# Hawaiian Electric
# Transmission Renewable Energy Zone (REZ) Study

November 2021

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# 1. Executive Summary

As part of the Integrated Grid Planning process, the Company has been undertaking an industry-leading approach, incorporating stakeholder and community input to shape the grid of the future. Within this process, the Renewable Energy Zone study was commissioned to understand the technical requirements to further increase grid-scale renewable energy in Hawaii, as well as to develop initial cost estimates of additional transmission capacity to incorporate in long-term resource planning analyses. This study focuses on the transmission system, which is the backbone of the electric grid allowing transfer of energy through long distances and throughout each island.

Implementing grid-scale renewable energy is not a plug and play exercise. The transmission system is approaching capacity limitations in areas where renewable resources are richer placing the Company and the State at somewhat of an inflection point. In order to add significant amounts of new renewable resources will require new transmission capacity to connect the current transmission system to these resources or to increase the capacity of the transmission system to harness electrical power from areas in which renewable resources are available and transmit that power to the rest of the island. Planning and building major transmission to support a 100% renewable future requires decade(s) of effort, and must be started now.

Ultimately, the success of implementing the identified transmission solutions, or other to-be-determined solutions, will require alignment with the community, stakeholders, and the State. This study represents the beginning of a process, and is expected to be used as a catalyst of further discussions regarding the future of Hawaii's electric system. With community, stakeholder, and the States' input and support, the Company anticipates future iterations and refinements of this study to develop realistic, achievable plans to support the increase of renewable energy.

Although this represents an early stage in the overall process, the following findings can be used to inform future iterations of analysis as plans are developed.

1. On Oahu, interconnection of REZ groups 1 to 7 (West, Central, East, and Southeast regions) requires minimum Transmission Network Expansions[1]. REZ Group 8 (Wahiawa, North Shore area) has a vast amount of renewable energy potential (over 1 GW), but realizing its full potential will require significant Transmission Network Expansions.
2. Two separate analyses to interconnect up to 600 MW and 400 MW of off-shore wind at Ko`olau, Halawa, Iwilei and Kahe substations (Oahu) was performed. The study assumed off-shore wind was interconnected after REZ groups 1 to 8.
    a. Interconnecting up to 600 MW of off-shore wind was found to be feasible only at Ko`olau substation. Additional Transmission Network Expansion requirements were also needed beyond those required to interconnection REZ groups 1 to 8.

[1] Transmission Network Expansions are transmission system upgrades not associated with a particular REZ group, and are required to support the flow of energy within the transmission system and provide generation dispatch flexibility.

b. Interconnecting up to 400 MW offshore wind still resulted in Ko`olau substation as the only feasible option for interconnection. No additional Transmission Network Expansions are required beyond those are required for interconnecting REZ groups 1 to 8.

3. On Maui, development of REZs should consider geographic diversity, and be planned in to diversify resources among west, south and central Maui. Interconnection of REZ Groups 1, 2, 3 and 4B1 (West and Central regions) requires limited Transmission Network Expansion. Interconnection of REZ 4A and REZ 4B2 (South and North regions) causes significant 69 kV conductor overloading, which requires a Transmission Network Expansion of South and Central Maui 69 kV system.
4. On Hawaii Island, similar to Maui, REZs should consider geographic diversity, and be planned to diversify resources among the east and west of Hawai`i island. The interconnection of REZ Groups 3, 4 and 5 (Central, North, and South regions) requires least Transmission Network Expansion.

# 2. Introduction

Hawaiian Electric has commenced a study to identify transmission infrastructure necessary to accommodate the large blocks of grid-scale renewable energy on the islands of Oʻahu, Maui, and Hawaiʻi Island. The objective of this study is to assess the technical feasibility and Transmission needs (for capacity) to interconnect additional amounts of renewable energy to achieve our State's RPS, and provide initial cost estimates. These costs will be incorporated in the Integrated Grid Planning (IGP) process to develop resource portfolio plans.

The existing transmission infrastructure is approaching its capacity limitations for which they were designed with the significant increases in Renewable Energy projects (e.g., RFP Stage 1 and 2). The Company is making efforts to maximize the utilization of existing transmission capacity, but in many cases, will not be enough to take advantage of the renewable energy potential in key areas of each island we serve. In certain areas, such as the West side of Hawaii Island, the capability to add grid-scale renewable energy is limited due to the power flow within the West of the Island, as well as power flow from West to East of Hawaii Island. Within the framework of the Company's Integrated Grid Planning process, the Company is taking a bold step to begin the conversation with stakeholders and the community to communicate, determine, and plan the requirements to attain higher levels of renewable energy.

This study represents an initial step in developing transmission infrastructure required to further increase utility-scale renewable energy. The process to develop Renewable Energy Zones (REZ) is outlined in Figure 1 in which this study covers steps 1-3. The Company anticipates multiple iterations of each step with stakeholder and community members as the process progresses. A draft of this study was presented to IGP stakeholders in October 2021, and the Company plans to pursue further stakeholder and community outreach upon filing this study.

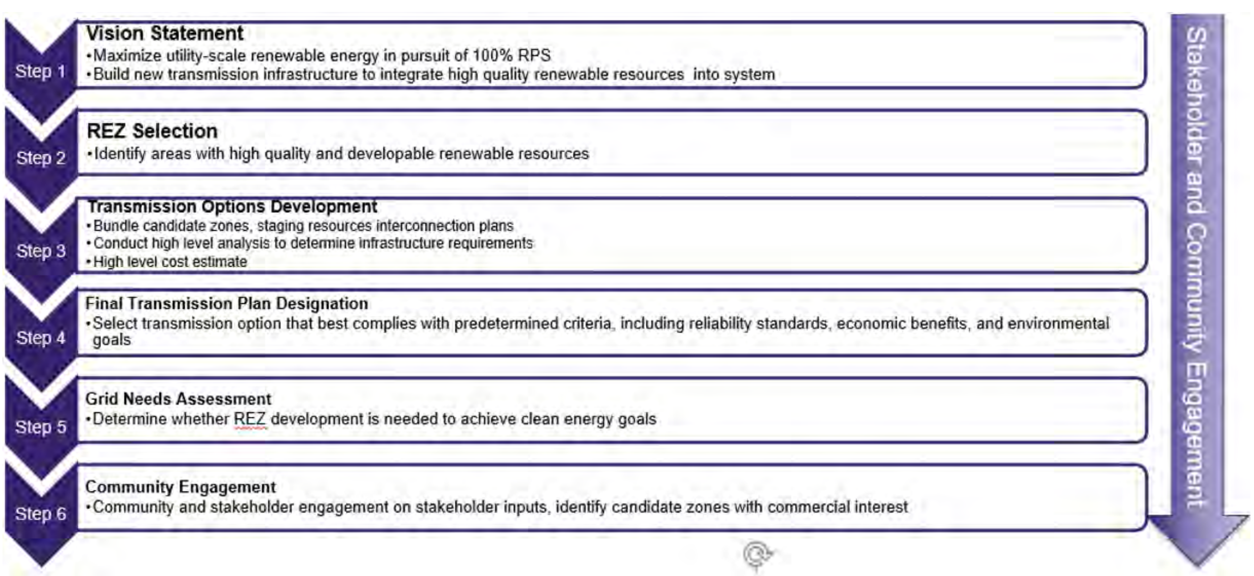


**Figure 1 Transmission Renewable Energy Zone Planning Process**

There are multiple uses for the information found in this study:

- The study will allow the Company and stakeholders to get an initial understanding of the capabilities of the existing transmission system, as well as transmission upgrade options to accommodate future amounts of grid-scale renewable energy.
- This information can be used to inform policy making discussions on land use and how best to use the limited land resources for competing purposes (e.g., agriculture, housing, energy, preservation, etc.).
- A future REZ plan developed through stakeholder and community outreach will serve as a long-term blueprint to align to. As resources are added to the system, transmission upgrades may be incrementally added in alignment with an overarching development plan.
- This information will also be used within the IGP process; including developing future resource costs and schedules, as well as educating and engaging with communities to gather feedback on these potential plans, while contemplating tradeoffs under various decarbonization and renewable goals.

As an example, there are high amounts of solar potential on the west and north ends of O`ahu; however, there are currently no transmission lines in those areas. Creating a REZ by extending transmission lines to these areas would facilitate further development of renewable energy. These transmission requirements and cost to interconnect various renewable energy zones will serve as an input into the RESOLVE model, which is the Company's tool to determine resource plans based on economic and operational requirements. The RESOLVE model will then be allowed to select a specific renewable energy zone based on the cost of the resource and transmission infrastructure required to interconnect that zone.

The study, based on steady-state power flow analyses, assesses the capacity of the existing transmission system and identifies the cost of different transmission upgrade options to interconnect the identified megawatt capacity of each renewable energy zones. The NREL potential study (Scenario Alt-1)[2] is used as a basis for identifying potential capacity within the identified zones. The Company acknowledges there are differing opinions from stakeholders regarding these assumptions; however, for purposes of this study, the scenario provides an appropriate capacity potential to determine the transmission requirements.

The study will identify transmission capacity requirements (i.e., major transmission lines and substations) necessary to facilitate the transfer of power (regardless of the generating resource technology) from the REZ to the rest of the system. For consistency and clarity, there are three terms used throughout the report:

- **Total REZ Upgrades**, which represents the collective of Transmission Network Expansions and REZ Enablements to interconnect all REZ groups.

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[2] *See* Hawaiian Electric Revision to Updated and Revised Inputs and Assumptions, Section 5.1.1, August 19, 2021. Dkt. No. 2018-0165.

- **Transmission Network Expansions**, which are transmission system upgrades not associated with a particular REZ group, and are required to support the flow of energy within the transmission system and provide generation dispatch flexibility.
- **REZ Enablements**, which are new or upgraded transmission lines and new or expanded substations required to connect the transmission hub of each REZ group to the nearest transmission substation.

Costs for interconnection requirements that are developed by specific projects are not included in this analysis (e.g., generation-tie lines). REZ enablement is used to create a system architecture that establishes a central point for interconnection in different areas of the island (i.e., a hub and spoke model). This will create a more efficient interconnection process and proactively identifies points of interconnection for future projects. It also mitigates technical issues associated with past practices of allowing individual projects to build their own substation, effectively “cutting” or segmenting a transmission line in multiple locations. The IGP Technical Advisory Panel (TAP) agreed “with the premise that it is preferable to provide planned interconnection points for renewables rather than piecemeal tapping of transmission lines as is currently being done (see Appendix B).” General steps to complete the REZ study for the Grid Needs Review Point filing is shown in Figure 2.

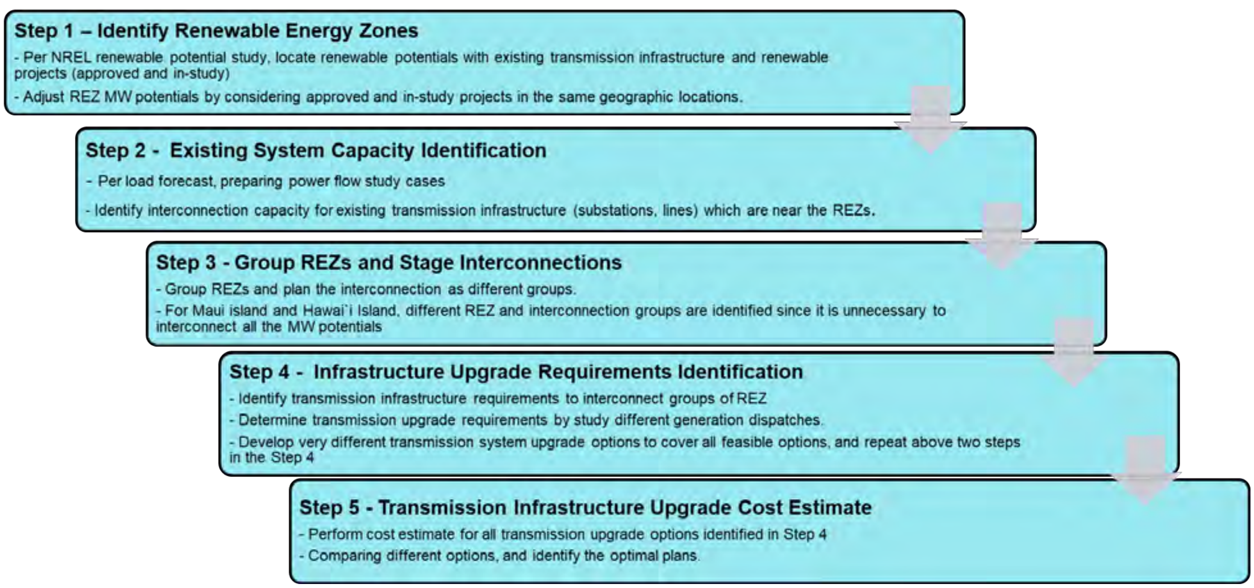


**Figure 2 Transmission Renewable Energy Zone Study Procedures**

# 3. Key Assumptions and Methodology

## 3.1. Assumptions for Power Flow Study

The year 2040 was used as a planning target, and the forecasted load in MW is provided in Table 3-1. The starting point for developing the potential interconnection in MWs was the NREL PV-Alt-1 scenario, which was adjusted as described in Section 3.2 to the Adjusted Potential Interconnection. The Adjusted Potential Interconnection MW represents the aggregated MW-ac size of all potential grid-scale renewable projects in the REZ. Although the study remains technology agnostic, should there be high amounts of non-firm type resources added, consideration was made to supply the forecasted peak load from various zones and at much higher levels of supply vs. load. Therefore, to maintain flexibility of dispatch for all REZ, different dispatch scenarios are created to determine system upgrade requirements in order to achieve the potential interconnection.

**Table 3-1 2040 Load Forecast and Potential Renewable Interconnection for Studied Islands**

| Island | Total Renewable Potential (MW)[3] | | | 2040 Forecasted Peak Load (MW) | Adjusted Potential Interconnection (MW) |
|---|---|---|---|---|---|
| | Utility Scale Solar | On-Shore Wind | Off-Shore Wind | | |
| Oahu | 3,344 | 256 | 600 | 1,400 | 3,344 + 600 |
| Maui | 13,507 | 767 | N/A | 287 | 847/872 |
| Hawaii | 76,056 | 5,037 | N/A | 216 | 720/830 |

Other key assumptions used in the study, include:

- IGP Inputs and Assumptions were used to inform the study. Specifically, the thermal generation retirement schedule[4], load forecast[5], and NREL Solar and Wind potential[6].
- 2040 evening peak load scenario is selected for the study as a 20-year horizon is aligned with a long-term planning scenario. The forecasted load does not include any centralized

[3] The capacity of each zone was adjusted from the NREL Alt-1 scenario to subtract the capacity of existing or approved solar projects.
[4] Ibid, Section 8.
[5] Ibid, Section 4.1.
[6] Ibid, Section 5.1.

standalone energy storage charging load. Distribution-level DER contribution is not considered in this study.

- The study assumed the new grid-scale renewable energy resources were paired with Battery Energy Storage Systems (BESS) which provide flexibility of dispatch; however, the study reviews capacity of the transmission elements (lines and transformers), so other types of resources such as non-inverter-based resources (e.g., synchronous machines) may also be interconnected within these Renewable Energy Zones.
- All grid scale renewable projects (including existing projects) can provide lagging 0.95 to leading 0.95 power factor reactive power capability anytime. When necessary, available fossil plants are also dispatched for reactive power support.
- To determine Transmission Network Expansions, for all studied dispatches, higher priority is assigned to dispatch generation in REZ and existing projects and fossil plant MW generation are dispatched only when it is necessary.

The study was performed through single snapshot power flow without performing a time series study. Therefore, the following issues are not addressed in this study, but can be evaluated in future iterations of plans and respective studies:

- Non-Transmission Alternative (NTA), such as centralized standalone energy storage system, is not considered in this study to defer any Transmission Network Expansion.
- Operational mitigation, such as generation curtailment, is not considered in this study, which can be used as an alternative for transmission infrastructure upgrade.
- The study only focuses on the system steady state capacity evaluation, but not including voltage optimization, dispatch optimization, loss minimization or stability study. All these aspects can be addressed in the further study after getting feedback from stakeholder about the current study.
- Cost estimates included in this study includes the REZ Enablement and Transmission Network Expansions identified in this study only. Other requirements that require further detailed studies and evaluation such as protection upgrades, SCADA system upgrades, control systems, etc. are not included in the cost estimates in this study.

## 3.2. Assumptions for Renewable Potential

The goal of the study is to determine the transmission requirements to support the integration of renewables based on certain potentials. The basis for the potentials were provided by the NREL solar and wind potential, as described in the Company's filing on August 19, 2021 under docket no. 2018-0165, *Hawaiian Electric Revision to Updated and Revised Inputs and Assumptions*, Section 5.1.1. The renewable potential identified in the NREL study garnered feedback and discussion among the IGP Stakeholder Technical Working Group, which based on the feedback provided, an alternative scenario (Alt-1) was created to address feedback provided. Section 5.1.1 states:

> *Taking into consideration the various viewpoints, the Company will use the Alt-1 scenario for wind and solar potential for various scenarios. The Company will also use*

*this Alt-1 scenario in developing transmission infrastructure needed to develop renewable energy zones, as discussed in the following Section 5.2. The Alt-1 scenario excludes DoD lands but includes development on land with slopes up to 30%.*

*It is worth noting that there is substantial overlap between areas with solar resource potential and wind resource potential. And the same system infrastructure can be used to interconnect both wind and solar resources and transfer the renewable energy to the other locations of the system.*

As provided in the Company's filing, the PV-Alt-1 scenario was used as a basis for developing the renewable energy zone potential interconnections. Using this scenario is appropriate for this REZ study as (1) the study is technology agnostic, as it studies the injection of MW capacity on transmission lines and substations to determine the infrastructure needed to add these potential amounts; and (2) PV-Alt-1[7] and Wind-Alt-1[8] scenarios largely overlapped with Solar potentials at higher levels than Wind potentials (see Figure 3).

[7] *See* https://nrel.carto.com/u/gds-member/builder/4d570d92-d17c-4bba-b592-8f4e55446d50/embed
[8] *See* https://nrel.carto.com/u/gds-member/builder/49af7cb6-fbd7-4278-8ec9-a1663a910f8c/embed

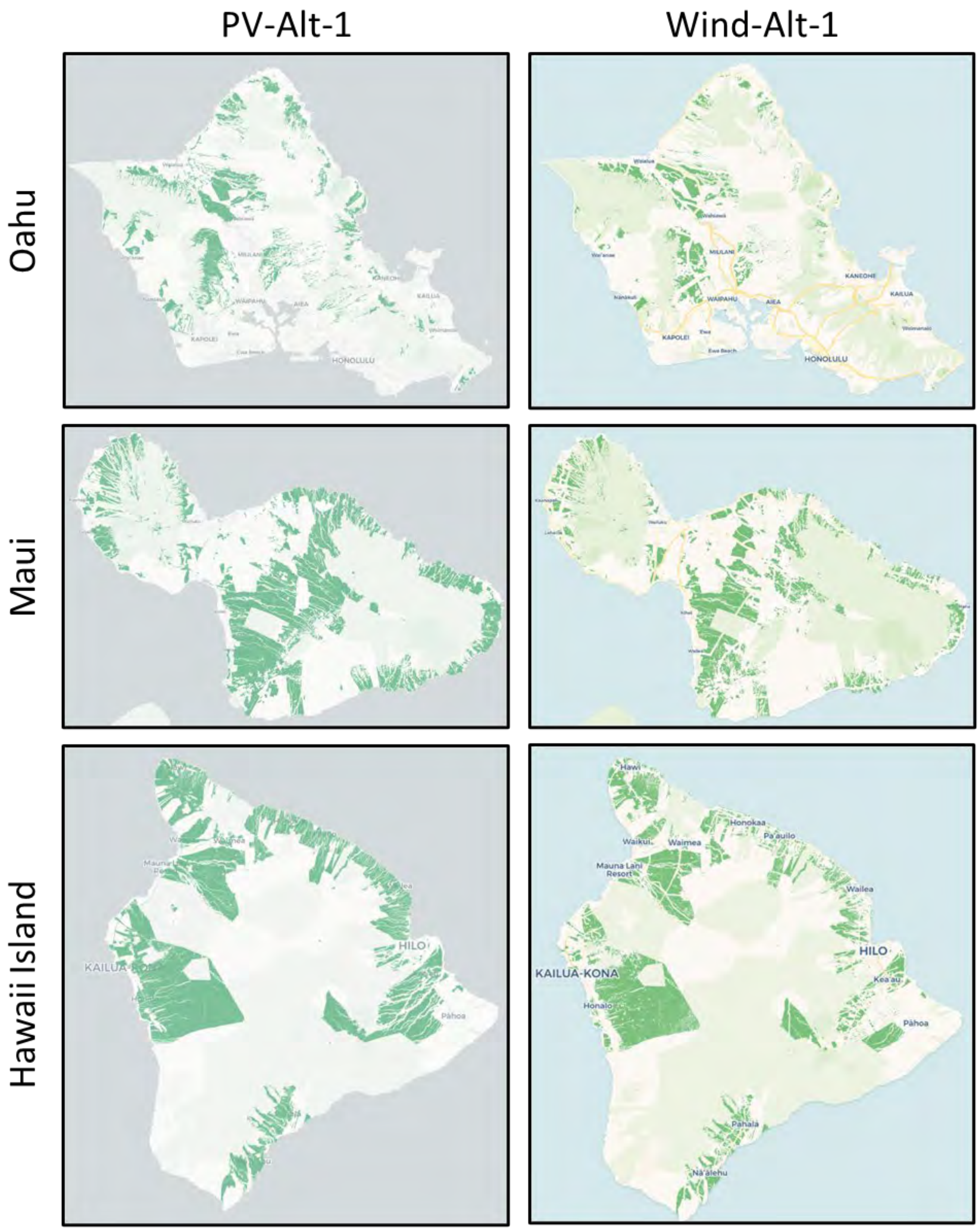


**Figure 3 NREL PV and Wind Potential by Island (in dark green)**

## 3.3.Assumptions for Cost Estimate

Transmission infrastructure upgrades are categorized as two parts in this study: 1) REZ Enablement which includes interconnecting the generation from the REZ to the system (e.g. switching station, transmission line extension, breaker-and-a-half (BAAH) and related substation expansion) and 2) Transmission Network Expansions which includes existing transmission system upgrades necessary to facilitate the transfer of energy throughout the system (e.g. re-conductor of existing transmission line, adding new transmission line between existing substations and related purchasing new right-of-way, adding new BAAH and substation expansion). The following assumptions are used for cost estimate in this study.

Regarding the design of interconnection facility to interconnecting the REZ groups to the transmission system, according to the Company's transmission planning criteria single-point failure capacity limit, trip of one gen-tie cannot cause a loss of centralized generation higher than 135 MW on O`ahu, 20 MW on Maui island, or 30 MW on Hawai`i island.

For REZ groups with high MW potentials, REZ Enablement cost for each interconnection with stepwise MW incremental are provided in this report, with assumption of fully realizing REZ MW potential. The cost estimates are provided on fixed MW increments based on the single-point failure capacity limit by island. The estimates are preliminary, will be impacted by many factors, such as interconnection MW size, relative location to interconnection substation or transmission line, new transmission infrastructure build-out status, substation available space, etc.

**Table 2-2 Per Unit Costs and Assumptions**

| No. | Item | Cost |
|---|---|---|
| **SUBSTATION ITEMS** | | |
| 1 | 138kV – One BAAH bay | $8,800,000 |
| 2 | 138kV – Add 2 BAAH bays (including substation expansion) | $15,400,000 |
| 3 | 138kV – Add 2 BAAH bays (assumes space available within substation) | $14,400,000 |
| 4 | 138kV – New 4-bay BAAH substation | $35,200,000 |
| 5 | 138kV – Convert 4-breaker Ring bus to BAAH | $2,400,000 |
| 6 | 138kV – Line Relay Upgrade | $550,000 |
| 7 | 138kV – Add breaker | $660,000 |
| 8 | 345kV – New 4-bay BAAH substation | $70,500,000 |
| 9 | 345-138kV transformer, 450/600MVA | $9,800,000 |
| 10 | 345-138kV transformer, 600/700MVA | $10,900,000 |
| 11 | 138-69kV transformer, 100MVA | $4,900,000 |
| 12 | 138-12kV transformer, 10MVA | $1,600,000 |
| 13 | 69kV – One BAAH bay | $5,500,000 |
| 14 | 69kV – Add breaker | $550,000 |
| 15 | 69kV – Convert 4-breaker Ring bus to BAAH | $2,200,000 |

| No. | Item | Cost |
|---|---|---|
| 16 | 69-23kV tie transformer, 20/50MVA | $2,200,000 |
| 17 | 23kV – New 2-bay BAAH substation | $10,900,000 |
| 18 | Telecom infrastructure for new substation | $500,000 |
| **T&D ITEMS** | | |
| **Overhead Accessible** | | |
| 20 | 138kV OH accessible (400ft spans) | $7,310,000 / mile |
| 21 | 138kV overbuild on existing lines (400ft spans) | $7,274,000 / mile |
| 22 | 138kV OH reconductor (500ft spans) | $7,678,000 / mile |
| 23 | 23kV-69kV OH accessible (250ft spans) | $1,179,000 / mile |
| 24 | 23kV-69kV overbuild on existing lines (150ft spans) | $2,135,000 / mile |
| 25 | 23kV-69kV OH reconductor (250ft spans) | $1,150,000 / mile |
| 26 | 69kV OH upgrade to double bundle (250ft spans) | $1,785,000 / mile |
| 27 | 345kV OH accessible (400ft spans) | $14,620,000 / mile |
| 28 | 345kV overbuild on existing lines (400ft spans) | $14,548,000 / mile |
| **Overhead Inaccessible** | | |
| 30 | 138kV OH inaccessible (600ft spans) | $11,75,000 / mile |
| 31 | 23kV-69kV OH inaccessible (250ft spans) | $1,984,000 / mile |
| 32 | 345kV OH inaccessible (600ft spans) | $23,501,000 / mile |
| **Underground** | | |
| 40 | 138kV UG (1000ft spans) | $16,451,000 / mile |
| 41 | 138kV riser pole | $887,000 each |
| 42 | 46kV-69kV UG (400ft spans) | $8,736,000 / mile |
| 43 | 46kV-69kV riser pole | $93,000 each |
| 44 | 23kV UG (200ft spans) | $7,404,000 / mile |
| 45 | 23kV riser pole | $91,000 |

Notes/Assumptions:
- Costs provided are 2025 dollars.
- Includes electrical and civil costs to engineer, procure, construct, and test all Company facilities.

| No. | Item | Cost |
|---|---|---|
| | - Costs listed in this table do not include project management (PM), permitting, land, or contingency costs. Costs for these items are added as percentages, if applicable, when calculating the total estimated cost of specific scenarios as laid out in subsequent sections of the report. These percentages are:<br>o PM costs – 5%<br>o Land/Permitting – 10%<br>o Contingency – 25%<br>- Accessible assumes accessible by vehicles.<br>- Inaccessible assumes helicopters are needed for crews and materials.<br>- Assumes land rights and permitting can be obtained for all new substations, expansion of existing substations, and routing of new transmission lines.<br>- 138kV and 345kV assumes steel poles.<br>- 69kV and below assumes wood poles.<br>- Overbuild assumes all poles need to be replaced.<br>- Reconductoring assumes an average cost between accessible and inaccessible<br>- 138kV reconductoring assumes 50% of poles need to be replaced.<br>- 23-69kV reconductoring assumes no poles need to be replaced.<br>- Upgrade to double bundle (69kV) assumes all poles need to be replaced.<br>- Substation expansion includes civil work to prepare site for installation of equipment.<br>- Ring bus to BAAH bus conversion assumes substation is already built to BAAH dimensions. | |

# 4. Study Methodology

The study methodology is described in Figure 4. As mentioned above, the study incorporates the renewable MW potential estimate based on the NREL potential study (Scenario Alt-1), and the forecasted load of year 2040 from the IGP forecast.

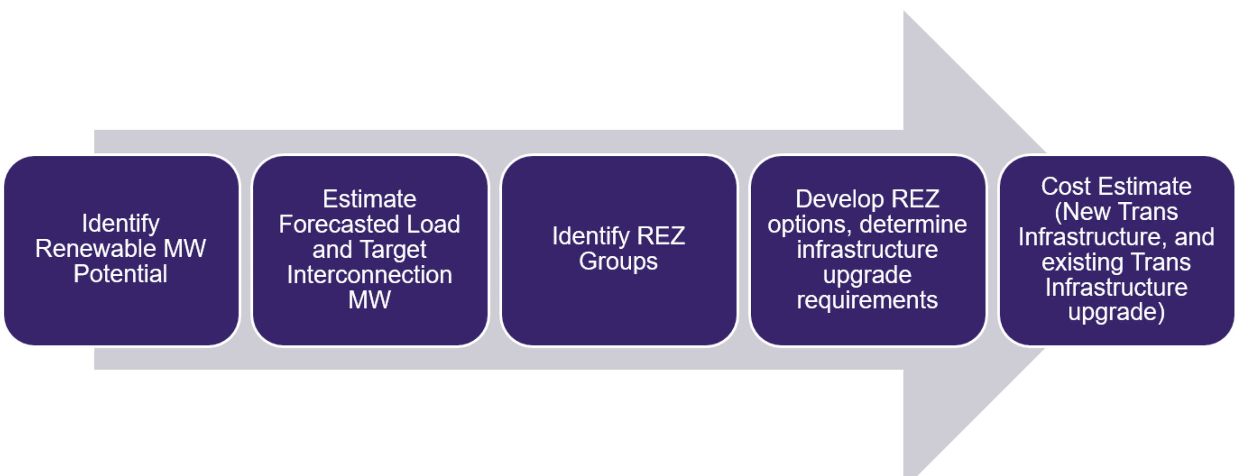


Figure 4 Transmission REZ Study Methodology

The REZ groups are identified by considering potential MW magnitude and geographic location related to existing transmission infrastructure. Based on the REZ groups, various system generation dispatches are studied to identify Transmission Network Expansion requirements for maintaining REZ dispatch flexibility. This is also the step in which different transmission upgrade options are considered. In the last step, cost estimates are produced for different transmission upgrade options for interconnection the same MW potential for stakeholders to review.

# 5. O‘ahu Transmission REZs

## 5.1. REZ Groups

The grid-scale MW potential located on O‘ahu is shown in green in Figure 5. The capacity of each zone is adjusted by subtracting the capacity of existing or approved grid-scale renewable projects (e.g., Stage 1, Stage 2 projects). According to the MW potential of renewable energy and the nearest existing transmission substations, 8 groups were created for the O`ahu study. The total potential MW capacity used for study is 3,344 MW on-shore renewable energy and 600 MW off-shore wind energy. Of the 8 REZ groups, only group 7 is considered to be interconnected through 46 kV sub-transmission lines. All remaining REZ groups are considered to be interconnected through the existing 138 kV transmission substations. The off-shore wind is considered to be interconnected to the system through Kahe 138 kV substation, Halawa 138 kV substation, Iwilei 138 kV substation or Ko`olau 138 kV substation.

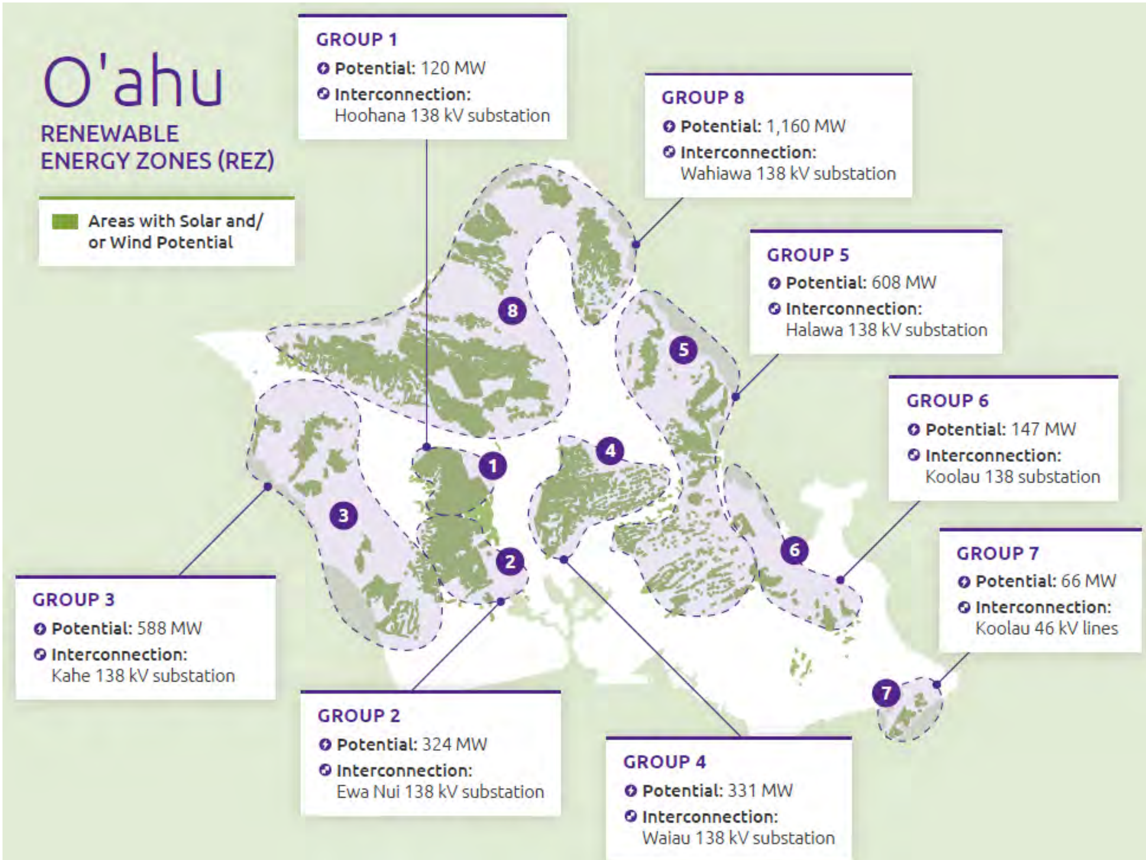


**Figure 5 Transmission REZ groups with MW Potential on O'ahu Island (Off-shore wind not shown)**

## 5.2.Studied Generation Dispatches

In order to identify Transmission Network Expansion requirements, various generation dispatches are designed by maximizing generation from potential and existing grid-scale generation in each REZ group. It is worth noting that the total required MW generation of each dispatch is always equal to 1,400 MW demand plus losses on the system. The studied dispatches are summarized in Table 5-1. The existing generation in the table refers to existing thermal generation and existing grid-scale BESS paired renewable projects. The existing generation is dispatched only if necessary. For example, in dispatch #1, generation in REZ Group 1 and 2 is not enough to supply the whole island load, and it is necessary to dispatch existing generation to supply load. In other scenarios, existing generation may be required to only supply reactive power.

To study the requirements of interconnecting 600 MW of off-shore wind, a sensitivity case was developed in addition to the dispatches listed in the Table 5-1. The study assumes the off-shore wind is added to the system after the interconnection of all eight REZ groups. The generation dispatches studied for the 600 MW off-shore wind are listed in Table 5-2. In the study results, the Total REZ Upgrade requirements for the 3,344 MW REZ interconnection and 600 MW off-shore wind interconnection are listed separately.

Table 5-1 Studied Generation Dispatches for O`ahu Transmission REZ

| Dispatch # | Group 1 (120 MW) | Group 2 (324 MW) | Group 3 (588 MW) | Group 4 (331 MW) | Group 5 (608 MW) | Group 6 (147 MW) | Group 7 (66 MW) | Group 8 (1,160 MW) | Existing Generation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Full | Full | 0 | 0 | 0 | 0 | 0 | 0 | Supply remaining load |
| 2 | Full | Full | Full | 0 | 0 | 0 | 0 | 0 | Dispatch if necessary |
| 3a | Full | Full | Full | Dispatch if necessary | 0 | 0 | 0 | 0 | 0 |
| 3b | Dispatch if necessary | Dispatch if necessary | Full | Full | 0 | 0 | 0 | 0 | 0 |
| 4 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | 0 | 0 | 0 | 0 |
| 5 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 0 | 0 | 0 |
| 6 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | Full | 0 | 0 |
| 7a | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 300 MW | 0 |
| 7b | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | 800 MW | 0 |
| 7c | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 0 |
| 7d | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |
| 7e | Dispatch if necessary | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |
| 7f | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |

Table 5-2 Studied Generation Dispatches for 600 MW Off-Shore Wind Sensitivity Case

| Dispatch # | Off-Shore Wind (600 MW) | Group 1 (120 MW) | Group 3 (588 MW) | Group 5 (608 MW) | Group 6 (147 MW) | Group 8 (1,160 MW) | Existing Generation |
|---|---|---|---|---|---|---|---|
| 8 | Full, through Kahe 138 kV | 0 | Full | 0 | 0 | Dispatch if necessary | Dispatch if necessary |
| 9 | Full, through Ko`olau 138 kV | 0 | 0 | 0 | Full | Dispatch if necessary | Dispatch if necessary |
| 10 | Full, through Ko`olau 138 kV | Full | 0 | 0 | Full | Dispatch if necessary | Dispatch if necessary |
| 11 | Full, through Ko`olau 138 kV | 0 | Full | 0 | Full | Dispatch if necessary | Dispatch if necessary |
| 12 | Full, through Halawa 138 kV | 0 | 0 | Full | 0 | Dispatch if necessary | Dispatch if necessary |
| 13 | Full, through Halawa 138 kV | 0 | 0 | 400 | 0 | Dispatch if necessary | Dispatch if necessary |
| 13 | Full, through Halawa 138 kV | 0 | 0 | 200 | 0 | Dispatch if necessary | Dispatch if necessary |

## 5.3.Studied Transmission Network Expansion Options

The largest REZ Group is Group 8 located north of the Wahiawa 138 kV substation with 1,160 MW potential. According to existing transmission infrastructure, the Wahiawa substation is the only transmission substation located in the area of REZ Group 8. The Wahiawa Substation is; however, designed differently than a generation switching station (e.g. Kahe 138 kV substation, Waiau 138 kV substation), as it was designed as a non-major load center substation which only has one BAAH bay (shown in Figure 6).

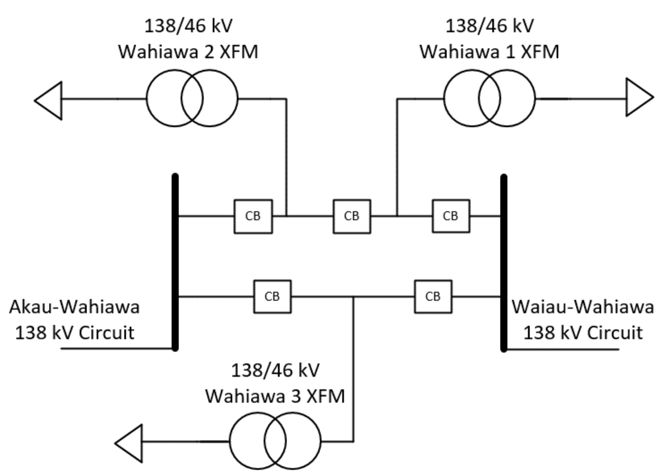


Figure 6 Current Wahiawa 138 kV substation single line diagram

The interconnection of Group 8 requires substantial transmission upgrades, as they are required to not only mitigate equipment overloading caused by the interconnection of other REZ or load



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growth, but also facilitate the export of 1,160 MW generation of REZ Group 8 from the Wahiawa 138 kV substation.

A steady-state power flow simulation provides transmission planners with certain values; such as voltage, current, etc. and used in conjunction with the transmission planning criteria, a determination is made on whether there were violations of criteria or not. In order to simulate future transmission system topologies, Transmission Network Expansion scenarios must be included in the transmission system model. The following three Transmission Network Expansion options were considered in this study, which were analyzed by using power flow simulations. Note that these do not include REZ Enablement which is necessary to interconnect renewable projects to the nearest transmission circuit or substation (see *Identifying Total REZ Upgrade Requirements* below):

- **Transmission Network Expansion Option 1** – new 138 kV transmission line between Kahe 138 kV and Wahiawa 138 kV substations (shown as Figure 7)

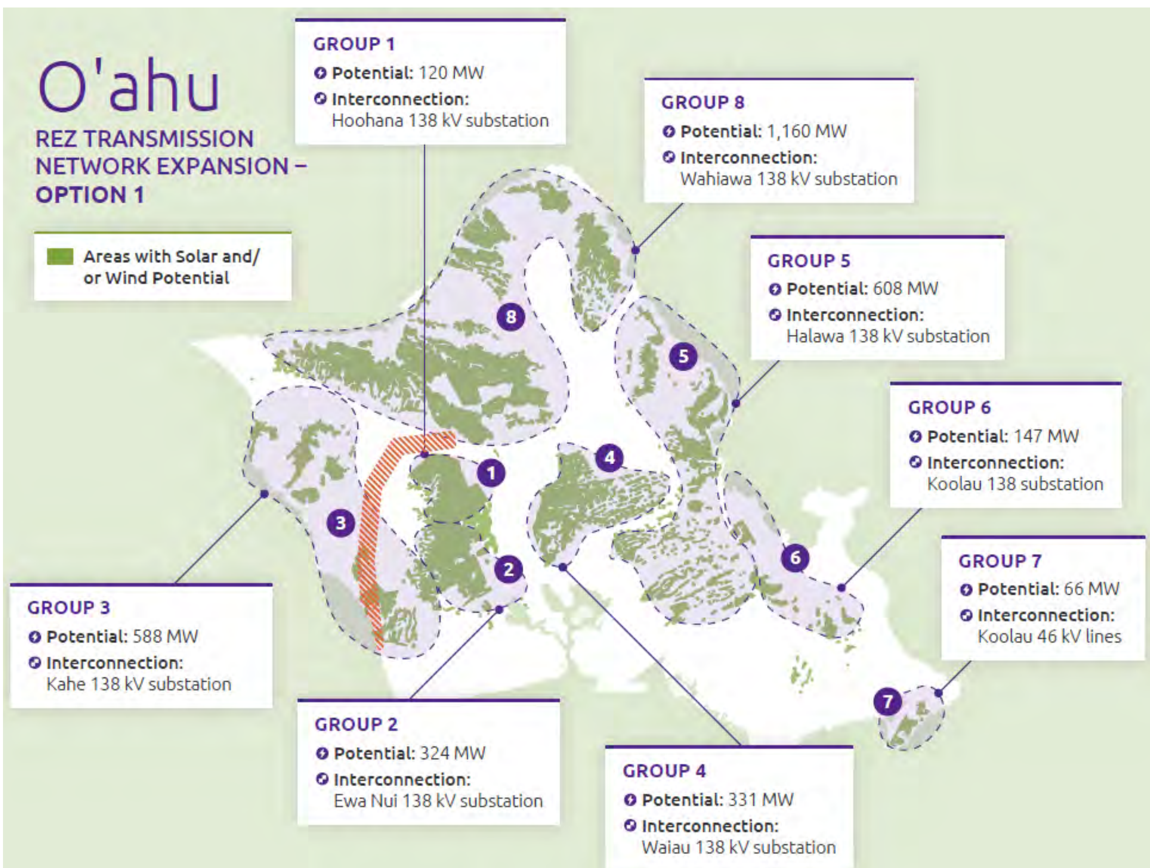



Figure 7 Option 1 - New 138 kV line between Kahe and Wahiawa substation (red shaded area)

- **Transmission Network Expansion Option 2** – re-conductor existing transmission circuits and adding new circuits if necessary (No figure provided)
- **Transmission Network Expansion Option 3** – new 345 kV loop between Wahiawa-Kahe-Waiau substations

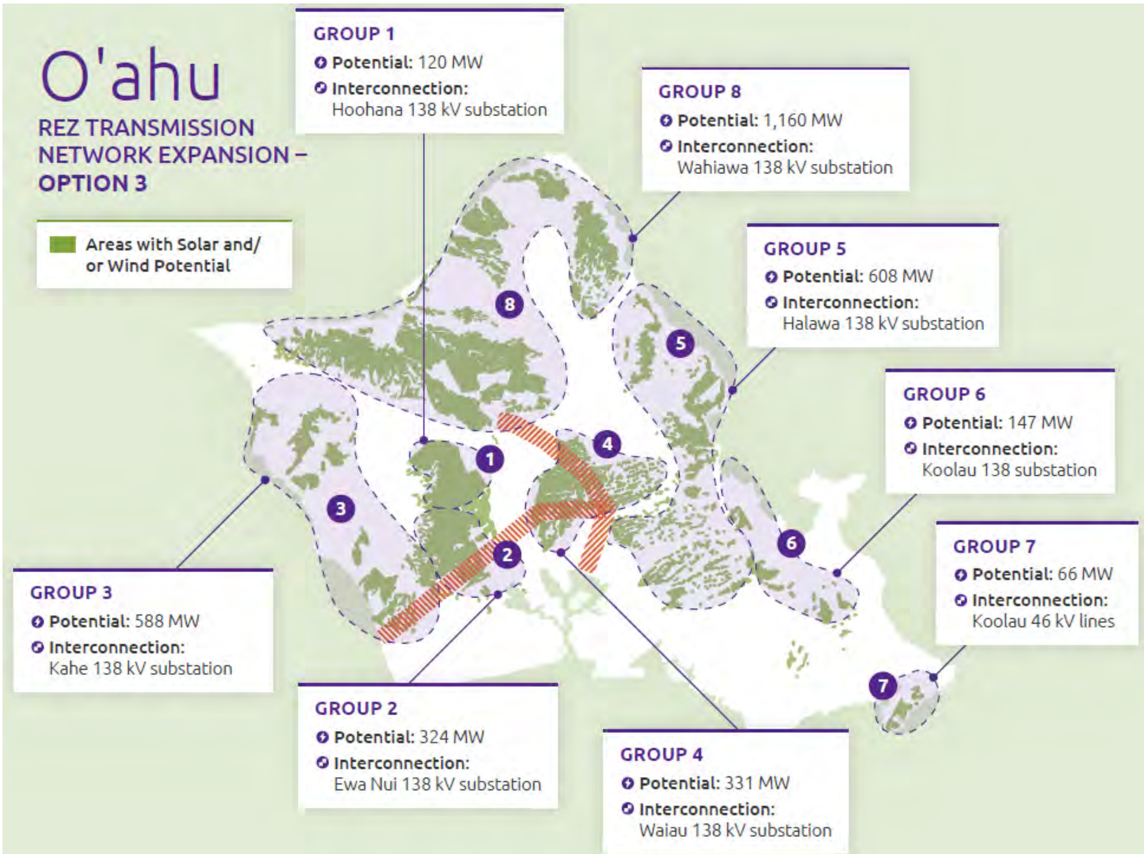



**Figure 8 Option 3 - 345 kV loop among Kahe, Waiau and Wahiawa substations (red shaded area)**

## 5.4.Identifying Total REZ Upgrade Requirements

The Transmission Network Expansion scenarios provided above provide a baseline system for studies. This section describes the Total REZ Upgrades required, which represent 1) Transmission Network Expansions, which include the scenarios provided above as well as additional upgrades required to mitigate criteria violations identified in accordance with the Hawaiian Electric transmission planning criteria and power flow study results, and 2) REZ Enablements, which are upgrades required to connect the center of each REZ to the nearest transmission substation. Examples of different types of transmission upgrades are listed in this section.

### 5.4.1. Transmission Network Expansions

Transmission Network Expansion requirements are identified through power flow study for dispatches listed in Table 5-1 and

Table 5-2. Per Hawaiian Electric's transmission planning criteria, both normal configurations and contingency configurations (N-1, and N-2) are considered in the study. According to the transmission planning criteria, equipment normal rating is used for both normal configuration and N-1 configurations study, and emergency rating is used for N-2 contingency configurations study.

Through the power flow study for the dispatches from dispatch 1 through dispatch 7a, it is concluded from the study results that there is no existing system equipment overloading issue. Therefore, the interconnection of REZ group 1 to the first 300 MW of Group 8 only requires the respective REZ Enablements, but not the Transmission Network Expansion to increase transmission capacity. Therefore, the three Transmission Network Expansion options listed in section 5.3 are considered only for interconnecting the entire 1,160 MW renewable energy of REZ Group 8 and 600 MW off-shore wind generation.

Detailed existing Transmission System Expansion descriptions (including single line diagrams and summary tables) for each group with each transmission upgrade option are listed in the Appendix.

### 5.4.2. Transmission Network Expansion - 138 kV transmission line upgrade

Using Transmission Network Expansion Option 1 as an example to demonstrate two types of transmission line upgrades considered: 1) building a new 138 kV transmission line and 2) re-conductoring an existing 138 kV transmission line. In this Transmission Network Expansion option, a new 138 kV transmission line between Kahe and Wahiawa substations is built in order to facilitate the export of renewable energy from the Wahiawa substation.

To facilitate interconnecting all 1,160 MW of Group 8 to the Wahiawa substation, according to the power flow study for dispatch 7b through dispatch 7f listed in Table 5-1, additional line re-conductor and new lines are required among Kahe, Wahiawa, and Waiau substations to expand transmission corridor among the three substations. The detailed upgrade requirements for these transmission lines are listed in Table 5-3.

**Table 5-3 Summary of 138 kV Transmission Line Upgrade Requirements for transmission upgrade option 1**

| No. | Transmission Line | Upgrade Type | Conductor Requirements |
|---|---|---|---|
| 1 | Kahe-Wahiawa | New Line, 138 kV | Three new circuits, with 1950 AAC conductor |
| 2 | Wahiawa-Waiau | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 3 | Wahiawa-Waiau | New Line, 138 kV | Two circuits, with double-bundled 795 AAC |
| 4 | Makalapa-Waiau #1 | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

### 5.4.3. Transmission Network Expansion - 138 kV substation expansion

Besides transmission line upgrade, existing substation expansion is also necessary in order to host the interconnection of the REZ and the new transmission lines. Using the Wahiawa substation as an example, the necessary substation expansion is described in Figure 9 in red. The substation is required to be expanded from 1 BAAH bay with 2 138 kV line connections to 6 BAAH bays with 11 138 kV line connections.

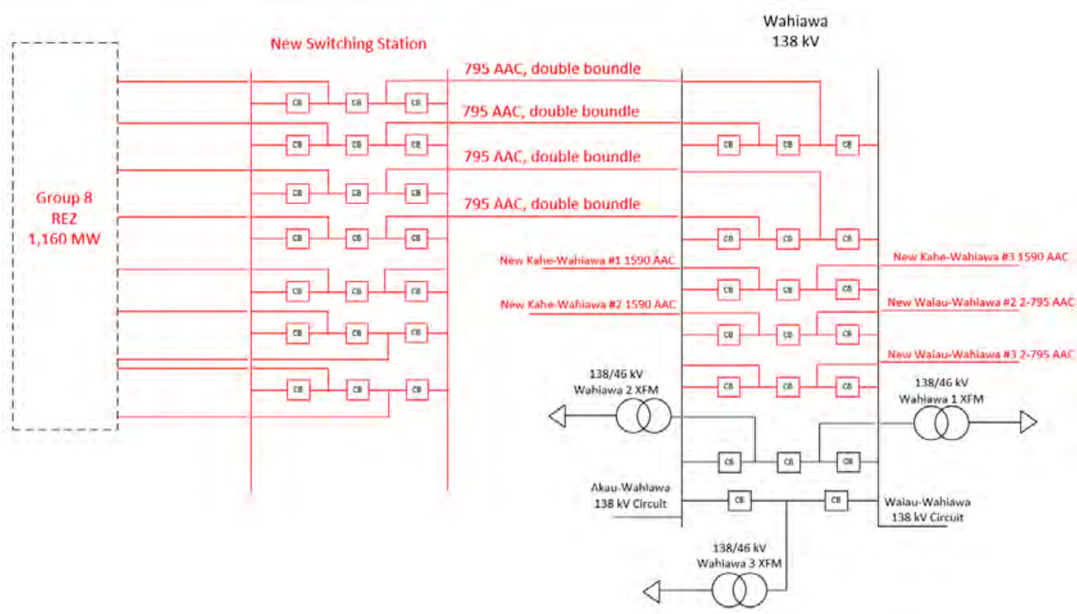



**Figure 9 Wahiawa substation expansion requirements under the transmission upgrade option 1**

### 5.4.4. Transmission Network Expansion - 345 kV Kahe-Wahiawa-Waiau loop

Considering the export of 1,160 MW renewable energy from the Wahiawa substation, and potential 600 MW off-shore wind, a very different Transmission Network Expansion – a 345 kV Kahe-Wahiawa-Waiau loop is considered in this study. Simplified single line diagram of the new 345 kV loop is shown as Figure 10.

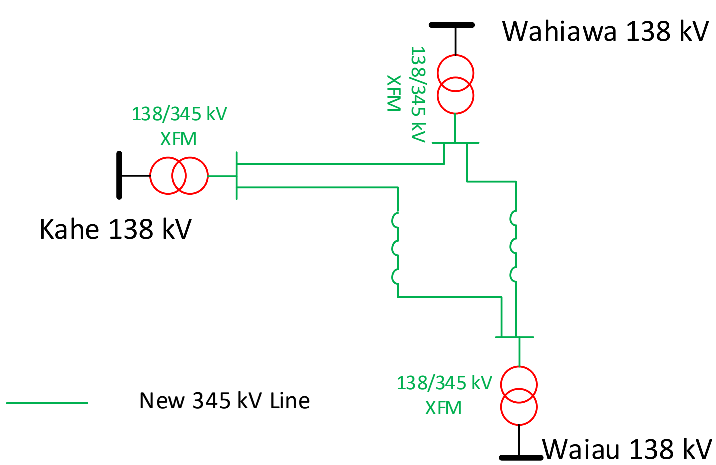



**Figure 10 Simplified single line diagram for the new 345 kV Kahe-Wahiawa-Waiau loop**

According to the power flow study, the new 345 kV loop can eliminate all 138 kV transmission line upgrade identified in the Transmission Network Expansion Option 1 and 2 for interconnecting the REZ groups 1-8, and only REZ Enablements are required. The minimum loading requirements for the 345 kV loop capacity related components are summarized in Table 5-4. It is worth noting that contingency of N-2 or loss one of 138/345 kV transformer contingency on the 345 kV loop is not considered in the study for the Transmission Network Expansion Option 3. Also, only capacity related equipment is identified in this study.

Although this study evaluates the performance of this option based on power flow simulations, in reality, a 345 kV system is an unchartered territory for Company; not only in terms of 345 kV equipment/device/apparatus, but also 345 kV related engineering/planning/system operation standards, and associated training should be considered as part of cost to have the 345 kV system. Note that 345 kV infrastructure generally requires larger (wider and/or taller) infrastructure as compared to 138 kV, which community, land, permitting, etc. would also need to be evaluated should this option be pursued further. The aforementioned considerations are not a comprehensive list, and were not evaluated in the scope of this study.

**Table 5-4 Summary of 345 kV Loop Upgrade Requirements for Transmission Upgrade Option 3**

| Transmission Equipment | Requirements Description |
|---|---|
| 138/345 kV Transformer | At Kahe substation, 1 unit, minimum continuous rating - 450 MVA, minimum emergency rating – 600 MVA |
| 138/345 kV Transformer | At Wahiawa substation, 1 unit, minimum continuous rating - 450 MVA, minimum emergency rating – 600 MVA |
| 138/345 kV Transformer | At Waiau substation, 1 unit, minimum continuous rating - 600 MVA, minimum emergency rating – 700 MVA |
| 345 kV Transmission Line | Kahe-Wahiawa, double-bundled, 795 AAC |
| 345 kV Transmission Line | Kahe-Waiau, double-bundled, 795 AAC |
| 345 kV Transmission Line | Converting existing 138 kV circuit Wahiawa-Waiau to 345 kV and reconductor the circuit with double-bundled, 795 AAC |
| 345 kV BAAH | 2 bays for each substation (Kahe, Waiau and Wahiawa) |

### 5.4.5. Transmission Network Expansion - Off-Shore Wind

*600 MW off-shore wind*

600 MW off-shore wind was evaluated as sensitivities for interconnection to either Kahe, Halawa, Iwilei, or Ko`olau 138 kV substations. In this sensitivity study scope, Transmission Network Expansions are identified in order to accommodate the 600 MW off-shore wind. The interconnection facilities between the off-shore wind resource to the interconnecting substation is not included in the study. Similar to what is identified for interconnecting REZ groups, to accommodate the offshore wind, new BAAH bays will be required at the hosting substation, and a Transmission Network Expansion will be required to mitigate overloading

identified through power flow study on the dispatch 8 to 13 listed in Table 5-2. Using Ko`olau substation as an example, Figure 11 demonstrates substation expansion requirements caused by both REZ Group 6 (in red) and the 600 MW off-shore wind interconnection (in blue) – two new BAAH bays are required for interconnecting 147 MW REZ Group 6 and four new BAAH bays with one new 138 kV line (Halawa-Ko`olau line with 1950 AAC conductor) are required for the interconnection of 600 MW off-shore wind. It is worth noting that Transmission Network Expansions identified in this study for interconnecting the off-shore wind depends on the sequence of interconnecting the offshore wind and the eight groups of REZ. The study assumes the off-shore wind will be interconnected to system after interconnecting eight groups of REZ.

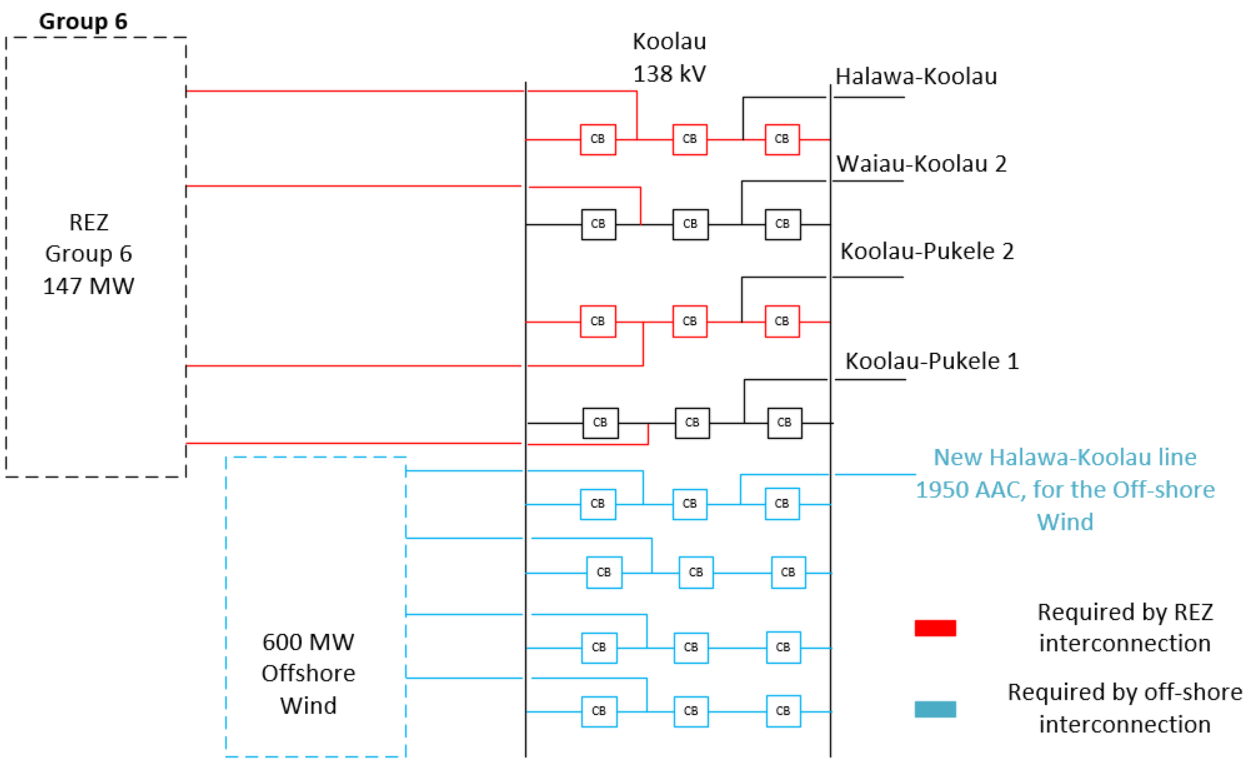



**Figure 11 Ko`olau substation expansion requirements for interconnecting REZ Group 6 and 600 MW off-shore wind, Transmission Network Expansion option 1**

During the study, it was concluded that Ho`ohana substation (hosting substation for REZ Group 1) expansion is required when interconnecting 600 MW off-shore wind resource to Kahe 138 kV substation, and Makalapa substation expansion is required when interconnecting off-shore wind at Halawa 138 kV substation. A feasibility analysis found that it is not feasible to expand either the Ho`ohana, Makalapa, or Iwilei substations. Therefore, the option of interconnecting the 600 MW offshore wind through the Kahe, Halawa, or Iwilei 138 kV substations (but not through 345 kV Kahe substation considered in the Transmission Network Expansion Option 3) were found to be infeasible.

*400 MW off-shore wind*

Based on stakeholder input provided in an October 6, 2021 meeting, additional analysis was performed to determine requirements for the interconnection of a 400 MW off-shore wind resource through Kahe (138 kV only), Halawa, Iwilei or Ko`olau substations. The same dispatch scenarios as what were analyzed for the 600 MW off-shore interconnection were analyzed. Transmission Network Expansion Options 1 and 2 were considered in this study. The analysis found the following:

- Kahe 138 kV substation interconnection is still not feasible due to the expansion requirement of the Ho`ohana substation.
- Halawa substation interconnection is still not feasible due to the expansion requirement of the Makalapa substation.
- Iwilei substation interconnection is not feasible due to space limitations.
- Ko`olau substation interconnection is feasible, and no additional Transmission Network Expansion is required in addition to the Transmission Network Expansion Option 1 or 2 (i.e., New Halawa-Koolau line is not required).

### 5.4.6. REZ Enablements

For REZ groups with lesser MW potentials, the REZ Enablements considered in the study scope is adding new BAAH bay(s) in the nearest, existing 138 kV substation. An example for this type of interconnection facility is shown in Figure 12 for Group 2. To interconnect 324 MW potential renewable of REZ Group 2, two new BAAH bays need to be added into Ewa Nui 138 kV substation, which is represented in color red in Figure 12.

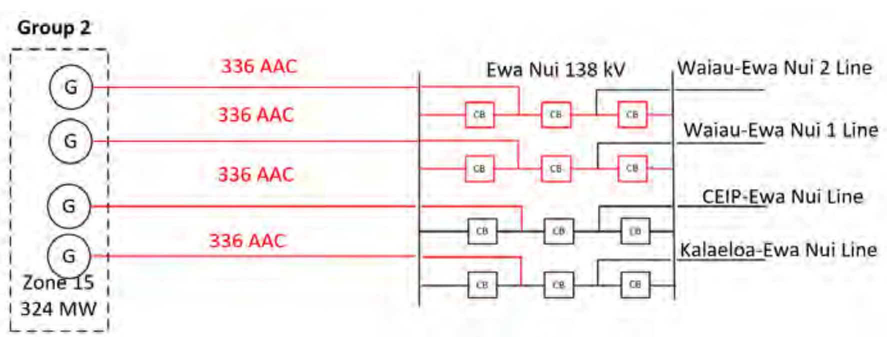



**Figure 12 Single line diagram for interconnection REZ Group 2 (324 MW)**

For REZ groups with higher MW potentials that exceed the capacity of existing substation, a new 138 kV switching station is required. Using REZ group 5 as an example, the single line diagram for the new switching station, as well as existing substation expansion is shown in Figure 13. With the support of the new switching station, limitations to sizes based on single point failure can be avoided.

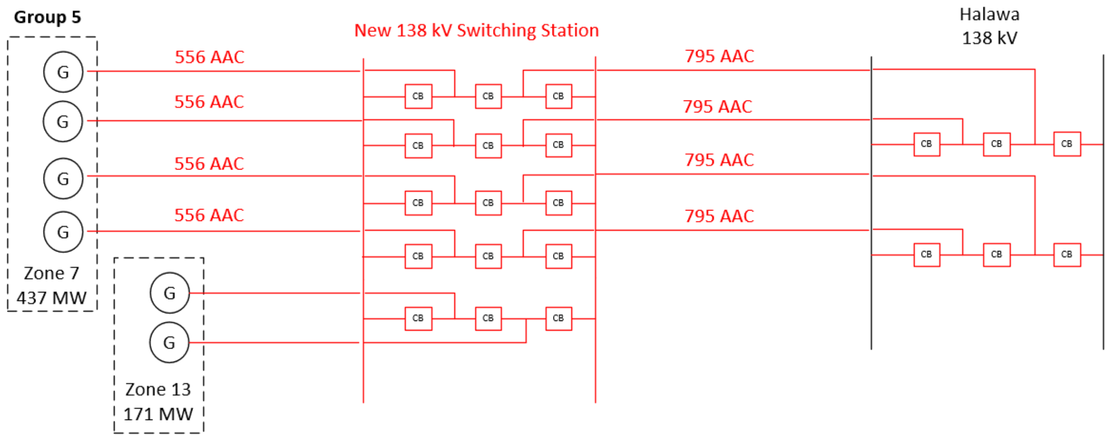



**Figure 13 New 138 kV switching station and Halawa substation expansion (shown in red) for the interconnection of REZ Group 5**

High-level single line diagrams for each REZ Group interconnection are shown in the Appendix. A high-level map of REZ Enablements required by REZ group are shown below in Figure 14.

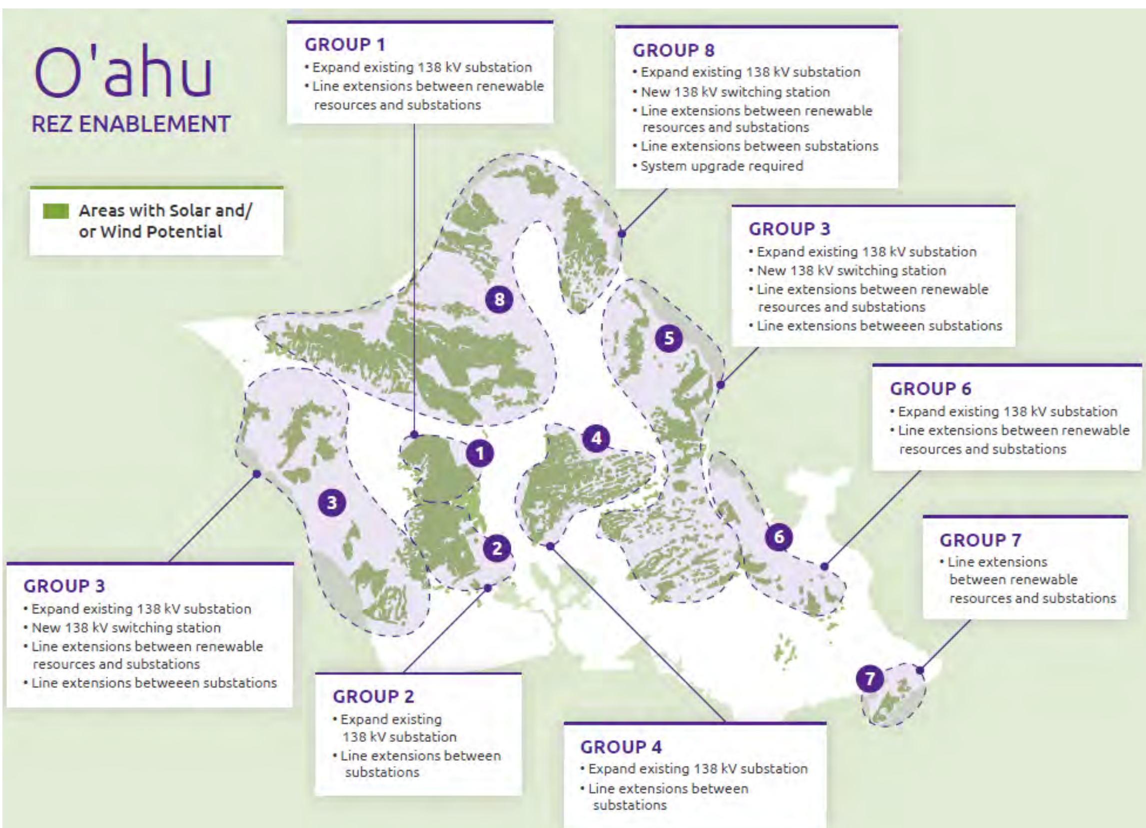



**Figure 14: O`ahu REZ Enablement by Group**

### 5.4.7. Summary of Total REZ Upgrades

A summary of the Total REZ Upgrades required to interconnect 3,344 MW REZ (total 8 groups) and 600 MW off-shore wind at three different substations are listed in this section. For each REZ group, the REZ Enablement requirements only depends on MW size and geographic location of the REZ group, and the interconnection substation current condition, and are independent among REZ groups.

The REZ Enablements required, which includes new switching stations, BAAH bays required in the new switching stations and existing substations, and new transmission line between new switching station and existing substations are summarized for the interconnection of each REZ group and the off-shore wind in Table 5-5 and Table 5-6. It is worth noting that REZ Group 7 is considered as a sub-transmission interconnection REZ, so no new transmission level interconnection facility for the interconnection of the REZ Group 7.

**Table 5-5 Summary of Interconnection Facility Requirements for O`ahu REZ Interconnection**

| New Interconnection Infrastructure | Group 1 120 MW | Group 2 324 MW | Group 3 588 MW | Group 4 331 MW | Group 5 608 MW | Group 6 147 MW | Group 7 66 MW | Group 8 1,166 MW |
|---|---|---|---|---|---|---|---|---|
| New 138 kV Switching Station | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 |
| No. of BAAH required in the new Switching Station | 0 | 0 | 6 | 0 | 5 | 0 | 0 | 7 |
| No. of new BAAH required in the existing Station | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 2 |
| New 138 kV Transmission Lines | 0 | 0 | 4 | 0 | 4 | 0 | 0 | 4 |
| New 345 kV switching Station* | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 1 |
| No. of BAAH required in the new 345 kV Switching Station* | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 6 |
| New 345 kV Transmission Lines* | n/a | n/a | n/a | n/a | n/a | n/a | n/a | 4 |

*Rows only for Transmission Upgrade Option 3 – new 345 kV loop.

**Table 5-6 Summary of Interconnection Facility Requirements for O`ahu 600 MW Off-Shore Wind**

| Transmission Upgrade Option | Option 1 | Option 2 | Option 3 | |
|---|---|---|---|---|
| New Interconnection Infrastructure | Off-Shore Wind @ Ko`olau | Off-Shore Wind @ Ko`olau | Off-Shore Wind @ Kahe | Off-Shore Wind @ Ko`olau |
| No. of new 138 kV BAAH required in the existing Station | 4 | 4 | 0 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| New 138 kV Transmission Lines | 0 | 0 | | 0 | 0 |
| No. of 345 kV BAAH | n/a | n/a | n/a | 3 | 0 |

The Transmission Network Expansion includes new transmission lines (138 kV and 345 kV for Transmission Network Expansion option 3) and associated new BAAH in existing substations, 138 kV transmission line re-conductor, and new 345/138 kV transformer (only for Transmission Network Expansion option 3).

The summary of identified Transmission Network Expansion requirements are listed in Table 5-7. In this table, Transmission Network Expansion required for the off-shore wind is in addition to the Transmission Network Expansion identified for the REZ Group 8 interconnection. It is worth noting that the interconnection of REZ Group 1 to Group 7 do not require any existing transmission line upgrade according to the power flow study results. Hence, the Group 1 to the Group 7 are not listed in this table.

**Table 5-7 Summary of Transmission Network Expansion for O`ahu REZ Interconnection**

| Transmission Upgrade Option | Transmission Upgrade | Group 8 (1,166 MW) | Off-Shore Wind @ Kahe | Off-Shore Wind @ Ko`olau |
|---|---|---|---|---|
| 1 | 138 kV line re-conductor | 2 | n/a | 2 |
| | New 138 kV line | 5 | | 1 |
| | New 138 kV BAAH | 3 | | 0 |
| 2 | 138 kV line re-conductor | 3 | n/a | 2 |
| | New 138 kV line | 4 | | 1 |
| | New 138 kV BAAH | 3 | | 0 |
| 3 | 138 kV line re-conductor | 0 | n/a | 2 |
| | New 138 kV line | 0 | | 1 |
| | New 138 kV BAAH | 2 | | 0 |
| | New 345 kV Lines | 3 | 0 | n/a |
| | New 345 kV BAAH | 6 | 0 | |
| | New 345/138 kV XFM | 3 | 0 | |

From studied dispatches with associated Total REZ Upgrade results, following conclusions can be made for initial O`ahu REZ study:

- Interconnection of REZ Group 1 to 7 requires less system upgrades, which means REZ Groups 1 to 7 are the "low hanging fruit" of REZ development. These groups do; however, require expansion of the transmission system to locations within the groups (REZ Enablements).
- To interconnect REZ Group 8 which is with the largest MW potential among all REZ groups, Wahiawa substation will be re-built, new transmission lines are required between Wahiawa, Kahe and Waiau substations, and large amount of REZ Enablement is required in order to interconnect REZ Group 8.
- The addition of 345 kV loop does not reduce the Transmission Network Expansion requirement for offshore wind interconnected at Koolau substation.

#### 5.4.8. Total REZ Upgrade Cost Estimate

Cost estimate of aforementioned Total REZ Upgrade are summarized in following tables, which includes the estimate of the cost for REZ Enablements, and Transmission Network Expansion. The cost of hosting the 600 MW offshore wind is separated, which is additional cost on the Total REZ Upgrade for hosting eight REZ groups.

Table 5-8 Summary of Cost Estimate for REZ Enablement of O`ahu REZ

| New Interconnection Infrastructure | Group 1 120 MW | Group 2 324 MW | Group 3 588 MW | Group 4 331 MW | Group 5 608 MW | Group 6 147 MW | Group 7 66 MW | Group 8 1,166 MW (138 kV) | Group 8 1,166 MW (345 kV) |
|---|---|---|---|---|---|---|---|---|---|
| REZ Enablement ($MM) | 24.6 | 87.6 | 773.9 | 272.2 | 916.7 | 91.2 | N/A | 1460.7 | 1139.0 |
| Cost ($MM) per MW | 0.21 | 0.27 | 1.32 | 0.82 | 1.51 | 0.62 | N/A | 1.25 | 0.98 |

Based on IGP Stakeholder and TAP feedback, incremental REZ Enablement costs are provided for interconnecting grid-scale project with different levels of MW potential, with the assumption of fully realizing REZ MW potential. The increments within each group are based on 135 MW steps (Single Point of Failure for O`ahu) and are shown in Table 5-9 to Table 5-13. Estimates are prepared for REZ Group 2, 3, 4, 5, and 8 as these groups exceed the 135 MW increment. It is worth noting that these REZ Enablement cost estimate are indicative estimates and factors such as project size, relative location to existing transmission infrastructure, new transmission infrastructure build-out status, substation available space will impact actual REZ Enablement costs.

Table 5-9 Cost Estimate for REZ Enablement for O`ahu REZ Group 2 with incremental MW Potential

| New Interconnection Infrastructure | Group 2 135 MW | Group 2 270 MW | Group 2 324 MW |
|---|---|---|---|
| REZ Enablement ($MM) | 22.6 | 47.1 | 87.6 |
| Cost ($MM) per MW | 0.17 | 0.17 | 0.27 |

Table 5-10 Cost Estimate for REZ Enablement for O`ahu REZ Group 3 with incremental MW Potential

| New Interconnection Infrastructure | Group 3 135 MW | Group 3 270 MW | Group 3 405 MW | Group 3 588 MW |
|---|---|---|---|---|
| REZ Enablement ($MM) | 113.8 | 185.3 | 522.3 | 773.9 |
| Cost ($MM) per MW | 0.84 | 0.69 | 1.29 | 1.32 |

Table 5-11 Cost Estimate for REZ Enablement for O`ahu REZ Group 4 with incremental MW Potential

| New Interconnection Infrastructure | Group 4 135 MW | Group 4 270 MW | Group 4 331 MW |
|---|---|---|---|
| REZ Enablement ($MM) | 58.2 | 127.6 | 272.2 |
| Cost ($MM) per MW | 0.43 | 0.47 | 0.82 |

Table 5-12 Cost Estimate for REZ Enablement for O`ahu REZ Group 5 with incremental MW Potential

| New Interconnection Infrastructure | Group 5 135 MW | Group 5 171 MW | Group 5 306 MW | Group 5 441 MW | Group 5 608 MW |
|---|---|---|---|---|---|
| REZ Enablement ($MM) | 109.4 | 158.8 | 329.2 | 500.5 | 916.7 |
| Cost ($MM) per MW | 0.81 | 0.93 | 1.08 | 1.13 | 1.51 |

Table 5-13 Cost Estimate for REZ Enablement for O`ahu REZ Group 8 with incremental MW Potential

| New Interconnection Infrastructure | Group 8 135 MW | Group 8 270 MW | Group 8 405 MW | Group 8 540 MW | Group 8 680 MW | Group 8 815 MW | Group 8 950 MW | Group 8 1,160 MW |
|---|---|---|---|---|---|---|---|---|
| REZ Enablement ($MM) | 138.8 | 250.6 | 380.7 | 526.0 | 526.9 | 729.7 | 965.1 | 1460.7 |
| Cost ($MM) per MW | 1.03 | 0.93 | 0.94 | 0.97 | 0.77 | 0.90 | 1.02 | 1.26 |

Table 5-14 Summary of Cost Estimate for Transmission Network Expansion for O`ahu REZ Group 8 (greater than 300 MW)

| | Transmission Network Expansion Option 1 | Transmission Network Expansion Option 2 | Transmission Network Expansion Option 3 |
|---|---|---|---|
| Cost Estimate ($MM) | 1,281.5 | 1,258.8 | 1,215.0 |

Table 5-15 Summary of Cost Estimate for 600 MW Offshore Wind Interconnection

| Description | Off-Shore Wind @ Ko`olau | | | Off-Shore Wind @ Kahe 345 kV |
|---|---|---|---|---|
| Transmission Network Expansion Options | 1 | 2 | 3 | 3 |

| | | |
|---|---|---|
| REZ Enablements Cost ($MM) | 50.6 | 76.0 |
| Transmission Network Expansion ($MM) | 532.8 | 0 |
| **Total ($MM)** | **583.5** | **76.0** |

**Table 5-16: Summary of Cost Estimate for 400 MW Offshore Wind Interconnection**

| Description | Off-Shore Wind @ Ko`olau | | | Off-Shore Wind @ Kahe 345 kV |
|---|---|---|---|---|
| **Transmission Network Expansion Options** | **1** | **2** | **3** | **3** |
| REZ Enablements Cost ($MM) | 50.6 | | | 76.0 |
| Transmission Network Expansion ($MM) | 0 | | | 0 |
| **Total ($MM)** | **50.6** | | | **76.0** |

# 6. Maui Island Transmission REZs

## 6.1. REZ Groups

According to the NREL study results, Maui has 13,507 MW of grid-scale solar potential (PV-Alt-1, after removing the approved projects and in-study projects) and 767 MW wind potential (WIND-Alt-1). The total potential is 14,274 MW. Compared to O'ahu, Maui's total PV and wind potential is much higher than the forecasted 2040 peak load (287 MW). However, many areas with high levels of grid-scale solar MW potential or wind MW potential are far away from existing transmission infrastructure (e.g., south and east side of Maui island) and are not considered in this REZ study. During the later steps of the study, it is observed that the original 1.5 GW potential could cause significant 69 kV substation upgrades and expansions for many 69 kV substations, and many dispatch scenarios associated with the 1.5 GW potential causes significant high amount of MW loss on the system, as well as requiring more than usual amount of var resource across the island to maintain system voltage stability. An example of these extreme dispatches is that the whole island is power supplied by west Maui REZ. Therefore, the total MW potential of the transmission REZ is reduced for more realistic cost estimate at current stage of the study. Therefore, two REZ options with reduced potential MW are considered in the study for Maui island, which are shown in Figure 15 and Figure 16. REZ option 1 has 847 MW potential and REZ option 2 has 872 MW potential. The study assumes that all the REZ groups (except Group 4B1) will be interconnected to 69 kV transmission substations. List of substations considered in the study as REZ hosting substations are shown in Table 6-1.

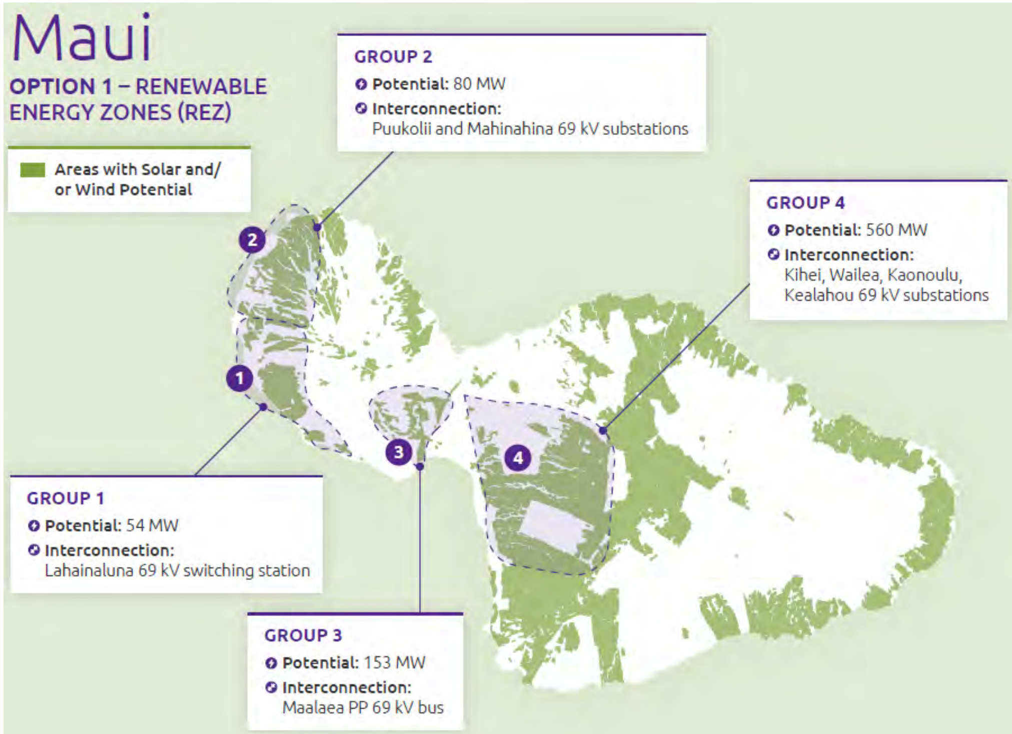



**Figure 15 Maui island transmission REZ Option 1**

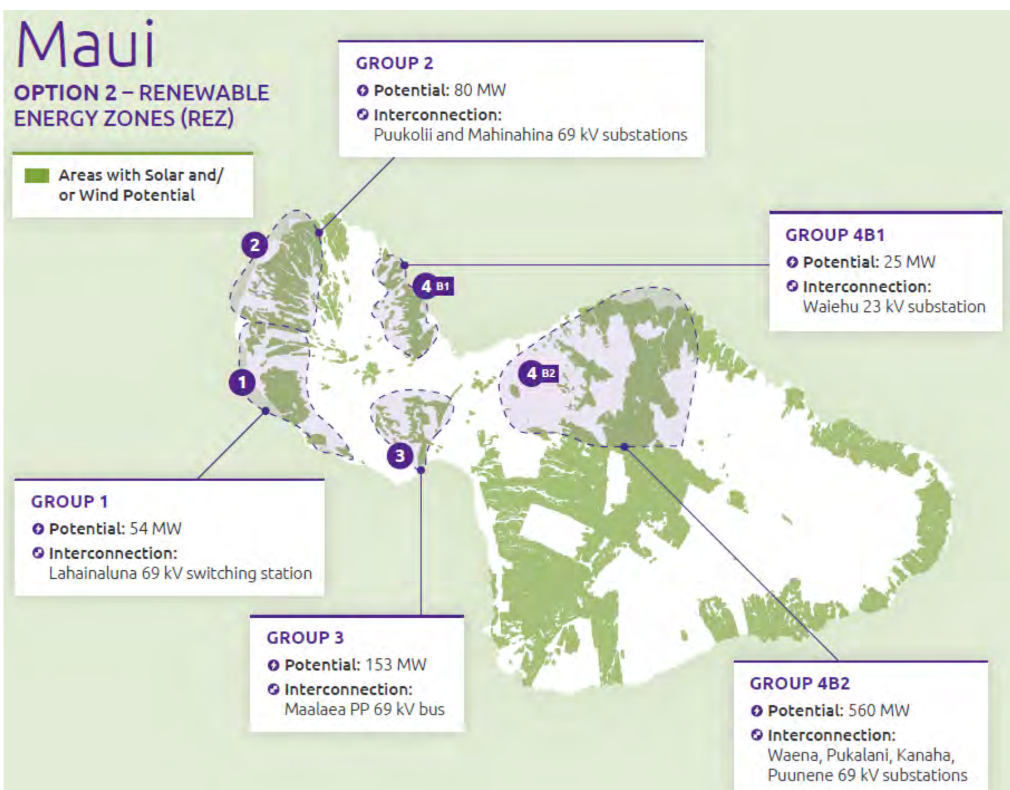



**Figure 16 Maui island transmission REZ – Option 2**

Table 6-1 69 kV Substations Considered for Maui Island REZ Interconnection Substation

| REZ Group No. | REZ MW Potential | Interconnection Substation |
|---|---|---|
| 1 | 54 | Lahainaluna (69 kV) |
| 2 | 80 | Puukolii (69 kV), Mahinahina (69 kV) |
| 3 | 153 | Maalaea (69 kV) |
| 4A | 560 | Kealahou (69 kV), Kihei (69 kV), Wailea (69 kV), Kaonoulu (69 kV) |
| 4B1 | 25 | Waiehu (23 kV) |
| 4B2 | 560 | Pukalani (69 kV), Puunene (69 kV), Kanaha (69 kV), Waena (69 kV) |

## 6.2.Studied Generation Dispatches

Similar as what was identified for O`ahu REZ study, a group of dispatches of MW interconnection among all REZ groups listed in Table 6-1 are identified for the power flow study. The dispatches are designed to push MW generation of one or several REZ groups to the limit, and Maui island Transmission Network Expansion requirements are identified through performing power flow study for those dispatches. The studied dispatch for Maui island is shown in Table 6-2.

Table 6-2 Studied Generation Dispatches for Maui Island Transmission REZ

| Dispatch # | Group 1 (54 MW) | Group 2 (80 MW) | Group 3 (153 MW) | Group 4A* (560 MW) | Group 4B1 (25 MW) | Group 4B2* (560 MW) | Existing Generation |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | Full | 0 | 0 | Full (Waena) | Dispatch if necessary |
| 2 | Full | Full | Full | 0 | 0 | 0 | Dispatch if necessary |
| 3 | 0 | 0 | Full | 0 | 0 | Full (Pukalani) | Dispatch if necessary |
| 4 | 0 | 0 | Full | Full (Wailea) | 0 | 0 | Dispatch if necessary |
| 5 | 0 | Full | Full | 0 | Full | Dispatch for remaining load (Pukalani) | Dispatch if necessary |

*Four substations are selected to interconnect REZ in Group 4A and 4B2. "Full" means dispatching full generation of REZ from one substation.

## 6.3.Studied Transmission Network Expansion Options

Two transmission upgrade options are considered in the study:

- **Transmission Network Expansion Option 1** – Reconductor 69 kV and 23 kV transmission circuits and build new transmission circuit if necessary.
- **Transmission Network Expansion Option 2** – Convert existing Waiinu-Onehee-Kahului-Kanaha 23 kV line to 69 kV line, and reconductor and/or build new transmission circuit if necessary.

It is worth noting that the option 2 has been considered as part of Central Maui Transmission Upgrade in previous studies. The voltage conversion for the circuit is represented in Figure 17. This option includes both conductor voltage conversion, pole replacement, and Onehee substation and Kahului substation conversion to 69 kV substations.

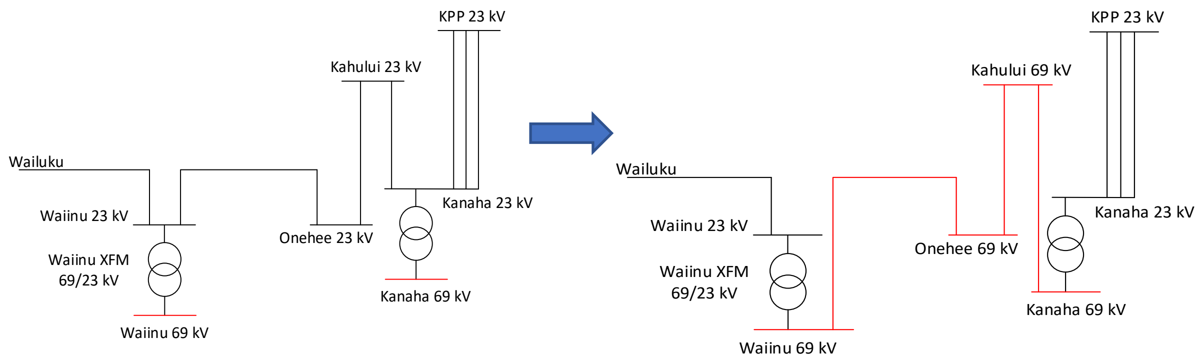



**Figure 17 Single line diagram for Maui Transmission Upgrade Option 2**

The Central Maui Transmission Upgrade project was evaluated as an alternative for the Waena switchyard and Kahului Power Plant (KPP) Synchronous condenser conversion projects to address system issues caused by the KPP retirement. During that evaluation, the Waena switchyard and KPP Synchronous condenser conversion projects were selected over the Central Maui Transmission Upgrade. Should option 2 be pursued in the future, the Waena switchyard and KPP synchronous condenser conversion projects will continue to effectively address system level issues and not become obsolete. Projects such as the Waena Switchyard and KPP SC projects were assumed to be in operation for purposes of this study, and additional mitigation (e.g., the Transmission Network Expansion Option 2) was found to be required to support Maui island load growth and REZ development.

## 6.4. Identifying Total REZ Upgrade Requirements

The Transmission Network Expansion scenarios provided above provide a baseline system for studies. This section describes the Total REZ Upgrades required, which represent 1) Transmission Network Expansions, which include the scenarios provided above as well as additional system upgrades required to mitigate criteria violations identified in accordance with the Hawaiian Electric transmission planning criteria and power flow study results, and 2) REZ Enablements, which are upgrades required to connect the center of each REZ to the nearest transmission substation. Examples of different types of transmission upgrades are listed in this section.

### 6.4.1. Transmission Network Expansions

Transmission Network Expansions are identified through a power flow study for system with both normal and contingency (N-1) configurations for all generation dispatches, which is shown in Table 6-2. It is worth noting that identified Transmission Network Expansion requirements on 69 kV side is very similar for both Transmission Network Expansion options.

The study is performed for both Transmission Network Expansion Option 1 and Option 2. Summary of required upgrades are listed in Table 6-3 for the Transmission Upgrade Option 1 and Table 6-4 for the Transmission Upgrade Option 2.

From studied dispatches with associated Transmission Network Expansion results, following conclusions can be made:

- Equipment overloading is triggered by both REZ interconnection and load growth. Primary reason of the overloading on 23 kV conductor and 69/23 kV tie transformers is load increase.
- Interconnection of REZ Group 1 and 2 does not cause equipment on West Maui side. This is because West Maui is a load center and there are three parallel circuits coming from Maalaea power plant 69 kV bus to West Maui which provides capacity there.
- Interconnection of REZ Group 3 on Maalaea power plant 69 kV bus does not cause any equipment overloading.
- Interconnection of REZ Group 4B1 on 23 kV circuit does not cause any equipment overloading.
- Interconnection of REZ 4A and REZ 4B2 causes significant 69 kV conductor overloading, which causes most part of South Maui and part of Central Maui 69 kV Transmission Network Expansion.
- Geographic balance should be considered as a constrain during REZ development.

**Table 6-3 Transmission Network Expansion Required for Interconnecting Maui Island REZ Groups, Transmission Network Expansion Option 1**

| Dispatch No. | 69 kV Tran. Line Reconductor | New 69 kV Tran. Line | 23 kV Tran. Line Reconductor | New 23 kV Tran. Line | 69/23 kV Tie XFM Upgrade (Cont./Emerg.) MVA |
|---|---|---|---|---|---|
| 1 | 2 Circuits, with 556 AAC<br>Waena-Kanaha,<br>Maalaea-Kuihelani | n/a | n/a | 2 Circuits, with 556 AAC<br>Kahului-Kanaha,<br>Kanaha-Puunene | Waiinu, 20/30<br>Kanaha, 22/50<br>Puunene, 22/45 |
| 2 | 7 Circuits, with 556 AAC<br>Maalaea-Waena, Waena-Kanaha<br>Maalaea-Kuihelani,<br>Maalaea-Kihei,<br>Puunene-Kuihelani,<br>Wailea-Auwahi Wind,<br>Auwahi Wind-Kealahou | 1 Circuit, with 556 AAC<br>Maalaea-Waena | n/a | 2 Circuits, with 556 AAC<br>Kahului-Kanaha,<br>Kanaha-Puunene | Waiinu, 25/33<br>Kanaha, 20/40<br>Puunene, 20/38 |
| 3 | 9 Circuits, with 556 AAC<br>Waena-Pukalani,<br>Waena-Kanaha,<br>Maalaea-Kuihelani,<br>Maalaea-Kihei,<br>Puunene-Kuihelani,<br>Wailea-Auwahi Wind,<br>Auwahi Wind-Kealahou,<br>Kealahou-Kula,<br>Kula-Pukalani | 3 Circuits, with 556 AAC<br>Kealahou-Kula<br>Waena-Pukalani<br>Kula-Pukalani | n/a | 2 Circuits, with 556 AAC<br>Kahului-Kanaha,<br>Kanaha-Puunene | Waiinu, 20/30<br>Kanaha, 24/41<br>Puunene, 20/40 |
| 4 | 7 Circuits, with 556 AAC<br>Wailea-Kihei,<br>Kihei-Maalaea,<br>Maalaea-Kuihelani,<br>Wailea-Auwahi Wind, | 4 Circuits, with 556 AAC<br>Wailea-Kihei,<br>Kihei-Maalaea,<br>Wailea-Auwahi Wind, | n/a | 2 Circuits, with 556 AAC<br>Kahului-Kanaha,<br>Kanaha-Puunene | Waiinu, 23/31<br>Kanaha, 22/40<br>Puunene, 22/37 |

| | | | | | |
|---|---|---|---|---|---|
| | Auwahi Wind-Kealahou, Waena-Kanaha, Puunene-Kuihelani | Auwahi Wind-Kealahou | | | |
| 5 | 2 Circuits, with 556 AAC Wailea-Auwahi Wind, Auwahi Wind-Kealahou | n/a | n/a | 1 Circuit, with 556 AAC Kahului-Kanaha | Kanaha, 20/33 Puunene, 20/30 |

**Table 6-4 Transmission Network Expansion Required for Interconnecting Maui Island REZ Groups, Transmission Network Expansion Option 2**

| Dispatch No. | 69 kV Tran. Line Reconductor | New 69 kV Tran. Line | 23 kV Tran. Line Reconductor | New 23 kV Tran. Line | 69/23 kV Tie XFM Upgrade (Cont./Emerg.) MVA |
|---|---|---|---|---|---|
| 1 | 1 Circuit, with 556 AAC Waena-Kanaha | n/a | n/a | n/a | n/a |
| 2 | 7 Circuits, with 556 AAC Maalaea-Waena, Waena-Kanaha, Maalaea-Kuihelani, Maalaea-Kihei, Puunene-Kuihelani, Wailea-Auwahi Wind, Auwahi Wind-Kealahou | 1 Circuit, with 556 AAC Maalaea-Waena | n/a | n/a | n/a |
| 3 | 9 Circuits, with 556 AAC Waena-Pukalani, Waena-Kanaha, Maalaea-Kuihelani, Maalaea-Kihei, Puunene-Kuihelani, Wailea-Auwahi Wind, Auwahi Wind-Kealahou, Kealahou-Kula, Kula-Pukalani | 3 Circuits, with 556 AAC Kealahou-Kula, Waena-Pukalani, Kula-Pukalani, | n/a | n/a | n/a |
| 4 | 7 Circuits, with 556 AAC Wailea-Kihei, Kihei-Maalaea, Maalaea-Kuihelani, Wailea-Auwahi Wind, Auwahi Wind-Kealahou, Waena-Kanaha, Puunene-Kuihelani | 4 Circuits, with 556 AAC Wailea-Kihei, Kihei-Maalaea, Wailea-Auwahi Wind, Auwahi Wind-Kealahou | n/a | n/a | n/a |
| 5 | 2 Circuits, with 556 AAC Wailea-Auwahi Wind, Auwahi Wind-Kealahou | n/a | n/a | n/a | n/a |

### 6.4.2. REZ Enablements

With the exception of Maalaea substation, which is designed as a power plant bus, many 69 kV transmission substations do not have BAAH topology. Therefore, in order to convert those load center substations to grid-scale renewable power plant interconnected substations, significant amounts of upgrades are required. Using Kihei 69 kV substation as an example. Current substation topology is shown in Figure 18. And Topology of Kihei substation with 140 MW interconnection capability is shown in Figure 19.

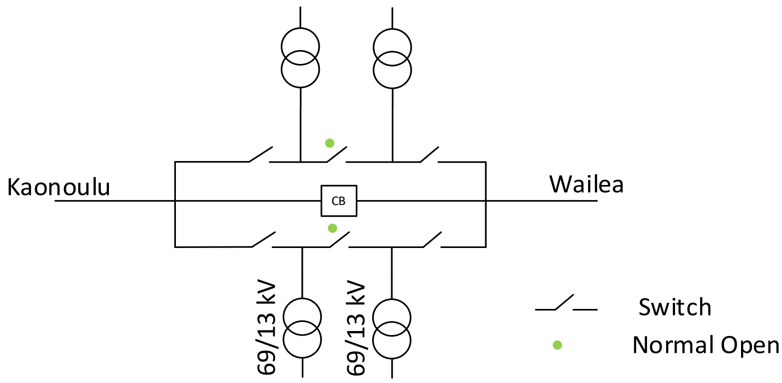



Figure 18 Current Kihei 69 kV substation topology

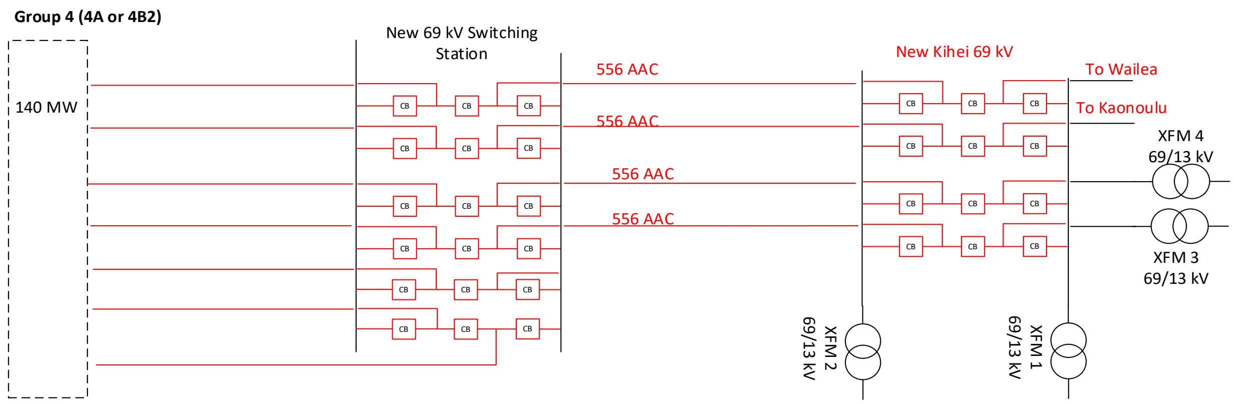



Figure 19 Topology of Kihei 69 kV substation with 140 MW interconnection capacity

A summary of interconnection facility requirements for interconnecting all REZ groups is listed in Table 6-5. Single line diagrams of these new transmission interconnection facilities are shown in the Appendix. A high-level map of REZ Enablements required by REZ group are shown below in Figure 20.

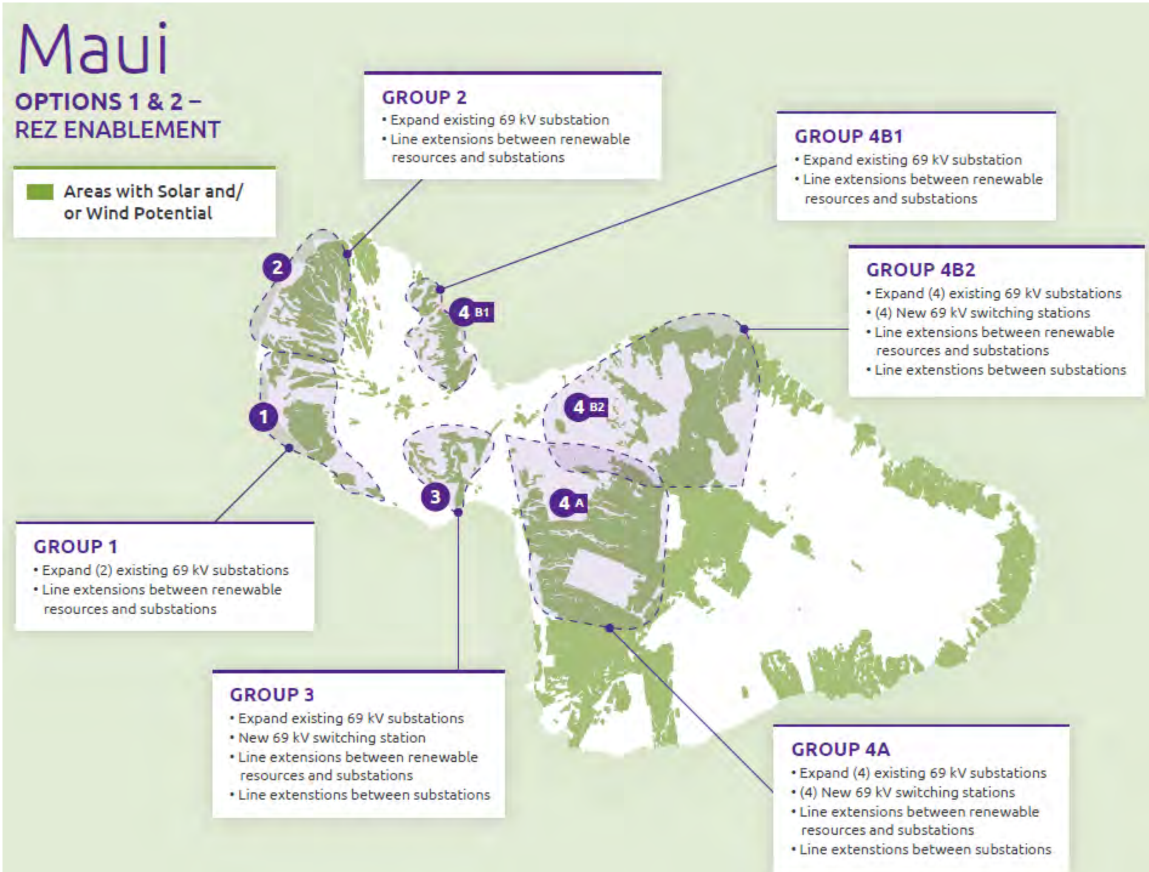



**Figure 20: Maui Island REZ Enablement by Group**

**Table 6-5 New Transmission Infrastructure Required for Interconnecting Maui Island REZ Groups**

| REZ Group No. | REZ MW Potential | Interconnected Substation | No. of New Switching Station | No. of New BAAH Bay Required in Hosting Substation | New Transmission Line |
|---|---|---|---|---|---|
| 1 | 54 | Lahainaluna | 0 | 4 | 0 |
| 2 | 40 | Puukolii | 0 | 2 | 0 |
| | 40 | Mahinahina | 0 | 2 | 0 |
| 3 | 153 | Maalaea | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| 4A | 140 | Kealahou | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| | 140 | Kihei | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| | 140 | Wailea | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| | 140 | Kaonoulu | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| 4B1 | 25 | Waiehu | 0 | 2 | 0 |
| 4B2 | 140 | Waena | 1, with 6 bays of BAAH | 2 | 4, with 556 AAC conductor |
| | 140 | Kanaha | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |

| | | | | | |
|---|---|---|---|---|---|
| | 140 | Puunene | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |
| | 140 | Pukalani | 1, with 6 bays of BAAH | 4 | 4, with 556 AAC conductor |

### 6.4.3. Total REZ Upgrade Cost Estimate

The cost of Total REZ Upgrade is estimated for interconnection facility for all REZ groups and system upgrade identified in the Transmission Network Expansion Option 1 and Option 2.

**Table 6-6: Cost Estimate for REZ Enablements for Maui Island REZ**

| REZ Group | REZ Option 1 | | | | REZ Option 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Group 1 54 MW | Group 2 80 MW | Group 3 153 MW | Group 4A 560 MW | Group 1 54 MW | Group 2 80 MW | Group 3 153 MW | Group 4B1 25 MW | Group 4B2 560 MW |
| REZ Enablement ($MM) | 35.8 | 55.6 | 84.9 | 426.9 | 35.8 | 55.6 | 84.9 | 37.4 | 632.7 |
| Transmission Network Expansion – Option 1 ($MM) | 205.6 | | | | 217.2 | | | | |
| Transmission Network Expansion – Option 2 ($MM) | 186.0 | | | | 194.2 | | | | |
| Total REZ Upgrade Cost Range ($MM) | 789.2 – 808.8 | | | | 1,040.6 – 1,063.6 | | | | |
| Total REZ Upgrade Cost Range ($MM) per MW | 0.93 – 0.95 | | | | 1.19 – 1.22 | | | | |

Based on IGP Stakeholder and TAP feedback, incremental REZ Enablement costs are provided for interconnecting grid-scale project with different levels of MW potential. The increments within each group are broken down to 20 MW steps and are shown in Table 6-7 to Table 6-9. These estimates are prepared for groups with higher potentials (i.e. REZ Group 3, 4A and 4B2). It is worth noting that these cost estimates are indicative estimates and factors such as project size, relative location to existing transmission infrastructure, new transmission infrastructure build-out status, substation available space will impact actual REZ Enablement costs.

**Table 6-7: Cost Estimate for REZ Enablement for Maui REZ Group 3 with incremental MW Potential**

| New Interconnection Infrastructure | Group 3 20 MW | Group 3 40 MW | Group 3 60 MW | Group 3 80 MW | Group 3 100 MW | Group 3 120 MW | Group 3 140 MW | Group 3 153 MW |
|---|---|---|---|---|---|---|---|---|
| REZ Enablement ($MM) | 19.6 | 35.4 | 51.2 | 70.6 | 77.0 | 77.7 | 84.2 | 84.9 |
| Cost ($MM) per MW | 0.98 | 0.89 | 0.85 | 0.88 | 0.77 | 0.65 | 0.60 | 0.55 |

**Table 6-8 Cost Estimate ($MM) for REZ Enablement for Maui REZ Group 4A with incremental MW Potential**

| Substation | Group 4A 20 MW/Sub | Group 4A 40 MW/Sub | Group 4A 60 MW/Sub | Group 4A 80 MW/Sub | Group 4A 100 MW/Sub | Group 4A 120 MW/Sub | Group 4A 140 MW/Sub |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Kihei REZ Enablement ($MM) | 58.7 | 75.2 | 92.0 | 112.0 | 118.5 | 119.2 | 125.7 |
| Kihei Cost ($MM) per MW | 2.94 | 1.88 | 1.53 | 1.40 | 1.19 | 0.99 | 0.90 |
| Wailea Enablement ($MM) | 54.3 | 66.0 | 77.7 | 90.0 | 96.4 | 97.1 | 103.6 |
| Wailea Cost ($MM) per MW | 2.72 | 1.65 | 1.30 | 1.13 | 0.96 | 0.81 | 0.74 |
| Kaonoulu Enablement ($MM) | 35.4 | 48.5 | 61.6 | 85.3 | 91.7 | 92.4 | 98.9 |
| Kaonoulu Cost ($MM) per MW | 1.77 | 1.21 | 1.03 | 1.07 | 0.92 | 0.77 | 0.71 |
| Kealahou Enablement ($MM) | 21.2 | 48.0 | 63.7 | 85.2 | 91.6 | 92.4 | 98.8 |
| Kealahou Cost ($MM) per MW | 1.06 | 1.20 | 1.06 | 1.07 | 0.92 | 0.77 | 0.71 |
| **Total Enablement ($MM)** | **169.6** | **237.7** | **295** | **372.5** | **398.2** | **401.1** | **427** |
| **Total Cost ($MM) per MW** | **2.12** | **1.49** | **1.23** | **1.16** | **1.00** | **0.84** | **0.76** |

**Table 6-9 Cost Estimate ($MM) for REZ Enablement for Maui REZ Group 4B2 with incremental MW Potential**

| Substation | Group 4B2 20 MW/Sub | Group 4B2 40 MW/Sub | Group 4B2 60 MW/Sub | Group 4B2 80 MW/Sub | Group 4B2 100 MW/Sub | Group 4B2 120 MW/Sub | Group 4B2 140 MW/Sub |
|---|---|---|---|---|---|---|---|
| Waena Enablement ($MM) | 32.8 | 54.2 | 85.1 | 110.0 | 116.4 | 117.2 | 123.6 |
| Waena Cost ($MM) per MW | 1.64 | 1.36 | 1.42 | 1.38 | 1.16 | 0.98 | 0.88 |
| Kanaha Enablement ($MM) | 76.4 | 96.3 | 127.9 | 159.5 | 165.9 | 166.7 | 173.1 |
| Kanaha Cost ($MM) per MW | 3.82 | 2.41 | 2.13 | 1.99 | 1.66 | 1.39 | 1.24 |
| Puunene Enablement ($MM) | 50.5 | 76.4 | 110.4 | 144.6 | 151.0 | 151.7 | 158.2 |
| Puunene Cost ($MM) per MW | 2.53 | 1.91 | 1.84 | 1.81 | 1.51 | 1.26 | 1.13 |
| Pukalani Enablement ($MM) | 61.6 | 90.5 | 119.2 | 164.2 | 170.6 | 171.3 | 177.8 |
| Pukalani Cost ($MM) per MW | 3.08 | 2.26 | 1.99 | 2.05 | 1.71 | 1.43 | 1.27 |
| **Total Enablement ($MM)** | **221.3** | **317.4** | **442.6** | **578.3** | **603.9** | **606.9** | **632.7** |
| **Total Cost ($MM) per MW** | **2.77** | **1.98** | **1.84** | **1.81** | **1.51** | **1.26** | **1.13** |

# 7. Hawaii Island Transmission REZs

## 7.1. REZ Groups

Similar to Maui island, Hawaiʻi island also has much larger renewable potential (around 76,000 MW) compared to the forecasted 2040 peak load (216 MW). However, many areas with high grid-scale solar MW potential or wind MW potential are far away from existing transmission infrastructure and are not considered in this REZ plan. Also, on Hawaiʻi island, there is a large amount of overlap between grid-scale PV potential zones and wind potential zones, and grid-scale PV potential MW is much larger than the wind potential; therefore, the grid-scale PV MW potential will be used for the study zones. However, the final renewable interconnection can consist of any renewable technology.

Considering balancing generation in different geographic locations of the island for resiliency, two different Transmission REZ options were developed on Hawaiʻi island, which are shown in Figure 21 and Figure 22.

In Option 1 (Figure 21), two REZs are planned on east and west side of Hawaiʻi island: Group 1 consists of 360 MW potential, and Group 2 consists of 360 MW potential. Total MW of interconnected REZ considered in the study is 720 MW.

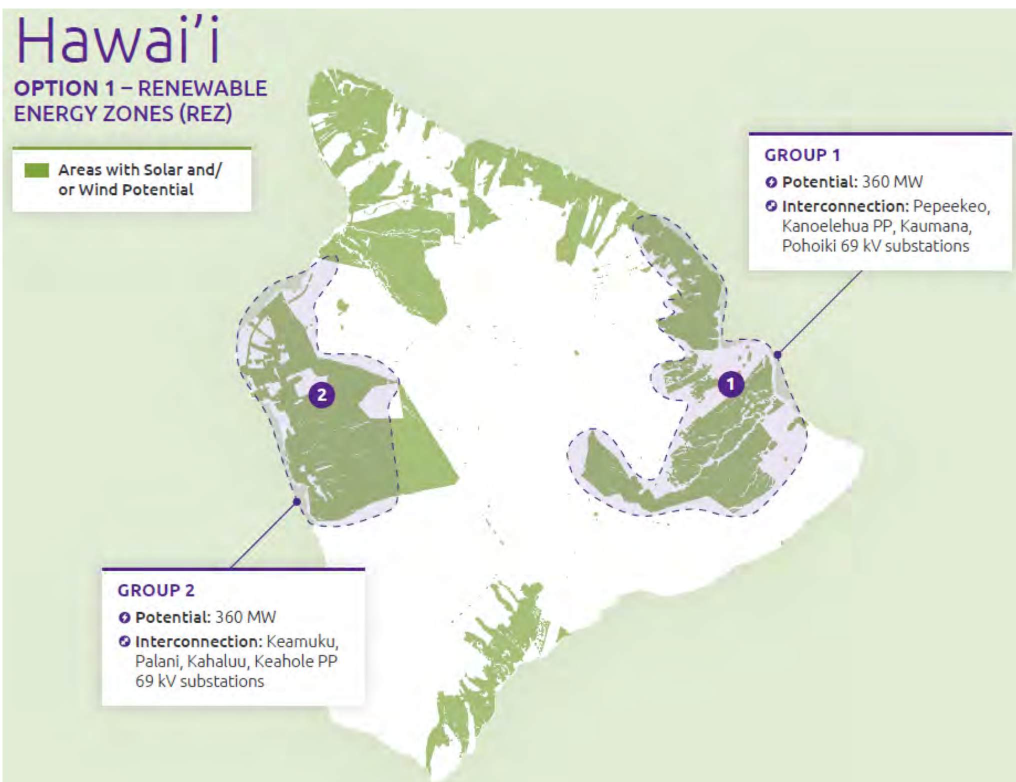



**Figure 21 Hawai`i island transmission REZ Option 1**

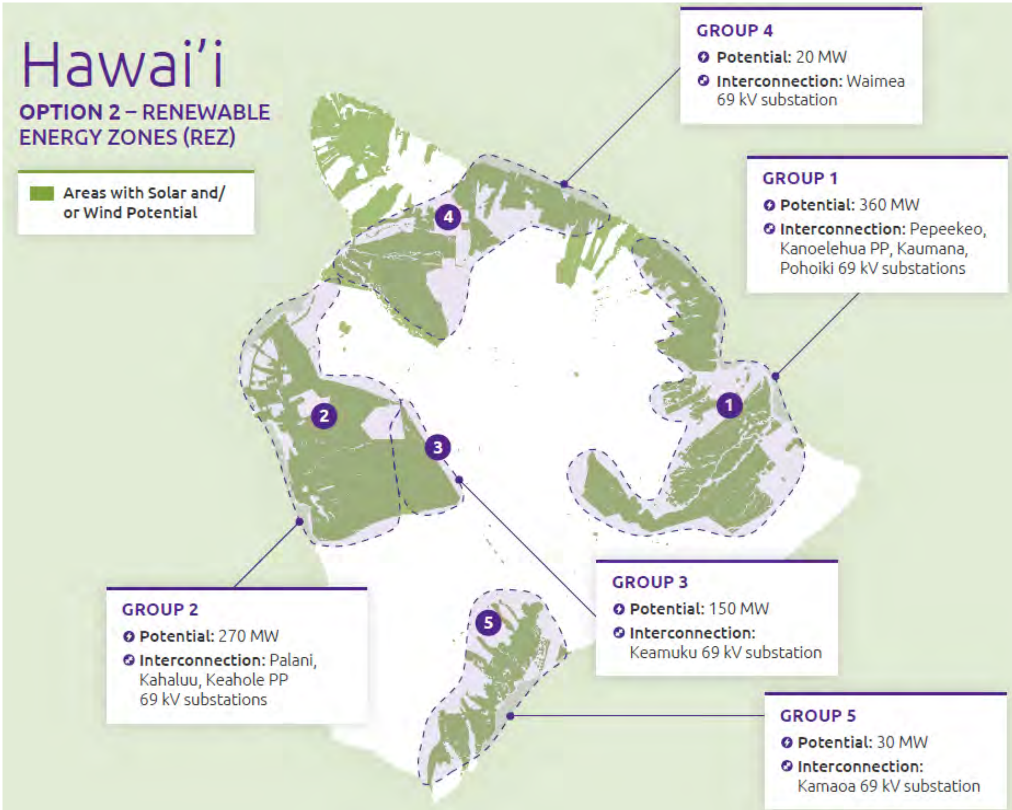



**Figure 22 Hawai`i island transmission REZ Option 2**

In Option 2 (Figure 22), five REZs are planned on east, west, north, south side and central of Hawai`i island: Group 1 consists of 360 MW potential, Group 2 consists of 270 MW potential, Group 3 consists of 150 MW, Group 4 consists of 20 MW, and Group 5 has 30 MW. The total MW of interconnected REZ considered in the study is 830 MW.

List of substations considered in the study as REZ hosting substations are shown in Table 7-1.

**Table 7-1 69 kV Substations Considered for Hawai`i Island REZ Interconnection Substation**

| REZ Option | REZ Group No. | REZ MW Potential | Interconnection Substation |
|---|---|---|---|
| 1 | 1 | 360 | Pepeekeo, Kanoelehua PP, Kaumana, Pohoiki |
| | 2 | 360 | Keamuku, Palani, Kahaluu, Keahole PP |
| 2 | 1 | 360 | Pepeekeo, Kanoelehua PP, Kaumana, Pohoiki |
| | 2 | 270 | Palani, Kahaluu, Keahole PP |
| | 3 | 150 | Keamuku |
| | 4 | 20 | Waimea |
| | 5 | 30 | Kamaoa |

## 7.2.Studied Generation Dispatch

Similar methodology as what was used for O`ahu and Maui island REZ study, a group of dispatches of renewable generation among all REZ groups identified for Hawai`i island are created for power flow study. The dispatches are designed to go through most, if not all, feasible combinations of REZ hosting substations with generation from REZ of all REZ groups in the power flow study, and identify Transmission Network Expansion requirements for those dispatches. The studied dispatch for Hawai`i island REZs is shown in Table 7-2 and Table 7-3.

**Table 7-2 Studied Generation Dispatches for Hawai`i Island Transmission REZ Option 1**

| Scenario | Dispatch # | Group 1 (MW) | | | | Group 2 (MW) | | | | Existing Generation |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Pepeekeo | Kanoelehua PP | Kaumana | Pohoiki | Keamuku | Palani | Kahaluu | Keahole PP | |
| 1 | 11 | 81 | 81 | 81 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 12 | 82 | 82 | 0 | 82 | 0 | 0 | 0 | 0 | 0 |
| | 13 | 82 | 0 | 82 | 82 | 0 | 0 | 0 | 0 | 0 |
| | 14 | 0 | 83 | 83 | 83 | 0 | 0 | 0 | 0 | 0 |
| | 15 | 0 | 84 | 29 | 84 | 0 | 0 | 0 | 0 | 55 |
| | 16 | 0 | 30 | 84 | 84 | 0 | 0 | 0 | 0 | 55 |
| 2 | 21 | 0 | 0 | 0 | 0 | 76 | 76 | 76 | 0 | 0 |
| | 22 | 0 | 0 | 0 | 0 | 77 | 76 | 0 | 76 | 0 |
| | 23 | 0 | 0 | 0 | 0 | 77 | 0 | 76 | 76 | 0 |
| | 24 | 0 | 0 | 0 | 0 | 0 | 81 | 81 | 81 | 0 |
| | 25 | 0 | 0 | 0 | 0 | 78 | 0 | 0 | 21 | 131 |
| | 26 | 0 | 0 | 0 | 0 | 0 | 72 | 72 | 74 | 21 |

Table 7-3 Studied Generation Dispatches for Hawai`i Island Transmission REZ Option 2

| Scenario | Dispatch # | Group 2 (MW) | | | Group 3 (MW) | Group 4 (MW) | Group 5 (MW) | Existing Generation |
|---|---|---|---|---|---|---|---|---|
| | | Kahaluu | Palani | Keahole | Keamuku | Waimea | Kamaoa | |
| 3 | 31 | 0 | 0 | 18 | 150 | 20 | 30 | Dispatch if necessary |
| 4 | 41 | 0 | 0 | 0 | 110 | 20 | 0 | 98 |
| | 42 | 0 | 0 | 32 | 105 | 20 | 0 | 71 |
| 5 | 51 | 75 | 0 | 0 | 100 | 0 | 30 | 21 |

## 7.3. Studied Transmission Network Expansion Options

Two transmission upgrade options are considered for Hawai`i island in this study:

- **Transmission Network Expansion Option 1** – Re-conductor existing 69 kV transmission line, and add new 69 kV transmission line if necessary
- **Transmission Network Expansion Option 2** – Conversion of existing L6200 cross island to a 138 kV cross island line, and re-conductor existing 69 kV transmission line/add new 69 kV transmission line if necessary

For the Transmission Network Expansion Option 2, a summary of existing 69 kV transmission infrastructure upgrades needed to convert the cross-island line from 69 kV to 138 kV is listed in Table 7-4. It is worth noting that possible protection system upgrades and/or transmission tower upgrades are not listed in the table.

Table 7-4 Summary of Transmission Infrastructure Upgrade Required for Converting L6200 to 138 kV

| Transmission Equipment | Requirements Description |
|---|---|
| 69/138 kV Transformer | Two units, with 171 MVA continuous rating and 196 MVA emergency rating requirements, at Kaumana and Keamuku substations |
| 12.47/138 kV Transformer | One unit, with 6.25 MVA continuous rating, at Waikii substation |
| 12.47/138 kV Transformer | One unit, with 2.5 MVA continuous rating, at Pohakuloa substation |

## 7.4. Identifying Transmission Network Expansion Requirements

The Transmission Network Expansion scenarios provided above provide a baseline system for studies. This section describes the Total REZ Upgrades required, which represent 1) Transmission Network Expansions, which include the scenarios provided above as well as additional system upgrades required to mitigate criteria violations identified in accordance with the Hawaiian Electric transmission planning criteria and power flow study results, and 2) REZ Enablements, which are upgrades required to connect the center of each REZ to the nearest transmission substation. Examples of different types of transmission upgrades are listed in this section.

### 7.4.1. Transmission Network Expansions

According to the power flow study results, several 69 kV transmission lines are identified with overloading condition. Mitigation requirements are identified and listed in Table 7-5 which represents Transmission Network Expansion requirements with both studied Transmission Network Expansion Option 1 and 2.

A few observations can be obtained from the comparison of mitigation requirements for Transmission Network Expansion Option 1 and Option 2:

- Upgrading L6200 to 138 kV has very limited effect on alleviating local line overloading on east and/or west side caused by the more than usual amount of generation exporting from REZ groups.
- Supplying the whole island from only one side of generation can cause significant overloading and require large amount of line re-conductoring. This type of generation dispatch should be avoided.  And REZ development needs to take generation location balance around the island into consideration.
- REZ Group 3, 4 and 5 appear to be "low-hanging fruit" type of groups. The interconnection of these REZ groups only causes limited Transmission Network Expansion requirements.

**Table 7-5 69 kV Transmission Line Re-Conductor Requirements**

| Scenario No. | Transmission Line Section | Line No. | Transmission Network Expansion Option 1 | Transmission Network Expansion Option 2 (138 kV L6200) |
|---|---|---|---|---|
| | | | Re-Conductor Requirements | Re-Conductor Requirements |
| 1 | Kaumana-Keamuku | L6200 | 556 AAC | 556 AAC |
| | Keamuku-Waikoloa Solar-Waikoloa Load Tap | L8100 | 556 AAC | 556 AAC |
| | Kanoelehua-Komohana | L6100 | 2-556 AAC | 2-556 AAC |
| | Kanoelehua-Puna | L6400 | 2-556 AAC | 2-556 AAC |
| | Kaumana-Kawailani-Paradise Park-Kapoho-Pohoiki | L6500 | 2-556 AAC | 2-556 AAC |
| | Puna-Ainaloa-Pohoiki | L8700 | 2-556 AAC | 2-556 AAC |
| 2 | Kaumana-Keamuku | L6200 | 556 AAC | 556 AAC |
| | Kealia-Captain Cook-Keauhou-Kahaluu | L8600 | 336 AAC | 336 AAC |
| | South Point-Punaluu | L6600 | 336 AAC | 336 AAC |
| | Keahole-Huehue-Puuwaawa-Puuhulu | L6800 | 2-556 AAC | 2-556 AAC |
| | Poopoomino-Anaehoomalu | L7100 | 2-556 AAC | 2-556 AAC |
| | Keahole-Poopoomino | L9100 | 2-556 AAC | 2-556 AAC |
| | Waiko-Keamuku | L8100 | None | 556 AAC |
| 3 | South Point-Punaluu | L6600 | 195.7 AAAC | 3/0 AAAC |
| 4 | Kaumana-Keamuku | L6200 | 556 AAC | 556 AAC |
| 5 | Kealia-Captain Cook-Keauhou-Kahaluu | L8600 | 336 AAC | 336 AAC |
| | Kealia-Kapua-Kamaoa | L9600 | 556 AAC | 556 AAC |
| | South Point-Punaluu | L6600 | 336 AAC | 336 AAC |
| | Kilauea-Kulani-Panaewa | L6300 | 336 AAC | 336 AAC |

### 7.4.2. REZ Enablements

According to the Hawai`i island transmission planning criteria, the single point of failure limit is 30 MW, which means for most of REZ hosting substations required to host 90 MW will need 3 BAAH open positions from 3 different BAAH bays for the REZ interconnection. For the Keamuku substation, since the potential generation for the associated REZ is 150 MW, it will need 5 BAAH open positions from 5 different BAAH bays for the REZ interconnection in the REZ option 2.

Similar to Maui island, for 69 kV substations that do not have BAAH topology, BAAH topology will be required in order to interconnection REZ. For example, Kaumana 69 kV substation current topology is shown in Figure 23 and the rebuilt substation topology is shown in Figure 24.

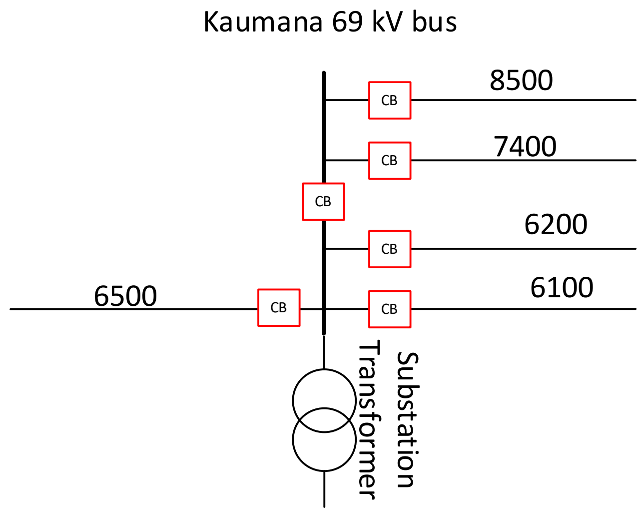



**Figure 23 Kaumana 69 kV substation topology**

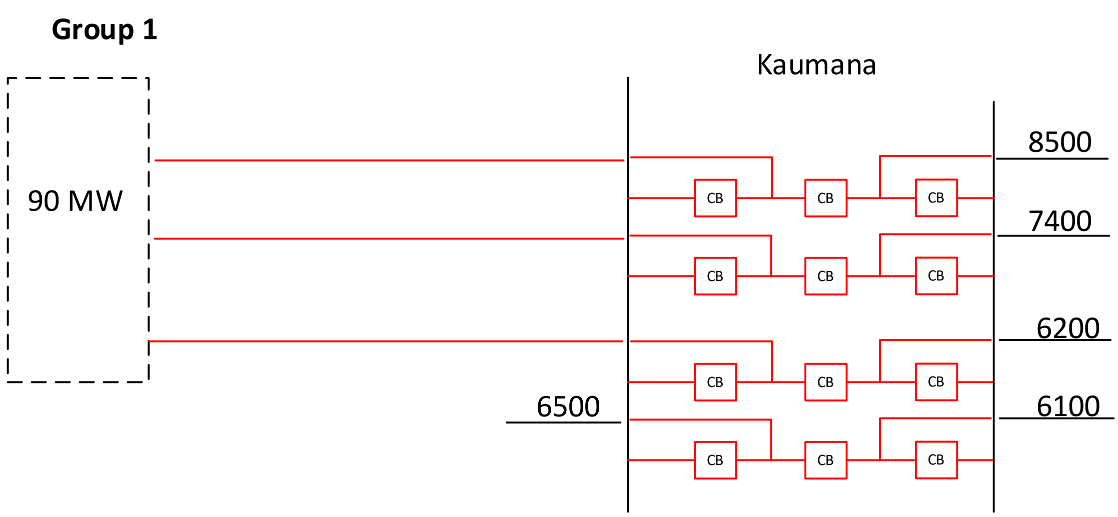



**Figure 24 Kaumana 69 kV substation topology after rebuilding**

Summary of REZ Enablements for interconnecting all REZ groups is listed in Table 7-6. Single line diagrams of these new transmission interconnection facilities are shown in the Appendix A. A high-level map of REZ Enablements required by REZ group are shown below in Figure 25.

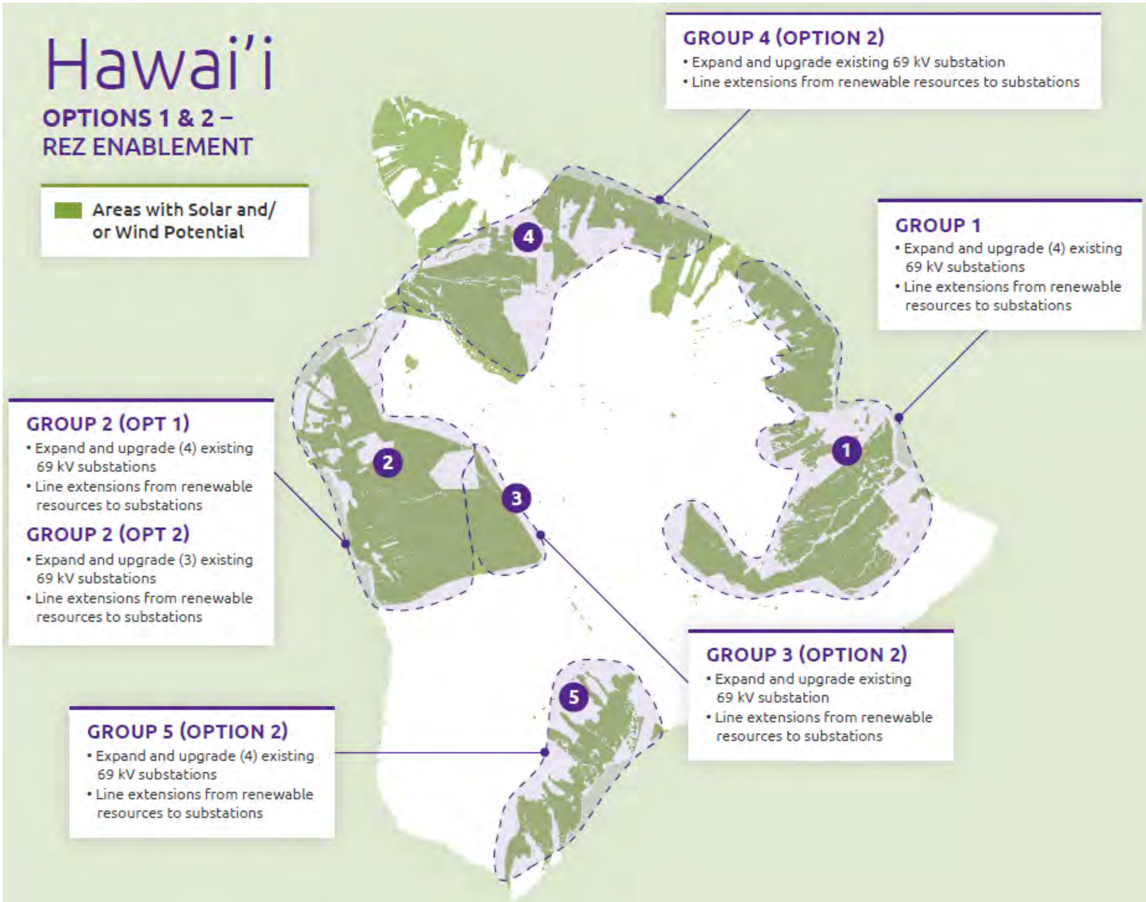



**Figure 25: Hawaii Island REZ Enablement by Group**

**Table 7-6 Interconnection Facility Required for Interconnecting Hawai`i Island REZ Groups**

| REZ Group No. | REZ MW Potential | Interconnected Substation | No. of New Switching Station | No. of New BAAH Bay Required in Hosting Substation |
|---|---|---|---|---|
| 1 | 90 | Pepeekeo | 0 | 3 |
| | 90 | Kanoelehua PP | 0 | 3 |
| | 90 | Kaumana | 0 | 4 |
| | 90 | Pohoiki | 0 | 3 |
| 2 | 90 | Keamuku | 0 | 4 |
| | 90 | Palani | 0 | 3 |
| | 90 | Kahaluu | 0 | 3 |
| | 90 | Keahole PP | 0 | 3 |
| 3 | 150 | Keamuku | 0 | 5 |
| 4 | 20 | Waimea | 0 | 2 |
| 5 | 30 | Kamaoa | 0 | 2 |

### 7.4.3. Total REZ Upgrade Cost Estimate

The cost of transmission infrastructure upgrade is estimated for interconnection facility for all REZ groups and system upgrades identified in the Transmission Network Expansion Options 1 and Option 2. For Transmission Network Expansion Option 2, the cost estimate to convert the existing L6200 line to a 138 kV line is $41 Million.

**Table 7-7 Cost Estimate for REZ Enablements for Hawai`i Island REZ Groups – REZ Option 1**

| REZ Group # | Group 1 | | | | Group 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | Pepeekeo | Kanoelehua PP | Kaumana | Pohoiki | Keamuku | Palani | Kahaluu | Keahole PP |
| Potential MW | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 90 |
| REZ Enablement Cost ($MM) | 68.7 | 105.0 | 42.6 | 97.7 | 163.5 | 104.4 | 136.6 | 64.3 |
| Cost ($MM) per MW | 0.76 | 1.17 | 0.47 | 1.09 | 1.82 | 1.16 | 1.52 | 0.71 |

Based on IGP Stakeholder and TAP feedback, incremental REZ Enablement costs are provided for interconnecting grid-scale projects with different levels of MW potential. The increments within each group are broken down to 30 MW step size incremental and are shown in Table 7-8 for all substations listed in Table 7-7). It is worth noting that these cost estimates are indicative estimates and factors such as project size, relative location to existing transmission infrastructure, new transmission infrastructure build-out status, substation available space will impact actual REZ Enablement costs.

**Table 7-8: Cost Estimate ($MM) for REZ Enablement for Hawai`i REZ Group 1 and 2 with incremental MW Potential in REZ Option 1**

| Substation | 30 MW/Sub | 60 MW/Sub | 90 MW/Sub |
|---|---|---|---|
| Pepeekeo REZ Enablement ($MM) | 33.8 | 48.6 | 68.7 |
| Pepeekeo Cost ($MM) per MW | 1.13 | 0.81 | 0.76 |
| Kanoelehua PP REZ Enablement ($MM) | 20.7 | 57.5 | 105.0 |
| Kanoelehua Cost ($MM) per MW | 0.69 | 0.96 | 1.17 |
| Kaumana REZ Enablement ($MM) | 41.2 | 41.9 | 42.6 |
| Kaumana Cost ($MM) per MW | 1.37 | 0.70 | 0.47 |
| Pohoiki REZ Enablement ($MM) | 32.5 | 74.5 | 97.7 |
| Pohoiki Cost ($MM) per MW | 1.08 | 1.24 | 1.09 |
| Keamuku REZ Enablement ($MM) | 79.2 | 121.2 | 163.5 |
| Keamuku Cost ($MM) per MW | 2.64 | 2.02 | 1.82 |
| Palani REZ Enablement ($MM) | 27.1 | 56.2 | 104.4 |

| | | | |
|---|---|---|---|
| Palani Cost ($MM) per MW | 0.90 | 0.94 | 1.16 |
| Kahaluu REZ Enablement ($MM) | 29.9 | 88.0 | 136.6 |
| Kahaluu Cost ($MM) per MW | 1.00 | 1.47 | 1.52 |
| Keahole PP REZ Enablement ($MM) | 25.5 | 51.1 | 64.3 |
| Keahole PP Cost ($MM) per MW | 0.85 | 0.85 | 0.71 |
| **Total REZ Enablement ($MM)** | **240.6** | **505.8** | **782.9** |
| **Total Cost ($MM) per MW** | **1.00** | **1.05** | **1.09** |

**Table 7-9 Cost Estimate for REZ Enablements for Hawai`i Island REZ Groups – REZ Option 2**

| REZ Group # | Group 1 | | | | Group 2 | | | Group 3 | Group 4 | Group 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Pepeekeo | Kanoelehua PP | Kaumana | Pohoiki | Palani | Kahaluu | Keahole PP | Keamuku | Waimea | Kamaoa |
| Potential MW | 90 | 90 | 90 | 90 | 90 | 90 | 90 | 150 | 20 | 30 |
| REZ Enablement Cost ($MM) | 68.7 | 105.0 | 42.6 | 97.7 | 104.4 | 163.5 | 64.3 | 272.9 | 34.7 | 37.8 |
| Cost ($MM) per MW | 0.76 | 1.17 | 0.47 | 1.09 | 1.16 | 1.82 | 0.71 | 1.82 | 1.74 | 1.26 |

REZ Enablements cost estimates for transmission interconnection grid-scale project with 30 MW step size incremental are prepared as Table 7-10 for all substations considered in Hawai`i island REZ Option 2.

**Table 7-10 Cost Estimate ($MM) for REZ Enablement for Hawai`i REZ Group 1, 2 and 3 with incremental MW Potential in REZ Option 2**

| Substation | 30 MW/Sub | 60 MW/Sub | 90 MW/Sub | 120 MW/Sub | 150 MW/Sub |
|---|---|---|---|---|---|
| Pepeekeo REZ Enablement ($MM) | 33.8 | 48.6 | 68.7 | n/a | n/a |
| Pepeekeo Cost ($MM) per MW | 1.13 | 0.81 | 0.76 | n/a | n/a |
| Kanoelehua PP REZ Enablement ($MM) | 20.7 | 57.5 | 105.0 | n/a | n/a |
| Kanoelehua Cost ($MM) per MW | 0.69 | 0.96 | 1.17 | n/a | n/a |
| Kaumana REZ Enablement ($MM) | 41.2 | 41.9 | 42.6 | n/a | n/a |
| Kaumana Cost ($MM) per MW | 1.37 | 0.70 | 0.47 | n/a | n/a |
| Pohoiki REZ Enablement ($MM) | 32.5 | 74.5 | 97.7 | n/a | n/a |
| Pohoiki Cost ($MM) per MW | 1.08 | 1.24 | 1.09 | n/a | n/a |
| Palani REZ Enablement ($MM) | 27.1 | 56.2 | 104.4 | n/a | n/a |

| | | | | | |
|---|---|---|---|---|---|
| Palani Cost ($MM) per MW | 0.90 | 0.94 | 1.16 | n/a | n/a |
| Kahaluu REZ Enablement ($MM) | 29.9 | 88.0 | 136.6 | n/a | n/a |
| Kahaluu Cost ($MM) per MW | 1.00 | 1.47 | 1.52 | n/a | n/a |
| Keahole PP REZ Enablement ($MM) | 25.5 | 51.1 | 64.3 | n/a | n/a |
| Keahole PP Cost ($MM) per MW | 0.85 | 0.85 | 0.71 | n/a | n/a |
| Keamuku REZ Enablement ($MM) | 79.2 | 121.2 | 163.5 | 208.5 | 272.9 |
| Keamuku Cost ($MM) per MW | 2.64 | 2.02 | 1.82 | 1.74 | 1.82 |
| Kamaoa REZ Enablement ($MM) | 37.8 | n/a | n/a | n/a | n/a |
| Kamaoa Cost ($MM) per MW | 1.26 | n/a | n/a | n/a | n/a |
| Waimea REZ Enablement ($MM) | 34.7[1] | n/a | n/a | n/a | n/a |
| Waimea Cost ($MM) per MW | 1.16 | n/a | n/a | n/a | n/a |
| **Total MW** | **290** | **530** | **770** | **800** | **830** |
| **Total REZ Enablement ($MM)** | **362.4** | **539.0** | **728.8** | **827.8**[2] | **892.2**[2] |
| **Total Cost ($MM) per MW** | **1.25** | **1.02** | **0.95** | **1.03** | **1.07** |

1 - For 20 MW capacity only
2 - Includes cost for all substations (except Keamuku) with 90 MW or below interconnection size.

**Table 7-11: Cost Estimate for Total REZ Upgrade for Hawai`i Island REZ Option 1 and 2**

| REZ Group | REZ Option 1 | | REZ Option 2 | | | | |
|---|---|---|---|---|---|---|---|
| | Group 1 360 MW | Group 2 360 MW | Group 1 360 MW | Group 2 270 MW | Group 3 150 MW | Group 4 20 MW | Group 5 30 MW |
| REZ Enablement ($MM) | 314.0 | 468.9 | 314.0 | 305.3 | 272.9 | 34.7 | 37.8 |
| Transmission Network Expansion – Option 1 ($MM) | 369.6 | | 408.3 | | | | |
| Transmission Network Expansion – Option 2 ($MM) | 382.9 | | 439.9 | | | | |
| Total REZ Upgrade Cost Range ($MM) | 1,152.5 – 1,165.8 | | 1,373.0 – 1,404.6 | | | | |
| Total REZ Upgrade Cost Range ($MM) per MW | 1.60 – 1.62 | | 1.65 – 1.69 | | | | |

# 8. IGP TAP & Stakeholder Review

The Company provided a draft of this document on October 1, 2021 to IGP stakeholders for review. The Company also presented the study to the IGP Technical Advisory Panel (TAP) on October 1, 2021 and the IGP Stakeholder Technical Working Group (STWG) on October 6, 2021. The TAP's feedback is included in Appendix B and summarized with responses below. Feedback from various organizations within the IGP STWG are included in Appendix C with responses as appropriate.

## 8.1. Summary of TAP Feedback and Responses

Prior presenting to IGP STWG meeting, the study was presented to IGP Technical Advisory Panel for review on October 1, 2021. Overall, the TAP team recognized that the study established transmission limits that may impact amounts of renewable energy that can be interconnected beyond what is seen from the resource analysis. The IGP TAP provided guidance regarding next steps of the study. A summary of key feedback provided by the IGP TAP (complete version included in Appendix B), as well as Company's responses are listed below.

1. **TAP advised that the REZ planning process also would need consider environmental and community acceptance constraints.**

   *Company Response: The Company agree with TAP's suggestion, and as planned, both environmental goal and community engagement are considered in the whole REZ planning process.*
2. **TAP recommended that more sophisticated power flow study than a single point snapshot study should be performed in future steps. This includes:**
   a. **Considering both voltage and thermal study criteria in the study**
   b. **Considering a chronological tool with an underlying transmission topology rather than a single point snapshot analysis**
   c. **Non-transmission alternatives such as power flow control devices (phase shifters, in-line compensators, etc) or even energy storage elements for congestion management should be considered in the study.**
   d. **Use of dynamic line rating technology to manage flows in operational time frame can also be considered.**
   e. **Considering Behind-The-Meter DER in the study**

   *Company Response: As mentioned before, the current study is just the starting point of the whole REZ planning process. It focuses on the initial feasibility exploration. It is expected that after receiving feedbacks from stakeholders, community and TAP team, more detailed study will be performed with more realistic assumptions for more detailed scope in next iterations.*
3. **An evaluation of more MW integration levels is strongly recommended for O`ahu REZ Group 8, and recommended for the other groups as it may determine a different priority/cost for integration in each zone; for example, a stepwise $/MW curve for each**

**group may be obtained. At the same time, the TAP recognized that this is an initial pass at transmission cost estimation that will be refined in future steps.**

*Company Response: The Company revised REZ Enablements cost with detailed estimate for stepwise MW incremental scenarios for REZ Groups with high MW potential. However, due to the limited time before November 1, 2021 filing, the Transmission Network Expansion cost for stepwise MW incremental scenarios is not performed. This will be considered in the future steps of the study.*

4. **The study may need address system resilience requirements for scenarios such as extreme weather condition.**

   *Company response: The system resilience requirement was not studied in the REZ study but may be needed as a future sensitivity as well as in separate studies. In developing severe weather scenarios, Company would also need to take into account the full suite of resilience-related solutions to manage the impact.*

5. **The TAP agrees with the premise that it is preferable to provide planned interconnection points for renewables rather than piecemeal tapping of transmission lines as is currently being done.**

6. **The 345 kV would be a new transmission voltage level for HECO, which means a need for a whole new class of equipment, spare parts, etc.**
   *Company response: Yes, and the associated cost, such as for equipment, right-of-way purchase, and personnel training, that is not directly related with the REZ development is not considered in the study. Therefore, the total cost of having a new 345 kV loop could be much more expensive than the preliminary estimate in the report.*

# 9. Conclusions and Next Steps

Following conclusions are reached for Oahu REZ study:

- Interconnecting REZ groups 1 to 7 requires minimum Transmission Network Expansions, and is the “low hanging fruit” identified in the study. Further efforts need to be spent to determine if Stakeholders are interested to develop grid-scale renewable energy in those zones.
- Due to the existing design and condition of the Wahiawa 138 kV substation, significant efforts need to be spent to convert the Wahiawa substation from a non-load center common substation to a GW size generation switching station for the interconnection of 1,160 MW potential of the REZ group 8 (located at north of the Wahiawa substation).

- Due to substation limitations, 600MW of off-shore wind cannot be interconnected at Halawa, Kahe, or Iwilei substations, but can only interconnected at Ko`olau substation and 345 kV Kahe substation under Transmission Network Expansion Option 3 among all options evaluated in the study.
- Additional analysis was performed for 400 MW of off-shore wind interconnection, which also found Ko`olau substation as the only feasible interconnection point among the Kahe substation, Iwilei substation, Ko`olau substation and Halawa substation. The 400 MW of interconnection also found that no additional Transmission Network Expansion was identified beyond the Transmission Network Expansion identified to interconnect REZ groups 1 to 8.

Following conclusion are reached for Maui island REZ study:

- Maui island REZ development should consider generation plant geographic diversity around the island. REZ development should be planned in geographic balance way among west Maui, south Maui and central Maui.
- Interconnection of REZ Group 1, 2, 3 and 4B1 could require limited Transmission Network Expansion. These four groups of REZ are the "low hanging fruit" of REZ development identified from the study.
- Interconnection of REZ 4A and REZ 4B2 causes significant 69 kV conductor overloading, which requires most part of South Maui and part of Central Maui 69 kV Transmission Network Expansion.

Following conclusion are reached for Hawaii island REZ study:

- Similar to Maui island, REZ development should consider generation plant geographic diversity around the island. REZ development should be planned in geographic balance way among east and west cost of Hawai`i island.
- Upgrading L6200 to 138 kV has very limited effect on alleviating line overloading on east and west side caused by the more than usual amount of generation exporting from REZ groups.
- Supplying the island with generation primarily from one area can cause significant overloading and require large amount of line re-conductoring. This type of generation dispatch should be avoided. And REZ development need take into generation location balance around the island into consideration.
- REZ Group 3, 4 and 5 are the "low-hanging fruit" type group. The interconnection of these REZ groups could require limited Transmission Network Expansion.

# 10. Appendix A – O`ahu REZ and Off-Shore Wind Interconnection

## 10.1. Transmission Upgrade Requirements Identified with Transmission Network Expansion Option 1

Single line diagrams of hosting 138 kV substation with upgrades required for REZ and off-shore wind interconnection, with Transmission Network Expansion Option 1 (red represents required upgrade, and black represent existing system) are shown as following. It is worth noting that re-conductor type of upgrade is not shown in the following single line diagram.

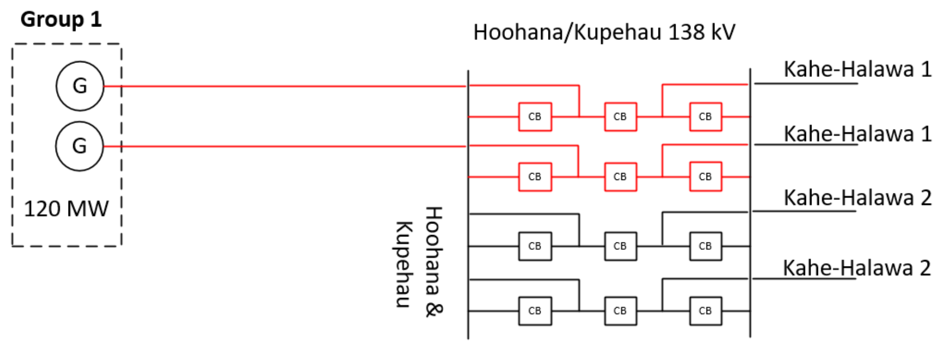



**Figure 26 Ho`ohana substation upgrade required for hosting REZ Group 1, Transmission Network Expansion Option 1**

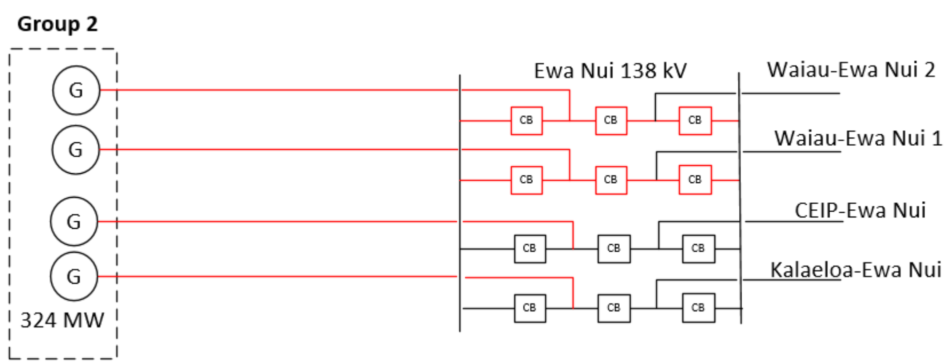



**Figure 27 Ewa Nui substation upgrade required for hosting REZ Group 2, Transmission Network Expansion Option 1**

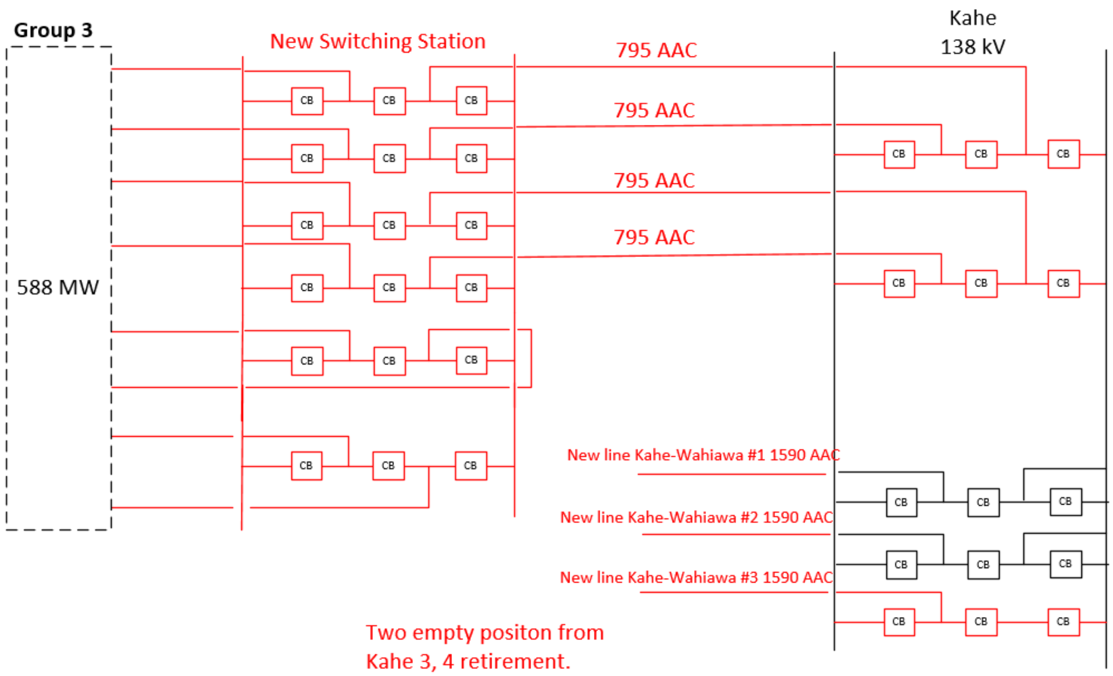



**Figure 28 Kahe substation upgrade required for hosting REZ Group 3, Transmission Network Expansion Option 1**

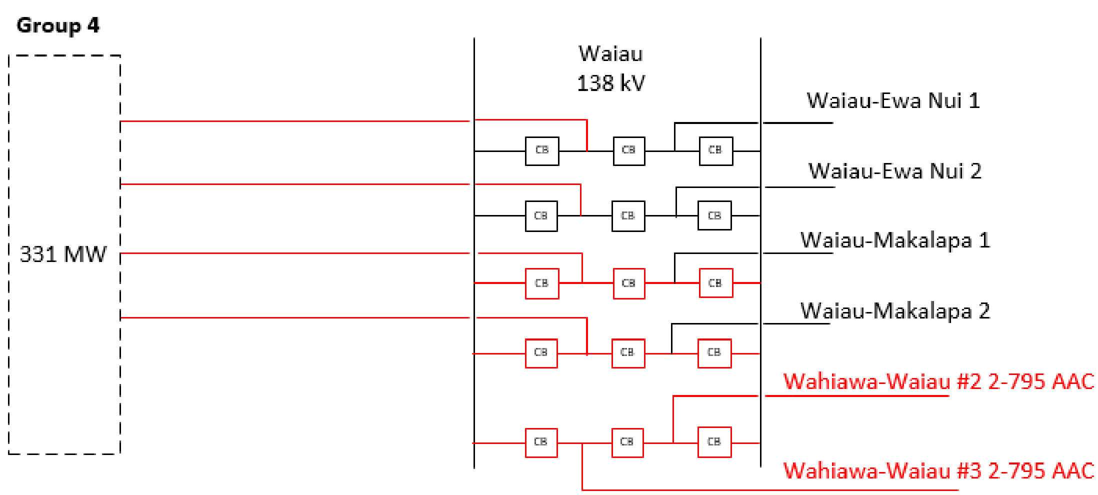



**Figure 29 Waiau substation upgrade required for hosting REZ Group 4, Transmission Network Expansion Option 1**

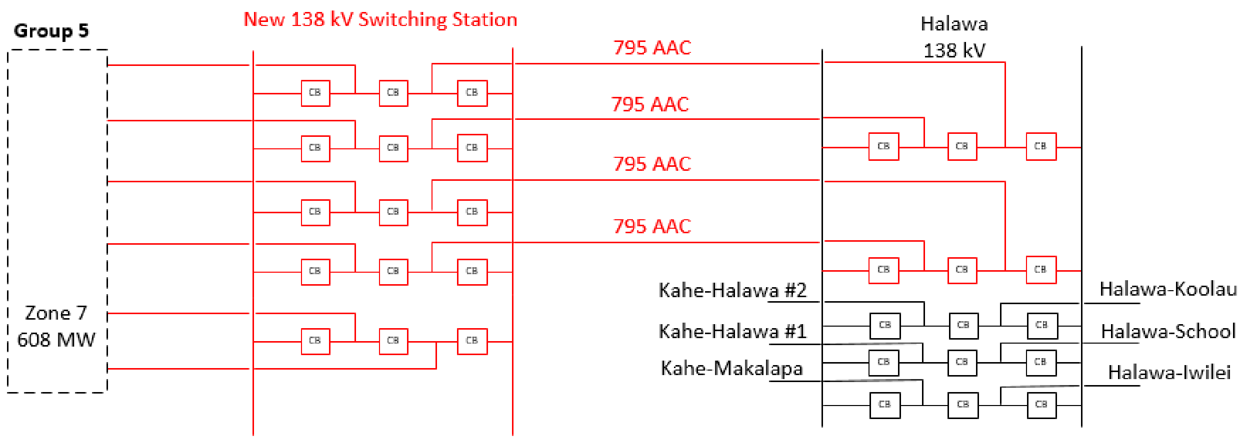



**Figure 30 Halawa substation upgrade required for hosting REZ Group 5, Transmission Network Expansion Option 1**

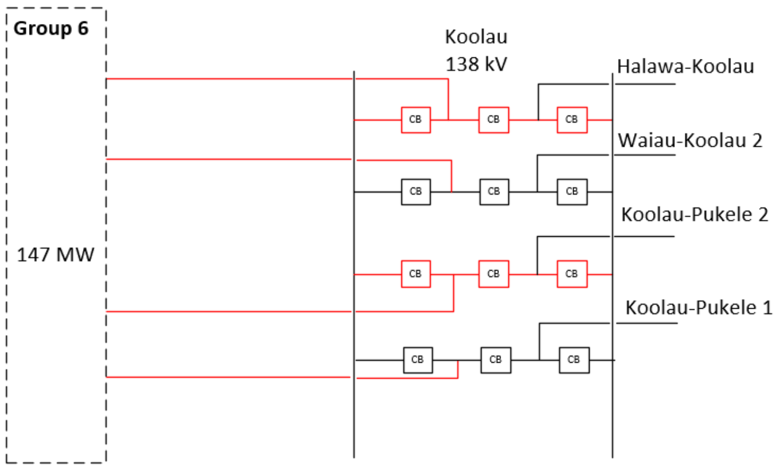



**Figure 31 Ko`olau substation upgrade required for hosting REZ Group 6, Transmission Network Expansion Option 1**

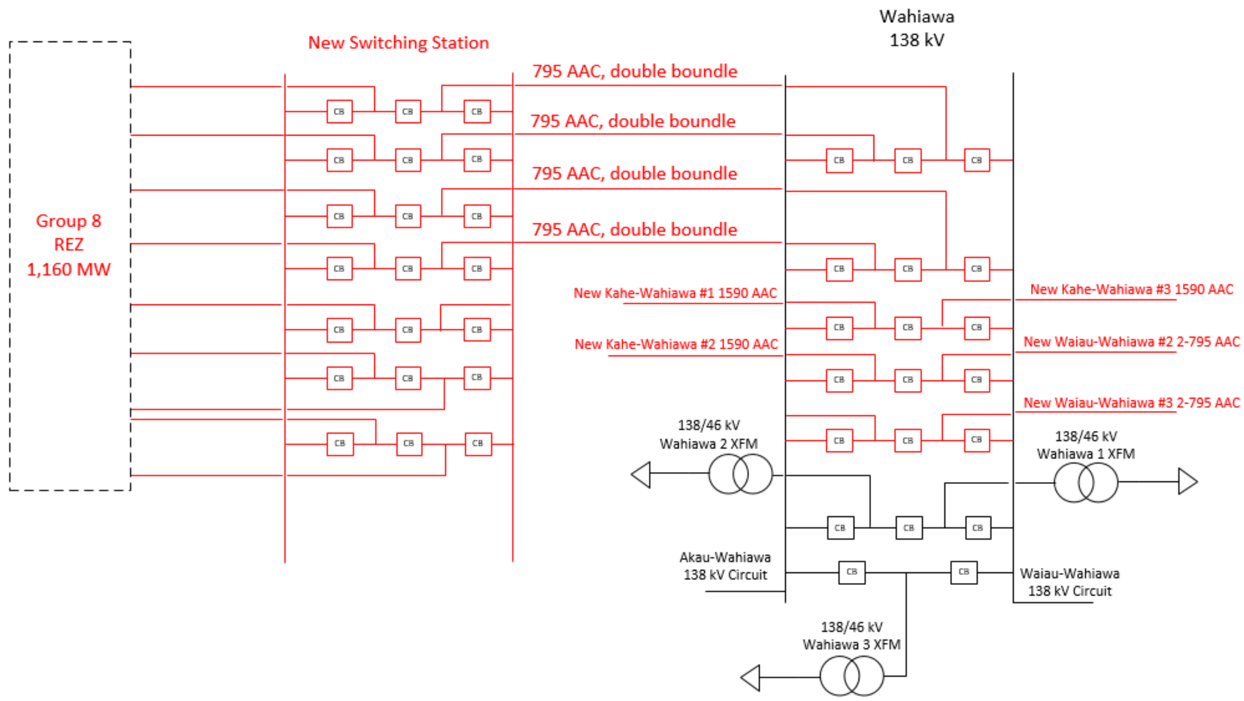



**Figure 32 Wahiawa substation upgrade required for hosting REZ Group 8, Transmission Network Expansion Option 1**

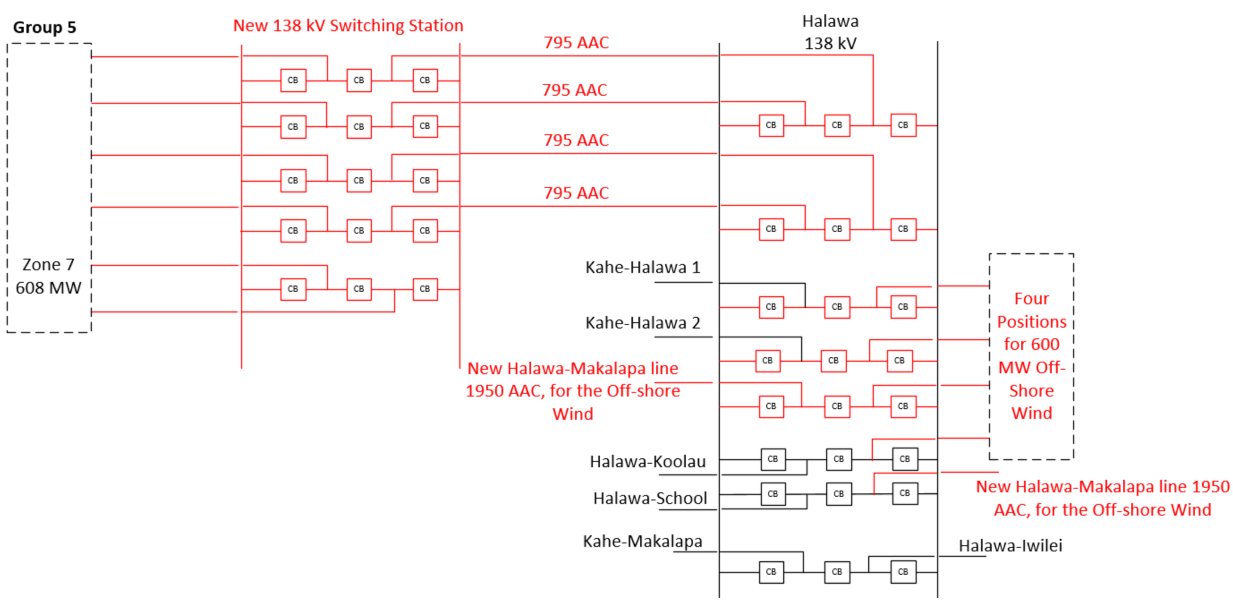



**Figure 33 Halawa substation upgrade required for hosting REZ Group 7 and 600 MW off-shore wind, Transmission Network Expansion Option 1**

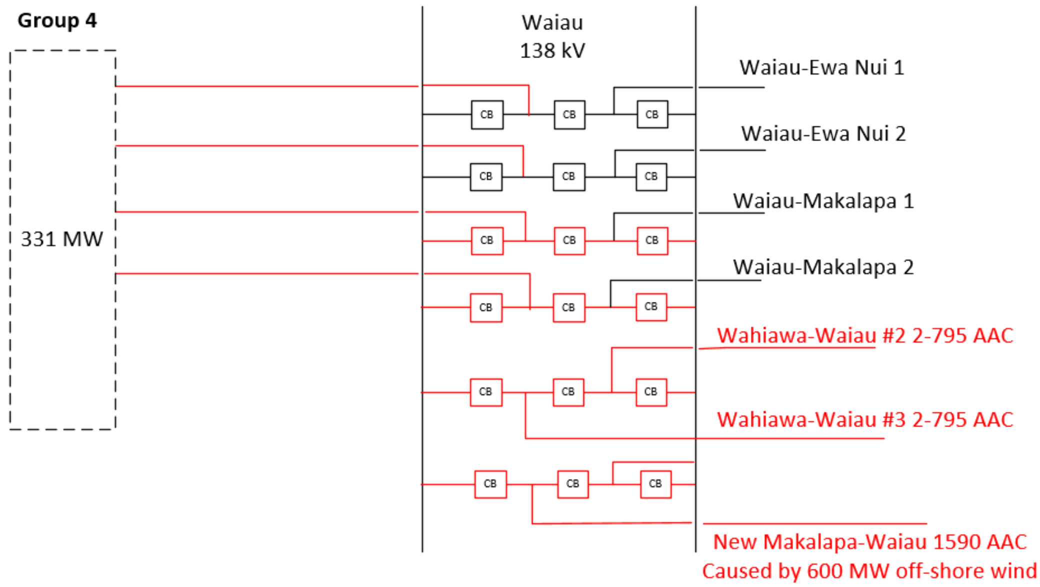



**Figure 34 Waiau substation upgrade required for hosting REZ Group 4 and hosting 600 MW off-shore wind at Halawa substation, Transmission Network Expansion Option 1**

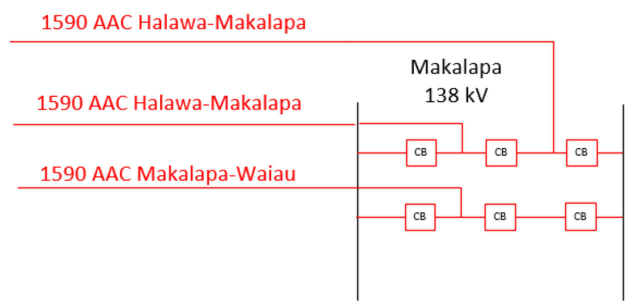



**Figure 35 Makalapa substation upgrade required for hosting 600 MW off-shore wind at Halawa substation, Transmission Network Expansion Option 1 (existing part of the Makalapa substation is illustrated)**

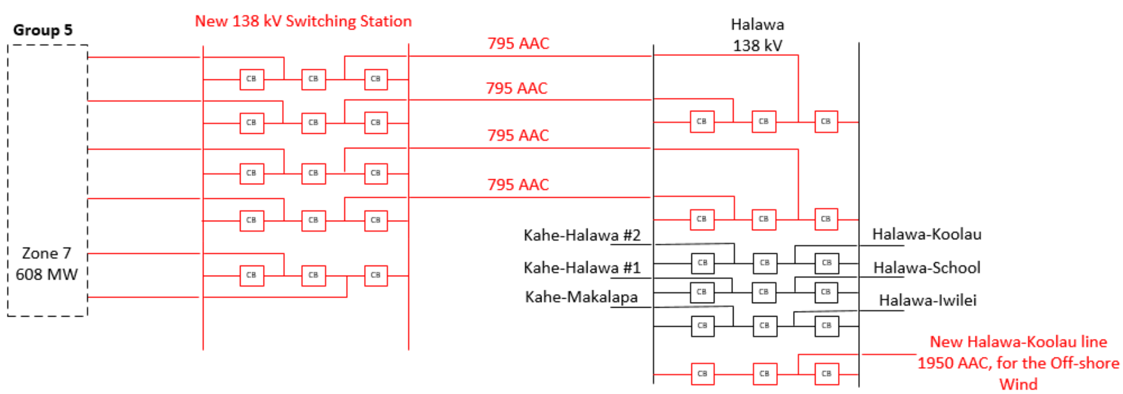



**Figure 36 Halawa substation upgrade required for hosting REZ Group 5 and hosting 600 MW off-shore wind at Ko`olau substation, Transmission Network Expansion Option 1**

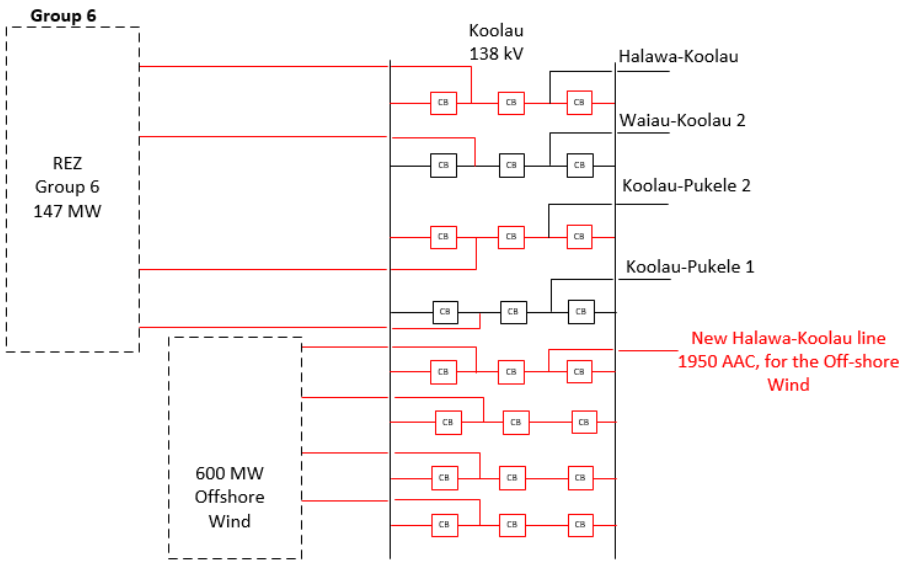



**Figure 37 Halawa substation upgrade required for hosting REZ Group 5 and hosting 600 MW off-shore wind at Ko`olau substation, Transmission Network Expansion Option 1**

**Table 10-1 Summary of 138 kV Transmission Line Upgrade Requirements for hosting REZ 8 Groups with Transmission Network Expansion Option 1**

| No. | Transmission Line | Upgrade Type | Conductor Requirements |
|---|---|---|---|
| 1 | Kahe-Wahiawa | New Line, 138 kV | Three new circuits, with 1950 AAC conductor |
| 2 | Wahiawa-Waiau | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 3 | Wahiawa-Waiau | New Line, 138 kV | Two circuits, with double-bundled 795 AAC |
| 4 | Makalapa-Waiau #1 | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

**Table 10-2 Summary of 138 kV Transmission Line Upgrade Requirements for hosting 600 MW Off-Shore Wind at Halawa Substation with Transmission Network Expansion Option 1**

| No. | Transmission Line | Upgrade Type | Conductor Requirements |
|---|---|---|---|
| 1 | Halawa-Makalapa | New Line, 138 kV | Two new circuits, with 1950 AAC conductor |
| 2 | Halawa-Makalapa | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 3 | Makalapa-Waiau | New Line, 138 kV | One circuit, with 1950 AAC conductor |
| 4 | Halawa-Iwilei | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 5 | Halawa-School | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

| | | | |
|---|---|---|---|
| 6 | Halawa-Ko`olau | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

**Table 10-3 Summary of 138 kV Transmission Line Upgrade Requirements for hosting 600 MW Off-Shore Wind at Koolau Substation with Transmission Network Expansion Option 1**

| No. | Transmission Line | Upgrade Type | Conductor Requirements |
|---|---|---|---|
| 1 | Halawa-Ko`olau | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 2 | Halawa-Ko`olau | New Line, 138 kV | One circuit, with 1950 AAC conductor |
| 3 | Ko`olau-Waiau #1 | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 4 | Ko`olau-Waiau #2 | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

## 10.2. Transmission Upgrade Requirements Identified with Transmission Network Expansion Option 2

Single line diagrams of hosting 138 kV substations with upgrades required for REZ and off-shore wind interconnection, with Transmission Network Expansion Option 2 (red represents required upgrade, and black represents existing system) are shown as following.

For Ho`ohana substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 26.

For Ewa Nui substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 27.

For Kahe substation, the upgrade requirements are shown in Figure 38, which only includes the upgrade requirements for interconnecting REZ Group 3.

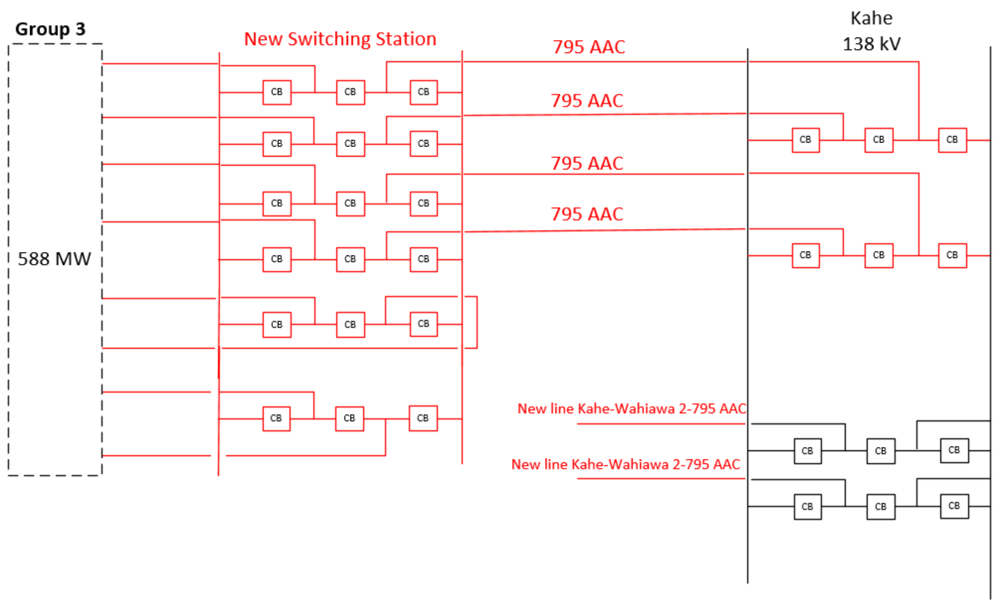



**Figure 38 Kahe substation upgrade required for hosting REZ Group 3, Transmission Network Expansion Option 2**

For Waiau substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 29.

For Halawa substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 30, which only includes the upgrade requirements for interconnecting REZ Group 5.

For Ko`olau substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 31.

For Wahiawa substation, the upgrade requirements are shown in Figure 39, which only include the upgrade requirements for interconnecting REZ Group 8.

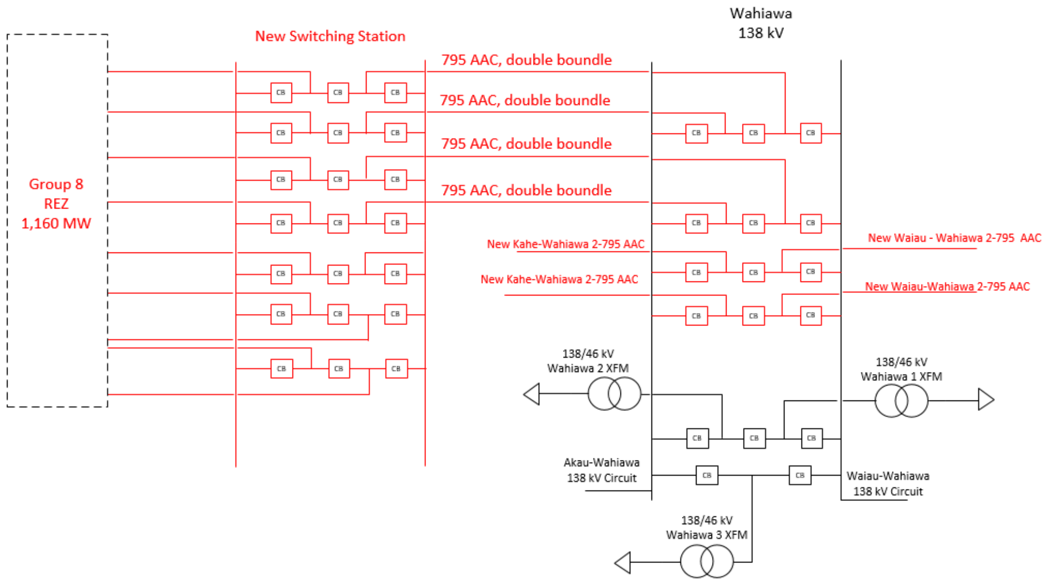



**Figure 39 Wahiawa substation upgrade required for hosting REZ Group 8, Transmission Network Expansion Option 2**

For the interconnection of the 600 MW off-shore wind, the infrastructure upgrade requirements are the same as what are identified in the Transmission Network Expansion Option 1, which is shown in Figure 33 to Figure 37.

The summary of existing transmission infrastructure upgrade requirements for hosting REZ 8 groups is listed in Table 10-4. The upgrade requirements for interconnecting the off-shore wind farm are the same as what are identified in the Transmission Network Expansion Option 1 study, which are summarized in Table 10-2 and Table 10-3.

**Table 10-4 Summary of 138 kV Transmission Line Upgrade Requirements for hosting REZ 8 Groups with Transmission Network Expansion Option 2**

| No. | Transmission Line | Upgrade Type | Conductor Requirements |
|---|---|---|---|
| 1 | Kahe-Akau-Hema-Wahiawa | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 2 | Wahiawa-Kahe | New Line, 138 kV | Two circuits, with double-bundled 795 AAC |
| 3 | Wahiawa-Waiau | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |
| 4 | Wahiawa-Waiau | New Line, 138 kV | Two circuits, with double-bundled 795 AAC |
| 5 | Waiau-Makalap #1 | Re-conductor | One circuit, re-conductor to double-bundled 795 AAC |

## 10.3. Transmission Upgrade Requirements Identified with Transmission Network Expansion Option 3

Single line diagrams of hosting 138 kV substations with upgrades required for REZ and off-shore wind interconnection, with Transmission Network Expansion Option 3 (color red represent required upgrade, and color black represent existing system) are shown as following.

For Ho`ohana substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 26.

For Ewa Nui substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 27.

For Kahe substation, the upgrade requirements are shown in Figure 40, which only includes the upgrade requirements for interconnecting REZ Group 3.

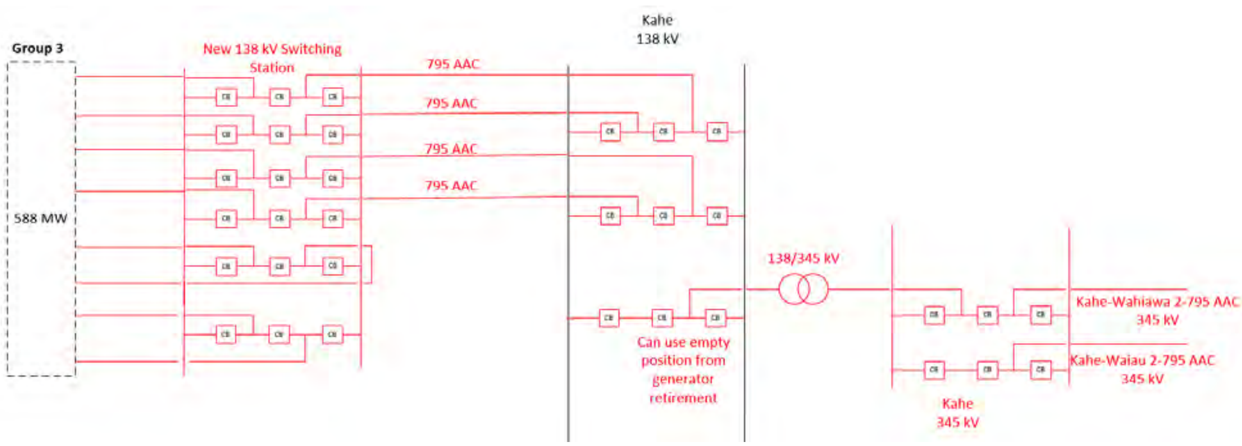



**Figure 40 Kahe substation upgrade required for hosting REZ Group 3, Transmission Network Expansion Option 3**

For Waiau substation, the upgrade requirements are shown in Figure 40, which only includes the upgrade requirements for interconnecting REZ Group 4.

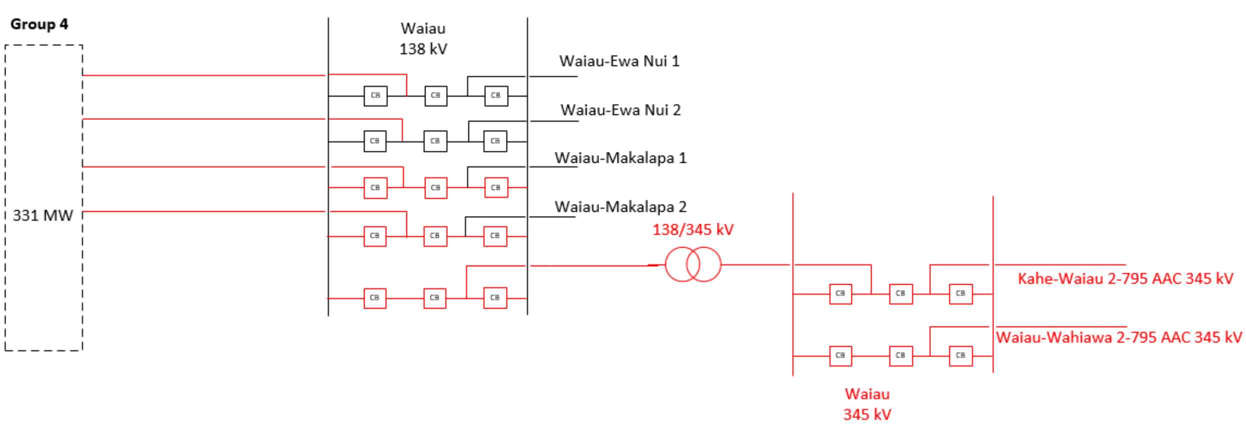



**Figure 41 Waiau substation upgrade required for hosting REZ Group 4, Transmission Network Expansion Option 3**

For Halawa substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 30, which only includes the upgrade requirements for interconnecting REZ Group 5.

For Ko`olau substation, the upgrade requirements are the same as the requirements identified in the Transmission Network Expansion Option 1 study, which is shown in Figure 31.

For Wahiawa substation, the upgrade requirements are shown in Figure 42, which only include the upgrade requirements for interconnecting REZ Group 8. It is worth noting that in this Transmission Network Expansion option, the 1,160 MW renewable potential is considered to be interconnected at 345 kV level.

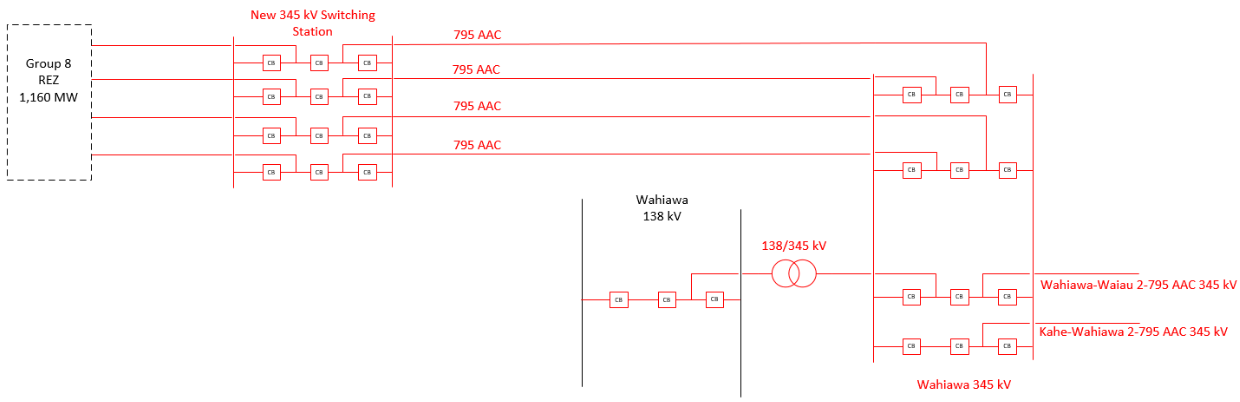



**Figure 42 Wahiawa substation upgrade required for hosting REZ Group 8, Transmission Network Expansion Option 3**

List of transmission infrastructure requirement for this options for interconnecting all groups of REZ is summarized in Table 5-4. For the 600 MW off-shore wind interconnection, it is considered to interconnecting the off-shore wind to system through the Kahe 345 kV bus. Single line diagram for this scenario is shown as Figure 43.

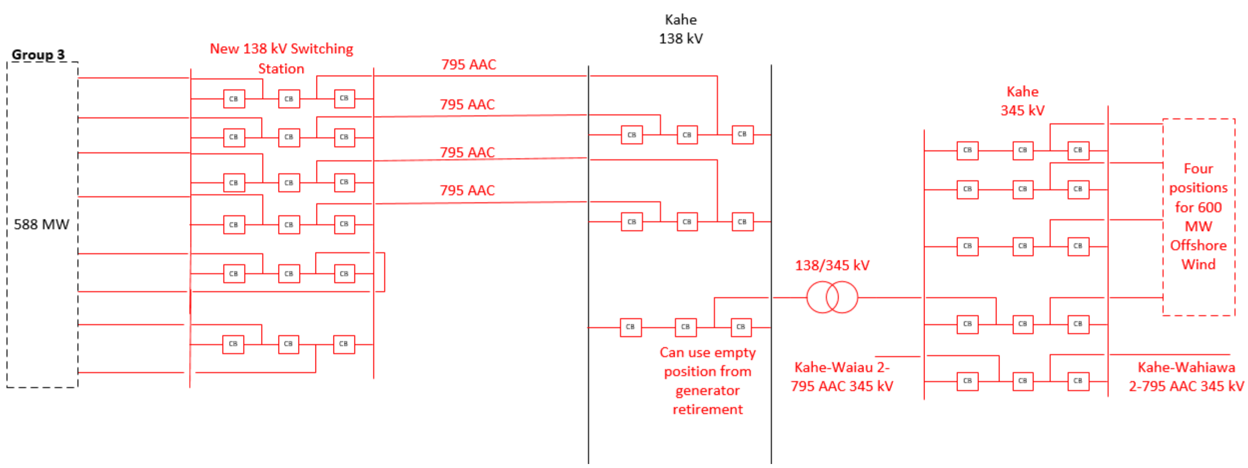



**Figure 43 Kahe substation upgrade required for hosting REZ Group 3 and the off-shore wind (through the 345 kV bus), Transmission Network Expansion Option 3**

Transmission Network Expansion requirements for interconnection the off-shore wind to Halawa substation or Waiau substation (through 138 kV connection) are the same as what are identified in Transmission Network Expansion Option 1 and 2 study.

## 10.4. Appendix – Maui Island REZ Interconnection

Single line diagrams of hosting 69 kV substation with upgrades required for REZ interconnection, (color red represent required upgrade, and color black represent existing system) are shown as following. It is worth noting that re-conductor type of upgrade is not shown in the following single line diagrams. All these upgrades apply for both Transmission Network Expansion Option 1 and Option 2.

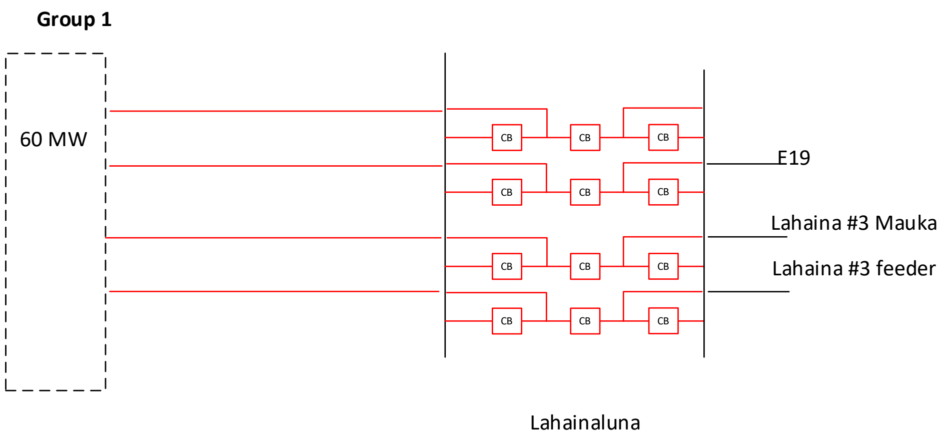



**Figure 44 Lahainaluna substation upgrade required for hosting REZ Group 1**

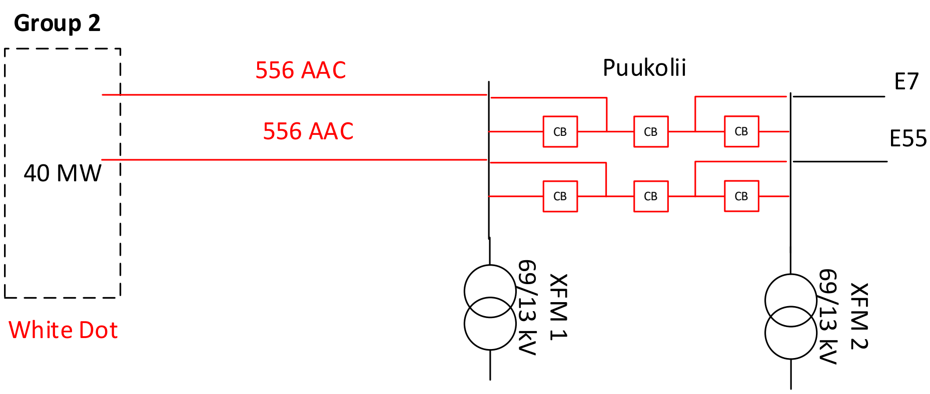



**Figure 45 Puukolii substation upgrade required for hosting REZ Group 2**

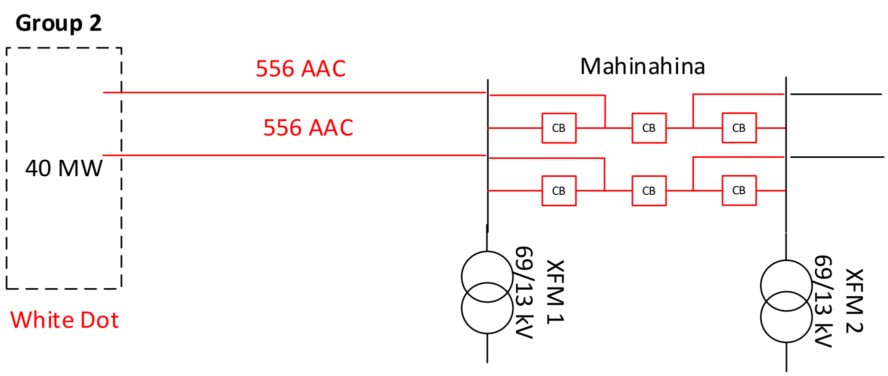



Figure 46 Mahinahina substation upgrade required for hosting REZ Group 2

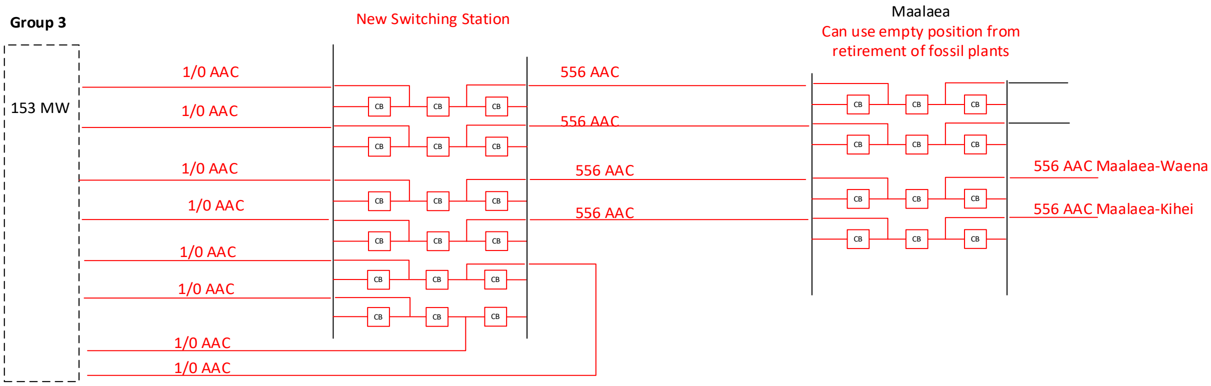



Figure 47 Maalaea substation upgrade required for hosting REZ Group 3

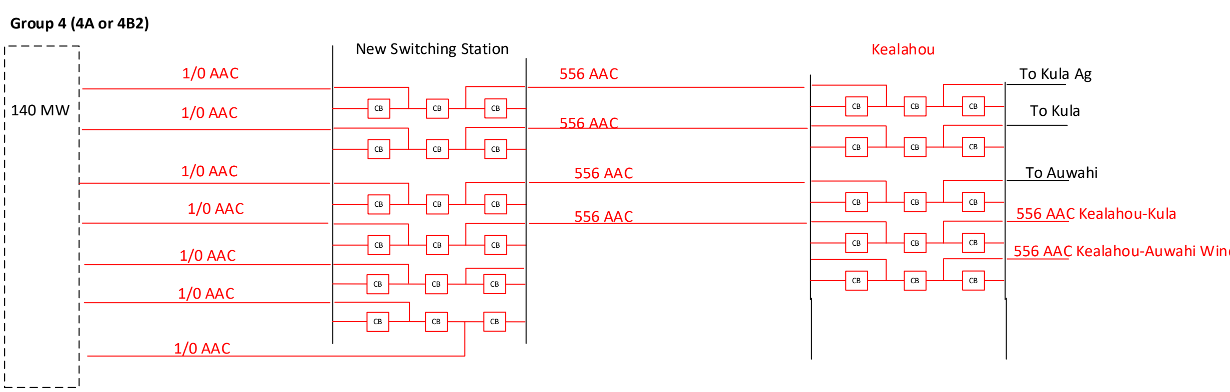



Figure 48 Kealahou substation upgrade required for hosting REZ Group 4A

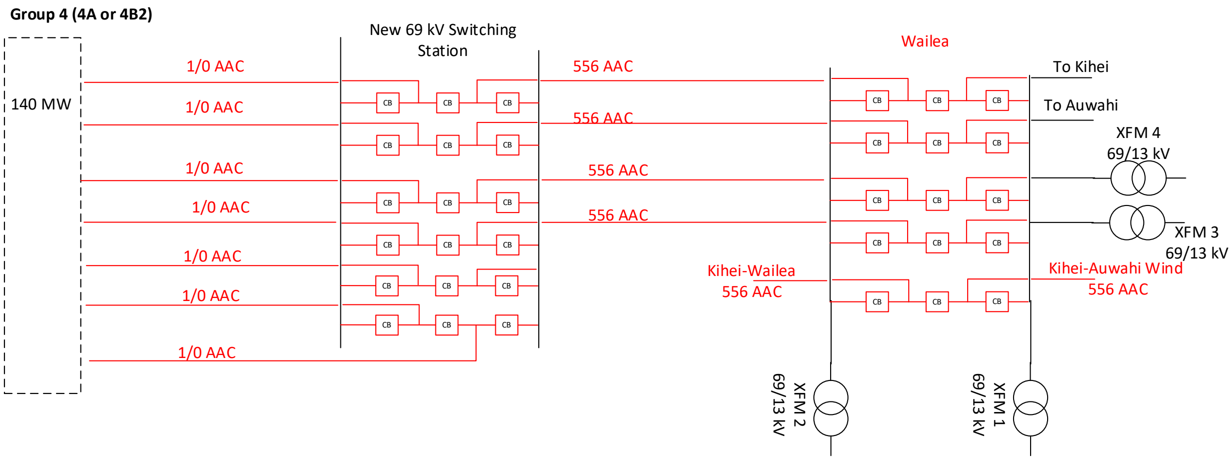



**Figure 49 Wailea substation upgrade required for hosting REZ Group 4A**

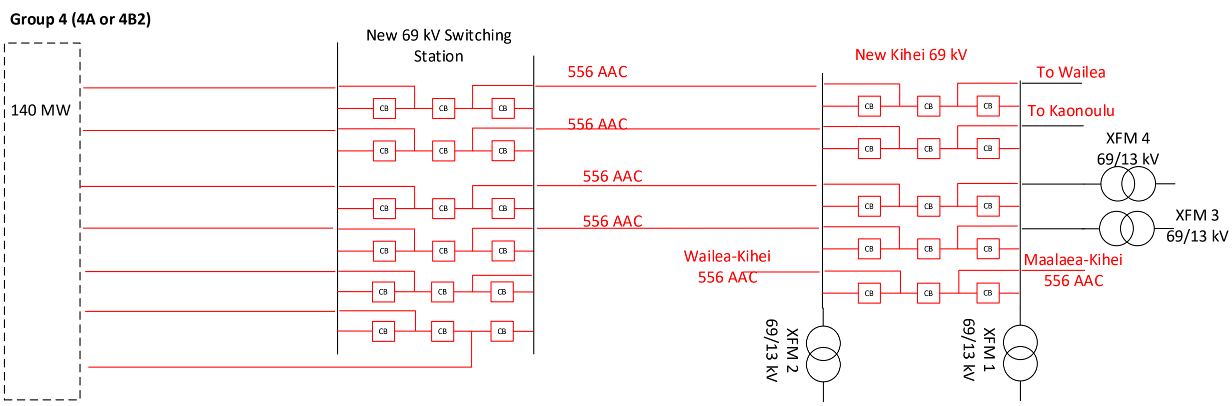



**Figure 50 Kihei substation upgrade required for hosting REZ Group 4A**

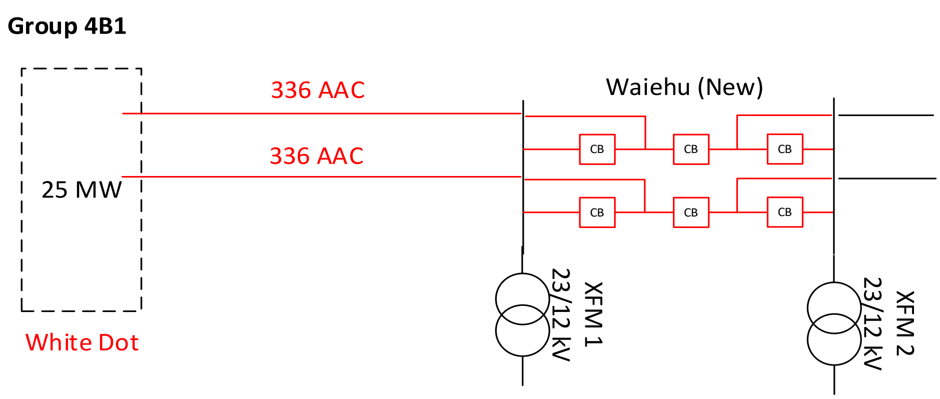



**Figure 51 Waiehu substation upgrade required for hosting REZ Group 4B1**

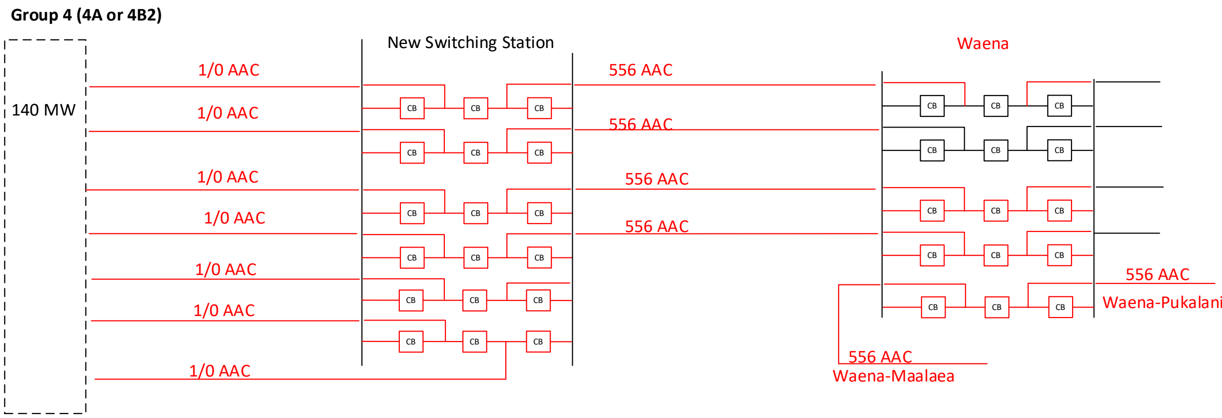



**Figure 52 Waena substation upgrade required for hosting REZ Group 4B2**

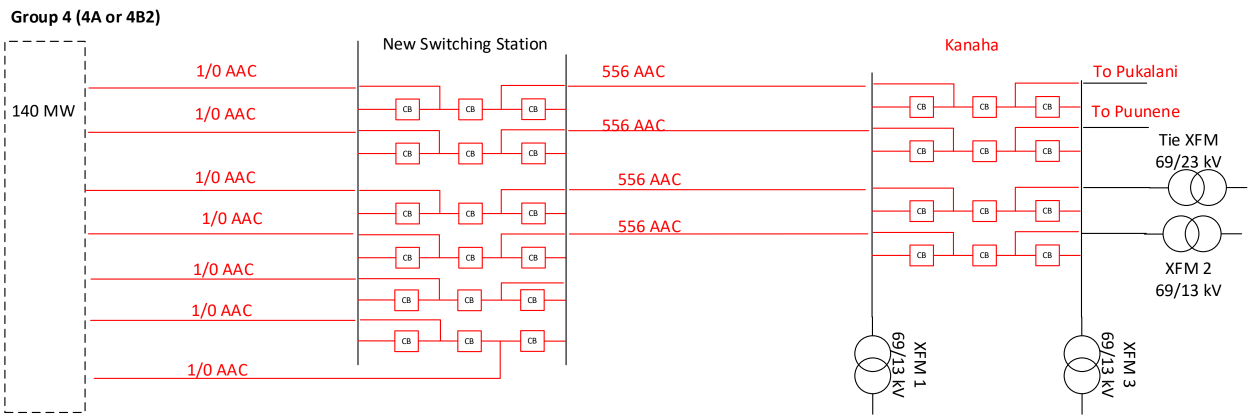



**Figure 53 Kanaha substation upgrade required for hosting REZ Group 4B2**

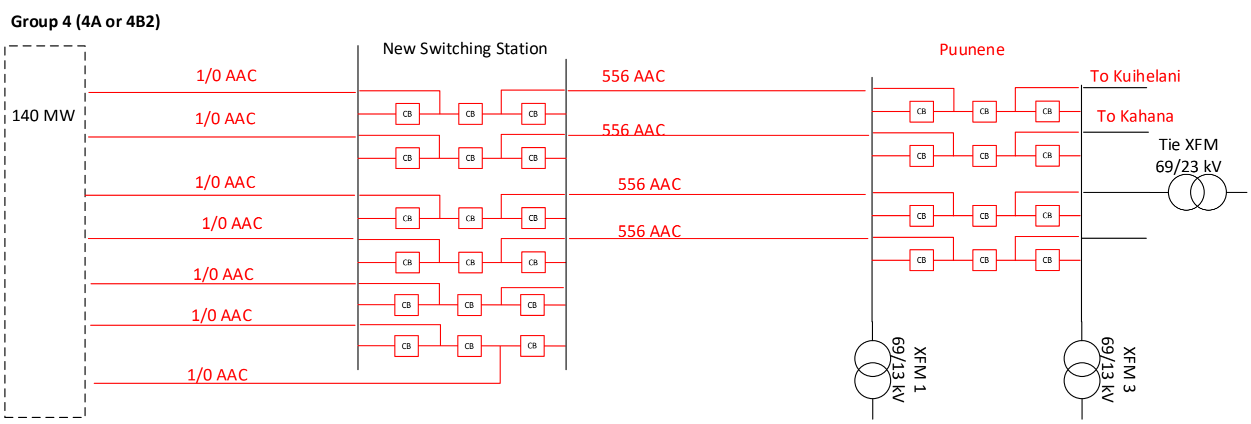



**Figure 54 Puunene substation upgrade required for hosting REZ Group 4B2**

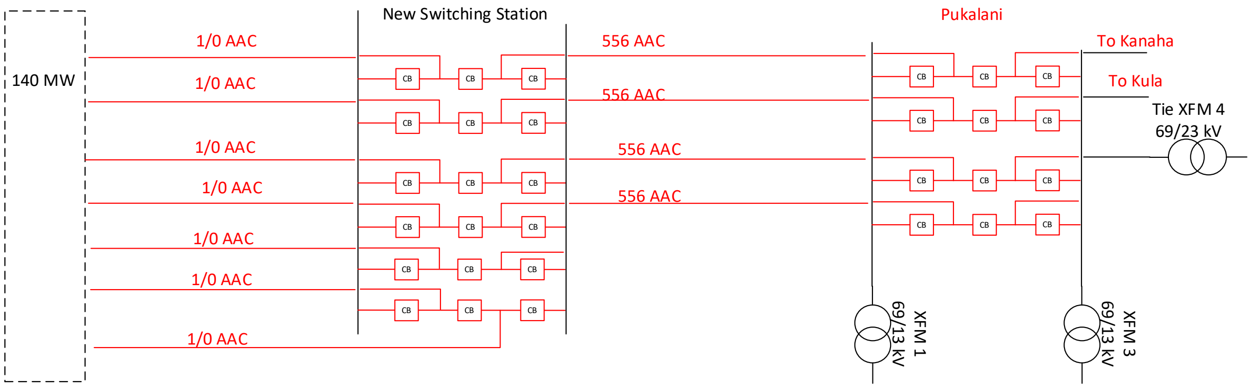



Figure 55 Pukalani substation upgrade required for hosting REZ Group 4B2

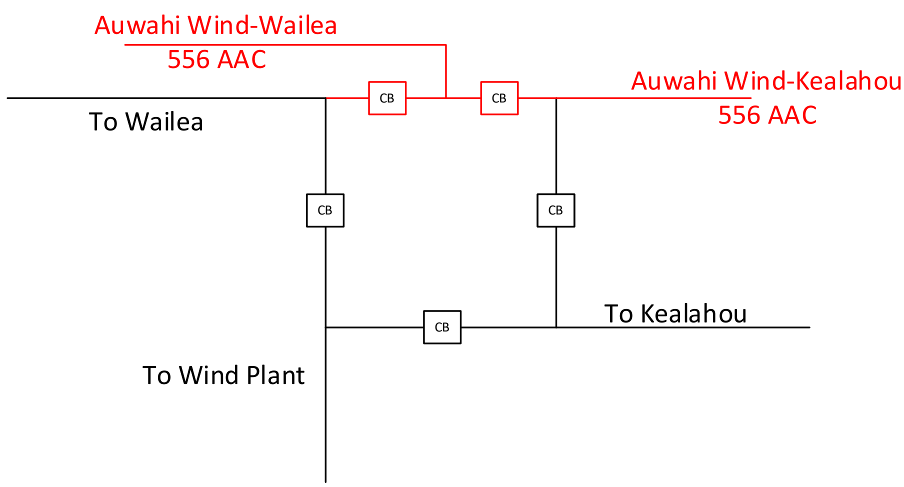



Figure 56 Auwahi Wind substation upgrade required for hosting REZ Group 4A

Following 23 kV transmission line upgrade is only applied for scenarios with Transmission Network Expansion Option 1.

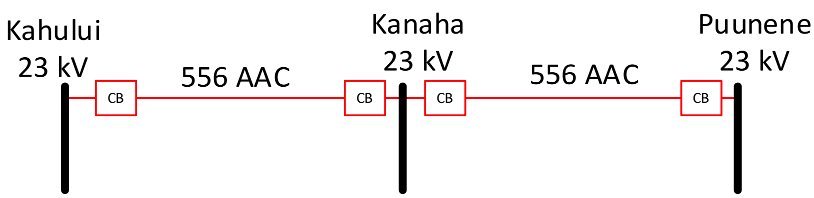



Figure 57 New 23 kV lines required on 23 kV transmission system with Transmission Network Expansion Option 1

## 10.5. Appendix – Hawai'i Island REZ Interconnection

Single line diagrams of hosting 69 kV substation with upgrades required for REZ interconnection, (color red represent required upgrade, and color black represent existing system) are shown as following. It is worth noting that re-conductor type of upgrade is not shown in the following single line diagrams. All these upgrades apply for both Transmission Network Expansion Option 1 and Option 2.

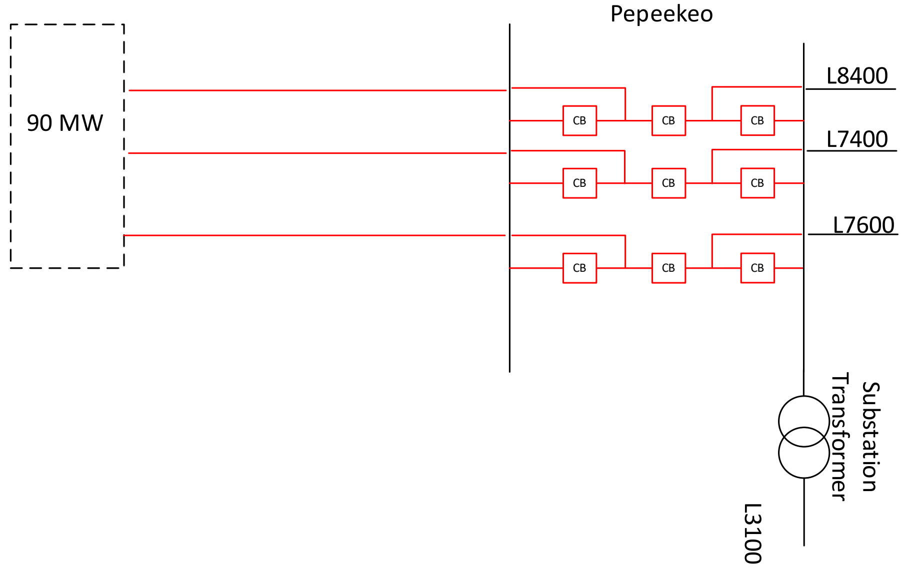



**Figure 58 Pepeekeo substation upgrade required for hosting REZ Group 1, REZ Option 1 & 2**

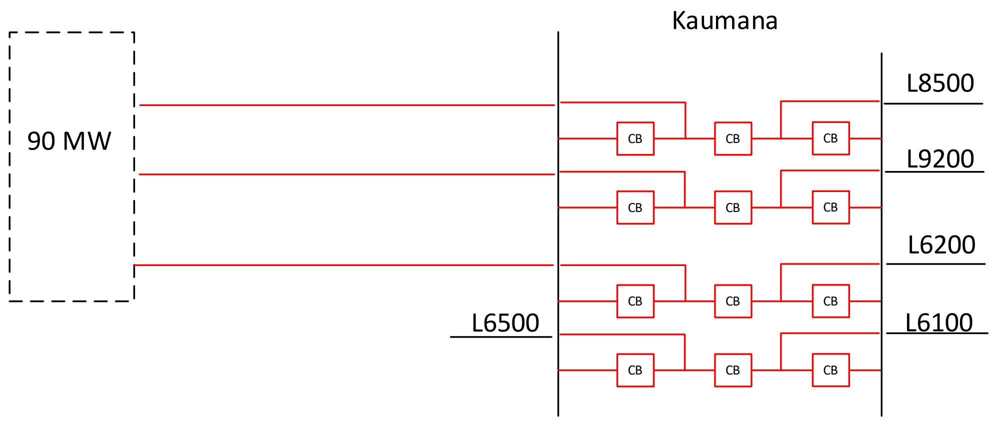



**Figure 59 Kaumana substation upgrade required for hosting REZ Group 1, REZ Option 1 & 2**

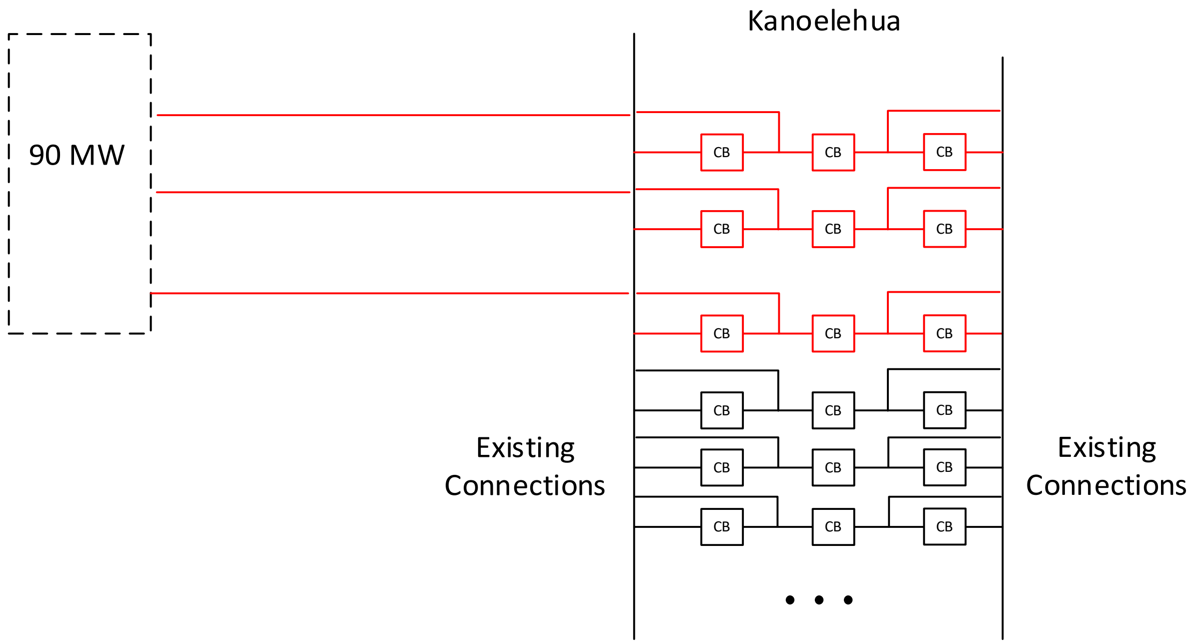



**Figure 60 Kanoelehua substation upgrade required for hosting REZ Group 1, REZ Option 1 & 2**

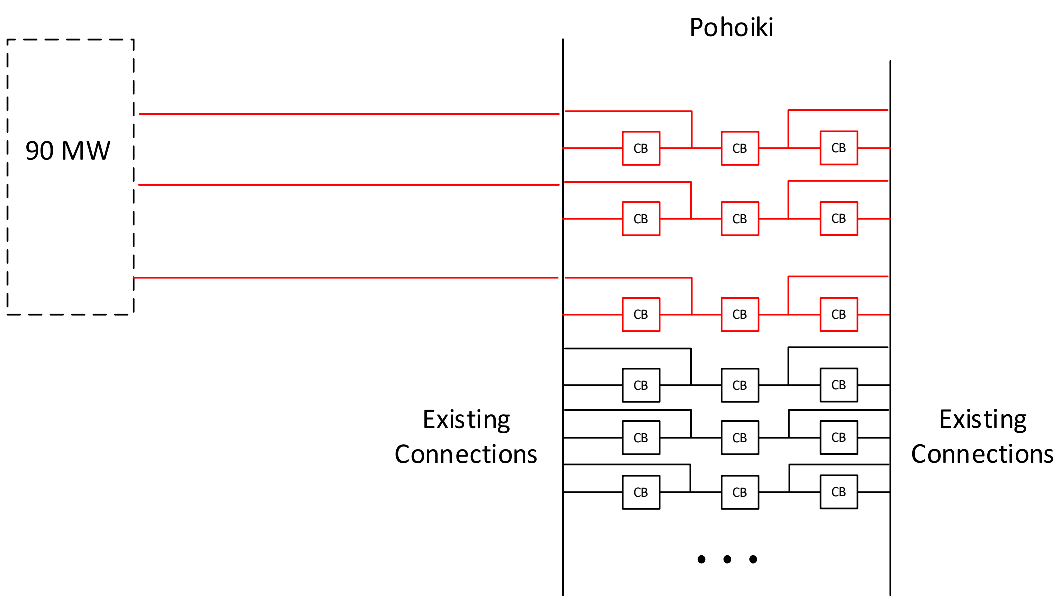



**Figure 61 Pohoiki substation upgrade required for hosting REZ Group 1, REZ Option 1 & 2**

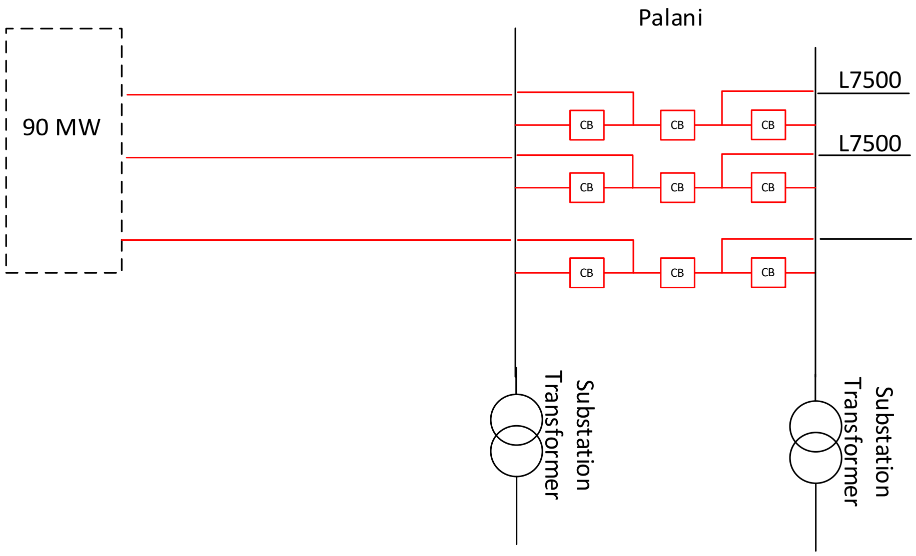



**Figure 62 Palani substation upgrade required for hosting REZ Group 2, REZ Option 1 & 2**

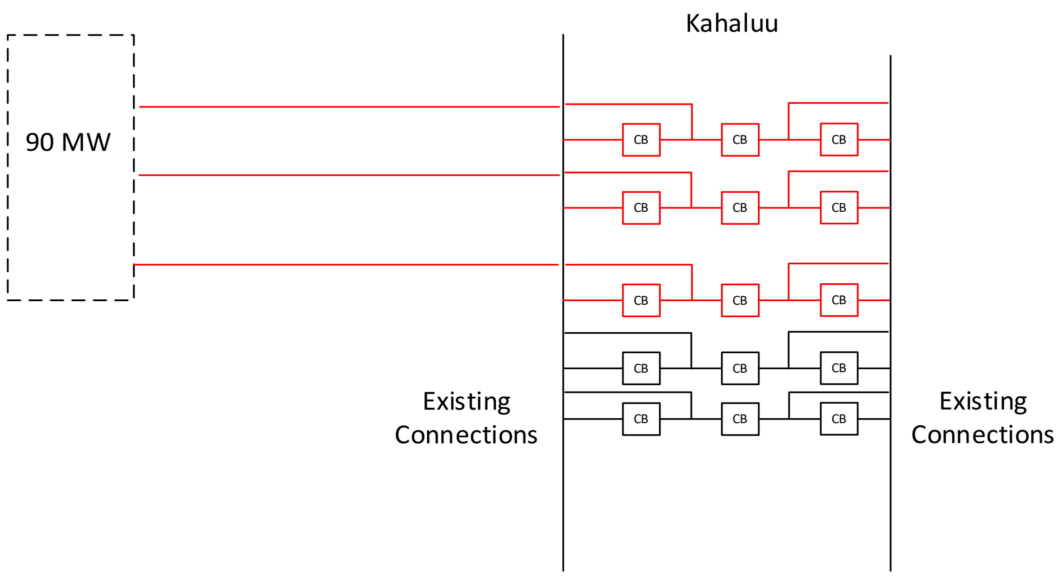



**Figure 63 Kahaluu substation upgrade required for hosting REZ Group 2, REZ Option 1 & 2**

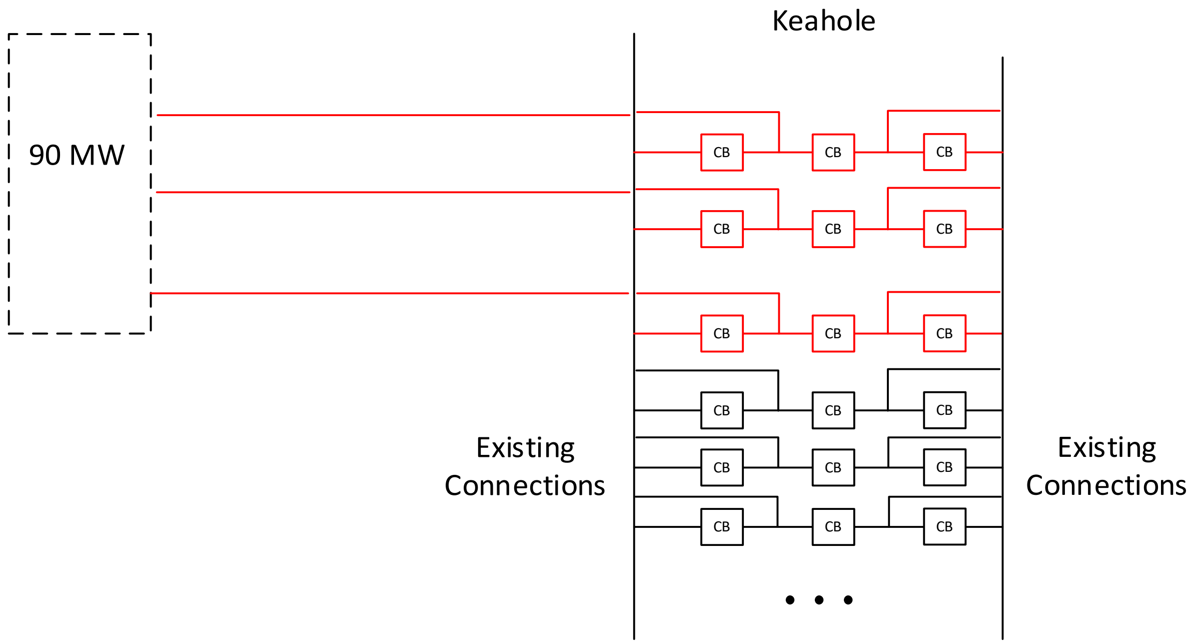



**Figure 64 Kahaluu substation upgrade required for hosting REZ Group 2, REZ Option 1 & 2**

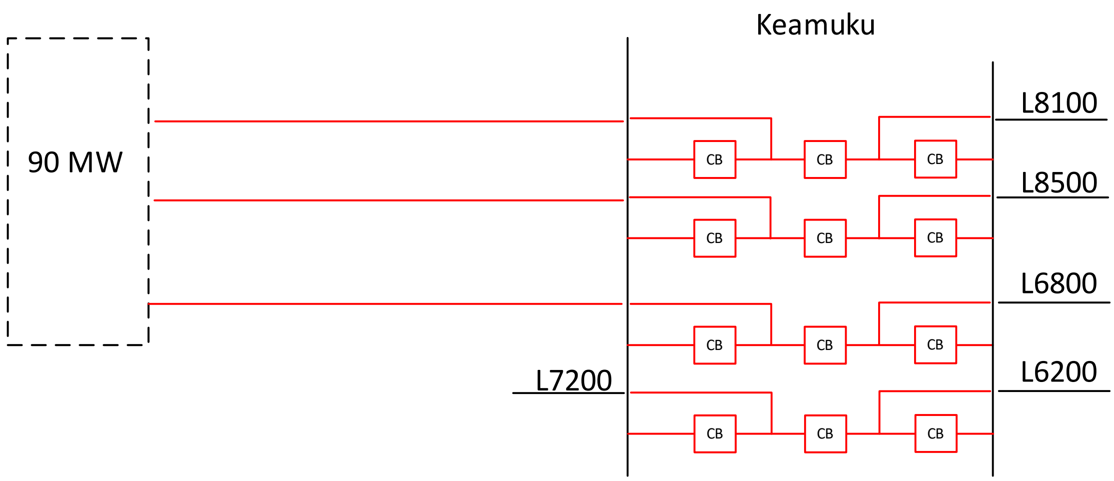



**Figure 65 Keamuku substation upgrade required for hosting REZ Group 2, REZ Option 1**

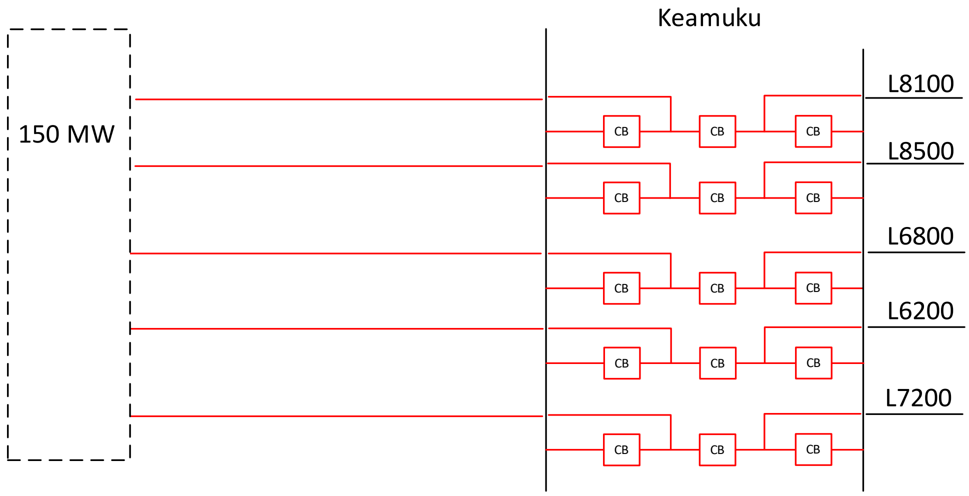



**Figure 66 Keamuku substation upgrade required for hosting REZ Group 3, REZ Option 2**

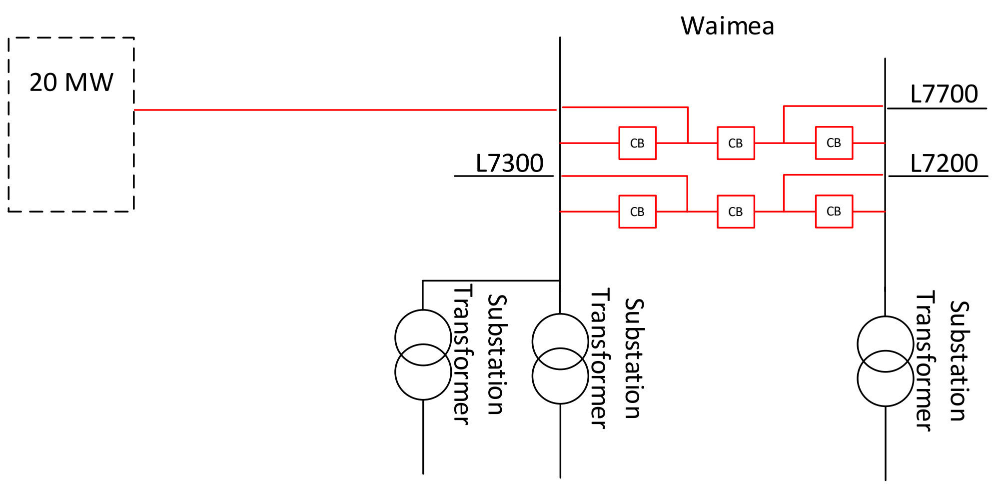



**Figure 67 Waimea substation upgrade required for hosting REZ Group 4, REZ Option 2**

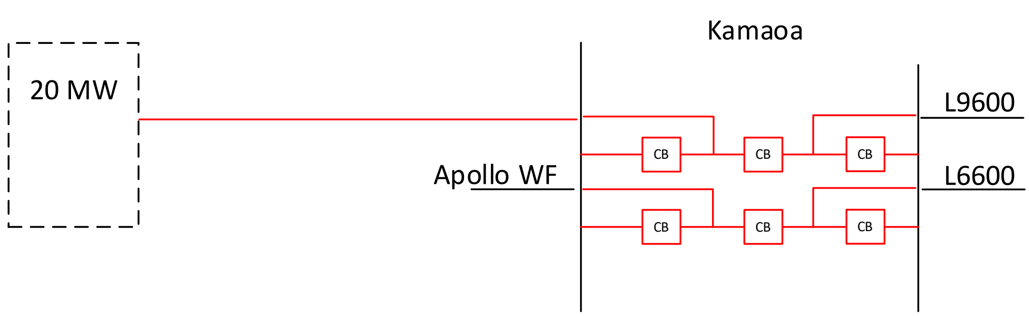



**Figure 68 Waimea substation upgrade required for hosting REZ Group 5, REZ Option 2**

# 11. Appendix B – IGP Technical Advisory Panel (TAP) Feedback

The Company presented the REZ Study methodology to the IGP TAP Transmission Subgroup on 10/1/21. This section includes the TAP Transmission Subgroup's notes, which includes feedback and Company responses. The meeting notes refer to a presentation or slide deck, which is the October 6, 2021 IGP STWG meeting. Feedback incorporated into this revision of the REZ study are denoted with this icon (and section number below, if applicable): #.#.#

The Company will continue to seek guidance and input as needed from the TAP to continue refining future revisions of the study.

**IGP TAP Transmission Subgroup**

**Feedback on REZ Study**

**10/6/2021**

This feedback to HECO is based on HECO's slides and presentation on their initial REZ Study on 10/1/2021.

**TAP members attending:** Andy Hoke (NREL, Chair), Dana Cabbell (SCE), Matt Richwine (Telos/HNEI), Deepak Ramasubramanian (EPRI). Not able to attend: Debbie Lew (ESIG)

**HECO presenters:** Ken Aramaki, Li Yu, Addison Li, Marc Asano, Chris Lau

TAP feedback and comments are divided into three categories:

1. Informational – no action needed.
2. Suggest revising REZ study before November 1 submission deadline.
3. Consider feedback for future portions of the IGP process (after the Nov 1 deadline).

## 11.1. TAP comments during meeting and HECO responses

Do the REZ zones consider environmental and community acceptance constraints?

- Response: Not at this stage. They are based on the NREL Alt 1 study with relaxed land slope constraints. A next step will obtain stakeholder feedback. We expect significant feedback from stakeholders, especially in certain potential REZ zones.

The REZ study examines a single point in time (evening peak). Is this because it is assumed to be the worst-case from transmission capacity perspective?

- Response: Yes.
- TAP follow up: Is this based on the assumption that future resources will include a BESS?

- Response: Yes, or that the resources will otherwise be made dispatchable.

What transmission constraints were considered? Thermal? Voltage?

- Response: Thermal (overcurrent) constraints are considered. Voltage constraints would be considered in a future more detailed study after receiving stakeholder input.

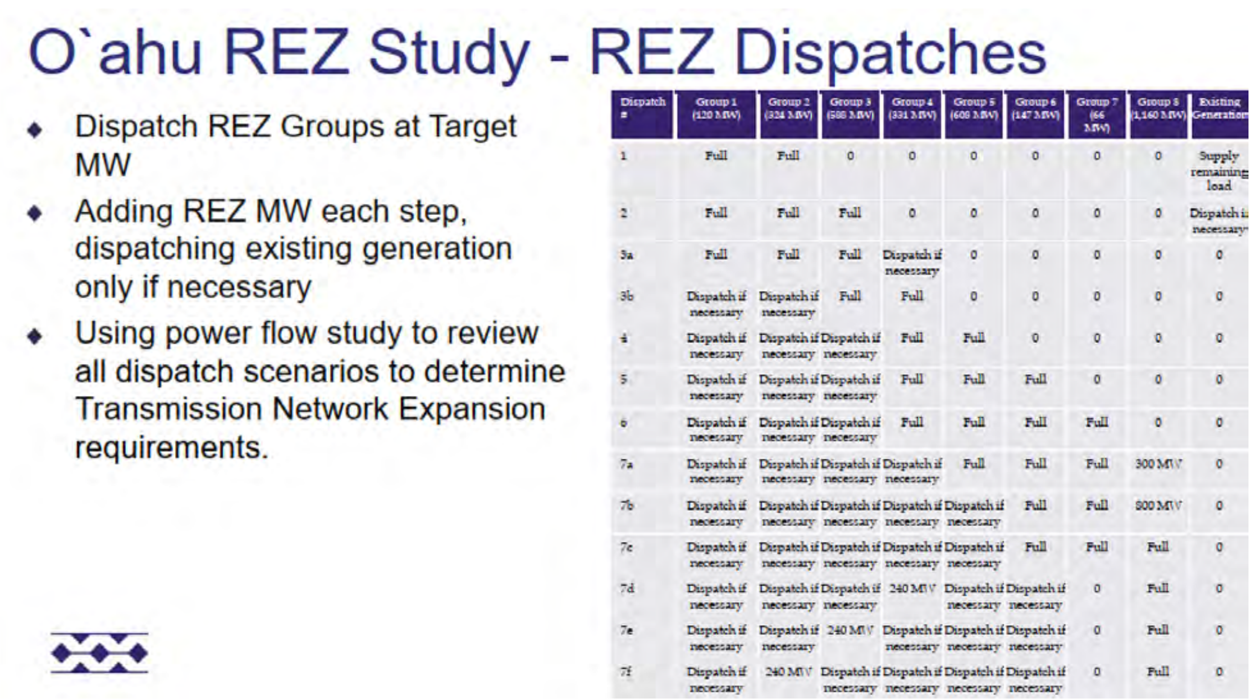
Were N-1 and N-1-1 contingencies considered in the REZ study power flows?

- Response: N-2 was considered for Oahu, and N-1 was considered for Maui and Hawaii. N-2 and N-1 scenarios were limited in scope for the study.
- TAP follow up: Future work could look at which contingencies drive needs for transmission upgrades in detail.

Why do you differentiate between "REZ enablement" and "Transmission network upgrades" separately rather than just considering the total transmission investment needed?

- Response: REZ enablement can be directly assigned to a project, whereas transmission upgrades may not be able to be. Also, see study results, where many REZ groups can be interconnected with only REZ enablement (i.e. a transmission intertie, and without network upgrades). We think this is a key finding.

How were the dispatches chosen? (For example, the dispatches in the screenshot below)




| Dispatch # | Group 1 (120 MW) | Group 2 (324 MW) | Group 3 (588 MW) | Group 4 (331 MW) | Group 5 (608 MW) | Group 6 (147 MW) | Group 7 (66 MW) | Group 8 (1,160 MW) | Existing Generation |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Full | Full | 0 | 0 | 0 | 0 | 0 | 0 | Supply remaining load |
| 2 | Full | Full | Full | 0 | 0 | 0 | 0 | 0 | Dispatch if necessary |
| 3a | Full | Full | Full | Dispatch if necessary | 0 | 0 | 0 | 0 | 0 |
| 3b | Dispatch if necessary | Dispatch if necessary | Full | Full | 0 | 0 | 0 | 0 | 0 |
| 4 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | 0 | 0 | 0 | 0 |
| 5 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 0 | 0 | 0 |
| 6 | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | Full | 0 | 0 |
| 7a | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 300 MW | 0 |
| 7b | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | 800 MW | 0 |
| 7c | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Full | Full | Full | 0 |
| 7d | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |
| 7e | Dispatch if necessary | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |
| 7f | Dispatch if necessary | 240 MW | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | Dispatch if necessary | 0 | Full | 0 |

- Response: We chose a range of dispatches designed to push each REZ zone to peak output.

- TAP follow up: The dispatches chosen are very important to the study outcome. Dispatches that draw from multiple REZ zones in parallel may produce a lower need for transmission.
- Response: Agreed. See the study outcomes. For Oahu, network upgrades are only needed for one REZ group (Group 8), and only beyond 300 MW. Beyond that threshold, Group 8 appears likely to be unfeasible. We will add a note about the 300 MW threshold to the slides. This REZ group is one of the most likely to see stakeholder pushback due to its location.
- TAP follow up: Agreed that this is an important finding. It can be important to consider not only active power redispatch but also reactive power dispatch and voltage profile across the network. This can determine network hosting capacity limits when considering multiple REZs at the same time.
- TAP follow up: The matrix on slide 17 is critical. Given the ~3x overbuild by nameplate of renewables, there should never be any case where any zone is at full export; it would be a very unusual and avoidable operating condition to have only one zone able to export and all other zones not able to. By all zones exporting and sharing the power generation, you're also distributing the power flows across the transmission infrastructure and reducing the chance of overloads. By considering any zone maxed out, it creates a local stress on the infrastructure and drives up the need for more infrastructure when in reality, the system may not need to be operated that way. Therefore, more dispatch conditions need to be evaluated where all zones are sharing the effort. Then when overloads are determined, shift more export to zones that do not as quickly overload the transmission system. This is very time-consuming to do manually; a chronological tool like PLEXOS with a nodal transmission model will greatly expedite such an analysis.

HECO should consider a chronological tool with an underlying transmission topology rather than a single point in time for this REZ analysis. For example, you need to make sure you have enough energy to charge the BESS. Also consider stacked BESS services. There are chronological tools that enable this, including iteration. It can be very hard to tell if you're close to a thermal constraint using manual dispatches since the constraints are binary.

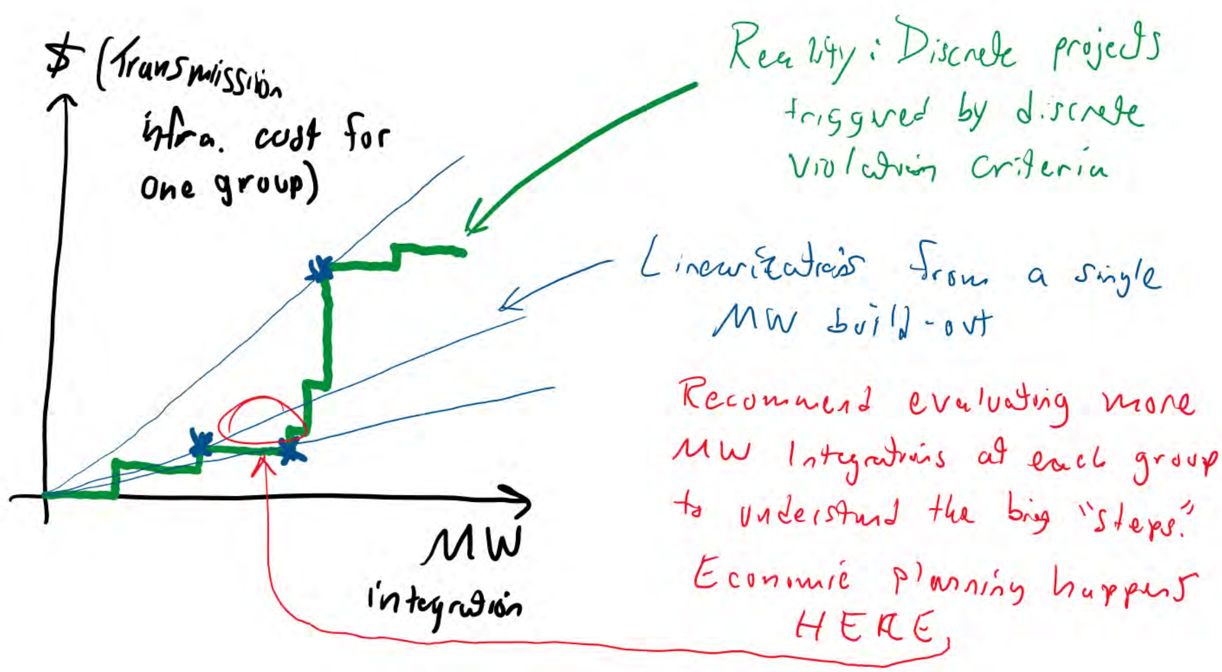
- Response: For this initial analysis, the goal is to obtain approximate $/MW transmission costs for different REZ zones to inform the RESOLVE study. That would then be followed by PLEXOS, which is chronological. There will be future iterations that go into greater detail. We also need the basic REZ costs to get stakeholder input on potential REZ/PV locations. The process will be iterative.
- TAP follow up: The approach of ranking groups is a good one. However, the per-unitized cost estimate (screenshot below) misses the very important fact that the cost of transmission infrastructure does not vary linearly with the MW of REN integration; it varies in discrete steps (see hand sketch below). Linearizing it can result in a misleading metric that then feeds into the beginning of the RESOLVE-PLEXOS process shown on

slide 57 and affects all downstream results. An evaluation of more MW integration levels is strongly recommended for Group 8, and recommended for the other groups as it may determine a different priority/cost for integration in each zone; for example, a stepwise $/MW curve for each group may be obtained, as sketched below. At the same time, the TAP recognizes that this is an initial pass at transmission cost estimation that will be refined in future steps.

5.4.8

# O`ahu REZ Study – Cost Estimate


| REZ Group | Group 1 (120 MW) | Group 2 (324 MW) | Group 3 (588 MW) | Group 4 (331 MW) | Group 5 (608 MW) | Group 6 (147 MW) | Group 7 (66 MW) | Group 8 (1,160 MW, 138 kV) | Group 8 (1,160 MW, 345 kV) |
|---|---|---|---|---|---|---|---|---|---|
| REZ Enablement Estimate ($MM) | 24.5 | 86.0 | 818.8 | 286.9 | 1,076.1 | 95.9 | N/A | 1,410.9 | 1,083.5 |
| Transmission Network Expansion ($MM) – See next slide | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 1,331.1 | 1,331.1 |
| Cost Estimate ($MM/MW) | 0.20 | 0.27 | 1.39 | 0.96 | 1.77 | 0.65 | N/A | 2.36 | 2.08 |



When will non-transmission alternatives be considered?

- Response: This would be considered in a more detailed analysis later in the process.
- TAP follow up: Non-transmission alternatives such as power flow control devices (phase shifters, in-line compensators, etc) or even energy storage elements for congestion management can help with improving power flow across the network. Use of dynamic line rating technology to manage flows in operational time frame can also be considered.

Why was offshore wind studied only for Oahu? Perhaps because there is sufficient PV resource on other islands?

- Response: This was based on an NREL study that looked at Oahu.

Why is the Kahe offshore wind location not feasible?

5.4.5
- Response: It is not feasible with the 138 kV option, but it is feasible with the 345 kV loop. We will clarify this.

The 345 kV would be a new transmission voltage level for HECO meaning a need for a whole new class of equipment, spare parts, etc.

- Response: Agreed. The 345 kV option is only slightly cheaper than the other options, and that does not consider the costs of adding equipment for a new voltage class, so we do not think it will be the best option from a cost perspective.
- TAP follow up: 345 kV would also come with additional land costs if your existing substations don't have room.

Does adding 138 kV make sense for Maui? Perhaps this is subject to the same considerations as 345 kV on Maui, since it would be a new voltage level for that island?

Does the eventual PLEXOS study feedback into another iteration of RESOLVE?

- Response: Yes, that is a later part of the IGP process not shown on the slide in question (screenshot at end of this document).

The TAP agrees with the premise that it is preferable to provide planned interconnection points for renewables rather than piecemeal tapping of transmission lines as is currently being done.

Overall, the REZ study does a good job of establishing transmission limits that may impact amounts of PV that can be interconnected beyond what is seen from the resource analysis. HECO should also consider environmental concerns and community feedback before finalizing REZ plans.

- Response: Agreed. A next step is to engage with the communities.

What is the motivation for the study and the resources the study aims to facilitate?

- Response: We are working towards 100% renewables.  Existing resource additions are already getting curtailed at times.  Putting in new transmission lines is expected to take 10-20+ years.  The IGP analysis needs to account for those long-term transmission costs.

### 11.2. Other TAP comments post-meeting:

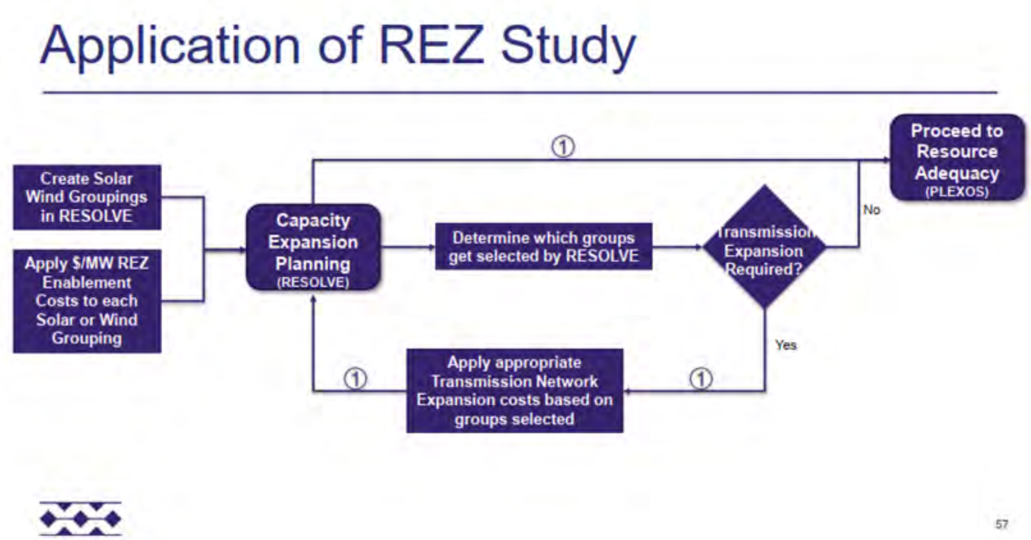
It appears the study did not include generation contribution from local DERs.  Couldn't BTM DERs with batteries serve a significant portion of evening load in the future, thereby reducing some transmission constraints?

- Response: The study did not include contributions from DER.  The study was narrowly focused on allowing large blocks of grid-scale resources.  RESOLVE would pick DER and/or grid-scale resources, and follow-on studies would be needed to determine what those specific transmission requirements would be.

The study noted that dispatches that source all the generation from one area should be avoided. That makes sense, but what about a severe weather scenario that makes generation one side of an island unavailable?  Does that need to be considered?

- Response: Good point and we will need to think about this one more.  This was not studied in the REZ study but may be needed as a future sensitivity as well as in separate studies.  In developing severe weather scenarios, would also need to take into account the full suite of resilience-related solutions to manage the impact.

The following flowchart was shown at the end of the presentation (from a different slide deck, we think) showing how the REZ study would feed into future steps using RESOLVE then PLEXOS. Perhaps that flowchart can be added to the presentation to help give context[9].




[9] *See* Slide 74.  Presented to IGP STWG October 6, 2021: https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/stakeholder_technical/20211006_stwg_meeting_presentation_materials.pdf

# 12. Appendix C – IGP Stakeholder Technical Working Group (STWG) Feedback

The Company recognizes stakeholder engagement as an integral part of the IGP process. In an effort to proactively solicit stakeholder feedback on this report, the Company provided a draft report[10] to stakeholders for review and comment on October 1, 2021. The Company subsequently met with the STWG on October 6, 2021 to address questions and receive feedback from the stakeholders. Meeting minutes capturing feedback from the discussion and presentation materials from the meeting can be found on the IGP website.[11]

The Company received feedback from various Organizations, which is consolidated anonymously below. Feedback from stakeholders in this section are shown in **bold**, and the Company's response to the questions or feedback are shown in *italics*.

1. **At 13, please explain and provide an example of how Hawaiian electric will "develop <u>very</u> different transmission system upgrade options to cover all feasible options" in Step 4.**
    a. *For all three islands, the Transmission Network Expansions developed within this study are considered very different transmission system upgrade options. For example, in O`ahu, to export 1.2 GW potential on the north of Wahiawa 138 kV substation, three different options are considered in the study – Option 1: building new 138 kV loop between Wahiawa and Kahe based on new right-of-way, Option 2: re-conductor existing circuits and adding new circuits based on existing right-of-way among Kahe, Wahiawa, and Waiau, and Option 3: building 345 kV networks among Kahe, Waiau and Wahiawa. For Maui island and Hawai`i island, different REZ options are developed which required different transmission system upgrades.*
2. **At 19, please provide the sources and methodology for developing unit costs for transmission costs.**
    a. **How were the percentage-based cost adders (e.g. PM costs) calculated? Please provide a description of the projects that were analyzed to develop these percentages.**
        i. *Per unit costs are developed using expected labor hours, materials, and outside services for typical projects of certain voltages based on experiences on past projects. They are high-level and intended for use in Class 4 or 5 estimates.*
            1. *Maturity level of project definition deliverables = 0-15%*

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[10] *See* https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/stakeholder_technical/20211001_renewable_energy_zones_draft.pdf

[11] *See* https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/stakeholder_technical/20211006_stwg_meeting_notes.pdf

2. *Purpose of estimate = Concept screening or study/feasibility*
3. *Methodology = capacity, equipment, judgement factors*
4. *Expected accuracy range = -50% to +100%*

ii. *Percentage-based cost adders were calculated as follows:*

1. *PM costs (5%) – Specific projects were not analyzed in determining this percentage. This was a rough estimate based on the types of projects considered. Each project will be unique and a more detailed look at the requirements of each project will be needed to determine the appropriate level of PM effort. This percentage was intended to acknowledge that there will likely be PM costs for each of these projects and to try to account for it in these high-level estimates.*
2. *Land/Permitting (10%) – Specific projects were not analyzed in determining this percentage. Land and permitting costs vary greatly depending on the requirements and location of each project. Land/permitting costs were added if new land was required for a new substation or substation expansion, if easements were required for new transmission lines, or if we expected major permitting requirements. No detailed analysis of the land/permitting costs were completed for this iteration of the study. The percentage was intended to acknowledge that there will be land/permitting costs for certain projects and to try to account for it in these high-level estimates.*

3. **Are the dispatch scenarios organized in a particular order, such as cost, difficulty to interconnect, and/or capacity size?**
   a. *There is no particular order for organizing dispatch scenarios. All dispatch scenarios are designed by considering all REZ Groups to be able to be dispatched at the potential MW values.*
4. **How will the cost estimates for REZ groups be communicated to developers?**
   a. *The Company intends to provide this REZ Study as well as any revisions to future developers, which will include cost estimates for developers to review.*
5. **Will Hawaiian Electric pursue any of the transmission upgrades proactively (i.e. before projects are identified through an RFP?)**
   a. *There are several major steps that need to take place before pursuing transmission upgrades identified in this study. In the near-term, the results of this study will be used to inform the IGP Process by providing more complete estimates of transmission costs needed to implement various renewable energy scenarios. The information from these analyses will help to support broad policy-related discussions, while including community and stakeholders, to understand the transmission-related requirements to attain higher levels of grid-scale renewable energy. These discussions and further study(s) will provide an overall plan, which can be incrementally built-to as renewable resources continue to be implemented.*
6. **Will Hawaiian Electric consider targeted RFPs limited to select REZ groups?**

a. *Yes, if the REZ work and further community and stakeholder feedback support targeted locations, the Company will consider future targeted RFPs based upon the information developed in the REZ study.*

7. **How would costs of the transmission projects that serve new and existing resources be shared by IPPs and the utility? For future projects, how will Hawaiian Electric mitigate the risk of projects dropping out and potentially resulting in cost-shares of REZ enablements increasing?**
   a. *This would need to be reviewed on a case-by-case basis. For example, if a certain REZ development required transmission upgrades prior to the implementation of renewable projects that require it, the Utility may request recovery ahead of approvals of PPAs for the resources, which would place costs at risk. However, there may be instances where transmission upgrades could be started concurrent to an RFP of a certain REZ, which would mitigate risk by knowing whether developers are pursuing renewable projects in the zone. Based on this variation, the answer will depend upon the specific situation, which is yet to be determined.*
8. **For each region identified in the REZ analysis, please explain how much additional capacity can be integrated into the existing transmission system without transmission upgrades or expansion (i.e., existing transmission interconnection capacity).**
   a. *The interconnection of REZ groups, at minimum, require an interconnection to an existing switching station, which generally require an expansion of a switching station to support the interconnection of the resource(s). The REZ study provides cost estimates to expand or build switching stations, and extend lines to the REZ(s). Based on stakeholder and TAP feedback, this version of the study has been revised to provide cost information for incrementally adding capacity to certain REZs.*
9. **Please explain how feasibility (e.g., land use, community acceptance, affordability, etc.) of transmission upgrades/expansion will be incorporated into the REZ analysis.**
   a. *The Company will rely on stakeholder and community feedback to prioritize REZ groups and/or revise REZ groups. Future REZ analyses will adjust the scope of the study based on feedback from the community and stakeholders.*
10. **We request additional information on how HECO is estimating the cost to upgrade infrastructure based on your analysis.**
    a. *In addition to the unit costs provided in Section 3.3 of this report, the following information is provided.*
    b. *Substation estimates*
       i. *Based on past experience with similar projects.*
       ii. *Based on a high-level look at the existing substations to check feasibility of expansion.*
       iii. *If expansion of existing substation not possible, assumed a full rebuild of the substation nearby if feasible or eliminated option.*
       iv. *Assumed land/permitting could be obtained.*
    c. *T&D estimates*
       i. *High-level routing of new transmission lines was completed to determine feasible routes.*

ii. *New lines were run from the existing substations to either a new substation in the REZ or to the edge of an REZ.*
iii. *If lines were running to the edge of an REZ, they ended at different points of zone so that projects in any part of the zone could interconnect to a line.*
iv. *If the substation (new or existing) that renewable projects would interconnect to was already in the zone, then it was assumed Proposers of projects would run the line to the substation and no costs were included in this study.*
v. *Assumes there is space in the ground for UG facilities and poles along the routes.*
vi. *Assumes easements/permitting can be obtained for new transmission lines.*

11. **We recommend that in future studies HECO look at the same scenarios (before and after upgrades) with transient stability studies (to include advanced inverter modeling and interconnections) and economic dispatch studies across many scenarios.**
    a. *The Company agrees and stability analyses will be included in future REZ studies and/or as part of the System Security step in the IGP process should certain REZ be selected by the modeling.*
12. **For clarification, is the current conclusion that OSW [Offshore Wind] could not be interconnected at Kahe or Halawa substations, because those substations cannot be expanded? And if so, are there other stations besides Ko'olau which could accommodate interconnection of OSW?**
    a. *Correct, the analysis found that interconnecting 400MW or 600 MW at Kahe, Halawa, and Iwilei are not feasible. The interconnection at Kahe substation required an expansion at Ho`ohana substation, which is not feasible due to space constraints. The interconnection at Halawa substation required an expansion at Makalapa substation, which is also not feasible due to space limitations. Iwilei substation, was found to also have space constraints for the required expansion. Koʻolau substation was found to be the most feasible option to accommodate an interconnection of OSW.*
13. **We appreciate the analysis of the sensitivity for 600 MW of OSW. Given that the majority of the transmission network upgrades are driven by new 138 kV transmission lines that would be required, what capacity of OSW could be accommodated at each identified substation without adding new transmission lines? This has practical and planning implications. For instance, it could be more economical to downsize OSW interconnection capacity or to interconnect to more than one substation at a lower capacity. Understanding the capacity of the existing system to accommodate OSW (to minimize upgrades) could help both the Company and developers arrive at proposed projects which could be more cost-effective for customers.**
    a. *As part of a REZ analysis, an assumption was made to keep the scope and schedule of interconnecting 600MW of OSW consistent with the BOEM/NREL study, which meant the interconnection was potentially after the implementation of Groups 1-*

*8. However, given the sizes of REZs 1-8, it can be reasonably assumed that OSW of the size of these REZs, interconnections at these points could be made. Note that such OSW interconnections would displace the ability to add onshore renewables within these REZ unless additional transmission assessment and solution options are developed.*

14. **Regarding timing, the REZ analysis currently assumes that OSW would be interconnected after the eight groups of onshore REZ. what would be the required transmission network expansions if OSW we're interconnected to a substation prior to the onshore REZ upgrades? For example, if a substation were identified for OSW only, instead of onshore REZ, would less transmission upgrades be required and how might that impact costs?**
    a. *See response to question 13 above. OSW could proceed similar to on shore renewables developed within an REZ. This REZ analysis identifies transmission requirements under a specific set of assumptions of the level of renewable potential that could be developed within a geographical area. If more potential exists, additional REZ analysis can be performed to determine the transmission requirements for this higher level of renewable energy systems.*