ELECTRICITY GRID IMPACT ASSESSMENT FOR THE ISLAND OF SAINT HELENA

Summary Report

Connect Saint Helena Ltd

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Objective: To determine the private PV hosting capacity of the Island of Saint Helena grid.

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1.1 Introduction

A series of simulation studies were conducted to determine the safe hosting capacity of the CSH network for private PV. These are:

- Steady-state evaluation

  The steady-state aspects include thermal loading of equipment and voltage regulation throughout the network for different contingencies of the network. It also evaluated the impact on the diesel generators, as well as the CSH-owned PV and wind generation.

  The impact of higher levels of private PV on the short-circuit levels in the network was also evaluated.

- Protection evaluation

  For this study, the existing protection settings were evaluated to determine if any settings should change, both for the existing installation as well as for potential future private PV systems connected to the grid. Both steady-state and dynamic behaviour was evaluated.

- Dynamic evaluation

  The dynamic evaluation comprised a selection of credible contingencies to evaluate the response of the diesel generators during these contingencies. Both voltage recovery after a fault and diesel generator response were evaluated to identify the scenarios where different operational procedures may be required.

- Power Quality evaluation

  The power quality evaluation extended effects seen in both the steady-state and dynamic evaluations to identify potential power quality problems in the CSH grid, when connecting private PV systems. The evaluation included voltage regulation and voltage unbalance from the steady-state evaluation and added voltage changes, voltage flicker and harmonic distortion as additional evaluations.

- Mitigation options

  For this report, a set of possible mitigation options was discussed. From these, an appropriate selection was discussed in context of the CSH grid, as well as where these options may be required.

1.2 Hosting capacity for private PV in the CSH network

The proposed maximum capacity for private PV in the CSH grid is 420 kW[1]. These systems need to comply with the requirements of EREC ER G98, including that no export is allowed.

This hosting capacity is based on the minimum 2021/22 daytime load in the CSH grid of 871 kW and the planned minimum load on the diesel generator of 450 kW. It was shown during the steady-state evaluation that allowing export could potentially result in tripping of the diesel generator during network contingencies, e.g. when one of the feeders are tripped and therefore the current philosophy of requiring zero export or export-blocking is supported going forward.

[1] Rounded to the nearest 10 kW

This proposal is based on the technical evaluation of the CSH network, i.e. network equipment, topology of the CSH network, demand and existing generation profiles. Although the principle of, amongst others, fairness is discussed during the course of the evaluation, many non-technical aspects, such as social-economic and environmental aspects should inform the final implementation by CSH.

Further, the evaluation was done using the 2021/22 generation data from the SCADA system and no load forecasting was attempted. CSH indicated towards the end of the project that the 2022/23 demand had decreased, resulting in a revised proposed capacity of 225 kW, as discussed in APPENDIX B.

1.3 Critical Mitigation Options

1.3.1 Communication Systems

The installed capacity of VRE owned by CSH in the CSH grid is 1604 kW, vs. the minimum load of 678 kW. The daytime minimum load (when both wind and PV can produce) is 871 kW. The 960 kW of wind generation is already curtailed automatically, i.e. 644 kW of PV also may need to be partially curtailed during low-load conditions, to ensure that the minimum load on the diesel generator remains above 450 kW.

As per section 6.2 and 6.3, communication to the CSH owned PV (solar farm) is considered critical to ensure that the solar farm can also be curtailed during very low load conditions or during a loss-of-load event.

The addition of private PV (including the existing private PV) will require more curtailment of the CSH-owned VRE. It may be desirable to share curtailment of private PV in line with the CSH-owned PV curtailment. This will require communication to private PV systems as well.

1.3.2 Battery Energy Storage

BESS is recommended to assist during any of the cases of low-load, loss-of-load or loss of generation. In order to support the network during these scenarios, grid-forming BESS is recommended.

Ongoing communication to the CSH owned PV (solar farm) is recommended even when BESS is installed.

1.3.3 Generator G5 on Standby

During average loading conditions, the generator G5 is required to operate in stand-by mode, in the event that the CSH solar farm trips. This scenario is partially mitigated by either the wind generation producing, or more private PV being installed up to the proposed limit 420 kW. The requirement is that sufficient reserve is available on generator G2 to withstand the tripping of the CSH solar farm, i.e. generator G2 should not operate at more than 1.1 MW.

2 ABBREVIATIONS

Abbreviation	Definition
BESS	Battery Energy Storage System
CSH	Connect Saint Helena
DER	Distributed Energy Resources
GPV	Grid-connected PV
PV	Photovoltaic
RTPV	Rooftop PV
VRE	Variable Renewable Energy
WTG	Wind Turbine Generator

3 PROJECT REFERENCES

A project was undertaken by Connect Saint Helena (CSH), to determine the hosting capacity of the CSH grid for private PV systems. The project considered the following aspects:

- Steady-state capacity of the CSH grid

  Presented in report: “Grid Impact Study: Loadflow and Short-Circuit Studies”, report number DNV-10388172-RP0-0002-04

- Protection impacts of private PV systems on the CSH grid

  Presented in report: “Grid Impact Study: Protection Impacts”, report number DNV-10388172-RP0-0003-03

- Dynamic capacity of the CSH grid

  Presented in report: “Grid Impact Study: Dynamic Study”, DNV-10388172-RP0-0004-03

- Forecasted impact of private PV systems on the power quality in the CSH grid

  Presented in report: “Grid Impact Study: Power Quality Investigation”, DNV-10388172-RP0-0006-04

- Mitigation options are proposed

  Presented in report: “Grid Impact Study: Mitigation Options”, DNV-10388172-RP0-0005-03

4 INTRODUCTION

A series of simulation studies were conducted to determine the safe hosting capacity of the CSH network for private PV. These are:

- Steady-state evaluation

  The steady-state aspects include thermal loading of equipment and voltage regulation throughout the network for different contingencies of the network. It also evaluated the impact on the diesel generators, as well as the CSH-owned PV and wind generation.

  The impact of higher levels of private PV on the short-circuit levels in the network is also evaluated.

  It was found that the network equipment can accommodate a relatively high penetration of private PV and the hosting capacity of the grid is limited by the low load, where the diesel generators may enter an unstable operating region.

- Protection evaluation

  For this study, the existing protection settings were evaluated to determine if any settings should change, both for the existing installation as well as for potential future private PV systems connected to the grid. Both steady-state and dynamic behaviour was evaluated.

- Dynamic evaluation

  The dynamic evaluation comprised a selection of credible contingencies to evaluate the response of the diesel generators during these contingencies. Both voltage recovery after a fault and diesel generator response were evaluated to identify the scenarios where different operational procedures may be required.

  It was found that the network can tolerate major faults for most operating conditions (both high and low load) provided that the CSH owned VRE is curtailed (i.e. the diesel generator is operating in the stable region). A scenario where the operating reserve needs to be increased has been identified, which will require the parallel operation of two diesel generators at relatively low load.

- Power Quality evaluation

  The power quality evaluation extended effects seen in both the steady-state and dynamic evaluations to identify potential power quality problems in the CSH grid, when connecting private PV systems. The evaluation included voltage regulation, voltage unbalance, voltage changes, voltage flicker and harmonic distortion.

- Mitigation options

  For this report, a set of possible mitigation options was discussed. From these, an appropriate selection was discussed in context of the CSH grid, as well as where these options may be required.

When considering the connection of private PV in the Connect Saint Helena (CSH) grid, the primary concern is the low load condition, i.e. during periods of high renewable energy production, the remaining load on the diesel generator is too low. Apart from the reduction in efficiency and increased maintenance, the diesel generator may enter an unstable operating region, typically at around 15% of the generator capacity. For the CSH generator G2 with a capacity of 1.6 MVA, this is 240 kW.

This report contains a summary of the work done in this project. The purpose is to clarify the proposals for hosting capacity and guide CSH on allowing private PV systems connected to the grid.

The summaries provided in this report include the conclusions from the Executive Summaries of the individual reports listed under the Project References.

5 SUMMARY OF PRIMARY CONCERNS

This section summarises the input data that was used as well as the different problems expected in the network.

The key problems expected are as follows:

1. Low-load problem

   From both the steady-state and dynamic simulation studies, the key concern is during low-load conditions, i.e. when the load is supplied almost completely or can be supplied completely by the renewable generation sources. It is shown that this problem already exists in the CSH grid, due to the CSH-owned PV and wind generation.

   Note that the PV (and wind) systems installed in the CSH grid are grid-following and cannot support any load. A strong grid-forming device, such as the diesel generator or a grid-forming BESS, is required to provide the reference for the other VRE generators. As per current technology, private PV systems to be connected to the CSH grid should not be grid-forming as this will lead to instability when all these generators attempt to control the voltage.

2. Loss-of-load problem

   Loss-of-load refers to the situation where a large portion of the load trips off, e.g. due to a fault on a feeder. The protection that clears this fault, would also remove a large portion of the load.

3. Loss of generation

   Similar to loss of load, loss of generation would imply that a significant generator is switched off, e.g. the CSH solar farm (480 kW). This will result in a sudden increase in the load on the diesel generator.

4. Voltage unbalance

   Voltage unbalance is not expected to become a problem on the MV network. However, it is a potential concern on low voltage networks, where a few private PV systems could increase the local voltage unbalance.

5. Harmonic distortion

   It was shown that there exists a resonance condition around the 8^{th} harmonic when two of the shunt banks are out of service. For the cases simulated, the 8^{th} harmonic was not a problem, both due to harmonic cancellation and damping in the system. It is, therefore, not expected that private PV will result in a problem, but caution is advised to monitor the harmonic distortion on the grid.

5.1 Data Inputs

The total generation from all CSH-owned generation, i.e. diesel, wind and PV, were provided for one year from 2021/04/01 to 2022/04/01. There are 35034 15-minute data points, provided as kW values. This data was used as follows:

- Determine the load profile for use in simulations
- Determine the maximum, average and minimum generation per technology type
- Determine the loading on the diesel generators

These profiles were used to set the different loading conditions for the simulations, as well as evaluate the risks to operating the diesel generator in the unstable region, or even cause a diesel generator trip due to reverse power conditions.

It was found that the wind generation did not reach the full output capacity. When the performance of wind generation improves (as the problems are fixed), the existing problem may be larger than what has been experienced to date.

5.2 Low-Load Problem

The existing generation in the CSH network is as follows:

- CSH has four diesel generators, of which a single 1.6 MW generator is used most of the time. Currently, the single 1.6 MW is supplemented by an 800 kW generator during high load conditions.
- CSH owns 644 kW of PV.
- CSH owns 960 kW of wind generation.
- Private PV systems up to 225 kW.

  Note that the private PV systems are limited to zero export.

As shown in Figure 1, the CSH owned VRE penetration is 1604 kW[2] at 67%. When adding the existing private PV, this increases to 1829 kW or 76% of the diesel generation installed capacity. VRE or PV penetration is defined as the capacity of all VRE or PV as a percentage of the base generation (diesel generation) capacity.

It is generally assumed that a variable renewable energy penetration level of 10% to 15% of the installed generation capacity is a manageable level and can be accommodated without any further precautions. The high level of existing penetration is a cause for concern, especially in terms of dynamic response.

As reference, a selection of PV and wind production daily profiles are provided in Figure 2 and Figure 3. The specific profiles are described as follows:

- Min Sum — Day with minimum energy [kWh]
- Max Sum — Day with maximum energy [kWh]
- Min Peak — Day where peak production was smallest [kW]
- Max Peak — Day where peak production was largest [kW]
- Ave Ave — Day where the average production is equal to the average of all days' demand [kWh]
- Max (Envelope) — Maximum production in any time slot [kW]
- Average (Envelope) — Average production in any time slot [kW]
- Min (Envelope) — Minimum production in any time slot [kW]

[2] 960 kW + 644 kW = 1604 kW

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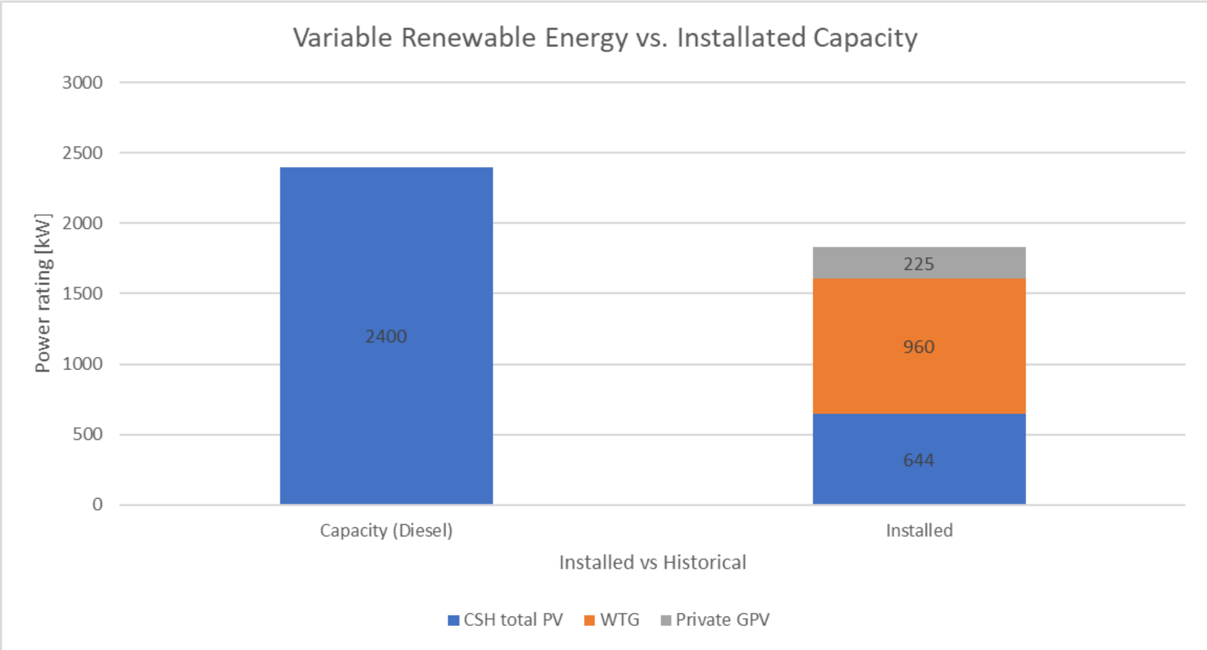

Figure 1: VRE penetration by generation capacity.

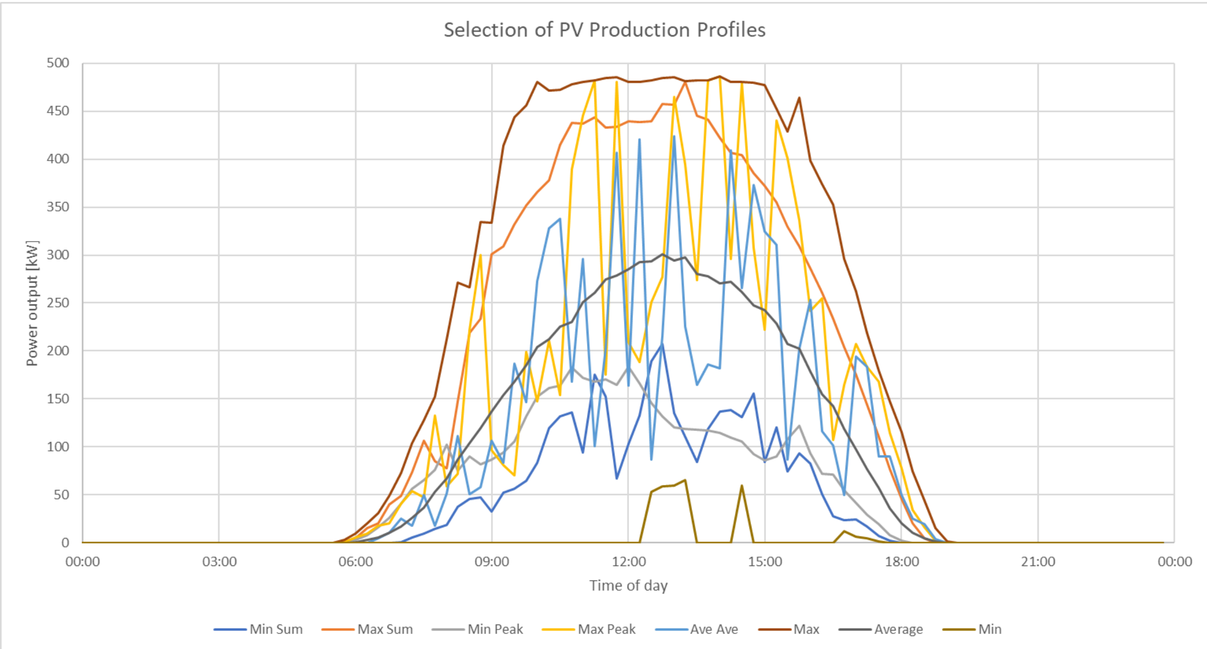

Figure 2: Selection of PV production daily profiles.

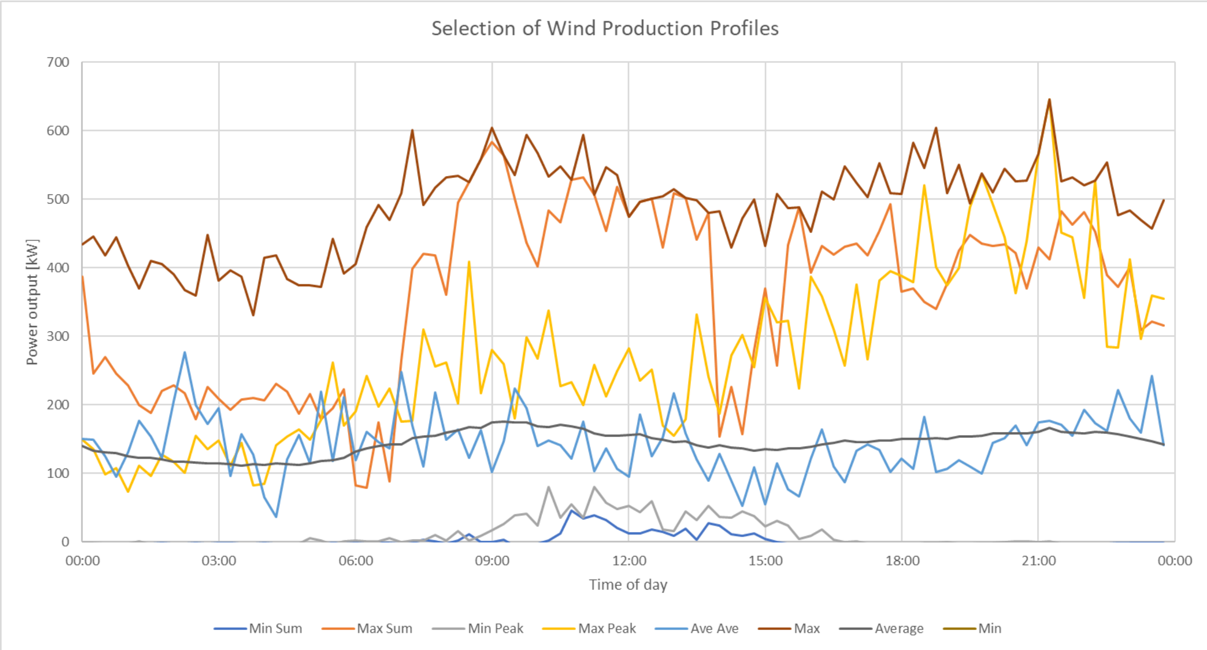

Figure 3: Selection of wind production daily profiles.

According to the SCADA data for 2021/22, loading on the CSH grid varies between 208 kW and 2305 kW. Generally, PV production will be at a maximum between 12h00 and 13h00. Historical records (consider the "Max" curve in Figure 2) indicate that the maximum value was reached over a period of 10h00 to 14h45. During this time, the load on the CSH grid varies between 871 kW and 2221 kW.

The minimum load during daytime (when PV production could be a maximum) is 871 kW. The historical PV and wind production during this time is a maximum of 903 kW (combined CSH PV and wind generation, excluding private PV systems). This shows the possibility of causing reverse power for the diesel generator. Note that low power operation, below 240 kW is not recommended for any prolonged period (longer than a few minutes), since the diesel generator may enter an unstable operating region.

This principle is demonstrated in Figure 4 for very low load conditions and high renewable generation conditions. Note that the days with maximum PV and wind have been selected (different days) for this figure. The sum of the renewable generation is shown as the yellow trace (VRE). In this case, the diesel generator would trip, due to the low-load condition.

There is already SCADA communication with the wind generation as well as the CSH Solar Farm, which will limit the wind generation during these conditions. Note that some of the historical information indicates that the curtailment is not 100% accurate, as shown in Table 1, where diesel generator output is less than 450 kW whilst the wind generators are still producing[3].

The CSH Solar Farm is set to automatic control according to the NRS 097-2-1 specification. The solar farm will therefore also trip for out-of-bound voltage and frequency conditions and support the grid.

When including the existing private PV systems, the load profiles may change as shown in Figure 5. It is now clear that there is excessive generation and either the wind has to be curtailed, or the diesel generator will trip. For this example, the remaining load on the generator will be about 200 kW, even if all wind generation is curtailed. Note that the reduction

[3] Note that these values are 15-minute average power values and may not indicate a problem, but it should be investigated to confirm that the wind curtailment operates correctly.

of private PV systems' output due to export blocking is not taken into account here, since the loading information is not available per PV system.

Table 1: Details of different generator technologies production when the diesel generator output is less than 300 kW[4].

Date	Time	Diesel [kW]	PV [kW]	Wind [kW]	Total Generation [kW]
2021/05/08	22:30	224.9	0.0	554.1	778.9
2021/08/26	11:30	299.8	346.7	467.7	1114.1
2021/10/01	13:45	294.9	475.3	284.7	1054.9
2021/10/18	12:45	283.2	480.4	416.3	1179.9
2021/11/04	11:30	296.1	432.4	286.9	1015.5
2021/11/08	15:00	234.1	460.0	411.8	1106.0
2021/12/06	13:30	277.1	480.4	274.1	1031.6

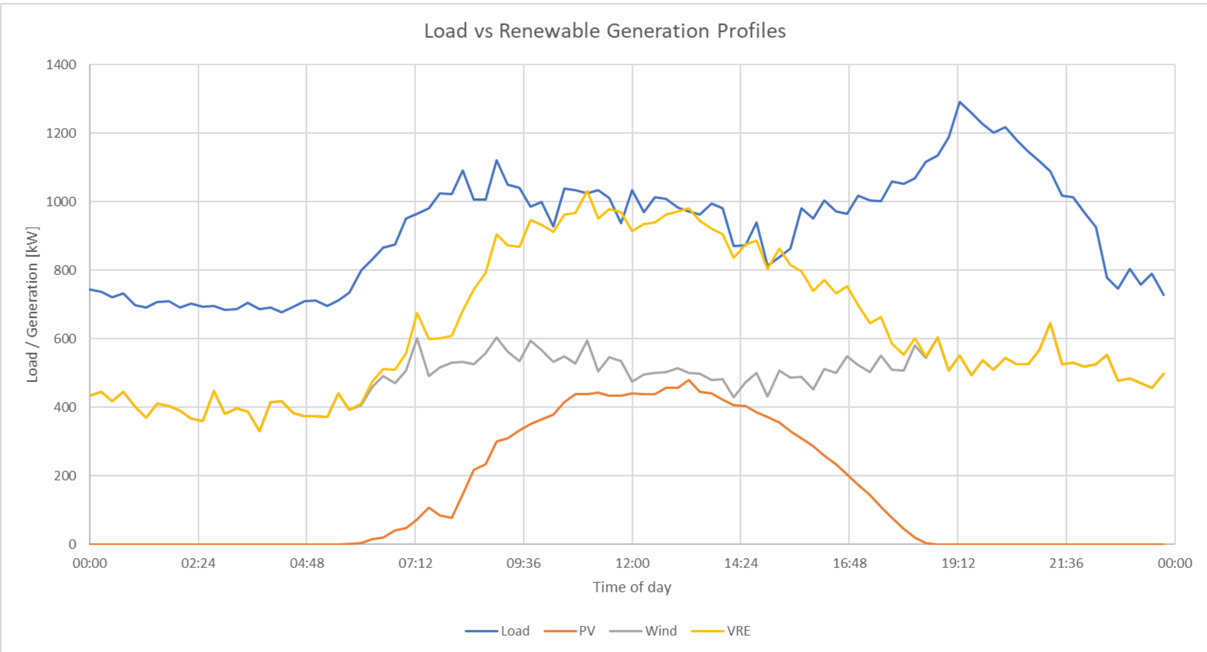

Figure 4: Example of load and renewable generation profiles for low-load conditions (no private PV).

[4] Note that these values are 15-minute average power values and may not indicate a problem, but it should be investigated to confirm that the wind curtailment operates correctly.

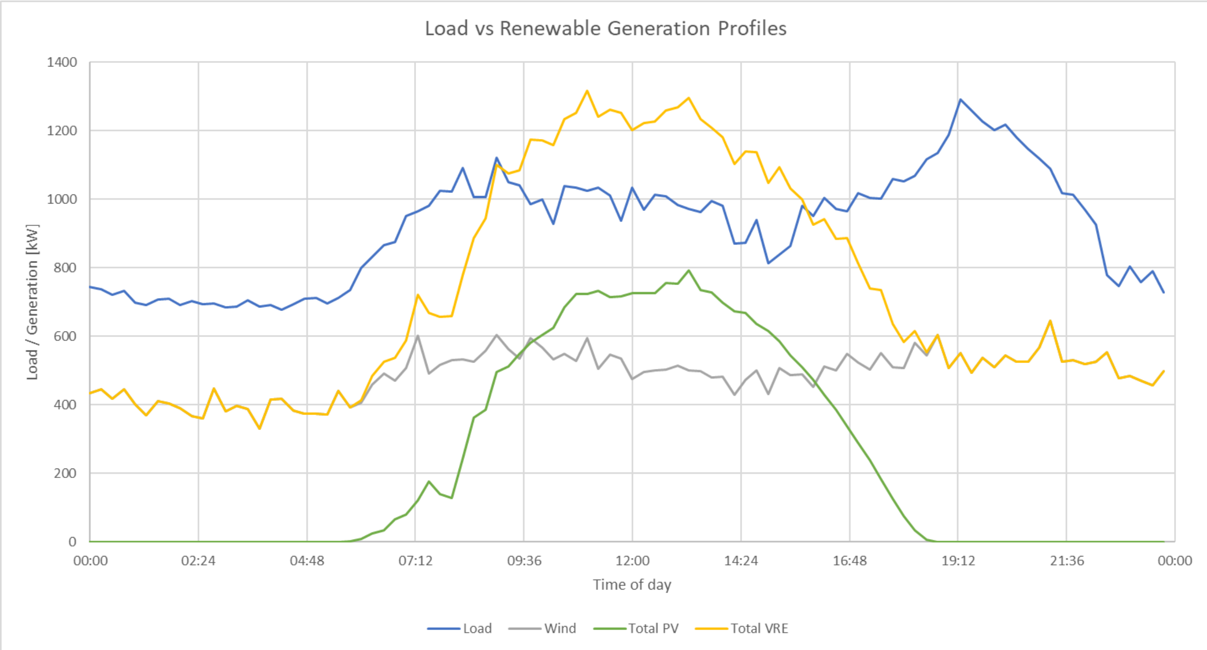

Figure 5: Example of load and renewable generation profiles for low-load conditions, including 420 kW of private PV.

5.3 Loss of Load

Loss of load is usually evaluated if a major load connected to the system should trip. In the case of CSH, the scenario where a fault occurs on one of the feeders, that will result in the trip of that feeder, is regarded as a plausible and significant loss of load event. The worst event would be tripping of feeder 2, which has the highest load.

When the system load is already low, the further reduction in load may exacerbate the low-load problem, i.e. the remaining load on the diesel generator is too low. This could likely result in a trip of the diesel generator.

The effect of tripping feeder 2 during low load conditions, and curtailment of CSH solar farm is shown in Figure 6. The load on the diesel generator drops to reverse power and recovers to a very low value before 3.3 s. The curtailment of the CSH solar farm at 3.3 s results in a slightly higher load on the generator G2.

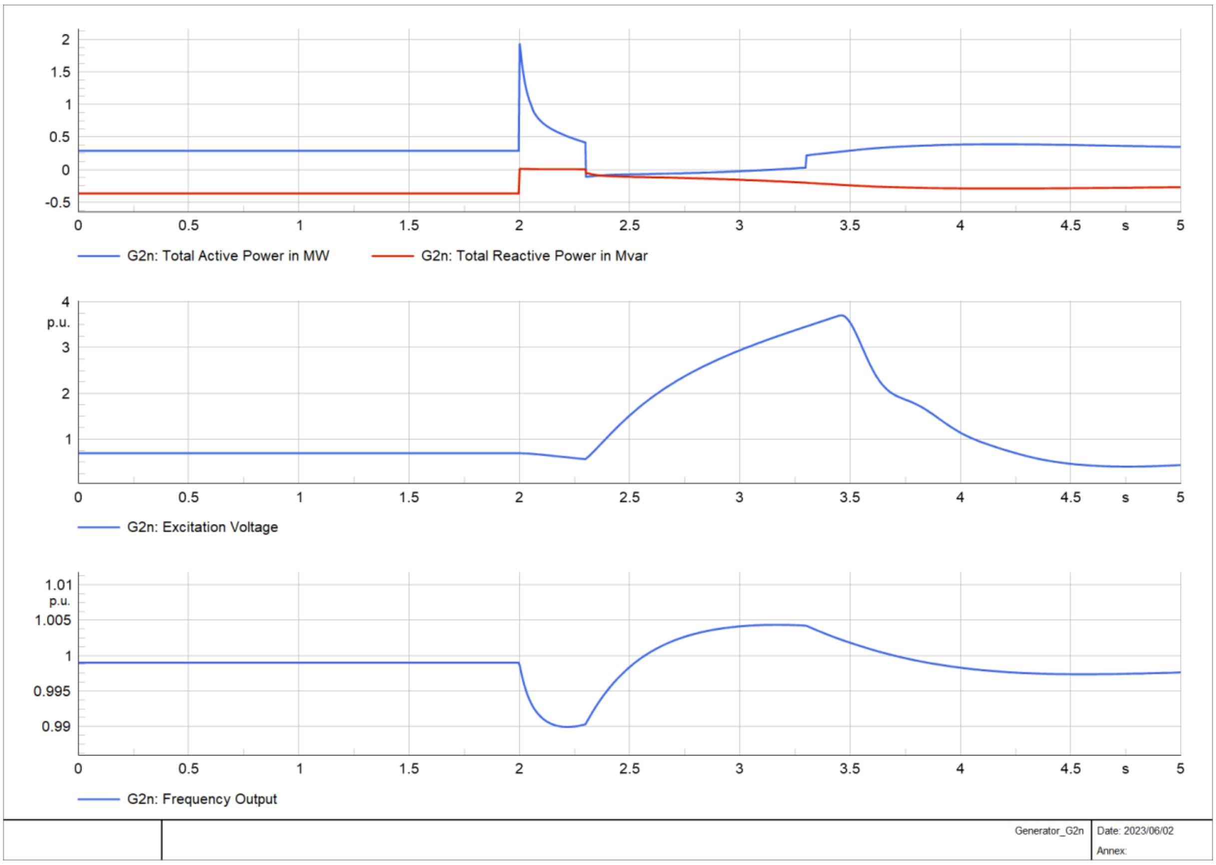

Figure 6: Effect of feeder 2 tripping during low load conditions and CSH solar farm curtailed (at 3.3 s).

5.4 Loss of Generation

Similar to loss of load, loss of generation would imply that a significant generator is switched off, e.g. the CSH solar farm (480 kW). This will result in a sudden increase in the load on the diesel generator. During average loading conditions, e.g. when the generator G2 is generating around 1.2 MW when the solar farm is at full output power, the increased load on the diesel generator would increase above 100%. Depending on the response time (start-up and synchronise) of the smaller generator, the system could recover. However, if the generator G5 is not available to support the network, this will result in a trip of generator G2 as well.

This is illustrated in Figure 7, where the load on generator G2 becomes too large and generator G2 will trip. The frequency keeps on decreasing due to the load on the generator being too high. When adding the existing and planned PV for this specific loading condition, this is prevented as shown in Figure 8, where the frequency stabilises at slightly less than 50 Hz. However, the operating condition shown in Figure 7, where only the generator G2 is operational and operating at 1.1 MW or higher, will result in generator G2 tripping, unless generator G5 is running as spinning reserve.

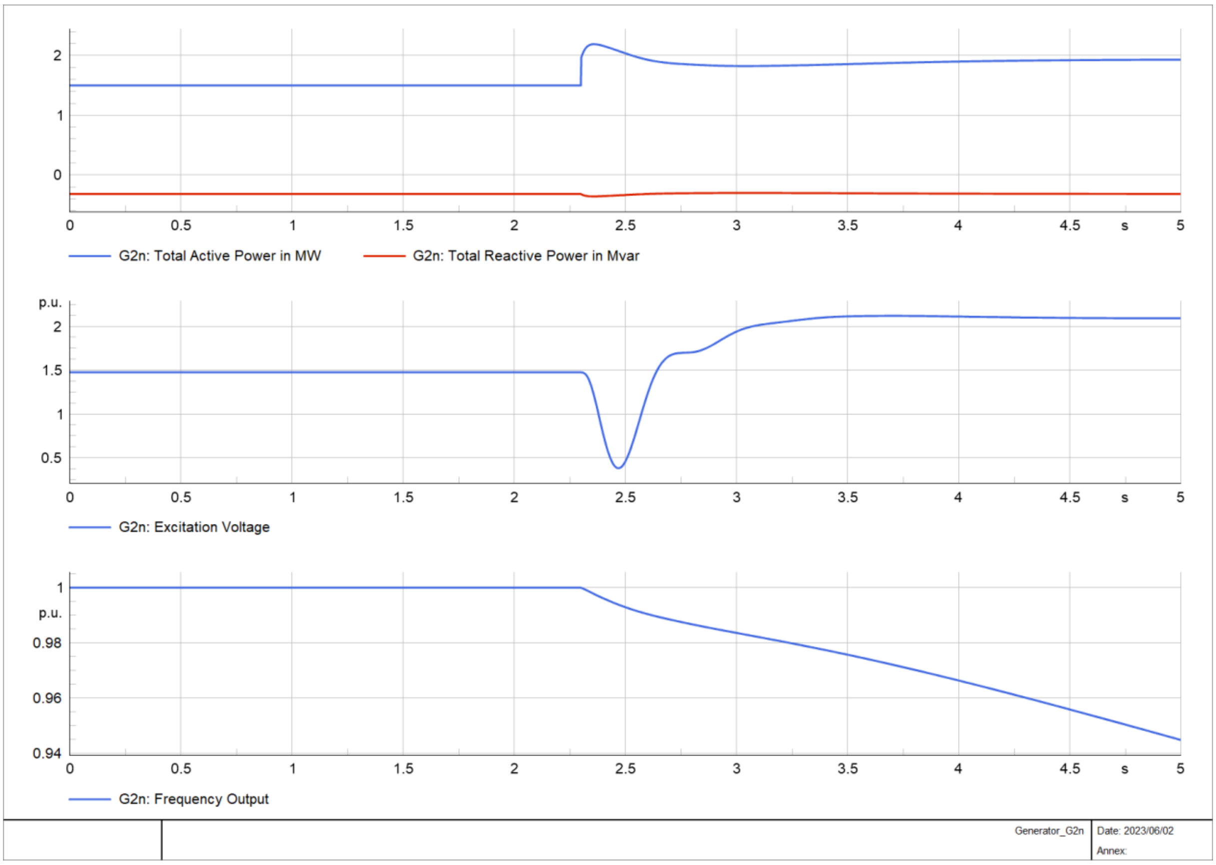

Figure 7: Effect of CSH solar farm tripping during high load conditions.

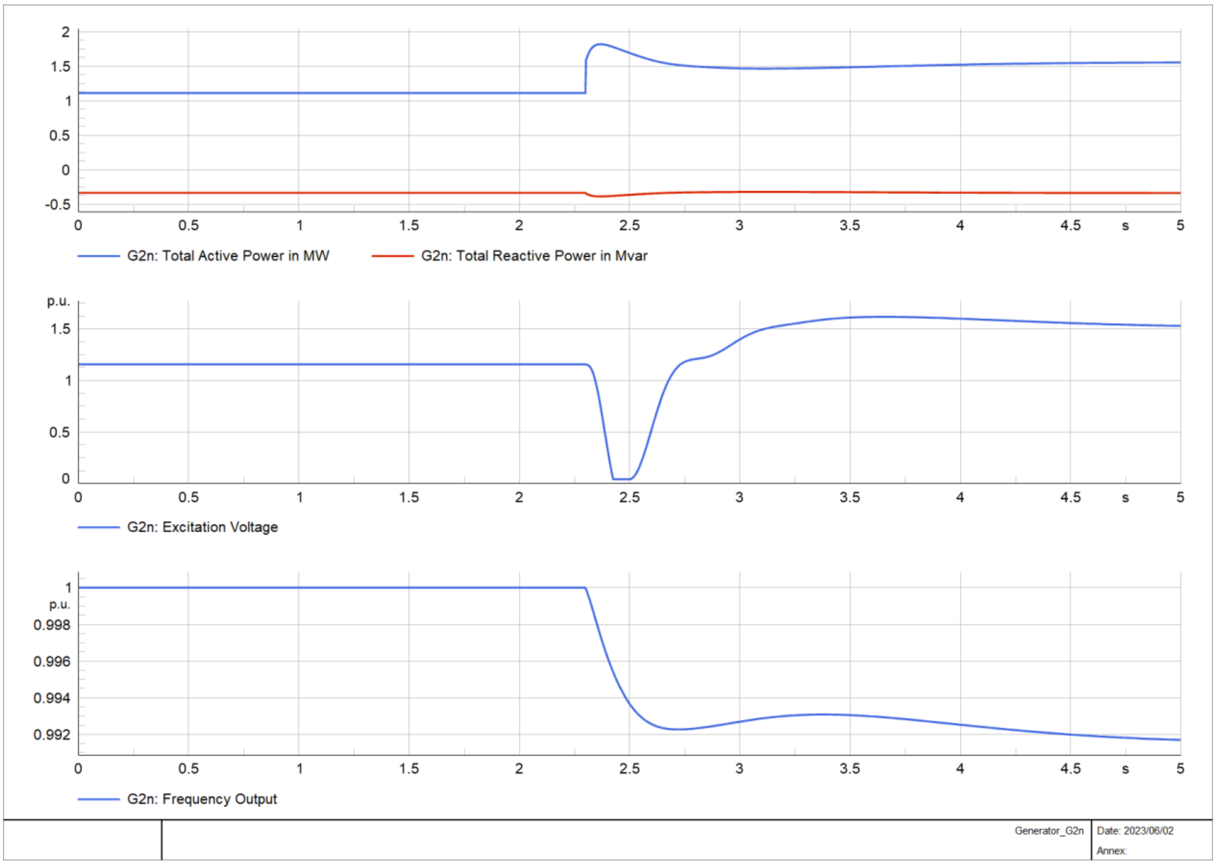

Figure 8: Effect of CSH solar farm tripping during high load conditions, when existing and planned PV is connected.

5.5 Voltage Unbalance

Voltage unbalance is not expected to become a problem on the MV network. However, it is a potential concern on low voltage networks, where a few private PV systems could increase the local voltage unbalance. This was shown in the Power Quality report, when analysing a selection of LV networks[5].

5.6 Harmonic Distortion

There are a few resonance conditions that were identified on the network. These were identified with no load connected to the grid, so that damping does not hide the resonance conditions. It was also shown that the severity of the resonances is damped significantly when load is connected, even when a limited number of private PV systems are connected. I.e. when load is added, no significant harmonic distortion problems are expected with existing loads and private PV connected.

It is not expected that private PV will increase an existing problem, but caution is advised to monitor the harmonic distortion on the grid. This will enable CSH to take appropriate mitigation measures before the harmonic distortion becomes a significant problem.

[5] The LV networks are generic due to the unavailability of detailed LV network data.

6 PROPOSED CAPACITY FOR PRIVATE PV SYSTEMS

The proposed PV system capacity is 420 kW for all private PV systems, including existing and planned PV systems. No export can be allowed for any private PV system, since this will result in too low load. The proposed capacity was determined from the steady-state analyses. Many iterations of connecting private PV at each transformer was done in Digsilent PowerFactory to evaluate the network parameters and generator loading for various contingencies and loading conditions. The effect of adding CSH owned PV and wind generation was also iteratively evaluated.

The basic analysis comprised the following:

1. Determine the network capacity in terms of private PV penetration[6], i.e. consider at which PV levels network parameters are exceeded. The network parameters are line and transformer loading and voltage levels at all nodes in the network.

   It was found that network parameters are exceeded only at fairly high penetration levels, relative to the diesel generation capacity. Only feeder 2 could host lower amounts of PV, due to the relatively long length of this feeder and the relatively large single-phase section on the feeder, as the short-circuit level reduces. This could result in overvoltages towards the end of the feeder and it was shown that the voltage unbalance in the entire network was affected by the single-phase section of this feeder.

   These high levels of PV penetration were significantly more than the load, resulting in the diesel generator(s) entering reverse power conditions (i.e. will trip, resulting in a system black-out). The limiting factor for VRE hosting capacity is therefore the load, i.e. a certain percentage of load must remain connected at all times.

2. The maximum PV hosting capacity per LV feeder, i.e. at each MV/LV transformer was determined by assuming no other private PV is installed. This analysis only considered the network parameters, i.e. line and transformer loading and voltage levels at all nodes in the network. It was found that most transformers could host up to the size of the transformer, without any detrimental effect in the MV network. LV networks were analysed separately and the limit between size and LV network parameters are provided separately.

3. The amount of private PV allowed was then reduced in relation to the maximum loading value, so that approximately 10% of the installed transformer capacity would remain as load. This means that a maximum amount of PV is allocated for each transformer according to the following equation:

$$P_{PV} = P_{load} - 10\% \cdot S_{transformer}$$

   Where:

   P_{PV} is the capacity of the PV systems per transformer

   P_{load} is the maximum load based on historical consumption per transformer

   $S\_transformer$ is the size of the transformer under consideration

   This resulted in a total PV hosting capacity of approximately 1200 kW. Under low load conditions, this still results in generator G2 entering reverse power mode, i.e. generator G2 will trip.

   An estimate of the PV that would be generating during low load conditions was made when export is blocked. This was done by decreasing the power output of each PV, again in relation to the load, but this time the minimum load. This would result in PV production (supplying own load only) of approximately 620 kW during low load conditions, which is still higher than what the system can host during low load conditions.

[6] The private PV in these simulations includes the existing and private PV, i.e. these are not added separately.

4. Based on these results and the high VRE penetration on the network, the conclusion would be that no private PV systems can be allowed on the network and the existing CSH owned PV also need communication systems so that it can be curtailed during low load conditions. However, it is acknowledged that citizens of Saint Helena has already installed private PV systems and more citizens may want to install such systems.

   High levels (as per point 2) of PV could be accommodated on the following conditions:

   a. Communication systems are installed for all private PV

   b. All private PV will be curtailed regularly to maintain system operability and stability

   These are not regarded as technically or economically feasible, especially point (b), since it may result in significant energy losses for citizens. Also, no such cases are known internationally. Such a value is based on the minimum load during daytime (871 kW), assuming that CSH owned wind and PV will be curtailed during low load conditions.

   Note that the curtailment of CSH owned wind and PV is also not preferred. The average load during PV production periods is 1218 kW. On average, the allowable production from VRE is therefore the difference between the average load and the 450 kW that should be maintained for the diesel generator, i.e. 768 kW. A portion of this will be allocated to private PV systems.

5. The final value for total PV to be allowed on the network was based on the minimum load during daytime. It assumes that both CSH owned PV and wind will be curtailed, to leave a minimum of 450 kW of load on the diesel generator, i.e.

$$P_{PVtotal} = S_{min} - 450\ kW$$

   Where:

   $P_{PVtotal}$ is the total hosting capacity

   S_{min} is the minimum daytime load, 871 kW

   The hosting capacity for private PV in the CSH grid is therefore 420 kW (rounded off to the nearest 10 kW). Note that this includes the existing private PV systems, i.e. approximately 195 kW of hosting capacity remains for private PV in the CSH grid.

6. Since the earlier analyses indicated that the voltage and line and transformer loadings are acceptable at higher levels of penetration, the exact distribution of the private PV systems is not important. The values obtained from step 3 is considered as maximum PV values per transformer.

   Note that that distribution transformers should not be loaded to 100% with inverter-based resources, since these transformers are not designed for significant harmonic currents. Therefore, in line with international best practices, a maximum PV system capacity of 75% of the transformer capacity is proposed per transformer. However, this capacity can only be used until the network hosting capacity for private PV of 420 kW is reached.

Further graphs are provided in section 7.1.

7 MITIGATION RECOMMENDATIONS

This section summarises proposed hosting capacity for private PV systems as well as the mitigation options required.

The mitigation options are again discussed according to the following:

1. Low-load problem
2. Loss-of-load problem
3. Loss of generation
4. Voltage unbalance
5. Harmonic distortion

7.1 Low-Load Problem

Based on the historical performance, curtailment of wind should maintain an acceptable margin of 450 kW on the diesel generators as shown in Figure 9. These traces show the same data as per previous graphs (Figure 4 and Figure 5) but adjusted for automatic curtailment of wind generation.

The red trace indicates the margin, or remaining load on the diesel generator.

When adding the proposed private PV of 420 kW, the scenario is shown in Figure 10. It is clear that private PV also needs to be curtailed now. When the effect of export-blocking is considered, the expected margin is slightly better as shown in Figure 11. In this case, the margin remains above 240 kW, which could be acceptable for short periods of time[7]. However, it would be better to curtail all CSH-owned PV as well, to maintain a larger margin. This would require communication systems to all CSH-owned PV, including roof-top PV.

Note that feed-in from private PV systems should not be allowed, due to the low-load problem, especially during some network fault conditions. Furthermore, feed-in from private PV systems will increase the times that CSH wind and/or PV needs to be curtailed.

[7] This margin should be confirmed with the diesel generator OEM.

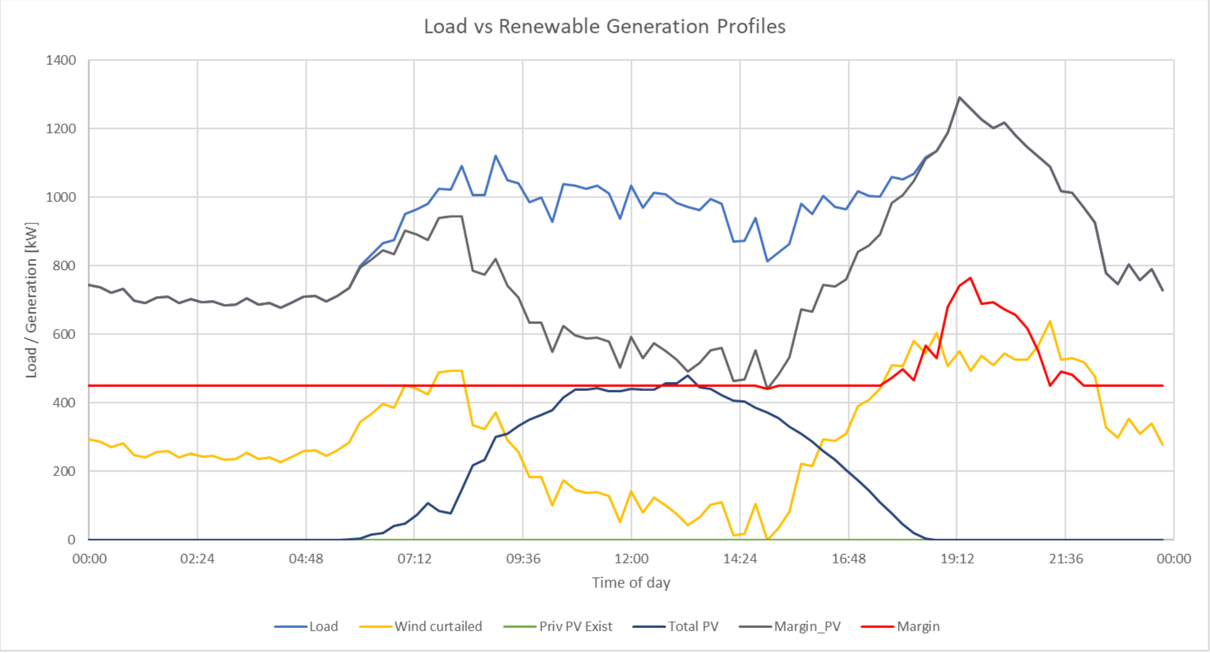

Figure 9: Example of load and renewable generation profiles when wind is curtailed (no private PV).

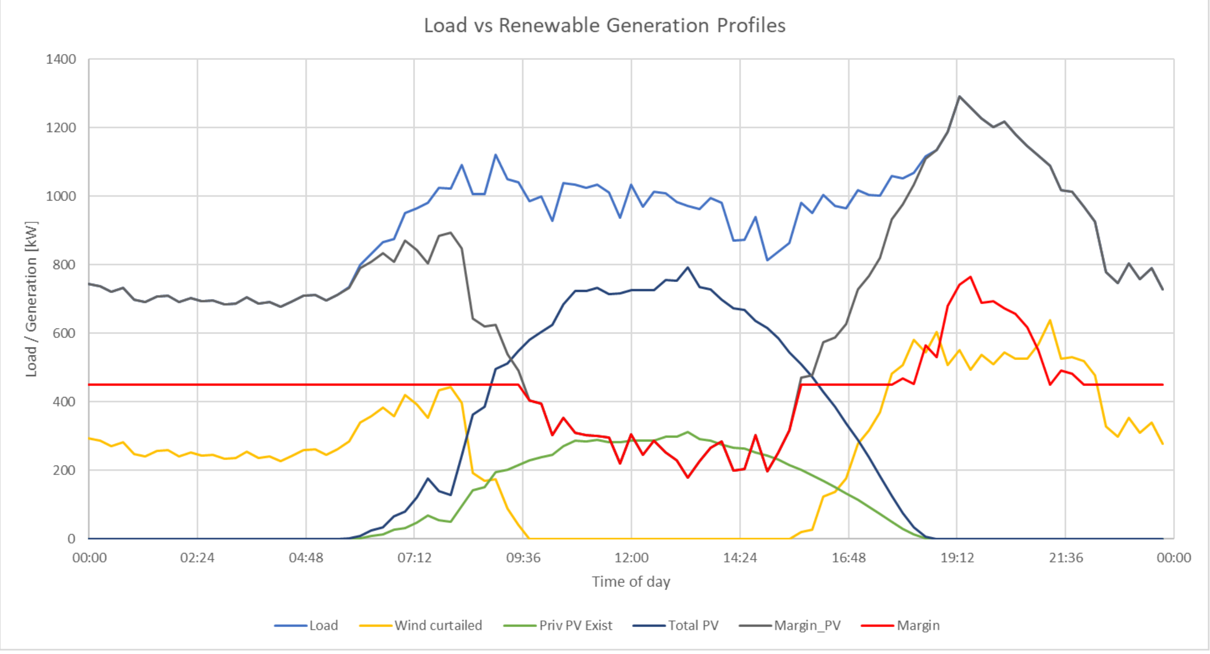

Figure 10: Example of load and renewable generation profiles when wind is curtailed, including private PV up to the limit of 420 kW.

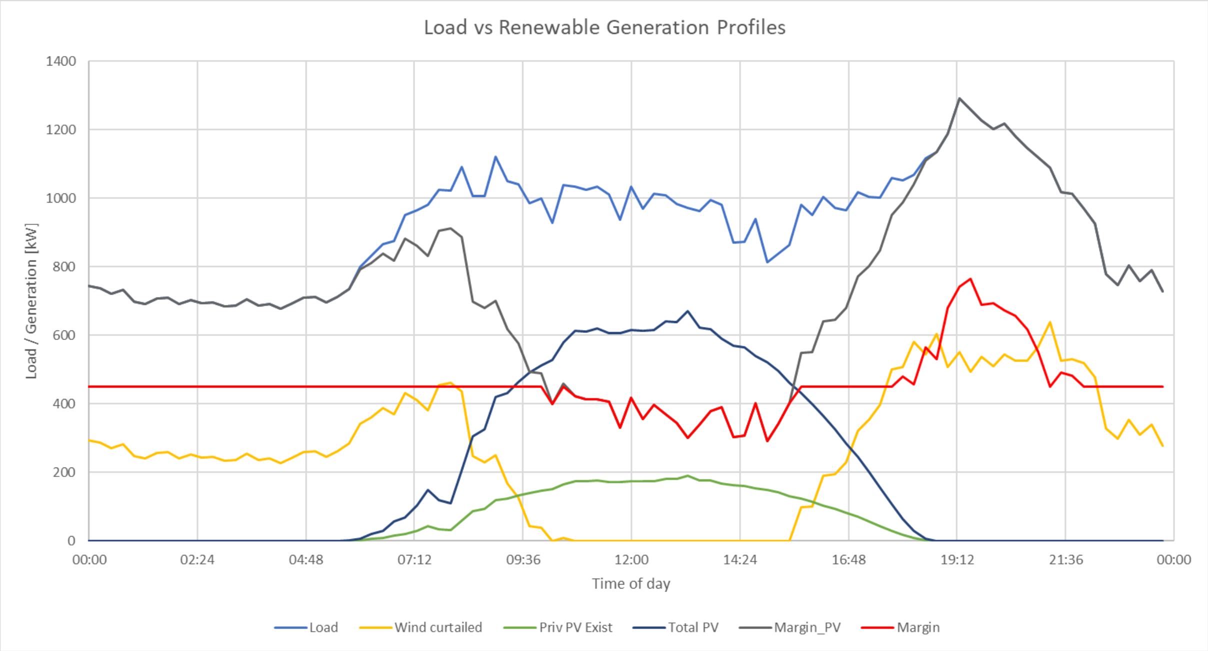

Figure 11: Example of load and renewable generation profiles when wind is curtailed and no export allowed for private PV systems, assuming that 60% of private PV generation will be curtailed due to export-blocking.

7.2 Loss of Load

No further comments.

7.3 Loss of Generation

No further comments.

7.4 Voltage Unbalance

No further comments.

7.5 Harmonic Distortion

No further comments.

7.6 Mitigation Options Recommended

Further details are provided per section below.

1. Low-load problem

   The low-load problem can be mitigated as follows:

a. Ensure that the wind curtailment is operating correctly.

b. Communication and curtailment ability of the CSH solar farm to be kept in place.

c. Add communication and curtailment ability to the smaller CSH owned PV.

d. Alternatively or additionally, add communication to all private PV systems to curtail or shut down in the event of low load on the diesel generator. Note that private PV systems with export-blocking will automatically reduce the output to be less than the private load to which it is connected.

e. Install a grid-forming battery energy storage system (BESS).

    i. The BESS can absorb energy during low-load conditions, i.e. artificially increase the load so that the diesel generator can operate at more efficient levels.

    ii. Provided that there is sufficient charge in the BESS, the BESS can take over during low-load conditions and the diesel generators be switched off.

Notes:

1. Option (c) would most likely be a lower capital cost, than option (d).

2. Communication with private PV would most likely not be required when a BESS is installed. However, communication to the CSH solar farm is recommended even when BESS is installed.

2. Loss-of-load problem

Loss of load can be mitigated in the same manner as the low-load problem, except that the curtailment of the CSH owned PV is critical.

BESS will be able to respond fast to a loss-of-load event as per point 1(e) above.

3. Loss of generation

Loss of generation can only be mitigated by reserve margin, i.e. there is sufficient generating capacity available to tolerate the maximum feasible generator trip.

The mitigation is proposed to operate the second diesel generator in idle mode when the load increases above the CSH solar farm generation output. This can be achieved as follows:

a. Based on forecasting and monitoring of the total load on the CSH grid, as well as the generation from the CSH solar farm, switch on the second generator (G5).

b. Update control of the CSH solar farm to monitor the output and issue an alert when the reserve margin is too low so that generator G5 can be switched on.

c. Update control of the CSH solar farm to monitor the output and automatically start generator G5 when the reserve margin is too low.

d. Install BESS to support the network during loss of generation scenarios.

4. Voltage unbalance

Voltage unbalance can be monitored using appropriate smart meters where single-phase private PV systems are installed. The load and generation need to be balanced when voltage unbalance occurs.

5. Harmonic distortion

It is recommended that the data from the existing power quality monitors be inspected regularly to evaluate all power quality parameters, especially harmonic distortion.

Based on the simulation results, it is recommended that all existing power factor correction banks be repaired to assist in shifting resonance points to frequencies where potential problems do not exist. It is further recommended that possible tuning of the banks be considered whilst repair is planned.

8 REPORT SUMMARIES

The final conclusions and recommendations are based on the results of all of the studies and each summary should be read with cognizance of the other reports.

8.1 LOADFLOW AND SHORT-CIRCUIT STUDY

8.1.1 MV Network Conclusion

The hosting capacity of the MV network equipment is between 40% and 50% of the total transformer sizes. It is only feeder 2 that can host between 10% and 20%.

The low loading on the majority of transformers reduces the total hosting capacity of the Connect Saint Helena network. A maximum penetration level of 18% is recommended based maximum load (or approximately 3% of the total installed transformer capacity). It is further recommended that export be blocked for all privately owned PV systems. The full list of transformers and their respective PV capacity is listed in Table 12.

8.1.2 LV Network Conclusion

The hosting capacity of an LV network depends on the transformer and line capacities, as well as the length of the LV feeder. It was shown that a worst-case calculation can be done by lumping the total load and total PV at the end of the LV feeder to determine whether a network can host a specific size PV system.

It is expected that the individual transformer hosting capacities, determined from the MV network, will limit the size of the PV systems, rather than the LV network parameters.

8.2 PROTECTION STUDY

This study considers the protection equipment as presently installed for the present and anticipated future WTGs, SPVs and DEG with respect to protection settings, and provides recommendations for the protective equipment to be installed, and settings thereof. The system has been modelled in DigSilent Powerfactory and the model will be submitted to the Grid Owner. It should, however, be noted that protection settings are network condition specific, and as such the study should be re-visited and protection settings re-evaluated each time there is a change to the network in order to ensure that the performance of the protection equipment remains optimal. The Powerfactory model should be kept up to date, and faults thru the network evaluated each time a new installation is commissioned. Any change from desirable to undesirable fault clearance indicates that the protection settings require a review.

The study found a few problems with the existing protection settings, which would have resulted in larger-than-necessary power outages for a number of MV grid faults. A number of protection setting revisions have been proposed in order to improve the fault clearance selectivity and reduce the area isolated when a fault occurs in the MV network and provide the coordination required.

The grid's protection is not exposed to large transients within the protection operating period.

Introduction of small-scale embedded generation in the CSH grid is not likely to place the grid protection at risk, as long as key requirements are legislated, such as power export limiting and harmonic content limiting. Monitoring should be carried out by introducing meters which can record power export, as a safe-check, since although inverters may be configured to restrict power export, this may not always be correctly applied.

Anti-islanding will be crucial for the short term for LV grid-tied generation, pending application of sync check protection to all circuit-breakers in the LV network, pole-mount switches/reclosers included.

The introduction of battery storage into the MV grid is recommended due to the highly variable nature of WTGs and Solar PV, but this should preferably be introduced as a bulk (as opposed to distributed) system coupled to the Diesel generation station. It is recommended to use 2 infeeds rated for the full load, i.e. redundant, to improve the reliability of the infeed.

8.3 DYNAMIC STUDY

Saint Helena Island aims to increase the integration of small-scale photovoltaic (PV) systems into its network to transition to greater renewable energy generation. However, to ensure the safety, reliability, and stability of the network, a grid impact assessment is necessary to evaluate the potential impact of these PV installations on the existing system. Small-scale PV systems offer numerous benefits, but their integration also poses potential challenges, such as variability and intermittency of solar energy, voltage fluctuations, and power quality issues.

A dynamic study of the network behaviour was conducted, considering fault locations and types to evaluate the network's response to disturbances. The simulations monitored various parameters to identify areas of concern and develop recommendations for maintaining system stability. The study revealed technical challenges that make it difficult to integrate private rooftop PV installations into the existing network. The high penetration of renewables on the network, the minimum output power requirement of the diesel generators, and the lack of control over private rooftop PV systems could lead to instability and potential damage to the generators.

The stability of the network depends on the duration and depth of faults, voltage dips, and sudden load reductions, and fast control may be necessary to mitigate the effects of network disturbances. Throughout this report, the "worst-case" scenarios are identified, where fault contingencies must be addressed to ensure network stability.

To evaluate the network's response to disturbances in a more detailed manner, several fault locations and fault types were considered. The fault locations were carefully chosen based on the location of the largest PV and wind farm installations in feeders 1 and 3, as well as the feeder with the longest load network, feeder 2. These locations were selected to simulate worst-case scenarios that would result in the largest changes in the network.

While the fault analysis did not reveal any immediate instability issues, it is important to note that the increase in rooftop PV generation can have a significant impact on the system response. This impact is due to the intermittent nature of solar power, which can result in fluctuations in voltage and frequency that can cause problems for the stability of the system. As more and more renewable energy sources are added to the network, there is a risk of uncontrolled power generation that could lead to power swings, voltage fluctuations, and instability in the grid.

From the results of the high load high generation case, it is clear that there is a risk of overloading the generator if the PV generation is reduced due to cloud coverage or loss of supply during a trip event requiring additional spinning reserve. This is a significant concern that needs to be addressed, as overloading the generator can lead to system instability and potential damage to equipment.

Therefore, it is not advisable to allow private rooftop PV installations on the Saint Helena network, and alternative solutions such as utility-scale solar PV or battery energy storage systems should be explored. These solutions would provide greater control over the output of the renewable sources and allow for better management of the network. While private rooftop PV systems have potential benefits, their integration into the Saint Helena network would be technically challenging and could lead to stability issues.

8.4 MITIGATION MEASURES

The key concern raised from both the steady-state and dynamic studies is the existing high penetration of VRE along with low load conditions that could exist during PV peak production periods. Further increases in private PV systems, if not under CSH's control, may result in too low demand on the diesel generator and system blackout.

Although the steady-state analysis indicates that a reasonable quantity of PV can still be accommodated, this does require that both PV and wind generation be curtailed under low loading conditions. The probability of this occurring is quite low at less than 1% of the time and could be regarded as an acceptable solution in the short-term as discussed in section 5.2.

When customers will be allowed to install private PV, the allowable sizes should be considered. The sizes selected will depend on commercially available inverters, as well as the principle of fairness, i.e. allowing those who want to install PV, to do so.

- The international benchmark for small-scale PV inverters had been the 16 A per phase limit, i.e. 3.68 kVA single phase. Many manufacturers offer slightly larger units as more economical and not the 3.68 kVA. However, smaller grid-tied PV inverters are commercially available and an allowable limit size per customer may be 2 kW as per discussions in section 5.2 of the mitigation report.
- The size of the PV system can be limited by installing a limited amount of PV panels, which reduces the maximum power that can be converted. In such a case, a slightly larger PV inverter is still acceptable.

For the CSH-owned PV and wind generation systems, it is recommended that CSH considers the following:

1. Add communication/control capabilities to the CSH-owned PV to enable curtailment in the event of severe low-load conditions.

For the existing and future private PV systems, it is recommended that CSH considers the following:

1. Install smart meters at all private PV systems to monitor consumption and export, but also to monitor potential power quality impacts.
2. In the case of single-phase installations, similar smart meters are proposed for installation at the LV terminals of the MV/LV transformer, i.e. metering the feeder consumption. This is mainly to assist in detecting possible voltage unbalance concerns as well.
3. Develop and implement a suitable tariff structure.

For the existing private PV systems, it is recommended that CSH considers the following:

1. Continue to enforce export-blocking.
2. Prohibit any increase in size, beyond what could be allowed for future PV systems.

For future private PV systems, it is recommended that CSH considers the following:

1. Require the communication port described in clause 11.1.3 of ER G99 and clause 9.4.4 of ER G98.

2. Require export-blocking.
3. Install appropriate communication infrastructure to enable control of small PV systems.

In terms of future renewable energy development, it is recommended that CSH considers the following:

1. Restrict the number of private PV systems.
2. Evaluate the optimal renewable energy mix for the island based on availability of PV and wind. Historical performance of these technologies should be included in such calculations.
3. Install additional utility-scale VRE as per the optimal mix identified.
4. Install grid-forming BESS to assist during low-load and high-load conditions.

8.5 POWER QUALITY STUDY

8.5.1 Voltage Regulation

Voltage regulation was evaluated during the steady-state report. It was shown that no major voltage regulation issues are expected due to the addition of private PV systems, as long as the number remains within the proposed penetration of 420 kW with no export allowed.

Note that voltage regulation in LV networks may need to be monitored and managed, especially for very long LV feeders. This is an operational aspect.

8.5.2 Frequency Sweeps and Harmonic Distortion

The frequency sweep and harmonic distortion analyses address the same parameter, i.e. harmonic voltage distortion. The frequency sweeps indicate the risk of harmonic voltage distortion, while the harmonic injection simulations indicate the expected harmonic distortion, based on the injections that were defined.

From the frequency sweeps, it is seen that the base network exhibit two resonance points, which shifts based on which generators (both diesel and VRE) are connected. The lower or first frequency resonance point is visible throughout the network on both MV and LV nodes for all cases evaluated. For the damped cases (when load is connected) the resonance point is damped completely on some LV nodes. For some cases, more resonance points exist and also depend on the operational scenarios.

The first resonance frequency ranges from 240 Hz (4.8th harmonic) to 350 Hz (7th harmonic). During low loading and generator G2 out of service, the short-circuit level is low and the resonance frequency is low (285 Hz). This is just above the 5th harmonic, which is a significant harmonic in most power systems. The addition of the inverter filter impedance (as simulated) reduces this to 240 Hz, just below the 5th harmonic.

The base harmonic frequency sweeps were done with no load, to identify the potential problem frequencies.

When adding load, the resonance factor is reduced significantly. At low load, the resonance factors are reduced to around 5 to 6 at the MV level and 1.5 to 3 at the LV level, which are acceptable levels. At high load, the resonance factors are reduced to around 1.8 to 2.4 at the MV level and unity or less at LV voltages.

A specific contingency was highlighted for evaluation, namely two faulty capacitor banks out of service. For this contingency, the base resonance frequency is around the 8^{th} harmonic, when generator G2 is operating. The harmonic injection simulations do not show an exceedance at the 8^{th} harmonic, most likely due to low injection at the 8^{th} harmonic from the VRE. When all capacitor banks are switched off, the resonance frequency is shifted to the 11^{th} harmonic.

The key concern scenarios are those with high resonance impedance factors from the 5^{th} to 11^{th} harmonic. This apply for the existing PV system penetration as well, since the contribution from the private PV systems is small and in many cases positive.

8.5.3 Voltage Unbalance

Past performance of the voltage unbalance in the CSH network is around 1.65%, with the voltage unbalance exceeding 2% at times. The base voltage unbalance simulations correlated well with the past performance.

The base voltage unbalance for the two LV networks evaluated varied from 0.38% to 0.65%.

For SS21, the voltage unbalance contribution does not increase significantly, even for low numbers of PV systems. When all customers on this network have PV systems, the voltage unbalance contribution is expected to improve significantly.

For SS115, the voltage unbalance contribution seemed to increase, even for low numbers of PV systems. This is to be expected due to the low number of customers on this network, i.e. higher customer numbers result in more diversity and likely less unbalance contribution from the particular LV network.

The recommendation is therefore that voltage unbalance should be monitored more carefully on LV networks with fewer customers.

8.5.4 Voltage Flicker

Voltage flicker does not appear to be a significant problem on the network, except due to larger CSH PV system. The concern is also not the continuous flicker contribution, but flicker contribution due to switching events.

Continuous flicker contribution is very low, with approximately 0.31 added when the maximum number of private PV systems are connected.

Flicker due to switching events can be managed by reducing the number of switching events. For large PV systems, typically commercial sizes, the power output should be managed by dynamic curtailment, i.e. not a switch off command. For typical residential size PV systems, the addition of a battery system with export prevention, will limit the switching of the inverter.

These are recommendations for the operational aspects of the CSH network and should be added to the operational procedures.

8.5.5 Voltage Changes

Voltage changes due to PV systems being tripped (or switched off due to curtailment) are generally low and should not cause any problems in the CSH network. Only larger PV systems or LV networks with a large number of PV systems may cause larger voltage changes.

As an example, switching of all private PV on SS2 or SS81 may result in voltage changes exceeding 1%. In contrast, the switching of CGPV-5 (480 kW) may result in a voltage change of 7.2%. The latter is the major concern and shows why the power output of this plant should be controlled and not switched only.

As part of the operational procedures, these systems should preferably be controlled in a similar fashion to the flicker management strategy.

When these plants should trip due to CSH network events or internal PV system events, it should typically be few enough not to be a concern for the power quality of the CSH network.

8.5.6 Reliability Impact

The reliability impact was not evaluated via simulation, but from a discussion, based on the results of previous studies. No significant impact on the reliability of the CSH network and equipment is expected due to private PV systems, as long as the number remains within the proposed penetration of 420 kW with no export allowed.

9 CONCLUSIONS

9.1 Hosting capacity for private PV in the CSH network

The proposed maximum capacity for private PV in the CSH grid is 420 kW. These systems need to comply with the requirements of EREC ER G98, including that no export is allowed.

This hosting capacity is based on the minimum daytime load in the CSH grid of 871 kW and the planned minimum load on the diesel generator of 450 kW (rounded to the nearest 10 kW). It is shown in section 6, that export-blocking supports the minimum load on the diesel generator and reduces the curtailment required from CSH-owned PV and wind.

9.2 Critical Mitigation Options

9.2.1 Communication Systems

The installed capacity of VRE owned by CSH in the CSH grid is 1604 kW, vs. the minimum load of 678 kW. The daytime minimum load (when both wind and PV can produce) is 871 kW. The 960 kW of wind generation is already curtailed automatically, i.e. 644 kW of PV also may need to be partially curtailed during low-load conditions, to ensure that the minimum load on the diesel generator remains above 450 kW.

As per section 6.2 and 6.3, ongoing communication to the CSH owned PV (solar farm) is considered critical to ensure that the solar farm can also be curtailed during very low load conditions or during a loss-of-load event.

The addition of private PV (including the existing private PV) will require more curtailment of the CSH-owned VRE. It may be desirable to share curtailment of private PV in line with the CSH-owned PV curtailment. This will require communication to private PV systems as well.

9.2.2 Battery Energy Storage

BESS is recommended to assist during any of the cases of low-load, loss-of-load or loss of generation. In order to support the network during these scenarios, grid-forming BESS is recommended.

Ongoing communication to the CSH owned PV (solar farm) is recommended even when BESS is installed.

9.2.3 Generator G5 on Standby

During average loading conditions, the generator G5 is required to operate in stand-by mode, in the event that the CSH solar farm trips. This scenario is partially mitigated by either the wind generation producing, or more private PV being installed.

APPENDIX A HOSTING CAPACITY PER TRANSFORMER

The maximum proposed PV size per transformer and the even distribution of the proposed 420 kW PV capacity is shown in Table 2.

The last column (Even Distribution PV Size [kW]) shows the allocation of PV systems per transformer, when the 420 kW is evenly distributed between all transformers, based on the minimum loading on the transformer. However, in many instances, the allowable size is too small to allow a realistic system and these capacities will not be used. In line with international recommendations along with maintaining a minimum load allocation per transformer, another value is calculated and provided in column 5 (Maximum Recommended PV Size [kW]).

The fifth column gives the recommended maximum PV hosting capacity per transformer, provided that the total PV capacity of 420 kW (for the total CSH grid) is not exceeded. The value is determined as follows:

1. The total size of PV installed per transformer should not exceed 75% of the transformer rating, and
2. The total size of the PV installed per transformer should not exceed 75% of the maximum load, as determined in this study. The maximum load is provided in column 2 (Max of Load Size [kW]).

Notes:

1. The 75% of transformer capacity limit is in line with international practice, such as South Africa, where many of the CSH transformers were manufactured.
2. Further, by limiting the PV size based on the maximum load (2021/22), the risk of inadvertent backfeed into the upstream network is reduced.
3. Due to the overall grid limit of 420 kW for private PV, most transformers will not reach the limit provided in column 5 or 6.

Table 2: PV hosting capacity per transformer, listed along with maximum and minimum load and transformer size.

Name	Transformer size [kVA]	Maximum Load Size [kW]	Min of Load Size [kW]	Max of PV Limit Size [kW]	Even Distribution Maximum PV Size [kW]
SS100_2_Load_Kingshurst	30	11.08	3.20	8.31	2.19
SS101_2_Load_W Clingham's	30	3.95	1.14	2.96	0.78
SS102_2_Load_Hutt's Gate Gardens	25	5.72	1.65	4.29	1.13
SS103_2_Load_Willow Bank	50	12.87	3.71	9.65	2.55
SS104_1_Load_Southerns	50	5.59	1.61	4.20	1.11
SS105_2_Load_Alarm Forest	30	12.64	3.64	9.48	2.50
SS106_2_Load_Horse Ridge	30	0.52	0.15	0.39	0.10
SS107_1_Load_Upper Sapper Way	50	7.18	2.07	5.39	1.42
SS109_1_Load_Cowpath	150	34.48	9.94	25.86	6.82
SS10_2_Load_Prospect	50	15.25	4.40	11.44	3.02
SS110_2_Load_Seismographic Station	25	1.69	0.49	1.27	0.34

Name	Transformer size [kVA]	Maximum Load Size [kW]	Min of Load Size [kW]	Max of PV Limit Size [kW]	Even Distribution Maximum PV Size [kW]
SS111_Quarantine	25	0.01	0.00	0.01	0.00
SS112_1_Load_Lower Cleughs	50	14.47	4.17	10.86	2.86
SS113_2_Load_Hutt's Gate Block Yard	80	0.00	0.00	0.00	0.00
SS114_1_Load_Central Garage	50	3.90	1.12	2.93	0.77
SS115_2_Load_Bluemans Field	100	8.25	2.38	6.19	1.63
SS116_3_Load_Black Field	200	26.53	7.65	19.90	5.25
SS117_4_Load_Fisheries	200	4.76	0.00	3.57	0.94
SS118_2_Load_Sheltered Accomodation 1	100	2.63	0.76	1.97	0.52
SS119_1_Load_Sheltered Accomodation 2	100	7.73	2.23	5.79	1.53
SS11_2_Load_Hutts Gate	100	2.95	0.66	2.21	0.58
SS120_3_Load_Horse Point	80	0.26	0.08	0.20	0.05
SS121_3_Load_Mulberry Gut	20	0.59	0.17	0.44	0.12
SS122_2_Load_Nr Peter Harris	15	0.28	0.08	0.21	0.06
SS123_2_Load_Nr Banyan Cottage	30	1.70	0.49	1.27	0.34
SS124_2_Load_Fitzstevens Estate	30	0.90	0.26	0.68	0.18
SS125_1_Load_CCC	150	20.96	6.04	15.72	4.15
SS126_2_Load_Farm Buildings	20	7.03	2.03	5.27	1.39
SS127_2_Load_Mollys Gut	20	0.00	0.00	0.00	0.00
SS128_2_Load_Woodcot (Thorpes)	30	2.71	0.78	2.04	0.54
SS129_2_Load_Rock Rose	30	1.06	0.31	0.79	0.21
SS130_2_Load_Gordons Post	50	10.28	2.96	7.71	2.03
SS131_2_Load_Burnt Rock	30	1.30	0.37	0.97	0.26
SS132_3_Load_Longwood Hangings	100	8.23	2.37	6.17	1.63
SS133_2_Load_Sea View	50	13.88	4.00	10.41	2.75
SS134_5_Load_Wharf	315	0.00	0.00	0.00	0.00
SS135_2_Load_Upper Briars	80	2.73	0.79	2.05	0.54
SS136_1_Load_Roads Section	80	0.49	0.14	0.37	0.10
SS137_3_Load_Stone Crusher	315	4.92	1.31	3.69	0.97
SS138_4_Load_Nr Church	50	10.39	2.99	7.79	2.06
SS139_1_Load_Main Hospital Complex	315	99.30	28.63	74.48	19.65
SS13_2_Load_Hutt's Gate Treatment Plant	50	13.78	3.97	10.34	2.73
SS140_1_Load_Friars Valley	30	0.00	0.00	0.00	0.00
SS141_2_Load_Lower Alarm Forest	80	3.53	0.88	2.64	0.70
SS142_2_Load_Paul Hickling	80	0.73	0.19	0.55	0.14
SS144_3_Load_Bradley's Camp	600	12.54	3.61	9.40	2.48
SS145_2_Load_Alarm Hill	80	0.02	0.01	0.01	0.00
SS147_3_Load_Airport	630	99.49	28.68	74.62	19.69

Name	Transformer size [kVA]	Maximum Load Size [kW]	Min of Load Size [kW]	Max of PV Limit Size [kW]	Even Distribution Maximum PV Size [kW]
SS148_3_Load_Bore Hole 5 Dry Gut	80	1.73	0.00	1.30	0.34
SS149_3_Load_Adrian Duncan Upper Ruperts	500	0.55	0.16	0.41	0.11
SS14_2_Load_Hallams	25	1.79	0.52	1.35	0.36
SS153_3_Load_Bulk Fuel Farm 1	500	1.30	0.37	0.97	0.26
SS154_1_Load_Printech	150	1.79	0.52	1.34	0.35
SS155_3_Load_VHF Site Bradley's Camp	50	2.70	0.78	2.03	0.54
SS157_3_Load_Nr Fire Training Site	100	0.47	0.13	0.35	0.09
SS158_2_Load_Knipe's Hill O'Wain	100	0.37	0.11	0.28	0.07
SS159_2_Load_Windy Point	30	1.26	0.36	0.94	0.25
SS15_2_Load_Brown's Hill	15	1.36	0.39	1.02	0.27
SS161_3_Load_Bertrand Cottage	200	4.99	1.44	3.74	0.99
SS162_5_Load_Lower Shy Road	200	7.20	2.08	5.40	1.43
SS163_3_Load_Fishers Valley	80	25.53	7.36	19.15	5.05
SS164_1_Load_Nr Rifle Range HTH	80	16.15	4.66	12.11	3.20
SS165_1_Load_Ladder Hill 2	100	12.20	3.52	9.15	2.41
SS166_2_Load_Wood-Cot Cottage	32	11.24	3.24	8.43	2.22
SS167_4_Load_Undersea Cable Supply	120	35.75	10.31	26.81	7.08
SS168_3_Load_CDA Bottomwoods	150	0.00	0.00	0.00	0.00
SS169_1_Load_HTH PV house load	1250	0.00	0.00	0.00	0.00
SS16_2_Load_Knollcombes	25	0.01	0.00	0.01	0.00
SS17_1_Load_Red Hill	80	56.60	16.32	42.45	11.20
SS18_1_Load_Half Way	50	15.30	4.41	11.48	3.03
SS19_1_Load_Nr H.T.H Supermarket	200	110.32	31.80	82.74	21.83
SS20_1_Load_Nr Sundale	80	22.05	6.36	16.54	4.36
SS21_1_Load_Ladder Hill	80	39.09	11.27	29.32	7.74
SS22_1_Load_Upper H.T.H	50	26.19	7.55	19.64	5.18
SS23_1_Load_Donkey Plain	500	1.89	0.54	1.41	0.37
SS24_1_Load_Lower Sapper Way	100	25.53	7.36	19.15	5.05
SS25_1_Load_Plantation Square	15	4.26	1.23	3.19	0.84
SS26_1_Load_Cleughs Plain	50	11.20	3.23	8.40	2.22
SS27_1_Load_New Ground	50	17.32	4.99	12.99	3.43
SS28_2_Load_Flax Ground	25	8.04	2.32	6.03	1.59
SS29_2_Load_Pounceys	100	8.37	2.41	6.28	1.66
SS2_5_Load_Nose Gay Lane	150	115.88	33.40	86.91	22.93
SS30_2_Load_PA School	315	42.17	12.16	31.63	8.35
SS31_3_Load_Nr Isaac's shop	80	6.96	2.01	5.22	1.38
SS32_3_Load_Longwood Old House	100	15.81	4.56	11.85	3.13

Name	Transformer size [kVA]	Maximum Load Size [kW]	Min of Load Size [kW]	Max of PV Limit Size [kW]	Even Distribution Maximum PV Size [kW]
SS33_3_Load_Harford School	40	0.00	0.00	0.00	0.00
SS34_3_Load_Deadwood	50	12.87	3.71	9.66	2.55
SS35_5_Load_Post Office	150	80.81	23.30	60.61	15.99
SS36_3_Load_Piccolo Hill	315	26.54	7.65	19.90	5.25
SS37_3_Load_Ropery Field	80	13.29	3.83	9.97	2.63
SS38_3_Load_Bottom Woods	100	22.85	6.59	17.14	4.52
SS39_3_Load_World Weather Watch	50	14.94	4.31	11.20	2.96
SS3_1_Load_Hospital	150	22.81	6.58	17.11	4.51
SS40_3_Load_Bradleys	80	1.33	0.38	0.99	0.26
SS41_2_Load_Radio Station	30	1.77	0.51	1.32	0.35
SS42_2_Load_White Gate	100	23.27	6.71	17.45	4.61
SS43_2_Load_Scotland	200	10.15	2.93	7.61	2.01
SS44_2_Load_Spring Knoll	50	6.66	1.92	4.99	1.32
SS45_2_Load_Guinea Grass	80	7.51	2.16	5.63	1.49
SS46_2_Load_Rosemary Field	50	4.74	1.37	3.56	0.94
SS47_2_Load_Crack Plain	15	1.88	0.54	1.41	0.37
SS48_2_Load_Thompson Hill	30	11.24	3.24	8.43	2.22
SS49_2_Load_Milking Pound	20	2.73	0.79	2.04	0.54
SS50_1_Load_Lower H.T.H	150	56.97	16.42	42.73	11.27
SS51_1_Load_H.T.H School	30	12.50	3.60	9.38	2.47
SS52_2_Load_Oakbank	25	1.45	0.42	1.09	0.29
SS53_2_Load_Iron Pot	15	2.26	0.65	1.70	0.45
SS54_2_Load_The Saddle	20	1.93	0.55	1.44	0.38
SS55_2_Load_Head O Wain	25	6.79	1.96	5.09	1.34
SS56_2_Load_Barren Ground	50	9.56	2.76	7.17	1.89
SS57_2_Load_West Lodge	30	3.21	0.92	2.41	0.63
SS58_2_Load_Cricket Pitch	40	6.17	1.78	4.63	1.22
SS59_2_Load_Blue Hill	40	2.78	0.80	2.09	0.55
SS5_2_Load_Briars Village	100	81.51	23.50	61.13	16.13
SS60_2_Load_High Hill	30	1.17	0.34	0.88	0.23
SS61_2_Load_Thompsons Wood	30	0.90	0.26	0.67	0.18
SS62_2_Load_Myrtle Grove	15	0.17	0.05	0.13	0.03
SS63_2_Load_Wells	15	0.44	0.13	0.33	0.09
SS64_2_Load_Alarm Hill 2	32	6.77	1.95	5.08	1.34
SS65_2_Load_Woody Ridge	80	4.78	1.38	3.59	0.95
SS66_2_Load_Red Hill Levelwood	100	10.67	3.07	8.00	2.11
SS67_2_Load_Nr Levelwood School	30	5.20	1.50	3.90	1.03

Name	Transformer size [kVA]	Maximum Load Size [kW]	Min of Load Size [kW]	Max of PV Limit Size [kW]	Even Distribution Maximum PV Size [kW]
SS68_2_Load_Silver Hill Shop	40	12.53	3.61	9.40	2.48
SS69_2_Load_Silver Hill Ridge	80	18.20	5.25	13.65	3.60
SS6_4_Load_Nr Fisheries	315	4.34	1.25	3.26	0.86
SS70_2_Load_Wranghams	40	8.51	2.45	6.38	1.68
SS71_2_Load_Leggs	30	2.26	0.65	1.70	0.45
SS72_2_Load_Bamboo Hedge	40	10.02	2.89	7.52	1.98
SS73_2_Load_Simpsons	32	3.07	0.88	2.30	0.61
SS74_2_Load_Nr Constantines	15	1.07	0.31	0.80	0.21
SS75_2_Load_Bagleys Point	30	5.15	1.49	3.87	1.02
SS76_2_Load_The Gun	20	1.50	0.43	1.12	0.30
SS77_2_Load_Frenches Gut	50	2.38	0.69	1.79	0.47
SS78_2_Load_Kunjie Field	50	7.58	2.19	5.69	1.50
SS79_1_Load_Ladder Hill Complex	100	5.16	1.49	3.87	1.02
SS7_2_Load_Two Gun Saddle	50	16.84	4.86	12.63	3.33
SS80_1_Load_Chub Spring	50	17.77	5.12	13.33	3.52
SS81_1_Load_Jamestown First	630	171.19	49.35	128.39	33.88
SS82_4_Load_Mid Valley	100	2.27	0.66	1.71	0.45
SS83_4_Load_Beach	315	4.90	1.41	3.68	0.97
SS84_5_Load_Old Power House	100	9.52	2.75	7.14	1.88
SS85_2_Load_High Hill Ridge	30	3.06	0.88	2.30	0.61
SS86_2_Load_Woodlands West	10	0.24	0.07	0.18	0.05
SS87_3_Load_ADA Resevoir	50	12.65	3.65	9.48	2.50
SS88_3_Load_Deadwood Plain	100	11.93	3.44	8.95	2.36
SS89_2_Load_Nr Coffee Grove	20	1.09	0.31	0.82	0.22
SS8_2_Load_Putty Hill	30	9.69	2.79	7.27	1.92
SS90_2_Load_Horse Pasture	20	3.49	1.01	2.62	0.69
SS91_5_Load_The Terrace	315	104.38	30.09	78.29	20.66
SS92_2_Load_Pink Grove	15	2.25	0.65	1.69	0.45
SS93_2_Load_Bellstone	50	4.75	1.37	3.56	0.94
SS94_2_Load_Tagalate Valley	20	4.78	1.38	3.58	0.95
SS95_1_Load_Clay Gut	50	7.94	2.29	5.95	1.57
SS96_2_Load_Unity Cottage	32	0.72	0.21	0.54	0.14
SS97_2_Load_Green Hill	30	1.25	0.36	0.94	0.25
SS98_2_Load_Lower Green Hill	20	1.02	0.29	0.76	0.20
SS99_2_Load_Tagalate WT Plant	50	10.00	2.88	7.50	1.98
SS9_2_Load_Grapevine Gut	50	5.43	1.57	4.07	1.07

APPENDIX B NOTES REGARDING DECREASING DEMAND

The CSH Technical team advised that the demand for electricity is decreasing. This is attributed primarily due to people leaving the island. It has been noted that there is reduced economic activity as well at the moment, which may also contribute to the reduction in demand.

Analysis of a limited set of generation data from 2022-2023 showed that the minimum daytime load may have decreased to approximately 750 kW, from 871 kW previously, a decrease of approximately 120 kW. The peak demand is less than the 2021-2022 by approximately 100 kW, down to 2.2 MW from 2.3 MW. The two sets of maximum and minimum daily demand curves are shown in Figure 12.

This is noted as a concern, since curtailing the CSH solar farm and wind may not be sufficient to maintain load on the diesel generator if the full 420 kW of PV is allocated to private customers. However, these numbers exclude the existing private PV systems as well as the other CSH owned PV systems, which means some margin remains above the 420 kW that was allocated.

Since the private PV may already curtail automatically due to export blocking, the private PV systems are excluded from the following calculation. Note that this means some of the contribution from these private PV systems are ignored and the margin may be larger than this calculation.

The times of concern are when the load on the diesel generator is fairly low and while PV is potentially at maximum generation. An estimated PV generation contribution from the other CSH owned PV systems was calculated as follows:

1. Select the time intervals where the total load is less than 1000 kW, when PV production is high.
2. Assume that the PV production from other PV systems is similar to the CSH solar farm and scale the production value from the other systems according to the output from the solar farm. The solar farm's capacity is 480 kW and the other CSH owned PV systems' total capacity is 164 kW. The following equation is used:

$$P_{PV(Other)} = \frac{P_{SolarFarm}}{480} \times 164\ kW$$

On average, it is found that the other PV systems generate approximately 120 kW, i.e. the CSH demand is 120 kW more than shown in the graphs. (Since the other PV systems' output is not included in the SCADA data used.) Therefore, the minimum load during PV peak production periods is still within acceptable limits, i.e. the estimated real minimum load is now around 870 kW (rather than 750 kW).

However, should the load continue to decrease, the minimum load during PV peak production will decrease too much and curtailment of the solar farm will not be sufficient. All CSH-owned PV systems will also have to be curtailed when the minimum load decreases by another 120 kW, or 630 kW using SCADA from the diesel, wind generation and CSH solar farm.

Should it decrease further, less than 630 kW, private PV systems will also be required to be curtailed. This will then require communication links to all private PV systems.

It is recommended that:

1. The proposed hosting capacity be reduced to the current installed capacity of 225 kW (and not 420 kW).
2. If more customers are to be allowed to connect private PV systems, then existing private PV systems are to be reduced to sizes provided in the ENA ER G98 (i.e. 3.68 kW and 11 kW).[8]

[8] The benefit may be two-fold: (a) customers may perceive this as fairer, since the available capacity is not allocated only to a few customers and (b) there will be more diversity in the PV production and potential negative effects will be spread as smaller impacts across the grid.

3. New or additional systems are allowed up to the current installed capacity of 225 kW.
4. Load forecast for the next 5-10 years be done, taking forecasted population numbers and economic activity into account. Updated hosting capacity limits can then be based on these forecasts.

This information can then be used to determine the upper limit (capacity) for private PV systems, along with other measures put in place by CSH to reduce the reliance on diesel generation.

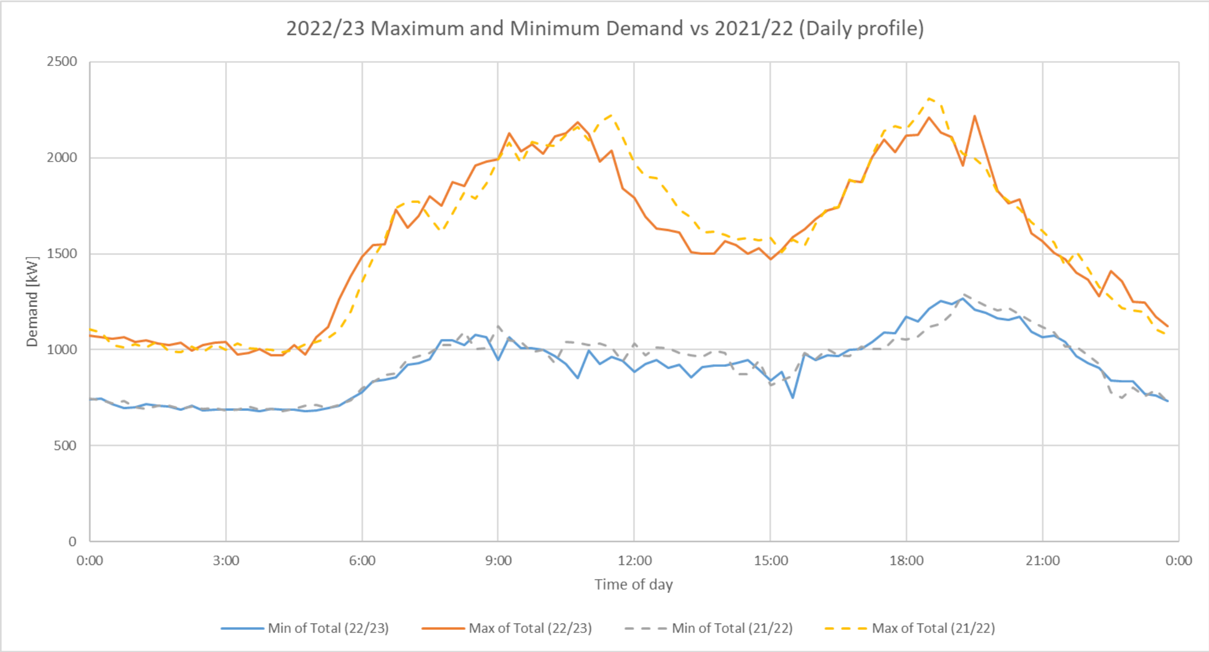

Figure 12: Daily profile comparison for 2022/23 to 2021/22.

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