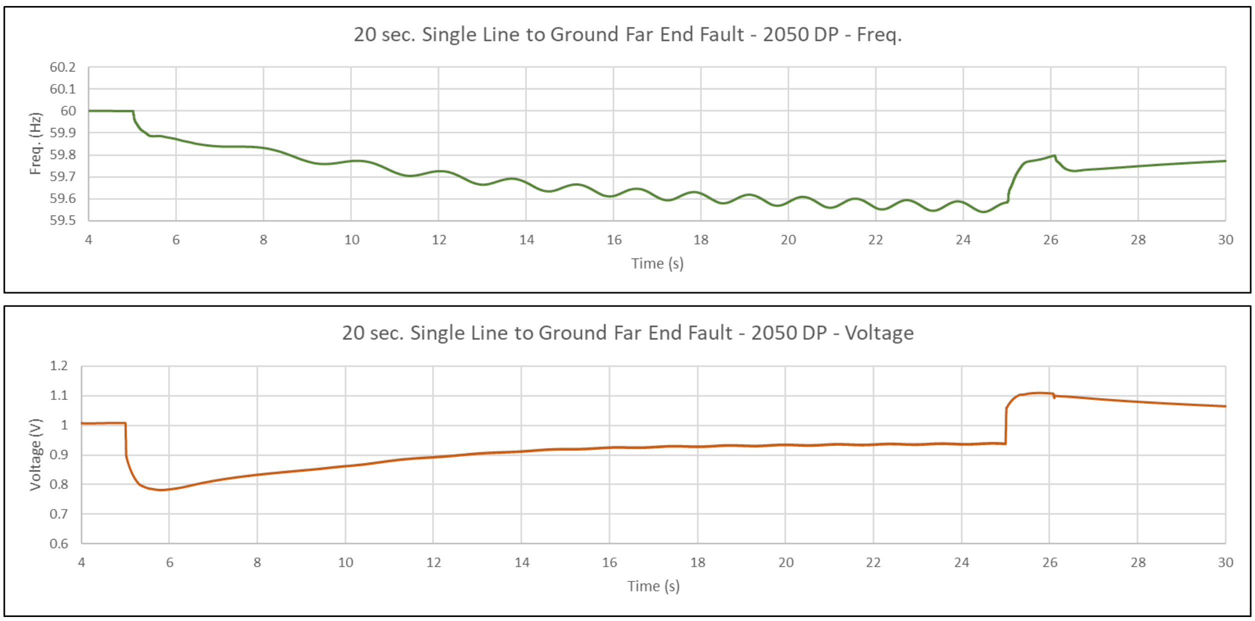


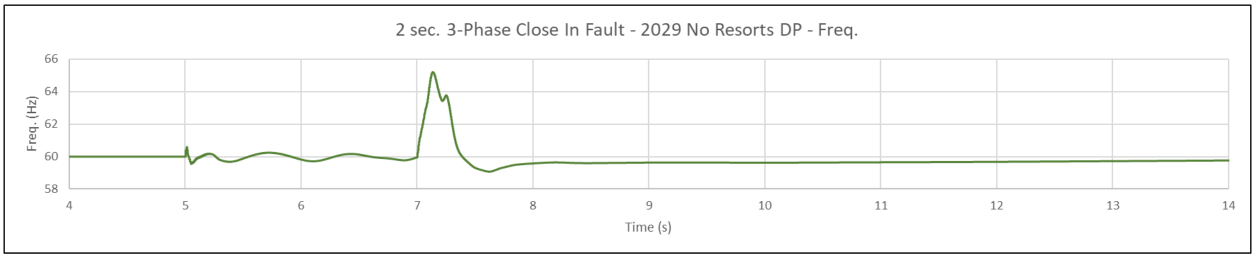
Figure 77 Dynamic stability simulation results, Lāna'i base scenario resource plan, year 2050, single phase far end fault with high fault impedance

High load scenario resource plan study

Lāna'i system high load scenario resource plan is the same as the base scenario resource plan, but with higher load forecast. Exact same generation dispatches are studied for the same selected years (2029 and 2050), with the same fault events. Simulation results indicate the same conclusion as what is found for the base resource scenario that GFM resource in 2029 and further years is sufficient to maintain system stability.

No resort load scenario resource plan, year 2029

In this resource plan, it is assumed that a big part of system load will be off grid. Hence, system load forecast is much smaller than what is shown in the base scenario and high load scenario resource plans. The load reduction also causes much smaller centralized resource planned for the system. For 2029, daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load is 2.9 MW, supplied by DER (0.28 MW), existing diesel unit (D8, generating 1.02 MW), centralized IBR (3.9 MW GFM BESS capacity, and 3.9 MW PV generation capacity). The same three-phase faults and single line to ground faults are simulated in the PSCAD. Simulation results are shown as Figure 78, Figure 79, and Figure 80. From the three-phase fault simulation results, it can be observed that the dispatched diesel unit would not be able to ride-through the 2 seconds duration fault. Instead, the diesel unit shows out of synchronism from the simulation, which could cause system frequency swing after clearing the fault. Also, the 3.9 MW GFM resource is not big enough apparently to absorb disturbance caused by the diesel unit out of synchronism. However, the 3.9 MW GFM unit can survive from both the three-phase fault and the high impedance single line to ground fault.



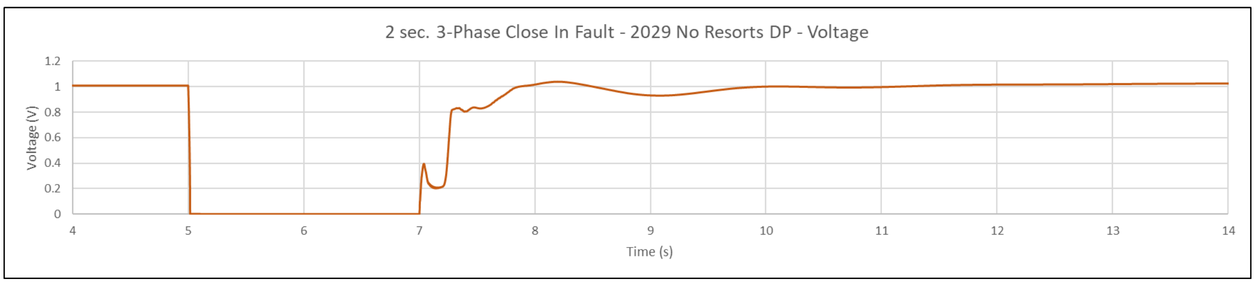


Figure 78 Dynamic stability simulation results, Lāna'i no resort scenario resource plan, year 2029, three-phase close in fault

Figure 79 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2029, three-phase close in fault

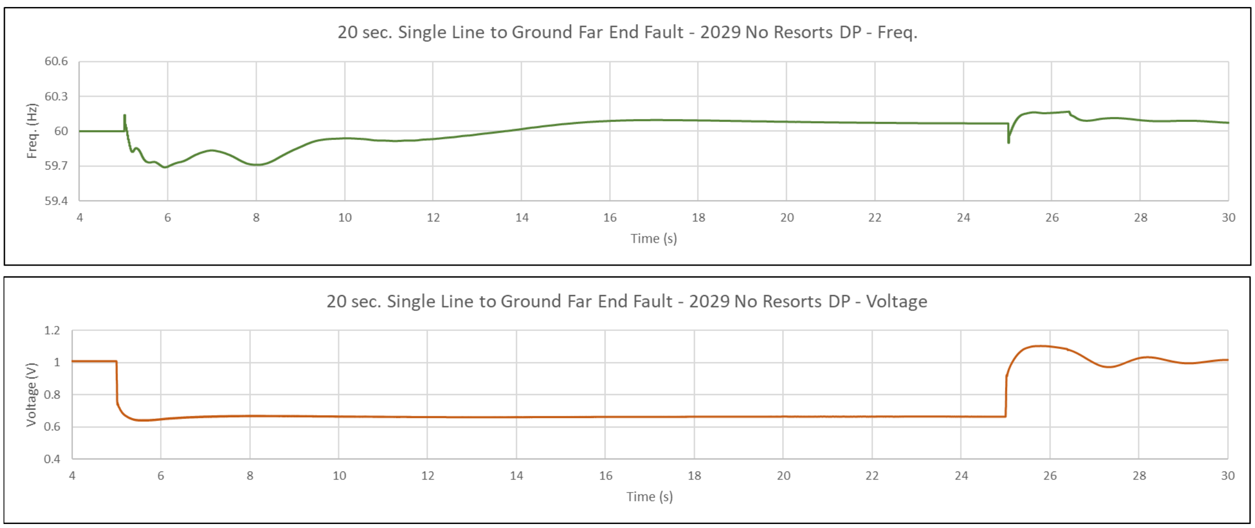


Figure 80 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2029, single phase far end fault with high fault impedance

No resort load scenario resource plan, year 2030

According to the resource plan, in 2030, 6.3 MW GFM resource will be added into the system. System peak load forecast is 3.0 MW. Daytime peak load low DER and low diesel generation dispatch is selected for the study. In this dispatch, system load (3 MW) is supplied by DER (0.28 MW), existing diesel unit (D8, generating 0.5 MW), centralized IBR (10.2 MW GFM BESS capacity, and 10.2 MW PV generation capacity). The same three-phase faults and high impedance single line to ground fault as what are studied previously are simulated in the PSCAD/EMTDC. From the simulation results, it is concluded that system stability can be maintained by the GFM resource, and system voltage and frequency can be recovered after clearing the fault. Simulation results are shown in Figure 81, Figure 82, and Figure 83.

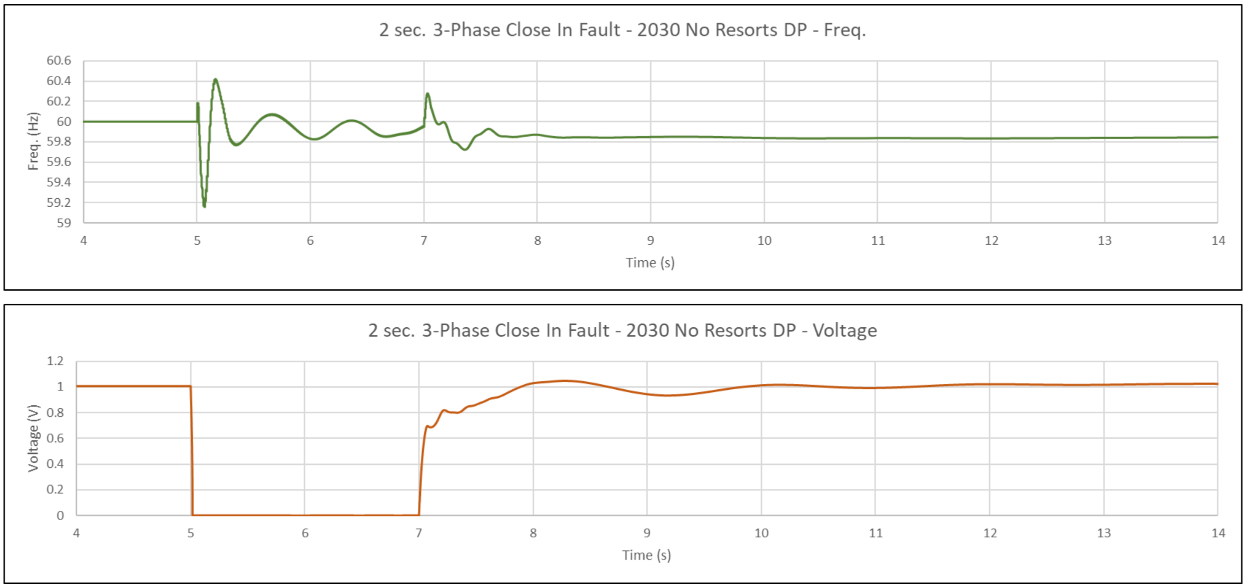


Figure 81 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2030, three-phase close in fault

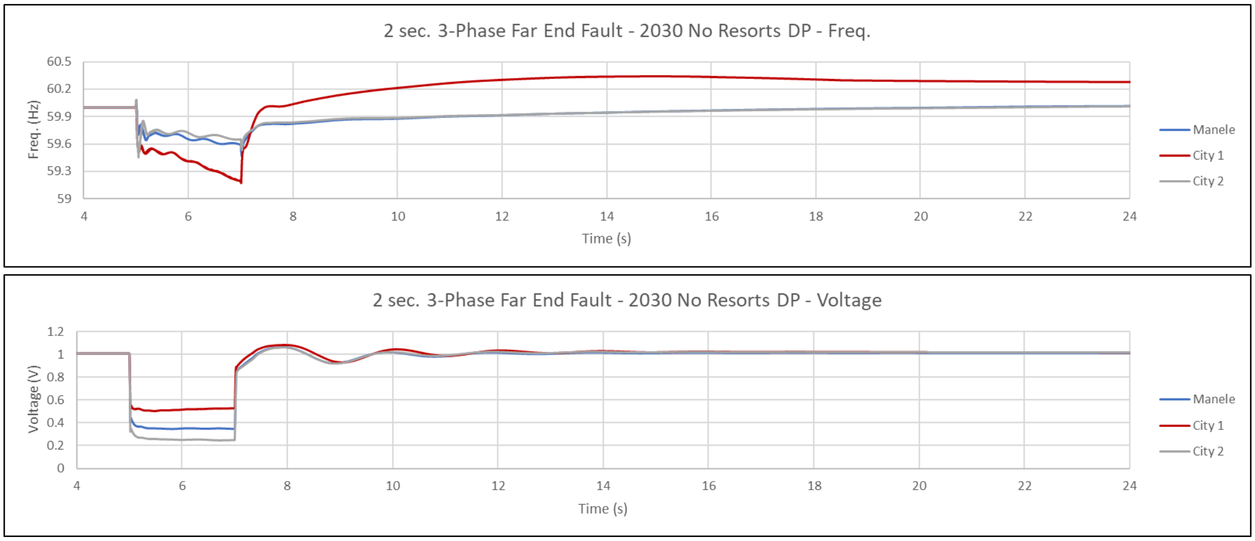


Figure 82 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2030, three-phase close in fault

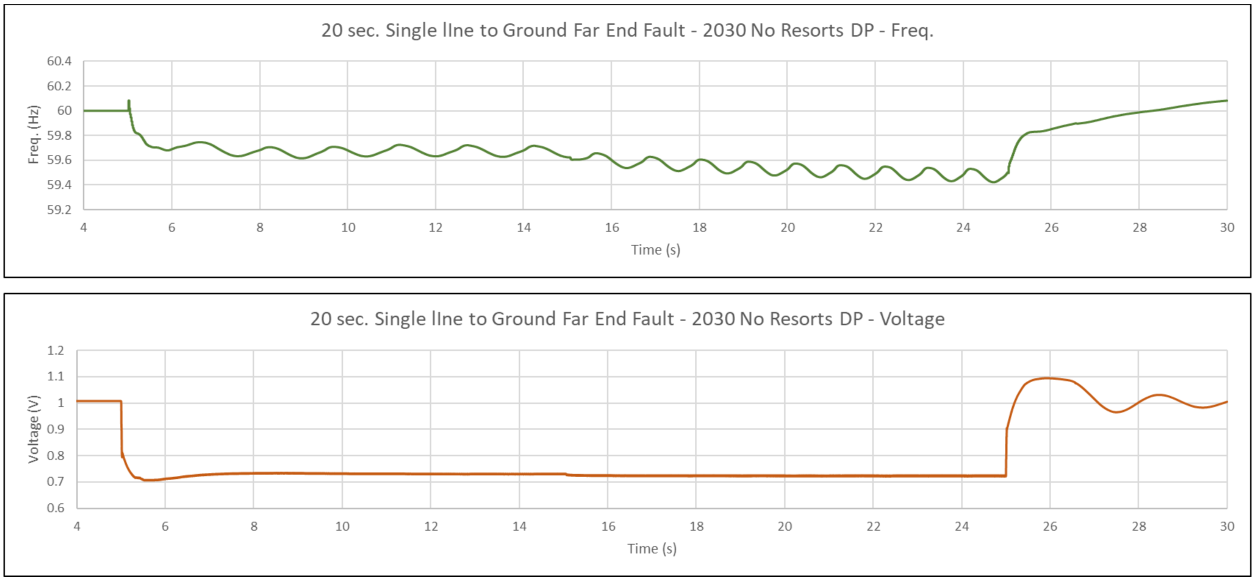


Figure 83 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2030, single phase far end fault with high fault impedance

No resort load scenario resource plan, year 2050

Another 2.3 MW GFM resource is added to system by 2050, with system peak load forecast as 3.3 MW. A daytime peak load with low DER and low diesel generation dispatch is selected for year 2050 study. In this dispatch, system load (3.3 MW) is supplied by DER (0.34 MW), existing diesel unit (D8, generating 1.0 MW), and centralized IBR (12.5 MW GFM BESS capacity, and 12.5 MW PV generation capacity). The same three-phase faults and high impedance single line to ground fault as what are studied previously are simulated in the PSCAD/EMTDC. Simulation results indicate that the 12.5 MW GFM resource is sufficient to maintain system stability during both the three-phase fault and the high impedance single phase fault. The simulation results are shown in Figure 84, Figure 85 and Figure 86.

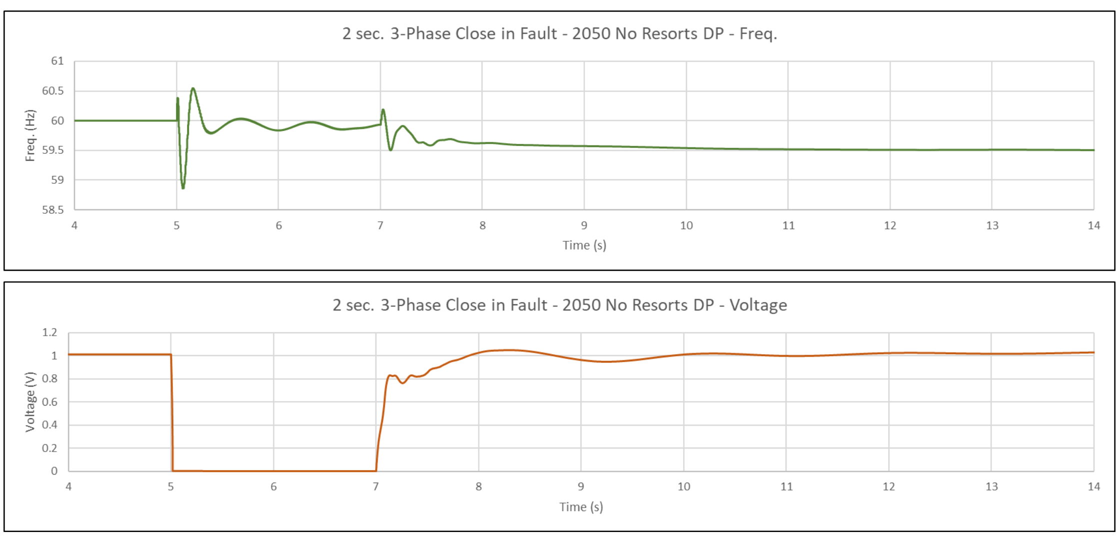


Figure 84 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2050, three-phase close in fault

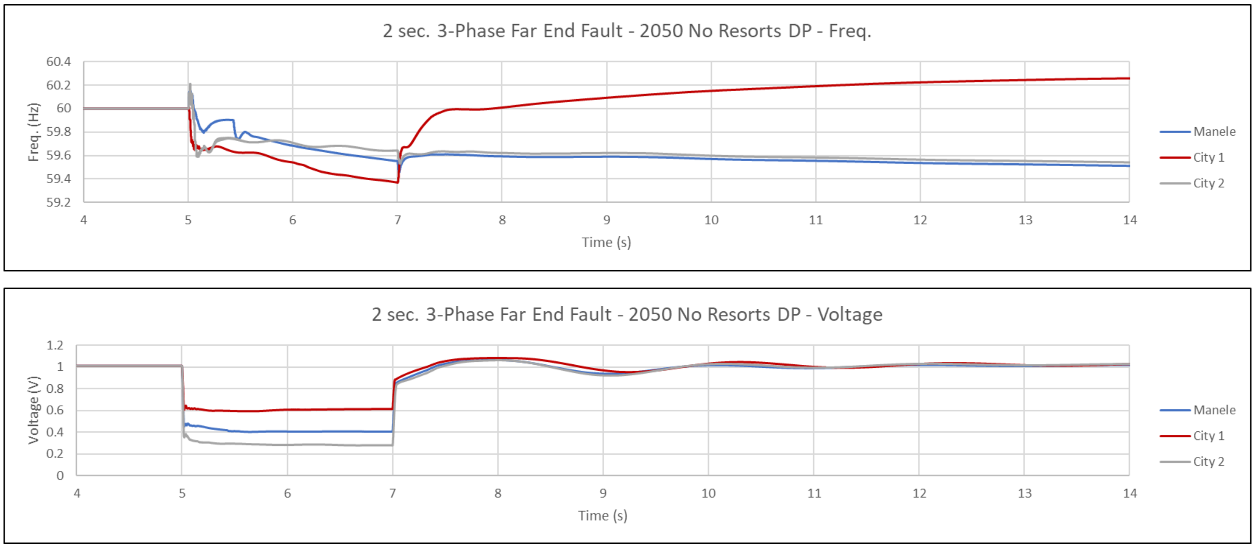


Figure 85 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2050, three-phase close in fault

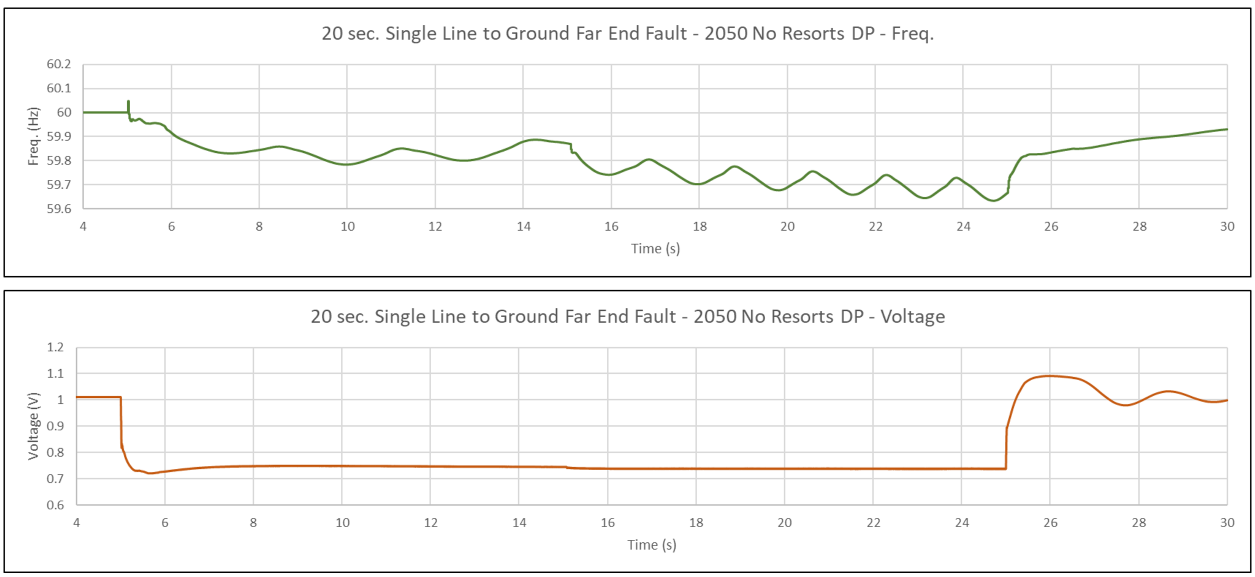


Figure 86 Dynamic stability simulation results, Lānaʻi no resort scenario resource plan, year 2050, single phase far end fault with high fault impedance

5. TECHNICAL ADVISORY PANEL FEEDBACKS

During the study, the IGP Technical Advisory Panel transmisison sub-committee met three times with Company to review the study methodology and results from December 2022 to February 2023. Summary of TAP's feedback are listed as following, and the detailed TAP feedback of each meeting are available from Company's IGP website[7].

In general, the TAP agrees with study methodology and findings. The following is a list of comments or questions on the details of the study, which were raised by the TAP as suggestion for future discussion or consideration.

1) The TAP agreed that the uncertainties in the inputs to the study are very high due to project timelines and withdrawals, future generation location uncertainty, load growth uncertainty, and DER growth uncertainty. The TAP noted that proactive construction of transmission to enable renewable resources has been very successful in California, Colorado, Texas, and other regions. HECO is already considering this and is encouraged to continue.
   Company is currently reviewing options of proactive construction of transmission system to enable renew energy zone development.
2) In the land-constrained scenario resource plan, the TAP agrees that it is a good idea to consider using grid-forming STATCOM to mitigate system stability issue when there is not sufficient grid-scale grid-forming resource. The TAP recommends to use Grid Needs Assessment process to do the cost/benefit analysis by comparing grid-forming STATCOM sulotion with a grid-forming BESS solution.
   Company identified system stability risk from the O'ahu land-constrained scenario resource plan, and currently is running model iteration according to the stability needs to determine if more synchronous machine based resource can be dispatched to maintain system stability or more grid-forming resources need to be procured in near term years. Company expects that in long term years under the land-constrained scenario resource plan, O'ahu system will need more grid-forming resources (e.g., grid-forming BESS and grid-forming STATCOM), and agrees with the TAP team's advice that a Grid Needs Assess process will be needed for the prcurement of grid stability related resource.
3) For Hawai'i Island, HECO presented the issue of unbalanced generation on the two sides of the island, which can lead to voltage collapse. The TAP supports continuing the discussion of potential solutions to the reliability issue of cross-island energy imbalance on Hawai'i Island. The TAP agreed with HECO that an active power resource is likely to be very helpful in the southern portion of Hawai'i Island given the severe undervoltage conditions identified, especially if/when the Pakini Nui wind plant retires. The dynamic portion of the study can further inform what type of resource is needed in that location.
   In the study, Company addressed generation balance issue between east and west side of the Hawai'i Island system, and identified requirements from both steady state analyses and dynamic stability analyses. Company also identifies minimum resources needs (both active and

[7] https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning

reactive resource) to maintain south part of the Hawai'i Island system voltage within planning criteria.

4) The TAP strongly supports working towards obtaining grid-forming capacity as soon as possible, including by converting Stage 1 plants and executing Stage 2 and Stage 3 plants, as well as by other means as appropriate.
In this study, Company identifies minimum requirements of grid-forming capacity for each island system in order to maintain system stability within planning criteria. Meanwhile, Company has been working with developers to negotiate PPA amendments regarding converting grid-following projects to grid-forming projects.
5) The TAP agree that using ratio of available MW headroom in GFM plants to DER generation ("GFM HR/DER") is a reasonable metric, and can easily be applied in production cost models. The TAP also suggested that some other metrics may also be needed for other times of day when DER generation is low. Such metrics could include a minimum online capacity of GFM and/or a minimum available energy (SOC) from GFM plants. The TAP looks forward to continuing to discuss metric development to improve resource planning and production cost modeling with HECO as industry learns more. Meanwhile, the TAP understands the metric (GFM HR/DER) is primarily proposed to improve the stability of schedules developed from production cost simulations, but could potentially also be used for operations in the future.
Company is actively looking into ways to integrate this GFM MW headroom/DER generation minimum contingency reserve requirement into the production cost models. Meanwhile, Company will include a MW/MWH requirement in the model for the GFM BESS component for responding system event. Regarding how to apply this requirement in future system operations, Company will look into ways to implment this contingency reserve requirement from the eligible GFM resources into the future EMS system.
6) As HECO begins to rely on GFM inverter-based plants for system security, the TAP advises HECO to be alert for potential signs that GFM plants could fail to perform as designed, especially if failure modes could affect multiple plants. GFM inverters for transmission-connected applications are still a relatively new technology, and initial results from plants in the field have generally been positive but have also required troubleshooting. Achieving reliable GFM performance to meet Hawaii's needs will likely require close monitoring of field performance and an ongoing collaborative relationship with the GFM plant owners and their inverter manufacturers. Arrangements with GFM plant owners should be designed and managed to promote collaboration rather than adversarial relationships as much as possible.
Company expects a great deal of additional study, monitoring, and evaluation of actual field performance will need to be done in order to assure GFM IBR is an effective solution to provide stability to the Company's systems. Besides refining GFM performance requirements for the RFP Stage 3 procurement, Company will also rely on generation technical model review process to make sure high quality generation facility models are obtained, and will require all the plants to install ditigal fault recorder ("DFR") to monitor plant performance during system events. Company will also use those measured data from the DFRs to validate the plant models and determine if the plant performan reached PPA performance standards. Company will work with plant owners if issues are identified.
7) The TAP agree that improved grid-supportive performance from DERs would be beneficial and may be feasible in the 2035 timeframe.

Company agrees to look for ways to obtain better grid support from DERs.

A. SUMMARY OF STUDY RESULTS

A.1 O‘ahu Study Results Summary

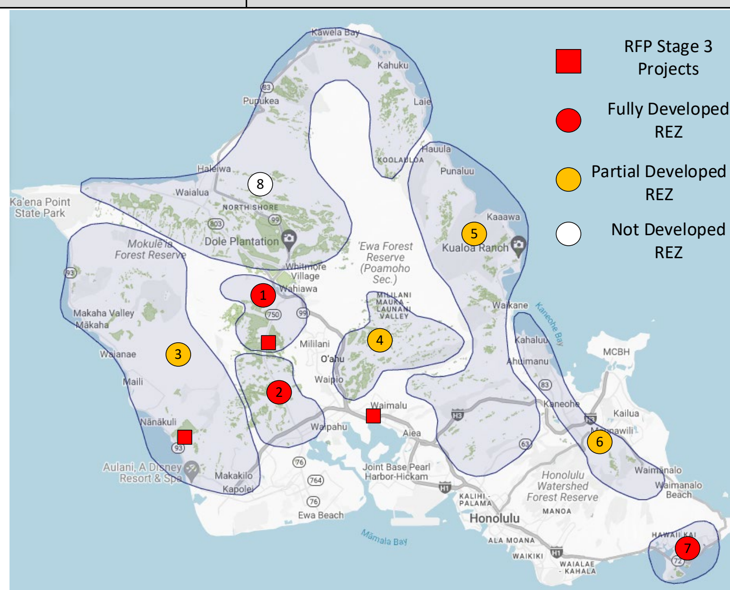
Summary of study results for the select years of O‘ahu base scenario resource plan, land constrainted scenario resouce plan and high load scenario resouce plan are shown as following tables.

Table A 1 O‘ahu Transmission System Grid Needs - Base Load Scenario, Year 2030

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2030**

By 2030, the O‘ahu system will have new generation from Stage 3 O‘ahu RFP procurement and initial Renewable Energy Zone (“REZ”) development. Specifically, there will be 450 MW renewable dispatch generation (“RDG”) and 300 MW firm generation procured through the Stage 3 O‘ahu RFP activity, 510 MW RDG development from the REZ zone 1, 2 and 7, and 543 MW RDG development from the REZ zone 3, 4, 5 and 6. Most of these new generation will be interconnected at O‘ahu 138 kV system. The REZ development is expected to have both solar and wind generation.

In this timeframe, it is also planned to remove 371 MW fossil generation from Waiau power plant.



System Grid Scale Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 O‘ahu RFP	Solar/BESS and Wind	450	2027	Central O‘ahu, West O‘ahu
	Firm Generation	300	2029	Central O‘ahu
REZ Development	Solar/BESS and Wind	510	2030	Zone 1, 2, and 7
		543	2030	Zone 3, 4, 5 and 6
Other	Standalone BESS	84	2030	138/46 kV Substations

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2030**

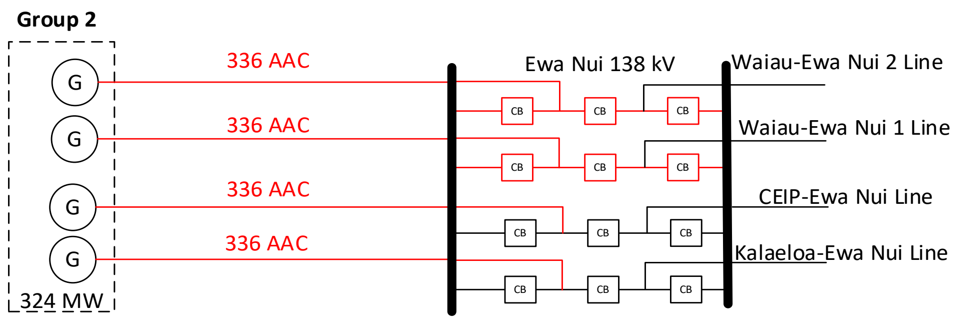
Removal	Generation Type	MW Capacity	Year	Location
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

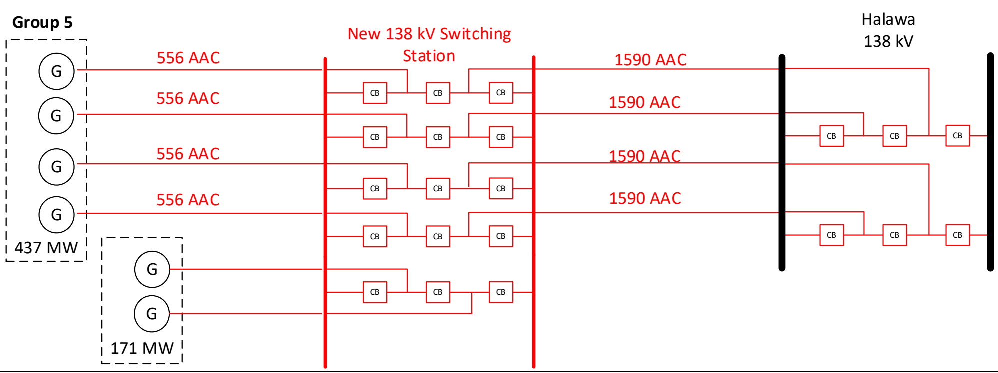
System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	257	168	1,573	219	1,171	1,364

REZ Enablement

Examples of REZ Enablment are shown as following for zones with lower MW potential (upper) and higher MW potential (lower). Red color means new enablment facility, and black color means existing facility.



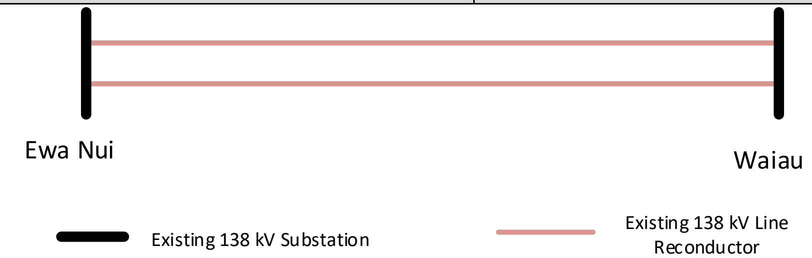


REZ Enablement Cost Estimate

REZ Zone	1	2	3	4	5	6	7
Cost ($MM) per MW	0.21	0.27	1.32	0.82	1.51	0.62	N/A
REZ Enablement ($MM)	24.6	87.6	448.4-819.9				N/A

Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2030**

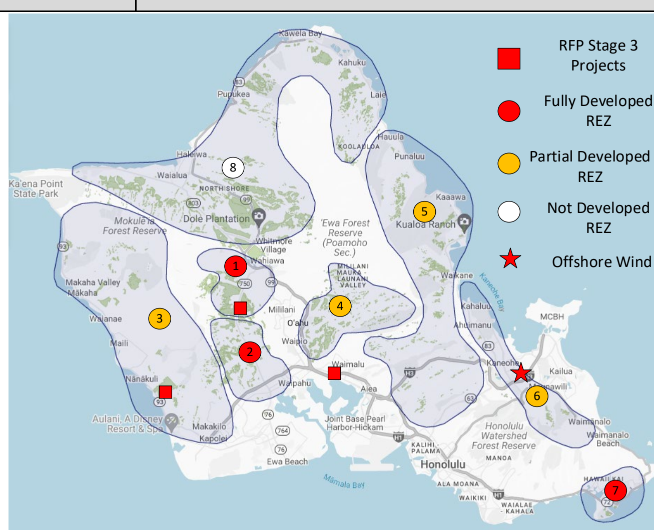


Networks Expansion Descriptions			Cost Estimate ($MM)
Transmission Line	Upgrade Type	Conductor Requirements	
Waiau-Ewa Nui 1&2	Re-conductor	Two circuits, re-conductor to double-bundled 795 AAC	161.4
Alternative for this conductor upgrade will be reduce Ewa Nui REZ generation interconnection from 324 MW to 175 MW.			
Grid Needs – System Stability Needs			
Grid has sufficient GFM resources to maintain system stability, but the system must be operated so that GFM Headroom/DER Generation ratio is at least 0.7.			

Table A 2 O'ahu Transmission System Grid Needs - Base Load Scenario, Year 2035

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2035**

In addtion to previous system resource changes by 2030, the O'ahu system will have 64 MW grid-scale standalone BESS and 509 MW offshore wind, by 2035. There is no futhur development of REZ. There will be 208 MW firm generation procured and interconnected at the Kalaeloa substation once the Kalaeloa power plant is removed.



System Grid Scale Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
Others	Firm Generation	208	2033	Kalaeloa Substation

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	2035

	Standalone BESS	64	2035	138/46 kV substations
	Offshore wind	509	2035	Koʻolau 138 kV substation
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustatinable Energy Park	Solar	1	2032	Kahe 46 kV substation
Kalaeloa Solar	Solar	5	2032	KS substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,297	257	509	157	1,573	282	1,295	1,432

REZ Enablement

There is no REZ development between 2031 to 2035. In this time frame, the development that requires interconneciton facility is the 509 MW offshore wind, which requires expansion of the Koʻolau substation by adding 4 BAAH bay for the offshore wind interconnection. The cost estimate is $50.6 million.

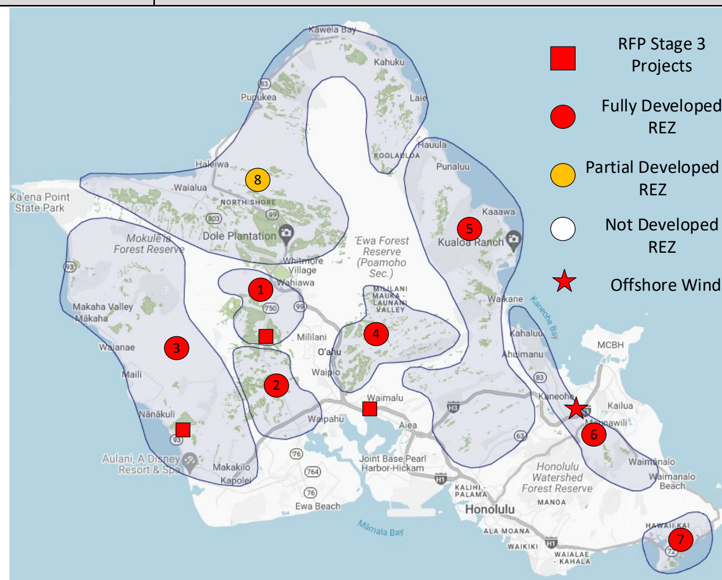
Grid Needs - Transmission System Networks Expansion

None. But high conductor loading is observed on multiple 138 kV overhead conductors. It is recommend to reduce grid-scale generation interconnection at Koʻolau substation by 10 MW.

Grid Needs – System Stability Needs

Grid has sufficient GFM resources to maintain system stability, but the system must be operated so that GFM Headroom/DER Generation ratio is at least 0.70.

Table A 3 O‘ahu Transmission System Grid Needs - Base Load Scenario, Year 2045

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2045**
In addtion to previous system resource changes, by 2045, the O‘ahu system will finish developing the majority of REZ zone 1, 2, 3, 4, 5, 6 and 7, only 106 MW potential remaining undeveloped. Meanwhile, 452 MW solar potential of the REZ zone 8 will be developped by 2045. System load is forecasted with significant growth: 1,692 MW peak demand at 2046. Both REZ development and system load growth drive large amount of O‘ahu transmission system network expansion.	

System Grid Scale Resource Changes since 2036

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Renewable Dispatchable Generation	521	2040	REZ zone 3, 4, 5, and 6
		504	2045	
		452	2045	REZ zone 8
Other	Standalone BESS	1	2040	Ho‘ohana substation
		32	2045	Ho‘ohana substation
Recovered Solar	Standalone Solar	168	2045	Waiver project locations
Recovered Wind	Wind	123	2045	Removed wind locations
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahe 3, 4	Fossil	172	2037	Kahe substation
Kawailoa Wind	Wind	69	2038	Wahiawa 46 kV
Waianae Solar	Solar	27.6	2039	Kahe 46 kV
Na Pua Makani Wind	Wind	24	2040	Ko‘olau 46 kV
Waiver Clearway Projects	Solar/Wind	110	2041	Various 138 kV and 46 kV substations
West Loch Solar	Solar	20	2044	CEIP 46 kV

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2045**

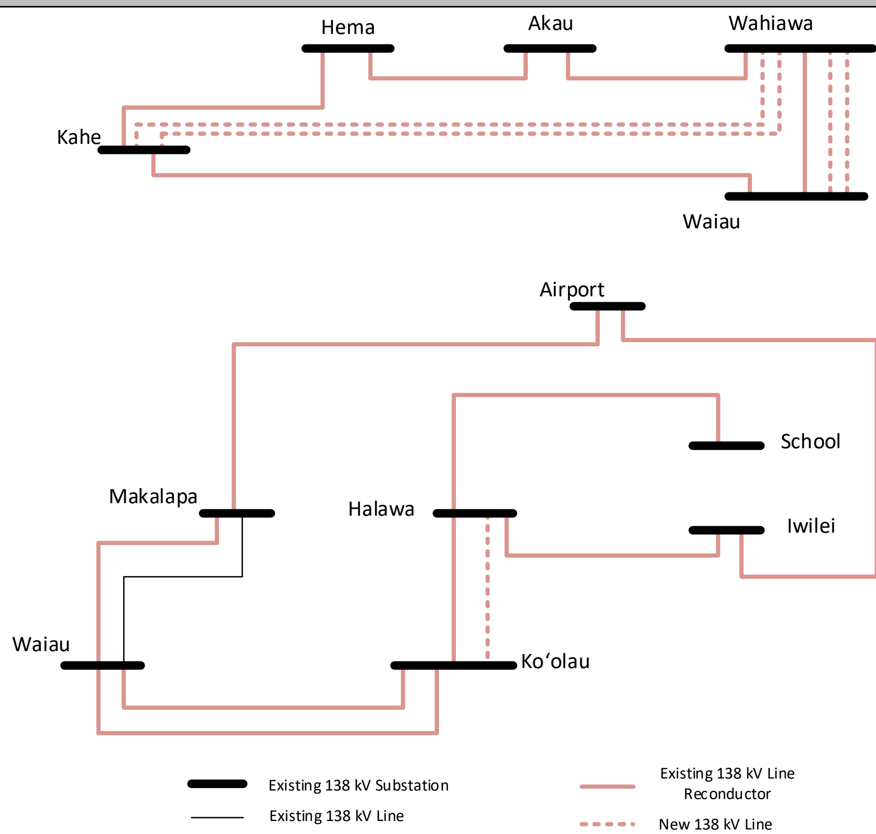
System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,126	287	509	441	2,777	315	1,454	1,692

REZ Enablement

REZ Zone	**3**	**4**	**5**	**6**	8
Cost ($MM) per MW	1.32	0.82	1.51	0.62	1.25
REZ Enablement ($MM)	1084.6-1468.5				565.0

Grid Needs - Transmission System Networks Expansion



The total estimated cost for these transmission networks expansion is $3,980.5 million.

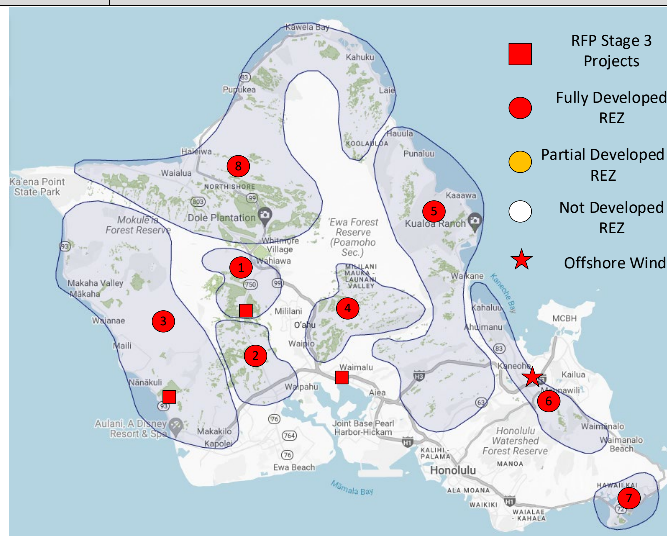
Grid Needs – System Stability Needs

Not studied.

Table A 4 O'ahu Transmission System Grid Needs - Base Load Scenario, Year 2050

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2050**

By 2050, 3,344 MW of all eight REZ zones will be fully developed. System load is forecasted with significant growth: 1,829 MW peak demand at 2050, which could possibly cause underground cable replacement for 138 kV underground cable among School Stree, Iwilei and Archer 138 kV substations. All Kahe fossil generation units will be retired by 2050. Besides switching fossil fuel to biodiesel fuel for remaining firm units, 135 MW new firm units will be added to the O'ahu system by 2050.



System Grid Scale Resource Changes since 2046

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Renewable Dispatchable Generation	106	2050	REZ zone 3, 4, 5, and 6
		714	2050	REZ zone 8
Other	Standalone BESS	18	2050	138 kV Substation
Other	Firm Generation	153	2050	Kahe Substation
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahe 5, 6	Fossil	270	2046	Kahe substation

System Resource Summary and Forecasted Demand (MW)

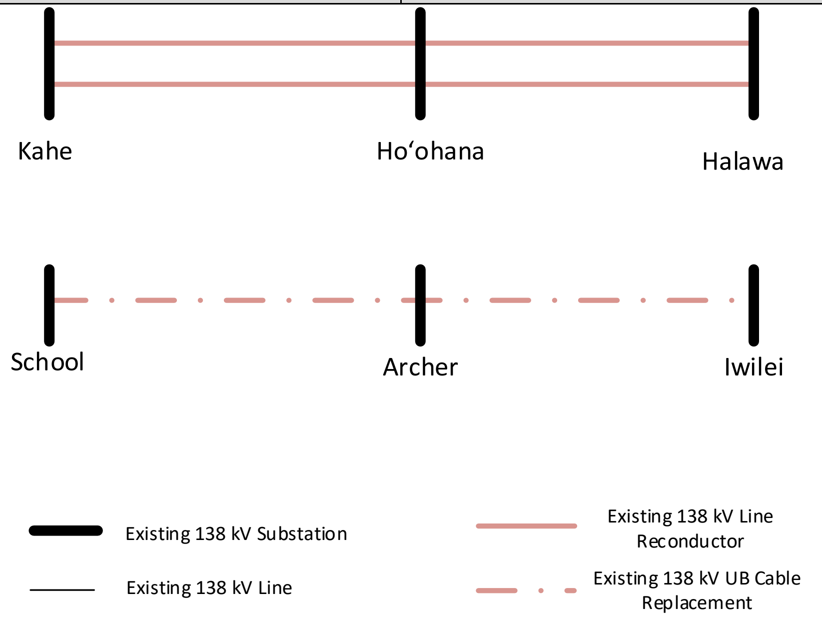
Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,010	287	509	480	3,558	333	1,497	1,829

REZ Enablement

REZ Zone	**3**	**4**	**5**	**6**	**8**
Cost ($MM) per MW	1.32	0.82	1.51	0.62	1.25
REZ Enablement ($MM)	86.9-160.1				892.5

Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2050**



The total estimated cost for these transmission networks expansion is $1,208.9 million.

Reducing load from 138 kV substations Kamoku, Kewalo, School St. and Iwilei by 20 MW can avoid cable replacement for the 138 kV underground cable Archer-School, Archer-Iweilei. This can be realized by adding generation such as grid-scale BESS in those substations, or procure demand response on circuits supplied by those substations, or implmenenting energy efficiency program.
Fully development of the north shore REZ zone (i.e., zone 8) would also cause overloadings on the 138 kV lines connected with Wahiawa substation. By reducing generation interconnection size at Wahiawa substation by 220 MW, the line overloading will be mitigated.

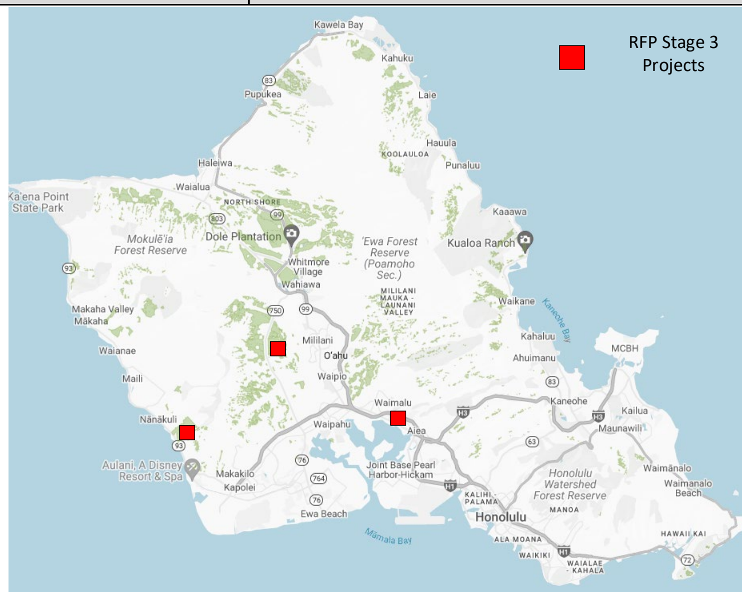
Grid Needs – System Stability Needs

Not studied.

Table A 5 Oʻahu Transmission System Grid Needs – Land Constrained Scenario, Year 2030

Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2030**

By 2030, the Oʻahu system will have all new generation from Stage 3 Oʻahu RFP procurement on transmission and sub-transmisison side. Specifically, there will be 450 MW renewable dispatch generation ("RDG") and 300 MW firm generation procured through the Stage 3 Oʻahu RFP activity. Most of these new generation are expected to be interconnected at Oʻahu 138 kV system. In this time frame, it is also planned to remove 371 MW generation from Waiau power plant.



System Grid- Scale Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Oʻahu RFP	Renewable Dispatchable Generation	450	2027	Central Oʻahu, West Oʻahu
	Firm Generation	300	2029	Central Oʻahu
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	123	168	684	135	1,171	1,364

Grid Needs - Transmission System Networks Expansion

None

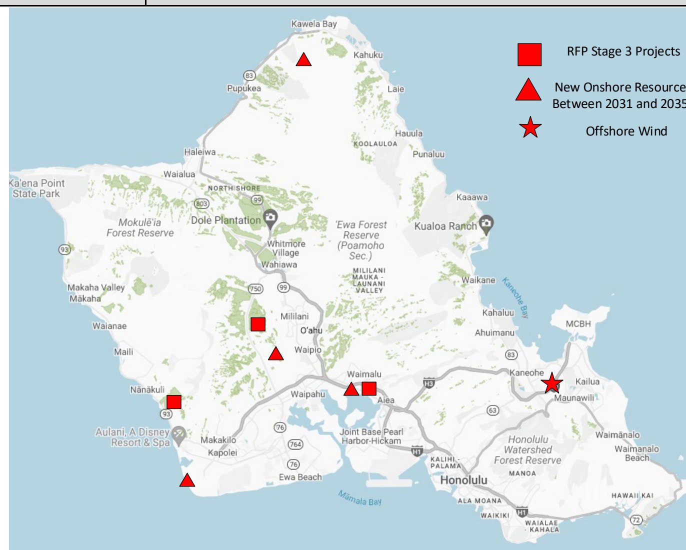
Grid Needs – System Stability Needs

System may need more GFM resource, and it is recommended to maintain MW headroom of GFM resource/DER generation ratio at least 0.7. If the ratio can't be maintained, it is recommend to dispatch more synchronous machine resources to create more head room from the GFM resource, or curtail DER generation.

Table A 6 Oʻahu Transmission System Grid Needs – Land Constrained Scenario, Year 2035

Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2035**

In addtion to previous system resource changes by 2030, the Oʻahu system will have 105 MW grid-scale standalone BESS and 400 MW offshore wind, by 2035. 153 MW Firm resource will also be added to system by 2035. There will be 208 MW firm generation procured and interconnected at the Kalaeloa substation once the Kalaeloa power plant is removed. 30 MW wind recovered wind resource from the retired wind power plant will be added to system to meet the system demand as well.



System Grid- Scale Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
Others	Firm Generation	208	2033	Kalaeloa Substation
	Firm Generation	153	2035	Waiau Power Plant
	Standalone BESS	105	2035	138/46 kV substations
	Offshore wind	400	2035	Koʻolau 138 kV substation
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustatinable Energy Park	Solar	1	2032	Kahe substation
Kalaeloa Solar	Solar	5	2033	Kahe 46 kV substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

System Resource Summary and Forecasted Demand (MW)

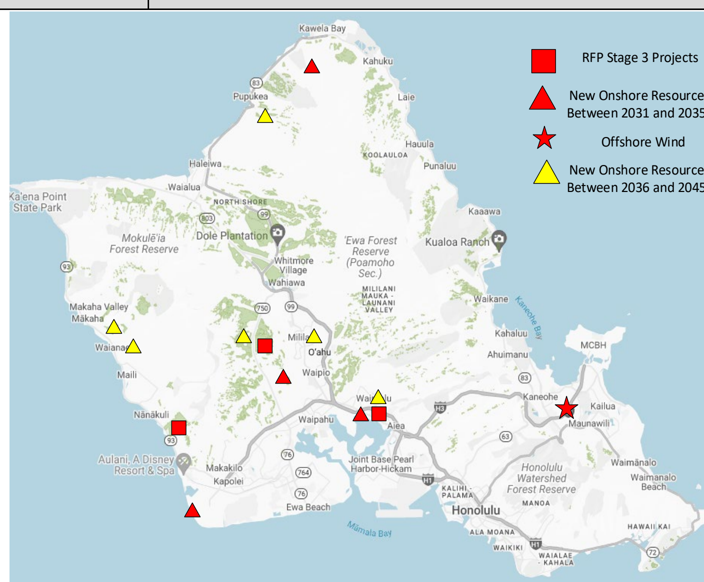
Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,450	123	400	157	684	240	1,295	1,432

Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2035**
Grid Needs - Transmission System Networks Expansion	
None	
Grid Needs – System Stability Needs	
System may need more GFM resources, and it is recommended to maintain MW headroom of GFM resource/DER generation ratio at least 0.7. If the ratio can't be maintained, it is recommended to dispatch more synchronous machine based resources to create more head room from the GFM resource.	

Table A 7 Oʻahu Transmission System Grid Needs – Land Constrained Scenario, Year 2045

Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2045**

In addtion to previous system resource changes, by 2045, the Oʻahu system will add another 153 MW firm generation into the system. Also, 169 MW standalone solar and 93 MW wind development from retired solar and wind locations will be completed by 2045. 169 MW new Grid-scale standalone BESS will be interconnected to system from transmission substations. System load is forecasted with significant growth: 1,692 MW peak demand at 2046. On the distribution side, 783 MW DER coupled with 1,567 MWh DER BESS will be added to the system to supply system load demand.



System Grid- Scale Resource Changes since 2036

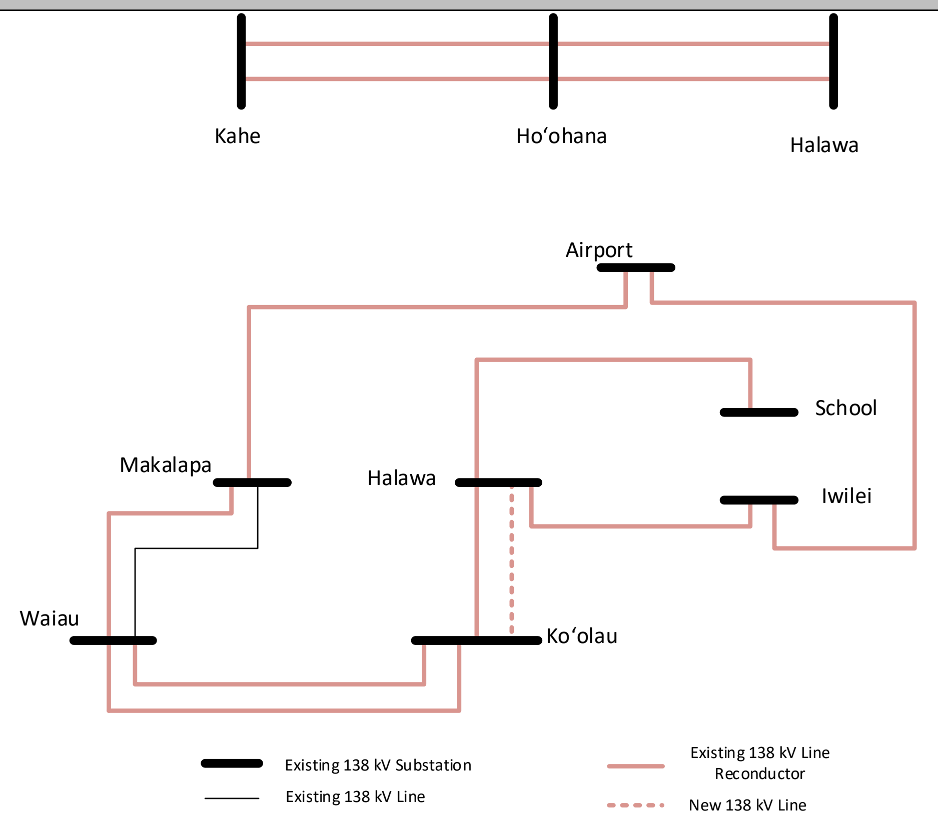
Development	Generation Type	MW Capacity	GCOD	Location
Other	Standalone BESS	14	2040	Hoʻohana substation
	Firm Generation	153	2040	Waiau substation
Recovered Solar	Standalone Solar	39	2040	Waiver project locations
Recovered Wind	Wind	93	2040	Retired wind locations
Other	Standalone BESS	145	2045	Hoʻohana substation
Recovered Solar	Standalone Solar	130	2045	Waiver project locations
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**

Studied Resource Plan				Studied Year
Land Constrained Scenario Resource Plan				**2045**
Kahe 3, 4	Fossil	172	2037	Kahe substation
Kawailoa Wind	Wind	69	2038	Wahiawa 46 kV
Waianae Solar	Solar	27.6	2039	Kahe 46 kV
Na Pua Makani Wind	Wind	24	2040	Koʻolau 46 kV
Waiver Clearway Projects	Solar/Wind	104	2041	Various 138 kV and 46 kV substations
West Loch Solar	Solar	20	2044	CEIP 46 kV

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,432	123	400	169	684	399	3,020	1,692

Grid Needs - Transmission System Networks Expansion

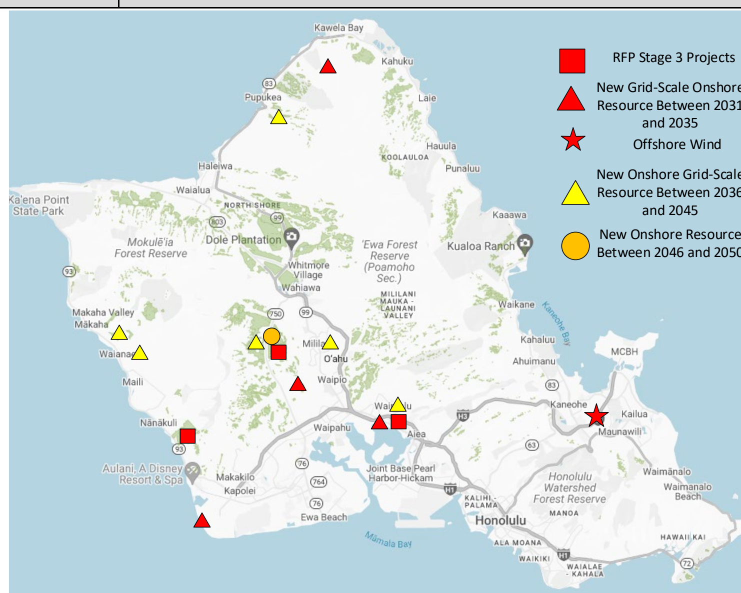


Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2045**
The total estimated cost for these transmission networks expansion is $2,291.6 million.	
Grid Needs – System Stability Needs	
The dynamic stability study is not performed. However, according to the avaiable GFM resource and signification growth of DER, the system may require more grid-scale GFM resource. This could be more GFM BESS interconnected on subtransmission or transmission grid, or GFM STATCOM interconnected on the transmission grid.	

Table A 8 O'ahu Transmission System Grid Needs – Land Constrained Scenario, Year 2050

Studied Resource Plan	Studied Year
Land Constrained Scenario Resource Plan	**2050**

From 2046 to 2050, the only grid-scale resource added to the O'ahu system as planned is a 119 MW/1,110 MWh grid-scale BESS. Kahe 5, 6, which will be the only remaining fossil generation at Kahe power plant by 2050, will be retired in 2050. It is also planned to add 1,017 MW DER, coupled with 2,033 MWh DER BESS into system distribution side. System peak load is forecasted to be 1,829 MW by 2050. The load increase will require cable replacement for the 138 kV underground conductors Archer-School and Archer-Iwilei.

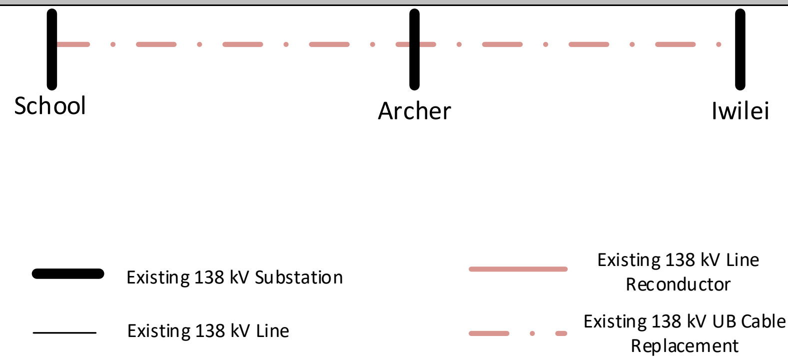


System Grid- Scale Resource Changes since 2036

Development	Generation Type	MW Capacity	GCOD	Location
Other	Standalone BESS	119	2050	138 kV Substation
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahe 5, 6	Fossil	270	2046	Kahe substation

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,163	123	400	169	684	519	5,097	1,829

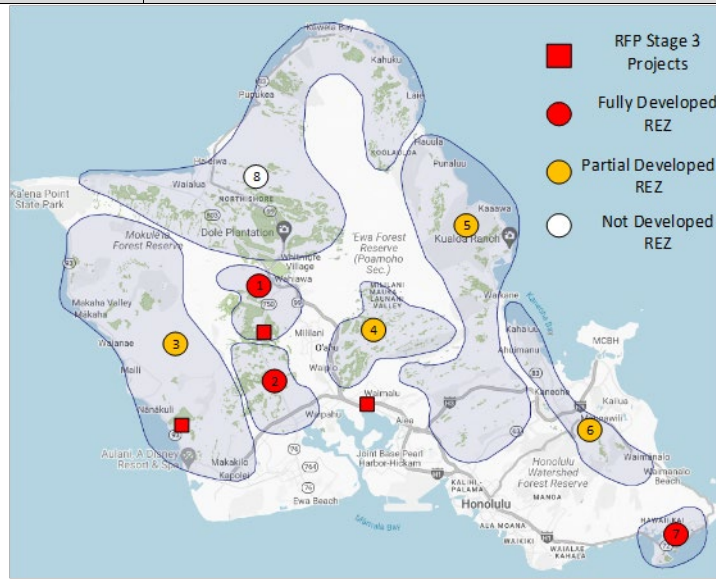
<table>
<tr><th>Studied Resource Plan</th><th>Studied Year</th></tr>
<tr><td>Land Constrained Scenario Resource Plan</td><td>2050</td></tr>
<tr><td colspan="2">Grid Needs - Transmission System Networks Expansion</td></tr>
<tr><td colspan="2">

The total estimated cost for these transmission networks expansion is $345.1 million.</td></tr>
<tr><td colspan="2">Reducing load from 138 kV substations Kamoku, Kewalo, School St. and Iwilei by 20 MW can avoid cable replacement for the 138 kV underground cable Archer-School, Archer-Iweilei. This can be realized by adding generation such as grid-scale BESS at those substations, acquiring demand response on circuits supplied by those substations, or implementing a targeted energy efficiency program.</td></tr>
<tr><td colspan="2">Grid Needs – System Stability Needs</td></tr>
<tr><td colspan="2">The dynamic stability study for this scenario is not performed. However, the recommendation for the Oʻahu system regarding system stability needs are simliar as what is recommended for the 2045 scenario.</td></tr>
</table>

Table A 9 Oʻahu Transmission System Grid Needs – High Load Scenario, Year 2030

Studied Resource Plan	Studied Year
High Load Resource Plan	**2030**

By 2030, the Oʻahu system will have new generation from Stage 3 Oʻahu RFP procurement and initial Renewable Energy Zone ("REZ") development. Specifically, there will be 450 MW renewable dispatch generation ("RDG") and 300 MW firm generation procured through the Stage 3 Oʻahu RFP activity, 510 MW RDG development from the REZ zone 1, 2 and 7, and 1,225 MW RDG development from the REZ zone 3, 4, 5 and 6. Most of these new generation will be interconnected at Oʻahu 138 kV system. The REZ development is expected to have both solar and wind generation.
In this time frame, it is also planned to add 60 MW standalone BESS into system and remove 371 MW generation from Waiau power plant.



System Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Oʻahu RFP	Renewable Dispatchable Generation	450	2027	Central Oʻahu, West Oʻahu
	Firm Generation	300	2029	Central Oʻahu
REZ Development	Renewable Dispatchable Generation	510	2030	Zone 1, 2, and 7
		1,225	2030	Zone 3, 4, 5 and 6
Other	Standalone BESS	60	2030	138/46 kV Substations
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Waiau 3, 4	Fossil Generation	94	2024	Waiau Power Plant
Waiau 5, 6		108	2027	
Waiau 7, 8		169	2029	

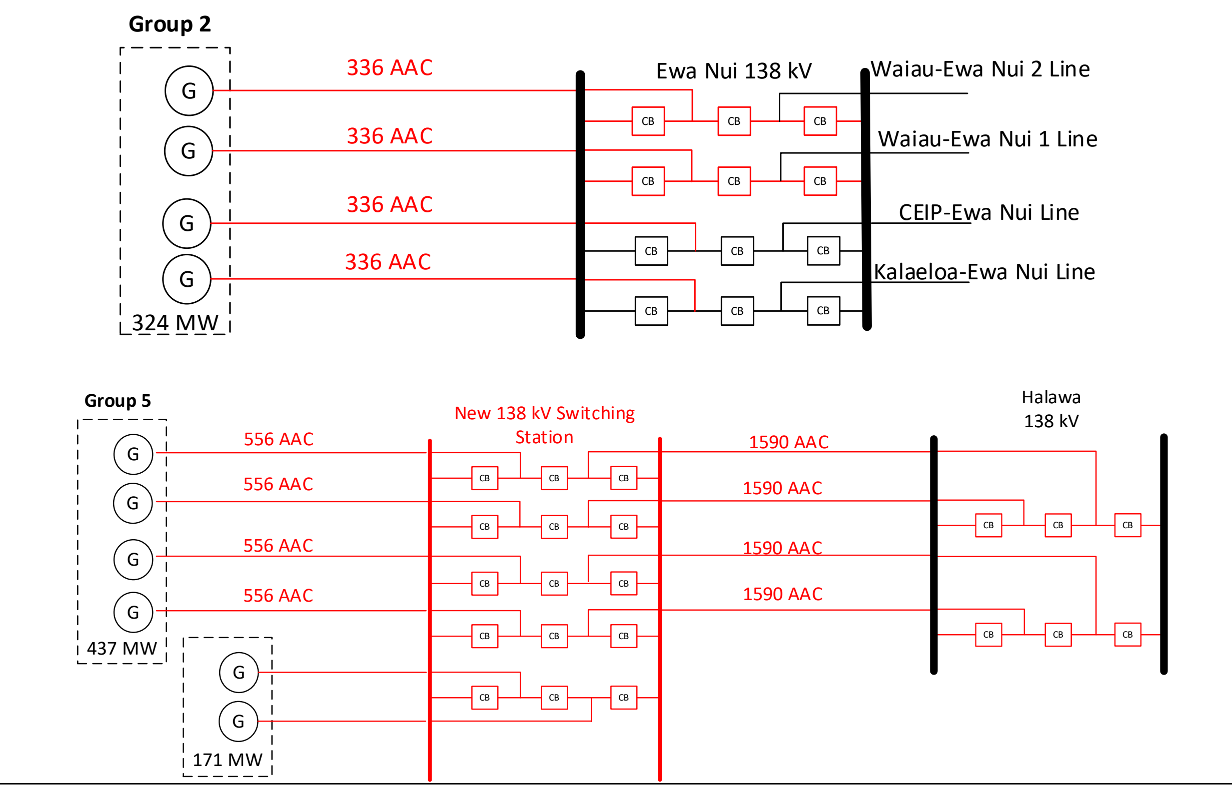
System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,462	123	168	2,419	195	1,147	1,595

REZ Enablement

Examples of REZ Enablment are shown as following for zones with lower MW potential (upper) and higher MW potential (lower). Red denotes new enablment facility, and black denotes existing facility.

Studied Resource Plan	Studied Year
High Load Resource Plan	2030

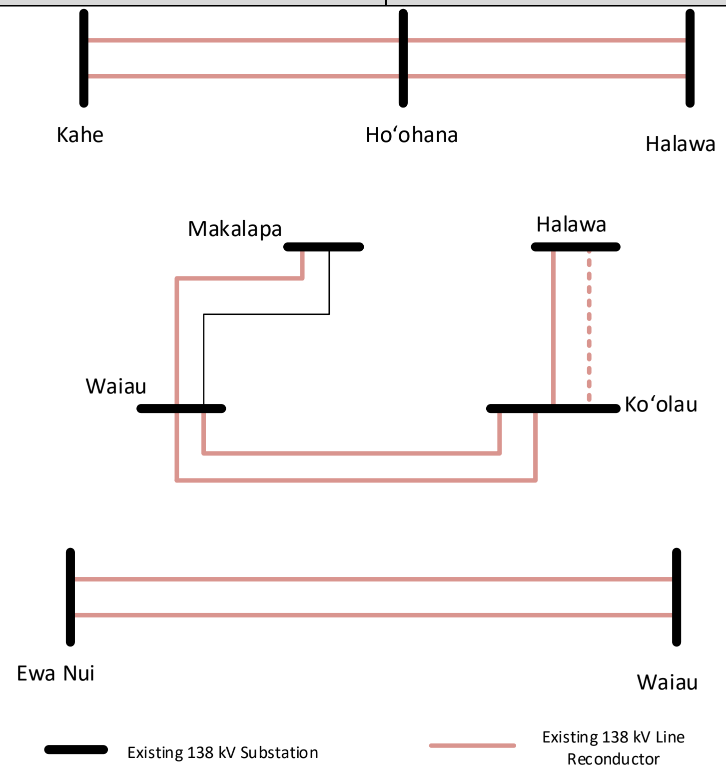


REZ Enablement Cost Estimate

REZ Zone	1	2	3	4	5	6	7
Cost ($MM) per MW	0.21	0.27	1.32	0.82	1.51	0.62	N/A
REZ Enablement ($MM)	24.6	87.6	1,378.8-1,718.0				N/A

Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
High Load Resource Plan	**2030**



The total estimated cost for these transmission networks expansion is $1,289 million.

Alternative option for deferral reconductor of Ewa Nui – Waiau #1 & #2 is reducing REZ zone 2 interconnection MW size at Ewa Nui substation by 150 MW, and dispatch more generation on the east side of island.

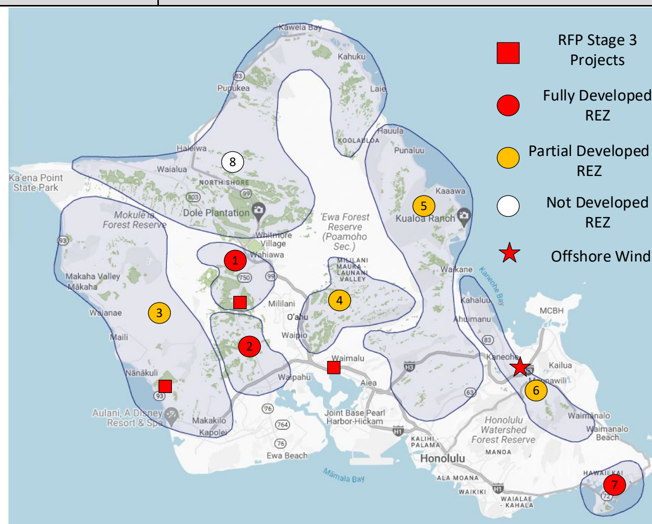
Grid Needs – System Stability Needs

Not studied.

Table A 10 O‘ahu Transmission System Grid Needs – High Load Scenario, Year 2035

Studied Resource Plan	Studied Year
High Load Resource Plan	2035

In addtion to previous system resource changes by 2030, the O‘ahu system will have 95 MW grid-scale standalone BESS and 600 MW offshore wind, by 2035. There is no further development of REZ. There will be 208 MW firm generation interconnected at the Kalaeloa substation. By 2035, the BESS MWh of the PV/BESS projects developed in REZ zones in 2030 will be increased as well.



System Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
Others	Firm Generation	208	2033	Kalaeloa Substation
	Standalone BESS	95	2035	138/46 kV substations
	Offshore wind	600	2035	Ko‘olau 138 kV substation
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kahuku Wind	Onshore Wind	30	2031	Kahuku 46 kV substation
Kapolei Sustainable Energy Park	Solar	1	2032	KREP substation
Kalaeloa Solar	Solar	5	2032	KS substation
Kahe 1, 2	Fossil	165	2033	Kahe substation
Kalaeloa Power Plant	Fossil	208	2033	KPLP substation
KREP	Solar	5	2034	KREP substation

System Resource Summary and Forecasted Demand (MW)

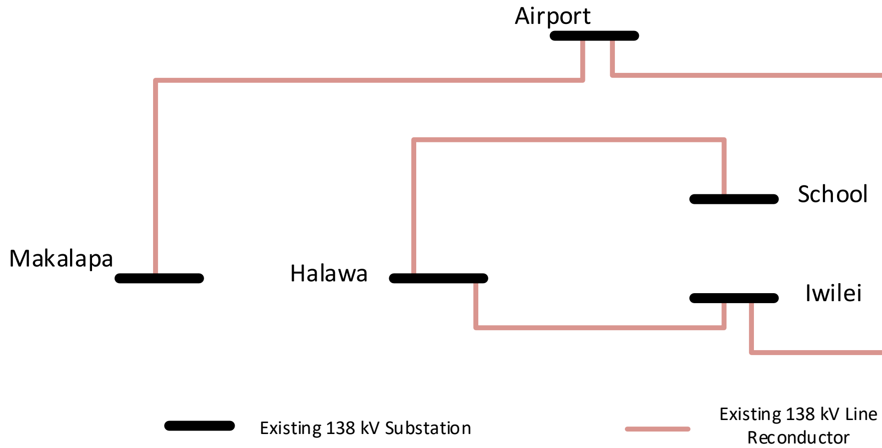
Firm Generation	Onshore Standalone Wind	Offshore Wind	Standalone Grid-Scale Solar	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
1,297	93	600	157	2,419	290	1,271	1,776

REZ Enablement

There is no REZ MW potential development between 2031 to 2035. In this timeframe, the development that requires interconneciton facility is the 600 MW offshore wind, which requires expansion of the Ko‘olau substation by adding 4 BAAH bay for the offshore wind interconnection. The cost estimate is $50.6 million.

Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
High Load Resource Plan	**2035**



The total estimated cost for these transmission networks expansion is $397.9 million.

In addition, 138 kV underground cable Archer-Iwilei, Archer-School also have high loading condition during contingencies. It is recommended to install a standalone BESS project in east side of island close to the urban core load center to reduce load, in order to avoid reconductoring or potential cable repalcement. Alternative options can be using DER programs, demand response programs, or energy efficiency programs to reduce load on east side of system.

Grid Needs – System Stability Needs

Not studied.

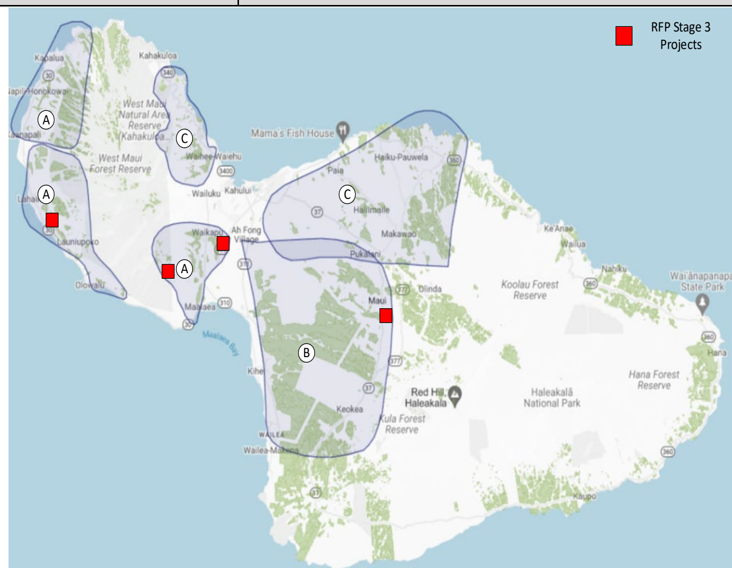
A.2 Maui Study Results Summary

Summary of study results for the Maui base scenario resource plan and high load scenario resouce plan are listed as following.

Table A 11 Maui Transmission System Grid Needs – Base Scenario, Year 2027

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2027**

By 2027, the Maui system will have new generation from Stage 3 RFP procurement which will be 171 MW renewable dispatchable generation ("RDG") PV/BESS and 36 MW firm generation, interconnected at Maui 69 kV system. Meanwhile, the Maui system will finish Waena switchyard construction, Kahului Power Plant ("KPP") retirement and conversion of KPP K3 and K4 units to synchronous condensers, and Maalaea Power Plant ("MPP") unit 10-13 retirement. The system peak load is forecasted to reach 207 MW by 2028.



System Grid Scale Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Maui RFP	Renewable Dispatchable Generation	171	2027	West Maui, Central Maui and South Maui
	Firm Generation	36	2027	Central Maui
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kaheawa Wind Power 1	Wind Generation	30	2027	KWP 1 substation
Kahului 1-4	Fossil Generation	32.5	2027	Kahului Power Plant
Maalaea 10-13	Fossil Generation	49.4	2027	Maalaea Power Plant

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
197.5	42	296	40	170.7	207

REZ Enablement

No REZ enablment cost estimate since by 2027 there will be only Stage 3 development but no REZ development. Interconnection sites for the 171 MW Stage 3 RFP projects and 36 MW firm generation are as following.

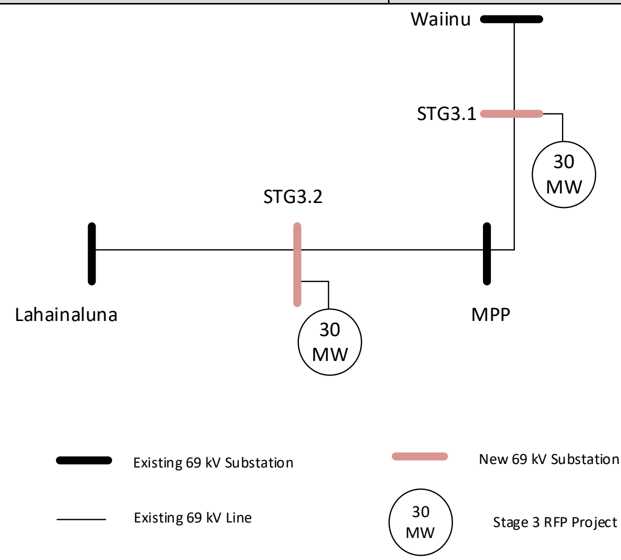
Substation/Switching station interconnections:

- Lahainaluna substation station – 60 MW
- KWP 2 substation – 30 MW
- Waena switch yard – 40 MW firm generation
- Kealahou substation – 21 MW

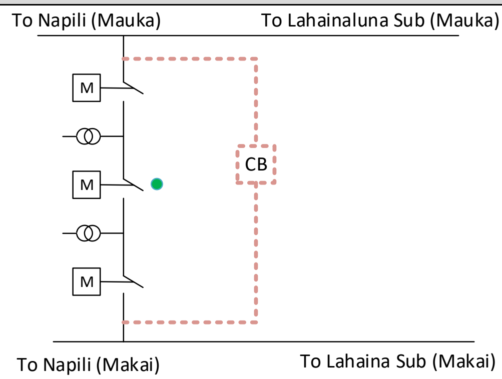
69 kV Transmisison line interconnection:

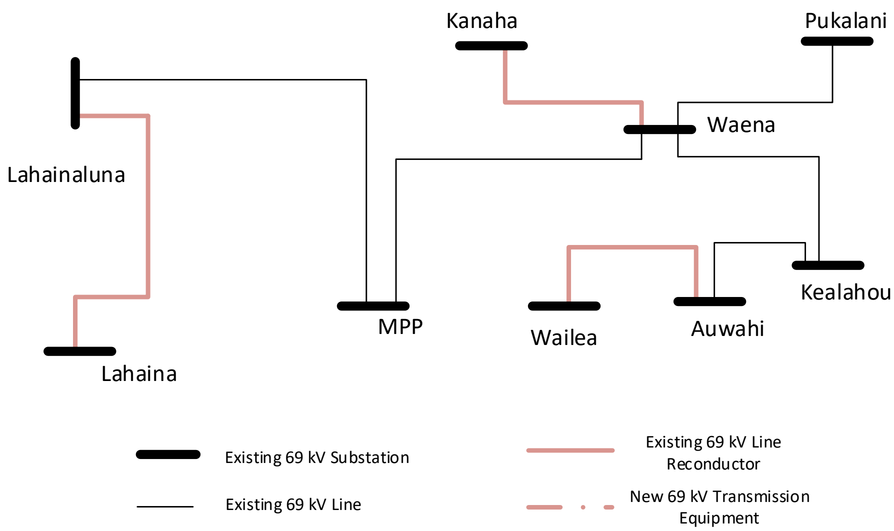
- MPP – Waiinu line interconnection – 30 MW, through a new substation STG3.1
- MPP – Lahainaluna line interconnection – 30 MW, through a new substation STG3.2

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	2027



Grid Needs - Transmission System Networks Expansion





Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2027**
The total estimated cost for these transmission networks expansion is $10.5 million.	
Alternative options for above re-conductor upgrade include reducing grid-scale resource interconnection MW size by 24 MW on west Maui and reducing grid-scale resource interconnection MW size in Waena switch yard, up-country or south Maui by 16 MW.	

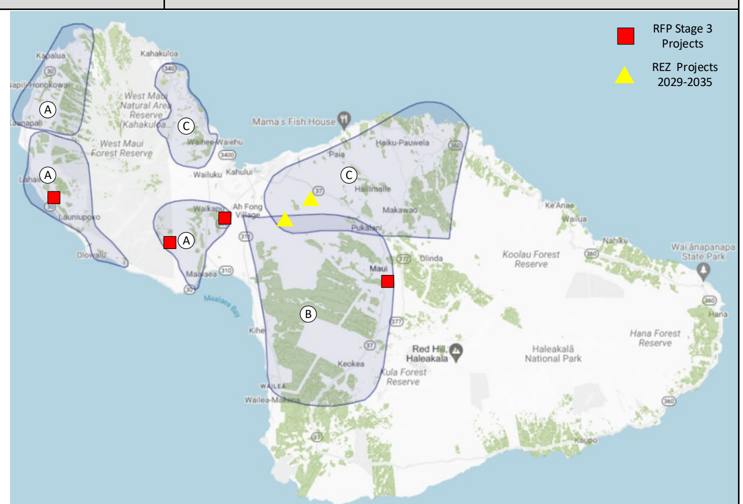
Grid Needs – System Stability Needs

After adding 171 MW Stage 3 RDG projects with grid forming ("GFM") BESS component, it is expected that Maui system stability performance stay within planning criteria, and no addtional grid needs regarding system stability is identified. Maui system single point of failure ("SPOF") limit can be increased to 30 MW as well.

Table A 12 Maui Transmission System Grid Needs – Base Scenario, Year 2035

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2035**

In addtion to previous system resource changes by 2027, by 2035, the Maui system will have 66 MW of grid-scale onshore wind generation and 37 MW of PV/BESS generation as addtional generation interconnected to the Maui transmission system. This new generation will be developed in the REZ zone C. Also, it is planned that MPP unit 1 to 9 will be removed by 2030, and wind power generation KWP 2 and Auwahi will be retired by 2033. The system annual peak load is forecasted to reach 235 MW by 2036.



System Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	5	2029	REZ Zone C
	Onshore Wind Generation	8	2030	REZ Zone C
	Onshore Wind Generation	53	2035	REZ Zone C
	Solar/BESS	37	2035	REZ Zone C
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Maalaea Power Plant Units 1-9	Fossil	40.5	2030	MPP
Kaheawa Wind Power 2	Onshore Wind Generation	21	2033	KWP 2 Substation

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2035**

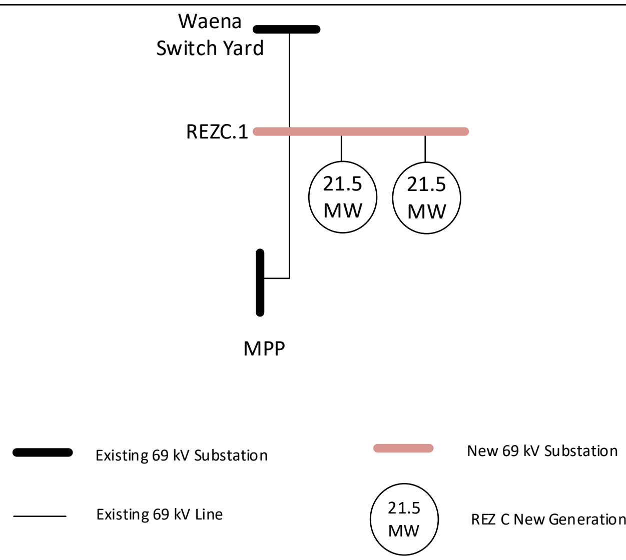
Auwahi Wind	Onshore Wind Generation	21	2033	Auwahi Substation

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	66	333	40	202	237

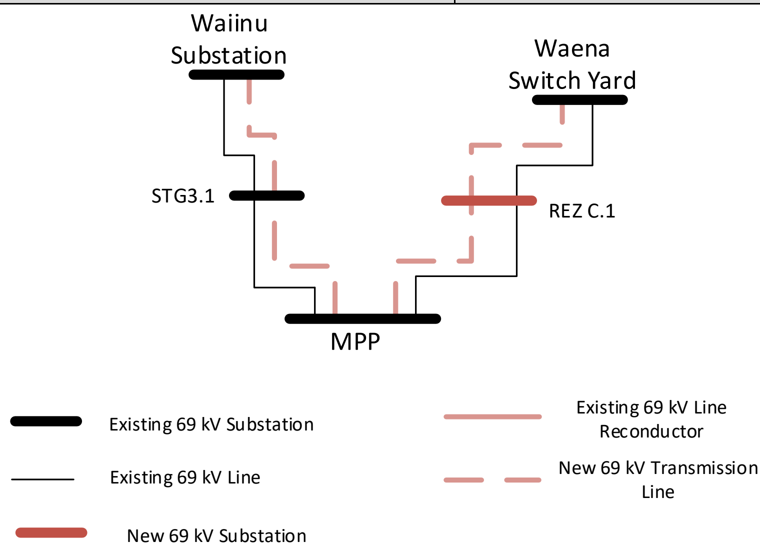
REZ Enablement

From 2028 to 2035, 5 MW onshore wind genration in 2029, 8 MW onshore wind generation in 2030, 53 MW onshore wind in 2035, and 37 MW PV/BESS, connected to zone C, totaling 103 MW. It is assumed that there will be a new switching station on the MPP-Waena line which will host 43 MW out of 103 MW generation, and the remaining 60 MW will be hosted in the Waena switchyard. The cost of REZ enablement through the Waena switchyard is estimated as $13.5 million. For the new switching station REZ C.1, the REZ enablement cost is estimated as $5.8 million.



Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2035**



The total estimated cost for these transmission networks expansion is $96.2 million.

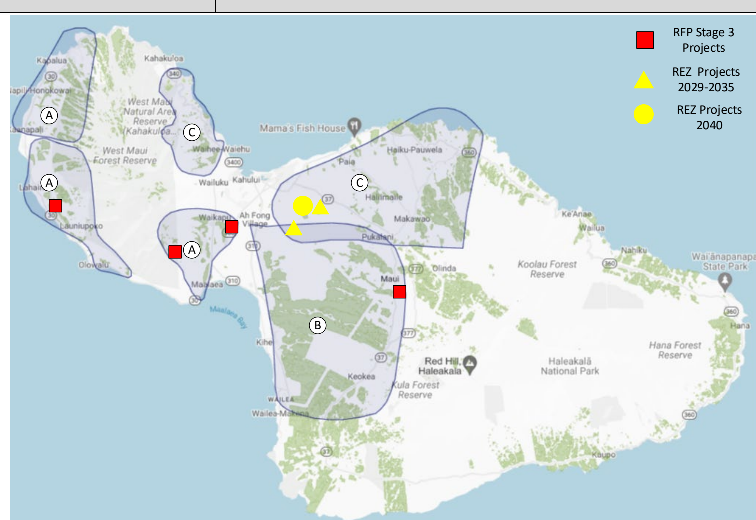
Grid Needs – System Stability Needs

None

Table A 13 Maui Transmission System Grid Needs – Base Scenario, Year 2040

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2040**

In 2040, another 61 MW REZ zone C development will be completed. It is assumed that 61 MW will be interconnected at Waena switchyard. Meanwhile, there will be retirement of existing 5.7 MW distribution interconnected PV. System annual peak demand is forecasted to reach 266 MW in 2041.



System Resource Changes since 2036

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	18	2040	REZ Zone C

Studied Resource Plan			Studied Year	
Base Scenario Resource Plan			**2040**	
	PV/BESS Generation	43	2040	REZ Zone C
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Distribution Interconnected PV	Solar	5.7	2040	12 kV Distribution System

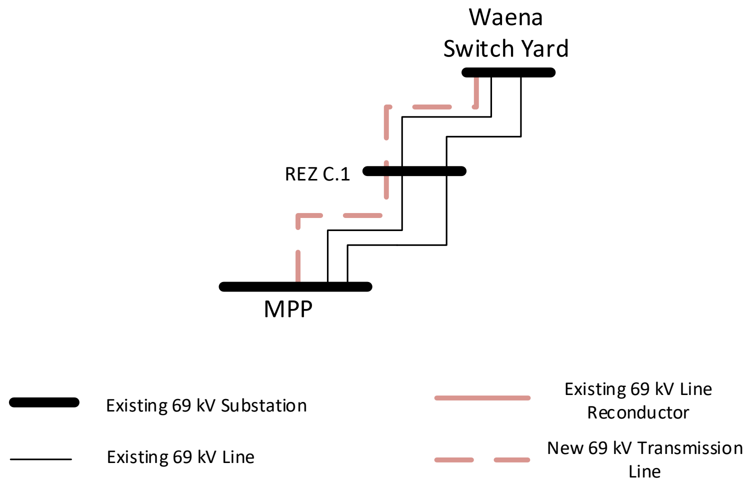
System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	84	376	40	218	266

REZ Enablement

The new 61 MW of generation in the REZ zone C development is assumed to interconnec at the Waena switchyard, which will require two BAAH bays for the generation interconnection.
The estimated cost of REZ enablement for 61 MW generation from REZ zone C development interconnected at the Waena switchyard is $15.6 million.

Grid Needs - Transmission System Networks Expansion



The total estimated cost for these transmission networks expansion is $51.9 million.

An alternative option for adding a new circuit between MPP and Waena switchyard is to reduce grid-scale generation interconnection from the REZ zone C development by 48.4 MW.

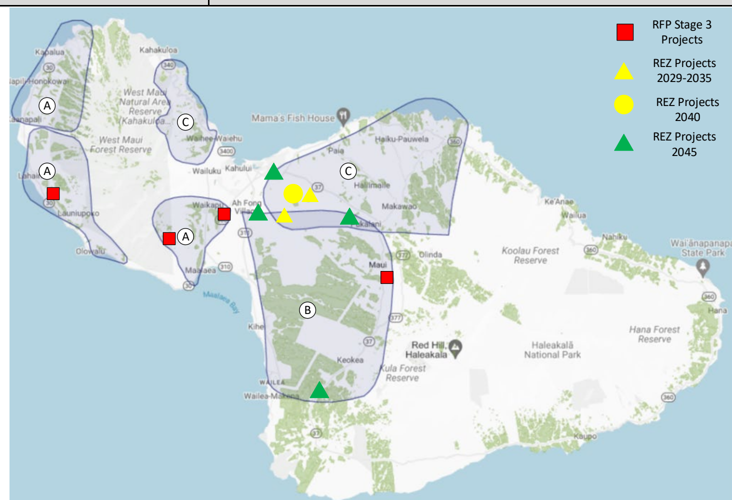
Grid Needs – System Stability Needs

None

Table A 14 Maui Transmission System Grid Needs – Base Scenario, Year 2045

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2045**

In 2045, 66 MW PV/BESS generation and 41 MW onshore wind generation will be developed in REZ zone C; 15 MW PV/BESS generation will be developed in REZ zone B. Also, all the remaining fossil units will switch to biodiesel. The system annual peak demand is forecasted to reach 289 MW in 2046.



System Resource Changes since 2041

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	PV/BESS Generation	15	2045	REZ Zone B
	PV/BESS Generation	66	2045	REZ Zone C
	Onshore Wind Generation	41	2045	REZ Zone C

System Resource Summary and Forecasted Demand (MW)

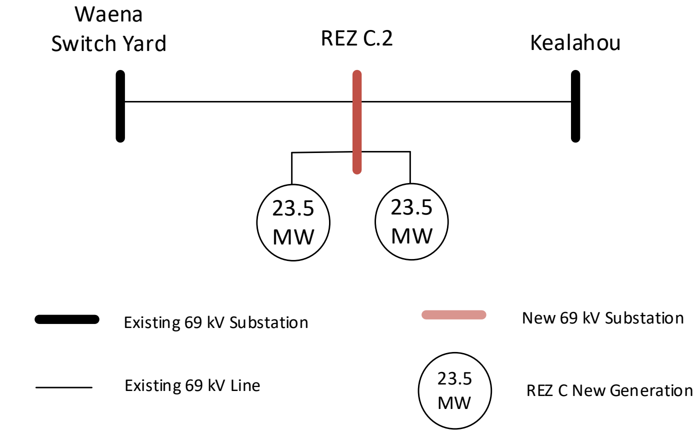
Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	125	457	40	229	289

REZ Enablement

According to the resource plan, 15 MW generation from REZ zone B and 107 MW generation from REZ zone C will be interconnected to the Maui system. In the study, following interconnection sites are assumed.

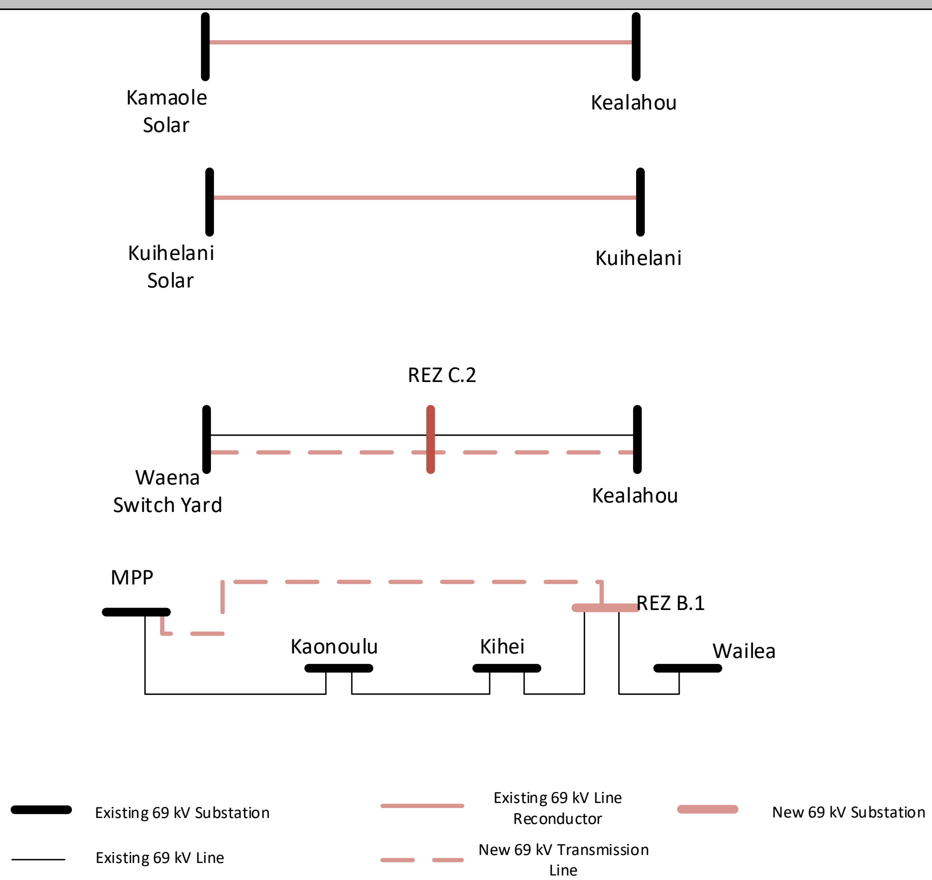
- Auwahi substation – 15 MW
- STG3.1 – 30 MW
- Kanaha substation (23 kV) – 30 MW
- New switching station, REZ C.2, on Waena-Kealahou line – 47 MW

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	2045



The cost estimate of the REZ enablement for the 30 MW interconnection at the STG 3.1 substation is $3.9 million, for the 30 MW interconnection at the Kanaha substation 23 kV side is $3.8 million, and for the 47 MW interconnection at the new substation REZ C.2 is $7.8 million. The total estimate for the REZ enablement is $15.4 million.

Grid Needs - Transmission System Networks Expansion



Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2045**

The total estimated cost for these transmission networks expansion is $171.2 million.

An alternative option for reconductor of Kamaole-Kealahou line is to reduce south Maui generation interconnection size by 7 MW.

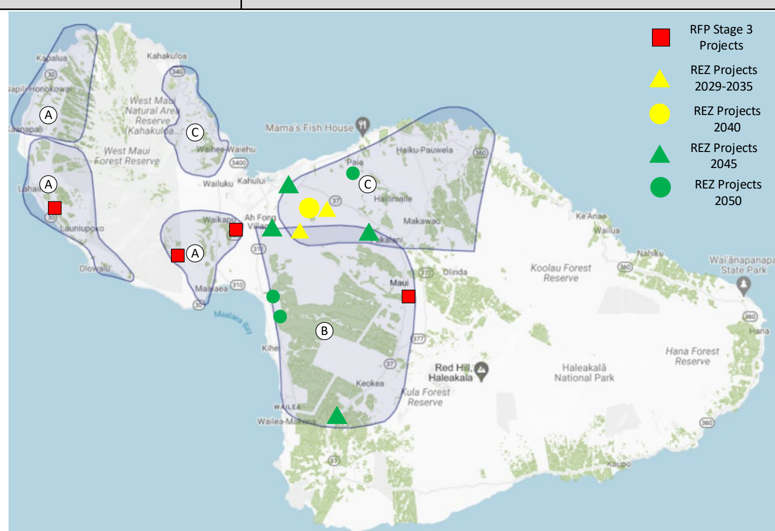
Grid Needs – System Stability Needs

Not studied.

Table A 15 Maui Transmission System Grid Needs – Base Scenario, Year 2050

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2050**

In 2050, 57 MW PV/BESS generation will be developed in REZ zone C; 57 MW PV/BESS generation will be developed in REZ zone B. System annual peak demand is forecasted to reach 310 MW in 2050.



System Resource Changes since 2036

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Solar/BESS Generation	57	2050	REZ Zone B
	Solar/BESS Generation	57	2050	REZ Zone C

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	125	571	40	240	310

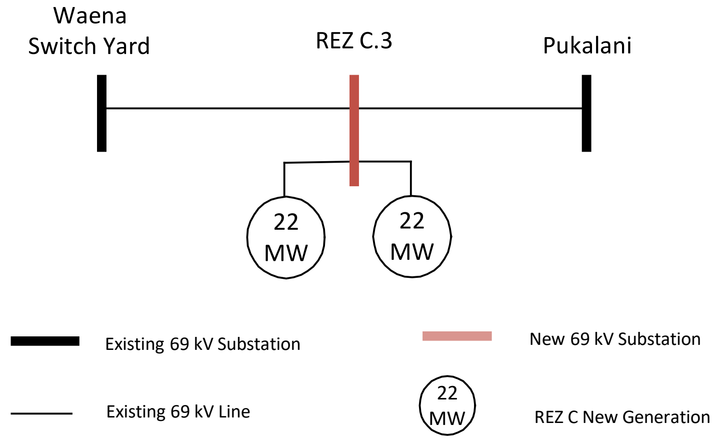
REZ Enablement

In the study, it is assumed following interconnection sites for the 114 MW generation development in the REZ zone B and C:

- REZ B.1 Substation – 51 MW

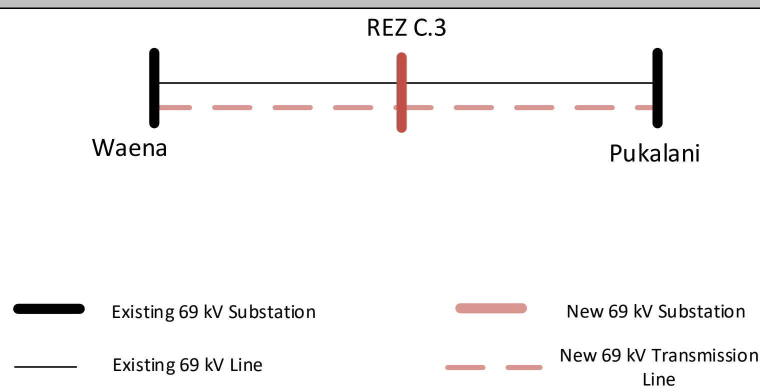
Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2050**

- Auwahi Substation – 7 MW
- REZ C.2 (Waena-Kealahou) Substation = 13MW
- New switching station, REZ C.3, on Waena-Pukalani line – 44 MW



The estimated cost for REZ enablement in REZ B.1 substation is $9.0 million and for REZ enablement of building the REZ C32 is $9.0 million. The total REZ enablement estimated cost is $18.0 million. It is assumed in the study that the 7 MW generation interconnection at the Auwahi substation and 13 MW generation interconnection at the REZ C.2 substation are interconnected without adding new BAAH bay but just expansion of previous developed projects.

Grid Needs - Transmission System Networks Expansion



Besides above adding a new 69 kV line between Waena switchyard and Pukalani substation, it is also proposed to replace the two 69/23 kV tie transformers at Kanaha substation by two units of larger transformers with at least FA rating as 24 MVA. The total estimated cost for these transmission networks expansion is $123.1 million.

An alternative of upgrading two units of the Kanaha tie transformer is to use DER program, or demand response program, or energy efficiency program to reduce peak load of the Maui 23 kV network by at least 4 MW.

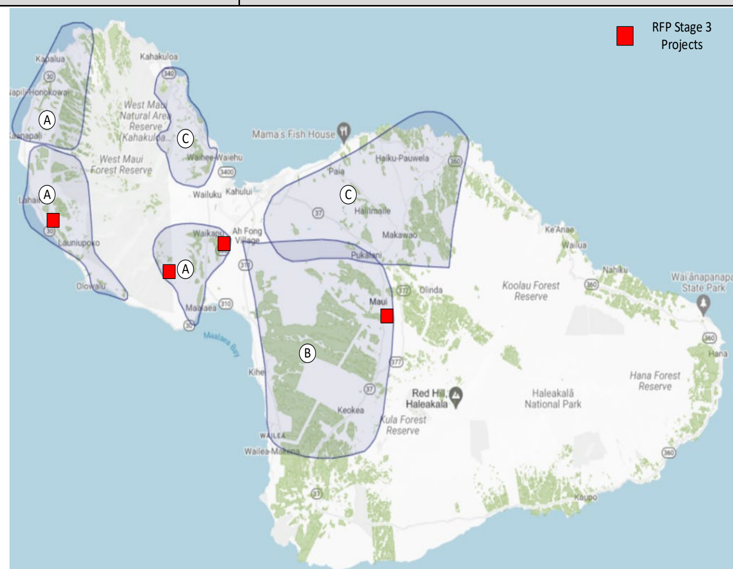
Grid Needs – System Stability Needs

Not studied

Table A 16 Maui Transmission System Grid Needs – High Load Scenario, Year 2027

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	2027

By 2027, the Maui system will have new generation from Stage 3 RFP procurement which will be 171 MW renewable dispatchable generation ("RDG") PV/BESS and 36 MW firm generation, interconnection at at Maui 69 kV system. Meanwhile, the Maui system will finish Waena switchyard construction, Kahului Power Plant ("KPP") retirement and conversion of KPP K3 and K4 units to synchronous condensers, and Maalaea Power Plant ("MPP") unit 10-13 retirement. The system peak load is forecasted to reach 239 MW by 2028.



System Grid Scale Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
Stage 3 Maui RFP	Renewable Dispatchable Generation	171	2027	West Maui, Central Maui and South Maui
	Firm Generation	36	2027	Central Maui
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kaheawa Wind Power 1	Wind Generation	30	2027	KWP 1 substation
Kahului 1-4	Fossil Generation	32.5	2027	Kahului Power Plant
Maalaea 10-13	Fossil Generation	49.4	2027	Maalaea Power Plant

System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
197.5	42	296	40	194	239

REZ Enablement

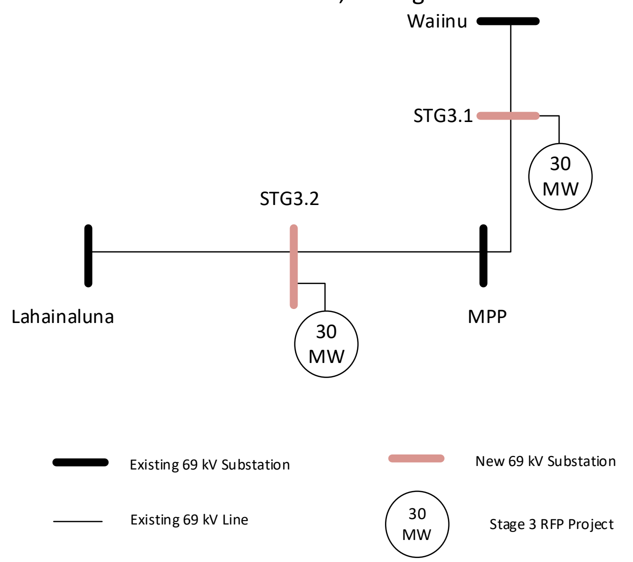
No REZ enablment cost estimate since by 2027 there will be only Stage 3 development but no REZ development. Interconnection sites for the 171 MW Stage 3 RFP projects and 36 MW firm generation are as following. Substation/Switching station interconnections:

- Lahainaluna substation station – 60 MW
- KWP 2 substation – 30 MW
- Waena switch yard – 40 MW firm generation
- Kealahou substation – 21 MW

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	**2027**

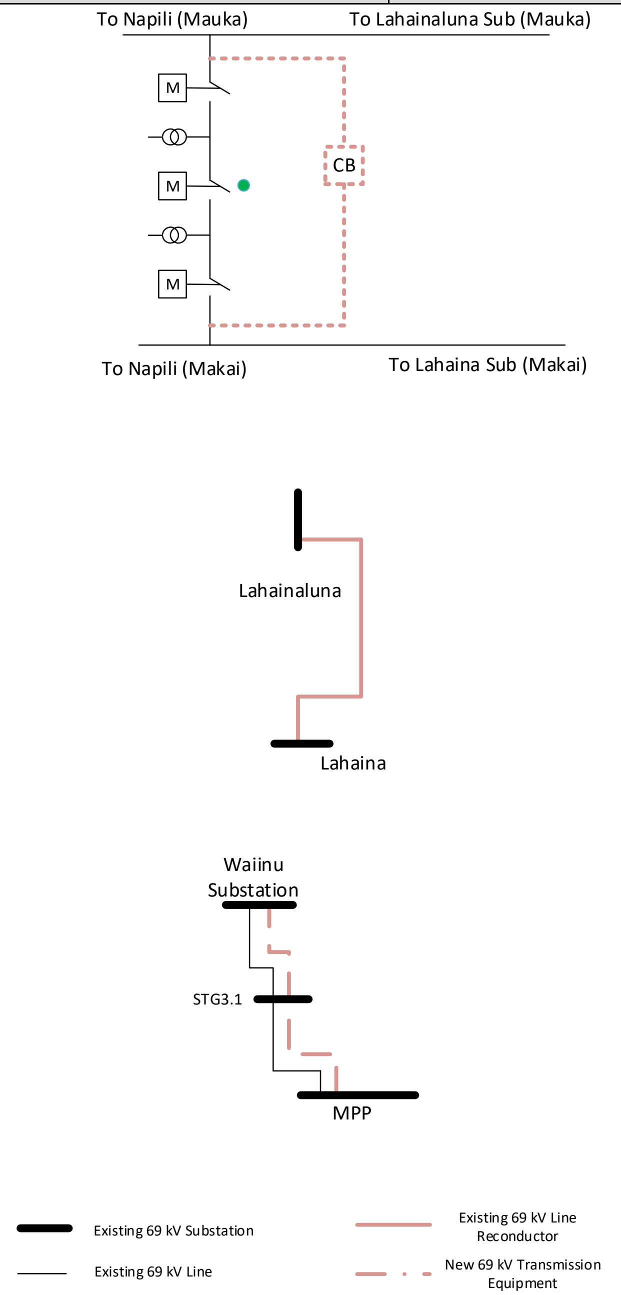
69 kV Transmisison line interconnection:

- MPP – Waiinu line interconnection – 30 MW, through a new substation STG3.1
- MPP – Lahainaluna line interconnection – 30 MW, through a new substation STG3.2



Grid Needs - Transmission System Networks Expansion

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	**2027**



The total estimated cost for these transmission networks expansion is $28.7 million.

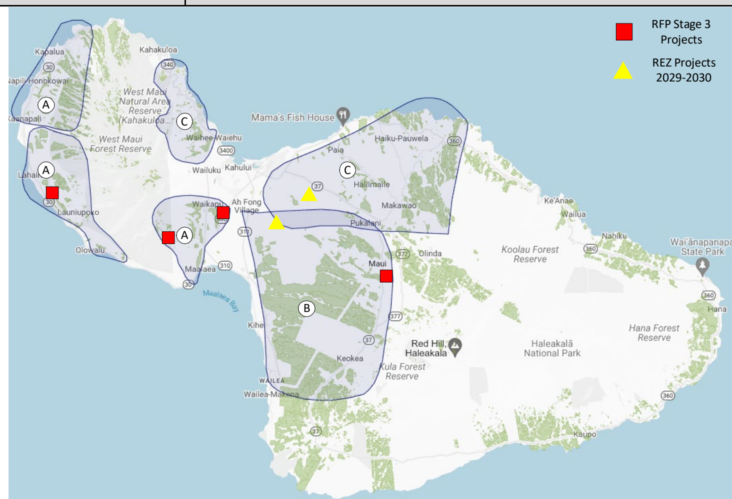
Grid Needs – System Stability Needs

Not studied

Table A 17 Maui Transmission System Grid Needs – High Load Scenario, Year 2030

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	2030

By 2030, the Maui system will have 69 MW grid-scale renewable generation from REZ zone C development. Also, it is planned that MPP unit 1 to 9 will be removed by 2030. The system annual peak load is forecasted to reach 266 MW by 2031.



System Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	6	2029	REZ Zone C
	Onshore Wind Generation	46	2035	REZ Zone C
	Solar/BESS	17	2035	REZ Zone C
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Maalaea Power Plant Units 1-9	Fossil	40.5	2030	MPP

System Resource Summary and Forecasted Demand (MW)

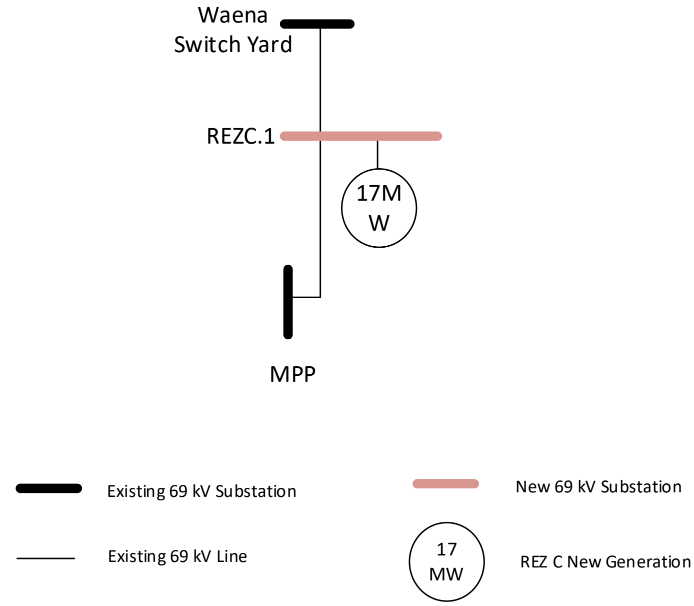
Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	94	313	40	217	266

REZ Enablement

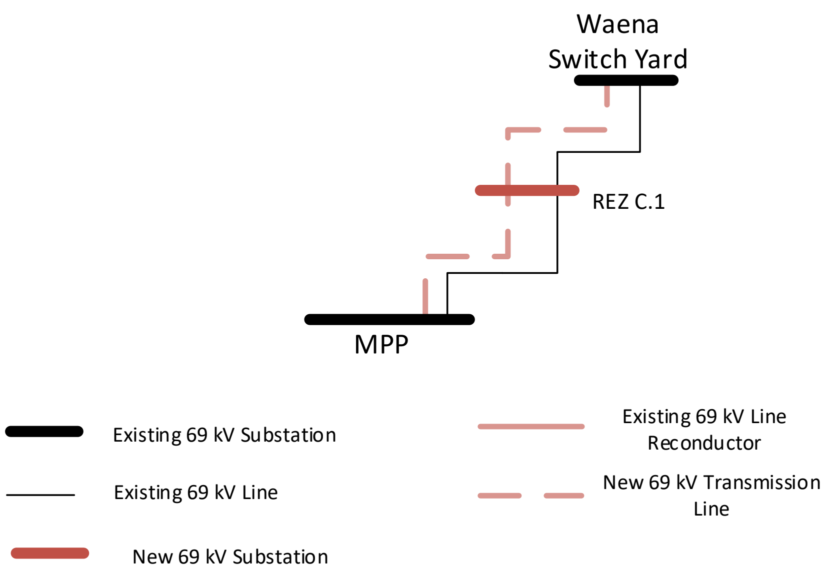
For the 2030 REZ development, 69 MW generation will be developed from REZ zone C and interconnected with Maui's 69 kV system. It is assumed that 52 MW will be interconnected at Waena switchyard, and 17 MW will be interconnected at a new substation REZ C.1 as shown in the following diagram. The estimated cost of REZ enablement for the 52 MW interconnection at the Waena switchyard is $11.6 million; the estimated cost of REZ enablement for the 17 MW interconnection at the REZ C.1 substation is $2.5 million.

REZ Enablement Cost Estimat for 17 MW Generation Interconnected at a new switching station REZC.1

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	2030



Grid Needs - Transmission System Networks Expansion



Besides adding the new 69 kV line from MPP to Waena via the REZ C.1 substation, converting Pukalani-Haiku 23 kV line into a 69 kV line and adding 1.8 Mvar cap bank at Kailu substation and Keanae substation are also proposed as part of the required trasmission networks expansion. The total estimated cost for these transmission networks expansion is $134.0 million.

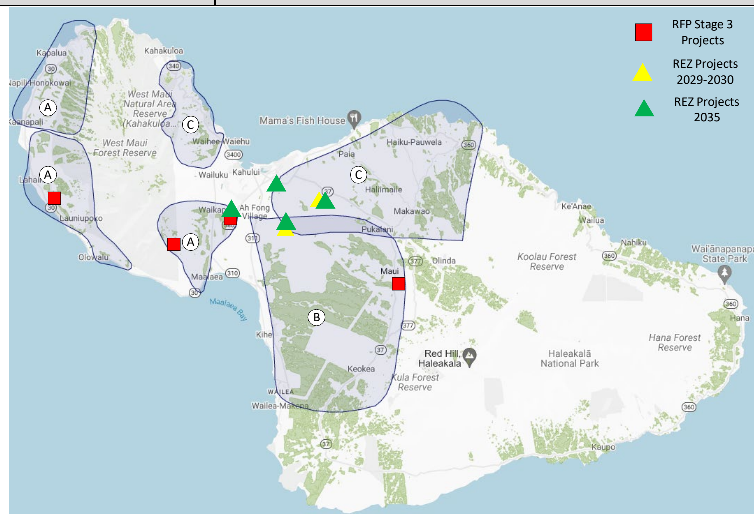
Grid Needs – System Stability Needs

Not studied.

Table A 18 Maui Transmission System Grid Needs – High Load Scenario, Year 2035

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	**2035**

In 2035, another 159 MW REZ zone C development will be completed. 38 MW will be interconnected at Waena switchyard, 60MW interconnected at REZC.1 30MW interconnected at STG3.1 and 30MW interconnected at Kanaha Substation on the 23kV bus. In addition, it is assumed the existing 42 MW wind contract expires. The system annual peak demand is forecasted to reach 313 MW in 2036.



System Resource Changes since 2036

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Onshore Wind Generation	75	2035	REZ Zone C
	PV/BESS Generation	84	2035	REZ Zone C
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Kaheawa Wind Power 2	Onshore Wind Generation	21	2033	KWP 2 Substation
Auwahi Wind	Onshore Wind Generation	21	2033	Auwahi Substation

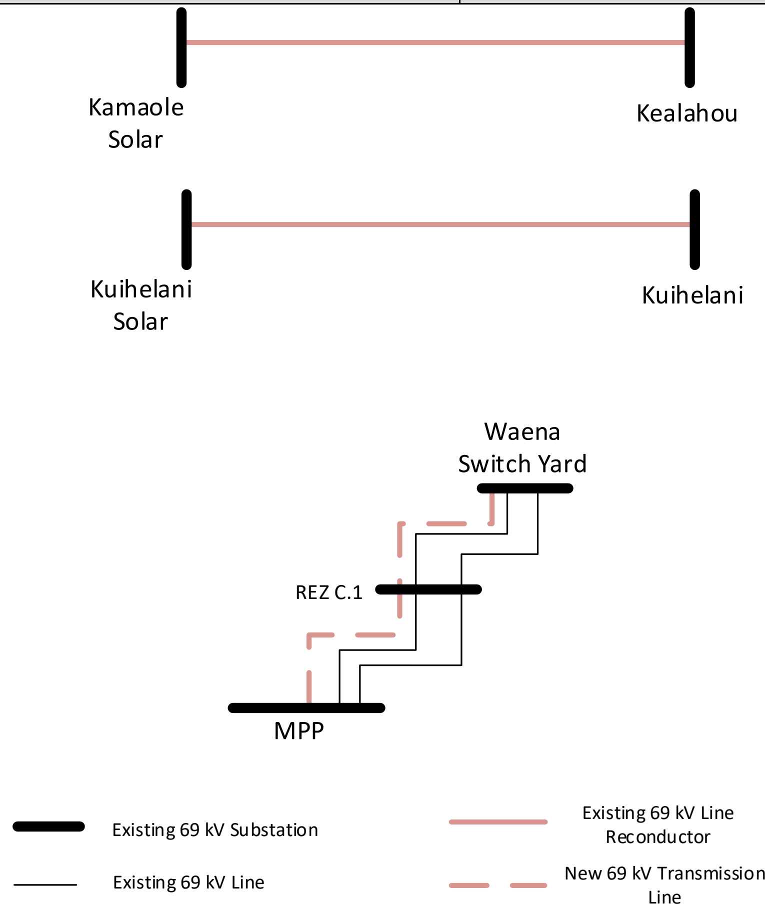
System Resource Summary and Forecasted Demand (MW)

Firm Generation	Onshore Standalone Wind	Grid-Scale Hybrid Solar/BESS	Standalone BESS	DER	System Peak Load
152	127	396	40	242	313

REZ Enablement

It is assumed that 38 MW generation will be interconnected at Waena switchyard (with estimated REZ enablement cost as $13.5 million), 60MW generation interconnected at REZC.1 (with estimated REZ enablement cost as $2.9 million), 30MW generation interconnected at STG3.1 (with estimated REZ enablement cost as $2.9 million), and 30MW generation interconnected at Kanaha Substation on the 23kV bus (with estimated REZ enablement cost as $2.8 million). The total estimated cost for the REZ enablement regarding the 158 MW generation from the REZ development is $22.1 million.

Grid Needs - Transmission System Networks Expansion

<table>
<tr><th>Studied Resource Plan</th><th>Studied Year</th></tr>
<tr><th>High Load Scenario Resource Plan</th><th>2035</th></tr>
<tr><td colspan="2">

Besides above mitigation solutions, it is also proposed to replace the two 69/23 kV tie transformers at Kanaha substation by two units of larger transformers with at least FA rating as 24 MVA. The total estimated cost for these transmission networks expansion is $70.0 million.</td></tr>
<tr><th colspan="2">Grid Needs – System Stability Needs</th></tr>
<tr><td colspan="2">Not studied.</td></tr>
</table>

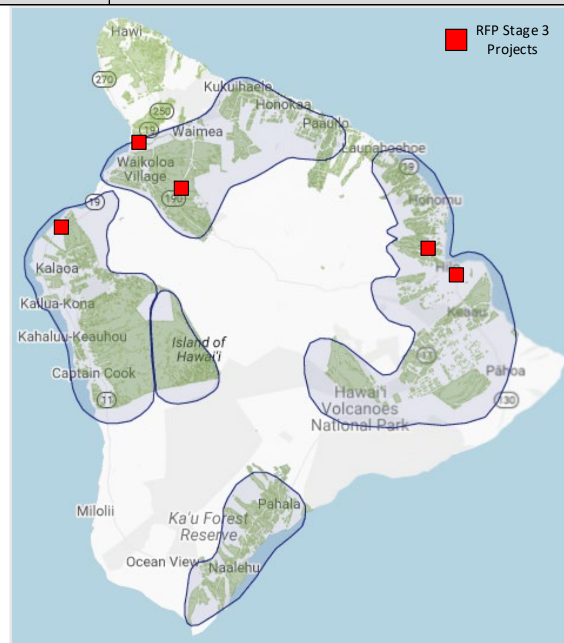
A.3 Hawaiʻi Island Results Summary

Summary of the study results for the Hawaiʻi Island base scenario and high load resource plan is as following.

Table A 19 Hawai'i Island Transmission System Grid Needs – Base Scenario, Year 2032

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2032**

By 2030, the Hawai'i Island system will have new generation from Stage 3 RFP procurement and REZ development, which will be 48 MW wind generation of REZ development by 2029 and 140 MW Stage 3 RFP PV/BESS generation by 2030. All of them will be interconnected to the Hawai'i Island 69 kV system. Also, three existing generation plants will be removed by 2031: the 34 MW Hill 5 and 6 will be removed by 2027; the 21 MW Tawhiri wind generation PPA is expected to expire by 2028; and the 58 MW Hamakua Energy Partners ("HEP") contract is expected to expire by 2031. The system peak load is forecasted to reach 214 MW by 2032.



System Grid Scale Resource Changes

Development	**Generation Type**	**MW Capacity**	**GCOD**	**Location**
REZ Development	Wind Generation	48	2029	West Hawai'i island
Stage 3 Hawai'i Island RFP	Solar/BESS Generation	140	2030	West and east side of Hawai'i island
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Hill 5, 6	Fossil Generation	34	2027	Kanoelehua substation
Tawhiri Generation	Wind Generation	21	2028	Kamaoa substation
HEP	Fossil Generation	49.4	2031	Haina substation

System Resource Summary and Forecasted Demand (MW)

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
85.8	58.5	46	200	16.6	214	214

REZ Enablement

Interconnection sites for the 140 MW Stage 3 RFP projects and 48 MW onshore wind generation are as following.

- Keamuku substation – 30 MW Stage 3 project
- Puueo substation – 30 MW
- Kanoelehua substation – 30 MW

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2032**

- Ouli substation – 20 MW
- Poopoomino substation – 30 MW

The interconnection of 48 MW wind generation from REZ development is assumed at the Keamuku substation. The estimated REZ enablement cost for the 48 MW offshore wind interconnection at the Keamuku substation is $37.8 million.

Grid Needs - Transmission System Networks Expansion

None

L6200 overloading observed in the study due for maximum west generation dispatches in which the 214 MW system load is solely supplied by generation from west side of island. This would be required for unconstrained use of the modeled base portfolio resources. The L6200 reconductor is not required if there is a minimum MW generation provided from east side of the system. as calculated by following equation:

East side minimum generation (MW) = $\frac{System\ total\ load - 174}{214 - 174} \cdot 20$

If system total load is lower than 178 MW, there is no mimimum MW requirement of generation on east side of the system.

Dependent on the system total load and the east side generation resources chosen to meet this minimum requirement, the east may require 20 MVAR of additional reactive power capability to resolve potential north/east voltage violations. At the peak load with 20 MW generation on east side of island, the following options are viable for mitigating north/east undervoltage violations:

- All 3 units of PGV online
- Puna CT3 online with 2.8 MVAR additional reactive capability required at Kanoelehua or Puueo substations
- Stage 3 Kanoelehua with 20 MVAR additional reactive capability required at Kanoelehua
- Stage 3 Kanoelehua & Puueo (split output) with 20 MVAR additional reactive capability required between the two locations. The Additional reactive capability at Kanoelehua and Puueo are in addition to the assumed capability of the Stage 3 resources at that location

To mitigate high loading condition of L8900/8100, it is necessary to move the generation resource interconnection location from Keamuku and the East towards the further west side system (e.g., Keahole substation) when the system total load reaches above 200 MW.

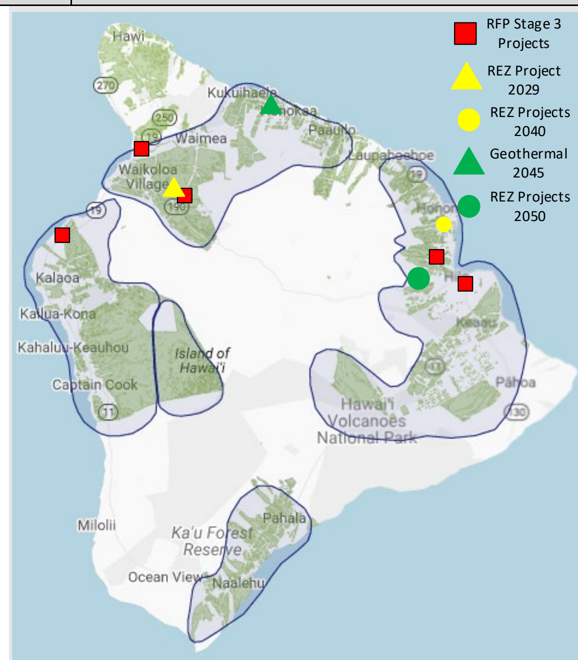
To mitigate undervoltage violation identifed on south side of system, it is recommend to have a resource interconnected at Keauhou substation with at least 10.4 Mvar capability or at Kamaoa substation with 13.7 Mvar or 13.3 MW capability. The reactive power capability can be replaced by active power capability, or the combination of reactive power and active power capability.

Grid Needs – System Stability Needs

After adding 140 MW Stage 3 PV/BESS projects with grid forming ("GFM") BESS component, it is expected that Hawaiʻi island system stability performance will stay within planning criteria, providing sufficient contingency reserve can be held on these resources - and no addtional grid needs regarding system stability were identified. When PGV units are online, at minimum, a total of 60 MW GFM PV/BESS project is required. A 30 MW GFM PV/BESS project is required on both East and West side of the Hawaiʻi island system, while maintaining GFM

Studied Resource Plan	Studied Year
Base Scenario Resource Plan	**2032**
resource headroom as 24% of DER generation. When PGV units are offline, at minimum, a total of 110 MW GFM resource is required. The east side of the system will need 50 MW GFM resource online and west side of the system will need 60 MW GFM resource online, while together maintaining GFM resource headroom as 61% of DER generation.	

Table A 20 Hawai'i Island Transmission System Grid Needs – Base Scenario, Year 2050

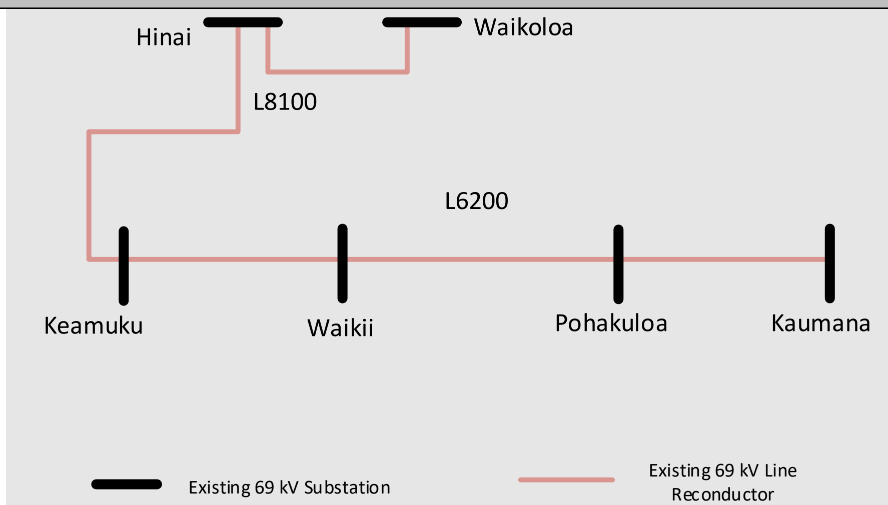
<table>
<tr><th colspan="3">Studied Resource Plan</th><th colspan="4">Studied Year</th></tr>
<tr><th colspan="3">Base Scenario Resource Plan</th><th colspan="4">2050</th></tr>
<tr><td colspan="3">In addition to previous system resource changes by 2031, the Hawai'i island system will have 2 MW standalone BESS and 3 MW Solar/BESS from the REZ development by 2035. It is assumed that both interconnections will be in distribution circuits considering their MW size. In 2040, there will be another 20 MW Solar/BESS generation developed from REZ. In 2045, all fossil generation will have fuel switch to biodisel. In the same year, there will be 30 MW geothermal generation and 2 MW standalone BESS interconnected to the system. By 2050, an additional 14 MW Solar/BESS and 2 MW onshore wind generation will be developed from REZ. The system annual peak load is forecasted to reach 295 MW by 2050.</td><td colspan="4">
</td></tr>
<tr><th colspan="7">System Resource Changes since 2031</th></tr>
<tr><th>Development</th><th>Generation Type</th><th>MW Capacity</th><th>GCOD</th><th colspan="3">Location</th></tr>
<tr><td>REZ Development</td><td>Solar/BESS</td><td>3</td><td>2035</td><td colspan="3">REZ, distribution interconnected</td></tr>
<tr><td>Other</td><td>Standalone BESS</td><td>2</td><td>2035</td><td colspan="3">Distribution interconnected</td></tr>
<tr><td>REZ Development</td><td>Solar/BESS</td><td>20</td><td>2040</td><td colspan="3">REZ, east side of Hawai'i island</td></tr>
<tr><td>Other</td><td>Geothermal</td><td>30</td><td>2045</td><td colspan="3">North side of Hawai'i island</td></tr>
<tr><td rowspan="2">REZ Development</td><td>Solar/BESS</td><td>14</td><td>2050</td><td colspan="3" rowspan="2">REZ, east side of Hawai'i island</td></tr>
<tr><td>Onshore wind</td><td>2</td><td>2050</td></tr>
<tr><th colspan="7">System Resource Summary and Forecasted Demand (MW)</th></tr>
<tr><td>Fossil Generation</td><td>Onshore Standalone Wind</td><td>Geothermal Generation</td><td>Grid-Scale Hybrid Solar/BESS</td><td>Hydro</td><td>DER</td><td>System Peak Load</td></tr>
</table>

Studied Resource Plan				Studied Year		
Base Scenario Resource Plan				2050		
85.8	60.5	76	237	16.6	271	295

REZ Enablement

It is assumed that the geothermal generation in service in 2045 will be interconnected at Haina substation, and the REZ generation will be interconnected at Pepeekeo substation (20 MW) in 2040 and Kaumana substation (17 MW) in 2050.
High level cost estimate for the 20 MW interconnection REZ enablement at the Pepeekeo substation is $24.5 million, and for the 17 MW interconnection REZ enablement at the Kaumana substation is $27.9 million.

Grid Needs - Transmission System Networks Expansion



The estimated cost for the two line reconductor is $100.1 million.

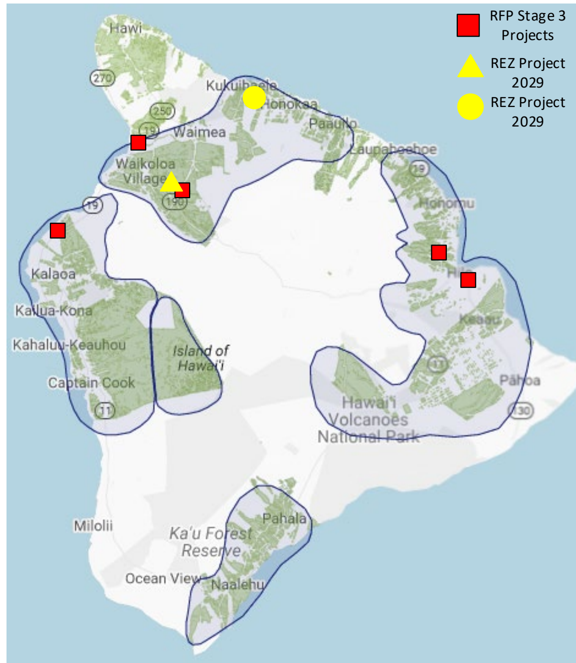
To mitigate undervoltage violations on the north side of the system, it is recommended to dispatch an East unit (e.g., PGV, etc.) at 5 MW or higher.

To mitigate undervoltage violation on south and southwest side of the system, it is recommend to have a resource interconnected at Kamaoa with 22.5 MW generation capacity and/or a minimum reactive power requirement (defined on further study when resouces are known).

Grid Needs – System Stability Needs

Not studied.

Table A 21 Hawaiʻi Island Transmission System Grid Needs – High Load, Year 2032

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	**2032**
According to the resource plan, by 2030, the Hawaiʻi system will have new generation from Stage 3 RFP procurement, REZ development and a new geothermal generation plant, which will be 48 MW wind generation of REZ development and 30 MW geothermal generation by 2029 and 140 MW Stage 3 RFP PV/BESS IBR generation by 2030. All of this new generation will be interconnected to the Hawaiʻi island 69 kV system. Meanwhile, three generation plants will be removed by 2031: the 34 MW Hill 5 and 6 will be removed by 2027; the 21 MW Tahiri wind generation will be removed by 2028; the 58 MW Hamakua Energy Partners ("HEP") will be removed from system by 2031. According to the forecast, system peak load will reach 280 MW by 2032.	

System Grid Scale Resource Changes

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Wind Generation	48	2029	West Hawaiʻi island
Other	Geothermal Generation	30	2029	North of Hawaiʻi island
Stage 3 Hawaiʻi Island RFP	Solar/BESS Generation	140	2030	West and east side of Hawaiʻi island
Removal	**Generation Type**	**MW Capacity**	**Year**	**Location**
Hill 5, 6	Fossil Generation	34	2027	Kanoelehua substation
Tawhiri Generation	Wind Generation	21	2028	Kamaoa substation
HEP	Fossil Generation	58	2031	Haina substation

System Resource Summary and Forecasted Demand (MW)

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
85.8	58.5	76	200	16.6	214	280

REZ Enablement

Interconnection sites for the 140 MW Stage 3 RFP projects and 48 MW onshore wind generation are as following.

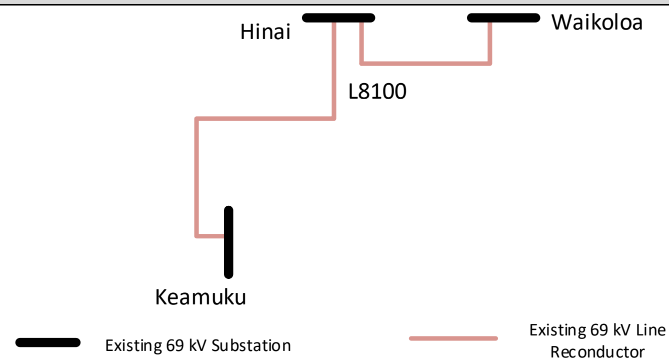
- Keamuku substation – 30 MW Stage 3 project

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	2032

- Puueo substation – 30 MW
- Kanoelehua substation – 30 MW
- Ouli substation – 20 MW
- Poopoomino substation – 30 MW

Also, it is assumed that the interconnection of 48 MW wind generation from REZ development is at the Keamuku substation and the interconnection of the 30 MW geothermal generation is at the Haina substation. The estimated REZ enablment cost for the 48 MW onshore wind interconnected at the Keamuku substation is $37.8 million.

Grid Needs - Transmission System Networks Expansion



The estimated cost for reconductoring L8100 is $10.9 million.

The alternative non-wire solution for deferring L6200 reconductor is to maintain minimum generation dispatch requirement on east side of the system. The minimum MW generation dispatched from east side of the system is calculated by following equation:

East side minimum generation (MW) = $\frac{System\ total\ load - 174}{214 - 174} \cdot 20$

If system total load is lower than 178 MW, there is no mimimum MW requirement of generation dispatched on east side of the system.

Depending on the system total load and the East side generation resources chosen to meet this minimum requirement, the East may require 28 MVAR of additional reactive power capability to resolve potential North/East voltage violations. 14 MVAR at Kanoelehua and 14 MVAR at Puueo are recommended to be installed (in addition to the assumed capability of Stage 3 resources at that location).

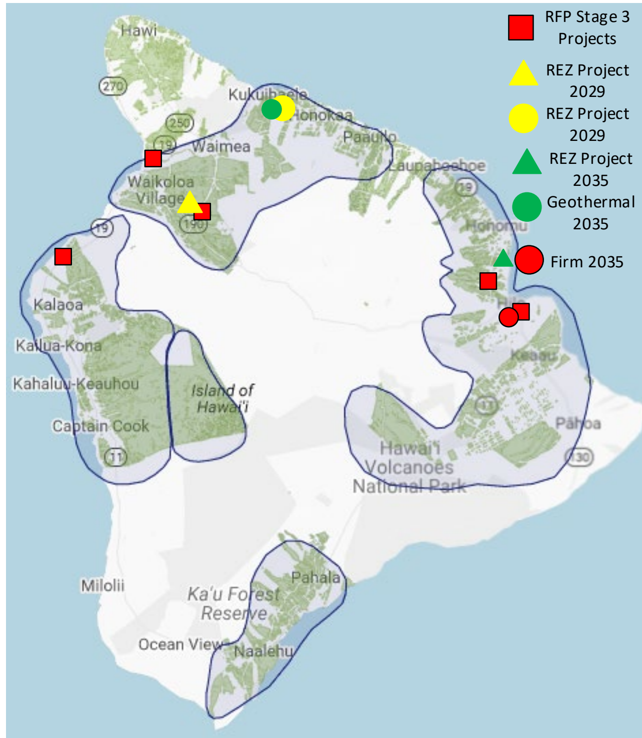
To mitigate undervoltage violation identifed on south side of system, it is recommend to have a resource interconnected at Kamaoa substation with at least 24 MW generation capability.

When the 30 MW geothermal is installed at Haina in 2029, there will be a total of 88 MW of generation capacity at Haina substation. During the time period between when the geothermal resource comes online and when HEP is removed in 2031, operational mitigation will be needed such that the total generation at Haina substation is limited to the existing capacity of 58 MW.

Grid Needs – System Stability Needs

Not studied.

Table A 22 Hawaiʻi Island Transmission System Grid Needs – High Load, Year 2036

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	**2036**
In addtion to previous system resource changes, by 2035 the Hawaiʻi island system will have another 30 MW geothermal generation, 30 MW firm generation and 22 MW solar/BESS generation from REZ development. Accoriding to the forecast, system annual peak load will be reached at 323 MW by 2036.	

System Resource Changes since 2031

Development	Generation Type	MW Capacity	GCOD	Location
REZ Development	Solar/BESS	22	2035	East side of Hawaiʻi island system
Other	Geothermal	30	2035	North side of Hawaiʻi island system
Other	Firm	30	2035	East side of Hawaiʻi island system

System Resource Summary and Forecasted Demand (MW)

Fossil Generation	Onshore Standalone Wind	Geothermal Generation	Grid-Scale Hybrid Solar/BESS	Hydro	DER	System Peak Load
115.8	58.5	106	220	16.6	230	323

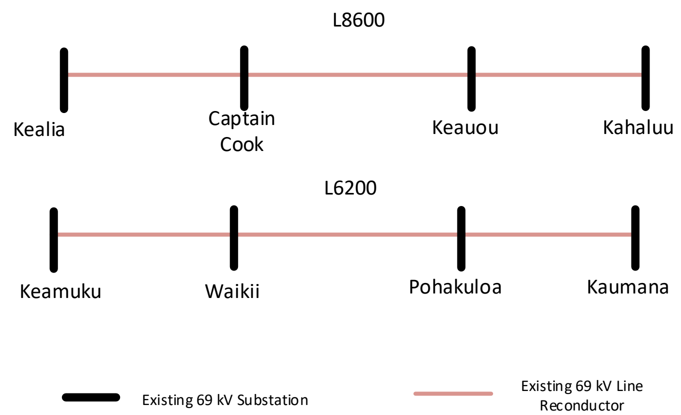
REZ Enablement

It is assumed that the geothermal generation in service in 2035 will be interconnected at Haina substation, and the REZ generation will be interconnected at Pepeekeo substation (22 MW) in 2035 and the firm generation will be interconnected at Kanoelehua substation (30 MW) in 2035.

Studied Resource Plan	Studied Year
High Load Scenario Resource Plan	2036

For the 22 MW Solar/BESS interconnection at the Pepeekeo substation, the estimated cost for REZ enablement is $24.5 million.

Grid Needs - Transmission System Networks Expansion



The estimated cost of reconductoring L8600 and L6200 is $121.5 million.

To mitigate undervoltage violations on the north side of the system, it is recommended to dispatch an East unit (e.g., PGV, etc.) at 14 MW or higher.
To mitigate undervoltage violation on south and southwest side of the system, , it is recommended to have a resource interconnected at Kamaoa with at least 24 MW active power generation capacity and 7.5 Mvar reactive power capability.
To mitigate undervoltage violations on the west side of the system during dispatches with high east generation, it is recommended to dispatch Keahole at 10 MW or higher.

Grid Needs – System Stability Needs

Not studied.