HEPBURN WIND FARM PSP SUPPORT

Power System Study for Hepburn Wind Farm with Additional Solar Capacity

Hepburn Community Wind Park Co-operative Ltd

Report No.: PP231111-AUME-R-01, Rev. F
Document No.: PP231111-AUME-R-01-F
Date: 19/11/2019

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Project name:	Hepburn Wind Farm PSP Support	
Report title:	Power System Study for Hepburn Wind Farm with Additional Solar Capacity	
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Date of issue:	19/11/2019	
Project No.:	PP231111	
Report No.:	PP231111-AUME-R-01, Rev. F	
Document No.:	PP231111-AUME-R-01-F	

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Task and objective:

Power systems modelling for Hepburn Wind Farm

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Keywords:
Hepburn Wind Farm; Power System Study

Rev. No.	Date	Reason for Issue	Prepared by	Verified by	Approved by
A	2019-06-06	Draft issue	Faraz Mirzaagha	DRAFT	DRAFT
B	2019-06-20	Final issue, Appendix added	Faraz Mirzaagha	Ronan McDermott	Richard Gledhill
C	2019-07-16	Additional data added in Appendix B	Faraz Mirzaagha		
D	2019-08-21	Plant size reduced due to limits proposed by Powercor	Faraz Mirzaagha		
E	2019-11-12	LDC setting, PV size changed	Faraz Mirzaagha		Richard Gledhill
F	2019-11-19	Powercor comments addressed	Faraz Mirzaagha		

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Acronym	Description
AVR	Automatic Voltage Regulator
EDC	(Victorian) Electricity Distribution Code
IEC	International Electrotechnical Commission
HV	High Voltage
HWF	Hepburn Wind Farm
kV	kilo-Volt (unit of voltage)
LDC	Line Drop Compensator
MVAr	Mega-VAr (unit of reactive power)
OLTC	On Load Tap Changer
p.u.	Per Unit
PF	Power Factor
POC	Point of Connection
PSP	Power System Planning

Executive Summary

DNV GL has carried out load flow and short circuit analysis to assess the maximum allowable **additional** generation and compliance of the Hepburn Wind Farm (HWF) (also known as Leonards Hill Wind Farm).

Compliance was checked against the Victorian Electricity Distribution Code (EDC) [1] and Powercor's planning limits, taking into consideration the expansion plans detailed further herein to co-locate a solar installation at HWF.

The limits assessed in this report are described in Table 1, below.

Table 1 Summary of results

Technical Criteria	Compliance Requirement	Assessment/Results
Thermal Loading	Powercor Planning Limit – Max 100% in model	Compliant
Steady State Voltage	Vic EDC – cl 4.2.2	Compliant
	Powercor Planning Limit Max 4.4% voltage fluctuation	Compliant
	Powercor Planning Limit Trip Max 5% voltage deviation	Compliant
Fault Studies	Vic EDC – cl. 7.8	Compliant

To achieve the compliance per Table 1 above, the system as modelled by DNV GL would operate per the following parameters:

- **Cumulative maximum power at POC is 7.8 MVA at 0.87 leading PF.** Data extracted from the simulation of which real power would be a maximum of 6.8 MW and -3.8Mvar reactive power absorbed by the plant.
- Existing wind turbines operating at fixed 0.93 leading power factor, for maximum output of 4.1 MVA from the wind generation, of which real power would be a maximum of 3.8 MW
- The proposed additional generation would ensure compliance using the above wind turbine operational regime and operating two SMA SC3000 central inverters each rated at 3.0MVA. For the purpose of this exercise the cumulative output of both solar inverters was **curtailed** to 3.8 MVA at fixed 0.83 leading power factor, of which real power would be a maximum of approximately 3.1 MW[1].

Considering the above points, the total site capacity is 10.1MW where export is curtailed to 6.8MW in Power Factor control mode using a Power Plant Controller (PPC).

The configuration above allows the existing STATCOM presently in service to be removed from service, which will introduce a benefit to the Customer as the STATCOM is known to have caused multiple spurious trips of the site resulting in project downtime.

However, it should be noted that operating the wind turbines in the proposed power factor will mean a maximum MW at each WTG of ~1.9MW.

[1] Stated export limit of 3.8MVA on two SMA inverters is for the power system simulation purposes. Due to the dynamic nature of wind and solar both the solar inverters and wind turbines output may change within their nameplate rating while making sure the POC limits are followed i.e. 7.8MVA at 0.87 leading PF.

The effect of this reduced maximum MW output from the wind turbines compared to present operating parameters should be considered by the Customer in relation to the financial model for the project.

1 Introduction

Hepburn Wind (the Customer) is currently in the planning process for a co-location project to attach solar generation to the existing 4.1MVA of wind generation at Hepburn Wind Farm (also known as Leonards Hill Wind Farm).

The aim of this report is to identify the maximum allowable amount of generation at the Point of Connection (POC) for Hepburn Wind Farm.

For this process DNV GL has considered thermal rating of the network equipment as well as voltage fluctuation limits set by DNSP and Victorian Electricity Distribution Code.

1.1 Site Location

The project site is approximately 10km south of the town of Daylesford, in North Western Victoria. A map showing the site location is provided in Figure 1-1.

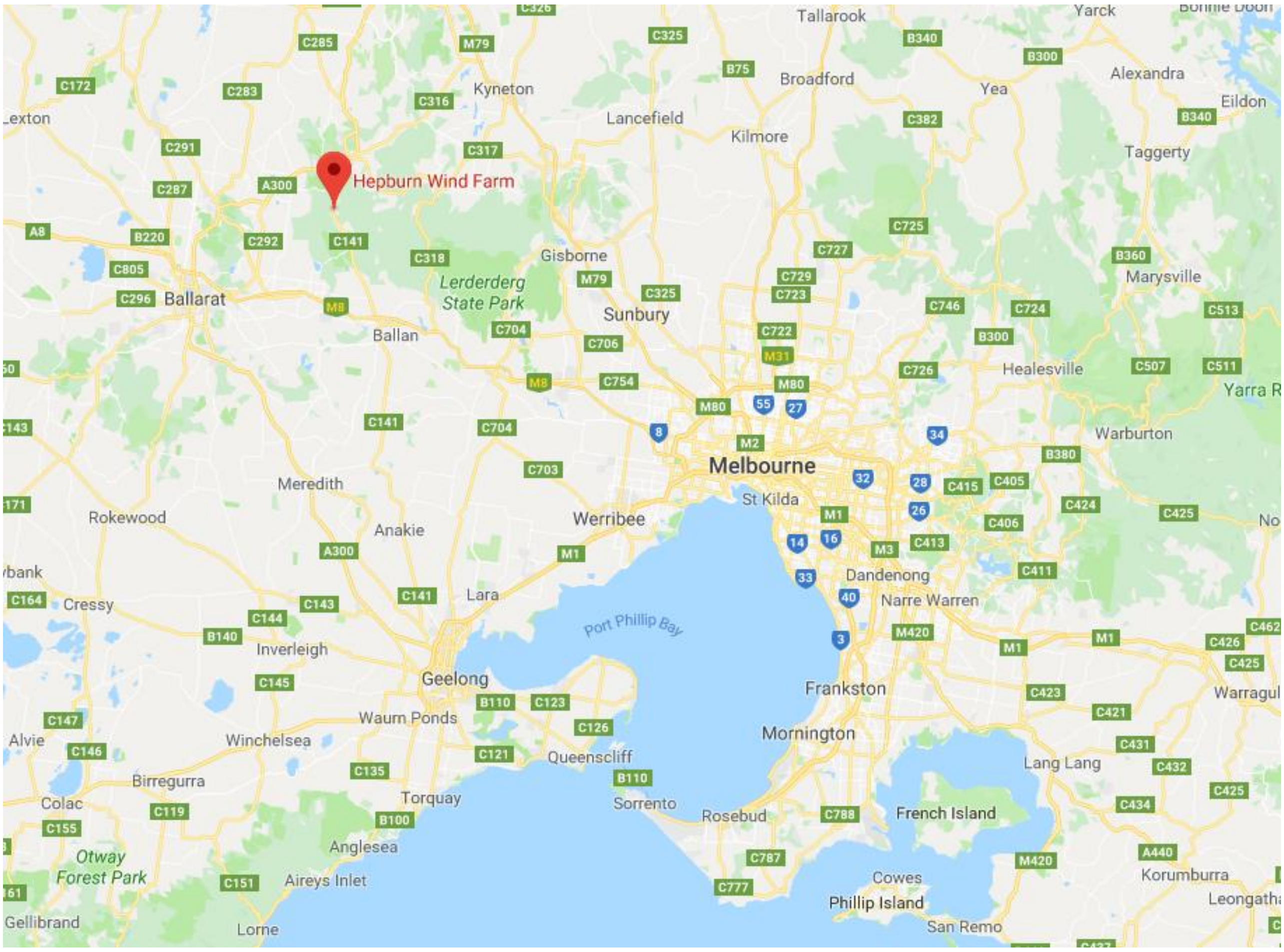


Figure 1-1 Site location

1.2 System Description

The existing Hepburn Wind Farm project consists of two REpower MM82 2.05 MVA wind turbines with a maximum power output capacity of 4.1MW.

The existing plant (which includes a STATCOM on site) and future plant are further described in Section 2.3 of this report.

The proposed expansion of the project to co-locate a solar farm consists of two SMA solar inverters with a name plate rating of 3.0 MVA each and associated solar generation units.

The site is located approximately 42km from Powercor's Ballarat North zone substation, and is connected via the Powercor 'BAN 011' 22 kV feeder circuit.

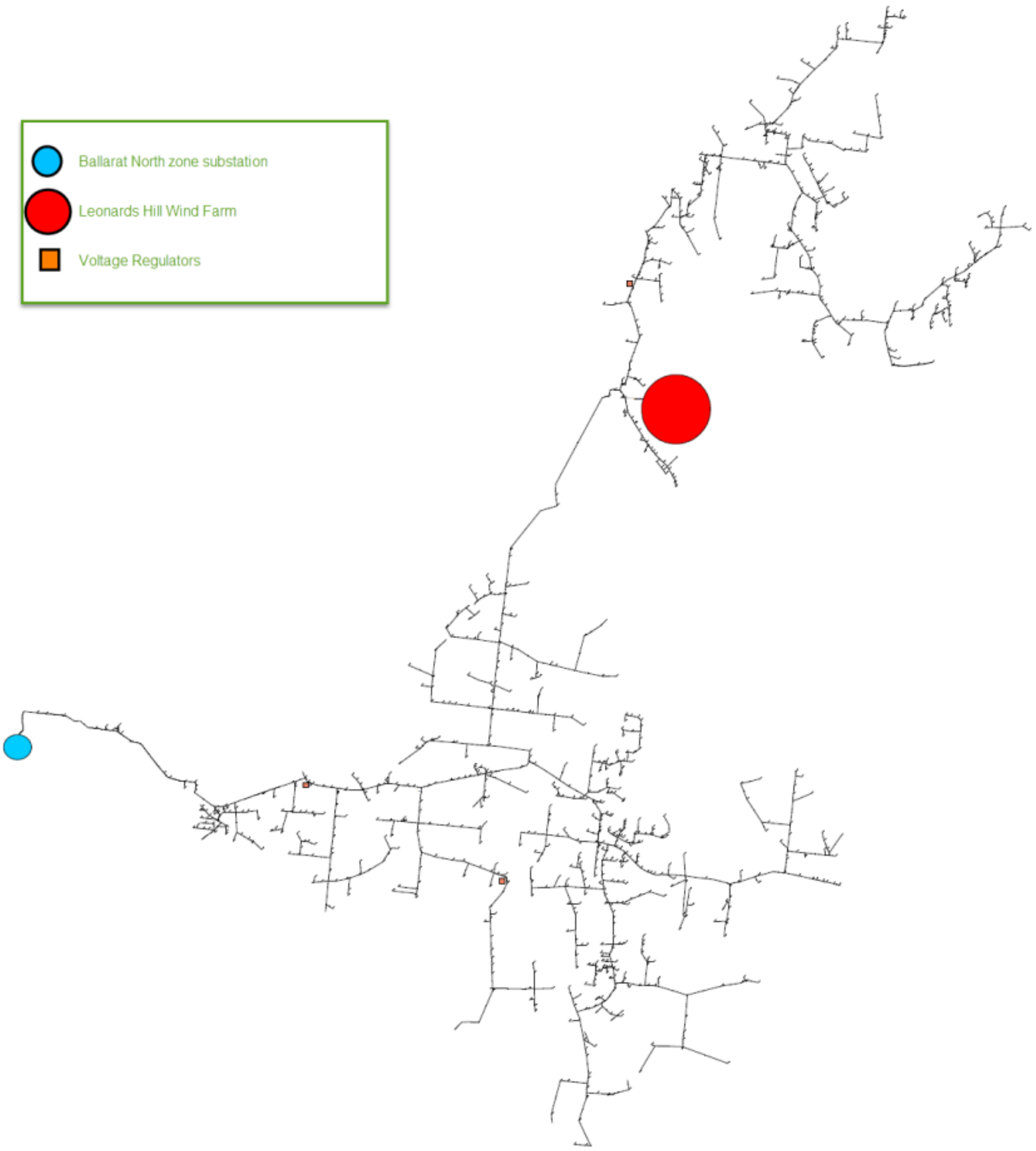


Figure 1-2 BAN 11 feeder

2 POWER SYSTEM MODEL

2.1 Development of the Model

The feeder model used for evaluation in this study was received as a Sincal model provided by Powercor via an email on 13/08/2019. The Sincal model was then converted to a DIgSILENT Power Factory model to perform the required simulations and studies.

It is assumed that the working Sincal model accurately represents the current conditions of the existing Powercor BAN 11 22 kV feeder.

All studies are based on the following files and associated correspondence from Powercor:

- Leonards Hill Wind Farm V3 FL.sin
- Leonards Hill Wind Farm V3 LL.sin
- database.mdb

As advised by Powercor, the Point of Connection (POC) of the existing wind farm on the COB011 feeder is located at terminal 84343815 on the BAN 11 22 kV feeder.

It is worth mentioning, DNV GL has identified many discrepancies in conductor current ratings in the provided model by Powercor. To this effect there were two main issues noted:

1. Conductors incorrectly rated and
2. Conductors incorrectly named

This was brought to Powercor's attention where they provided DNV GL with updated conductor ratings [2]. The correct ratings were applied to the model.

2.2 Model Settings

The BAN011 loading conditions were provided to DNV GL in an email from Powercor [3] on 8 May 2019 as described below.

Table 2 BAN011 Feeder Loading scenarios

Load Scenario	Feeder Current (A)
LOW LOAD	55
HIGH LOAD	222

The model provided by Powercor includes three Voltage Regulators with Line Drop Compensators (LDCs) and an AVR at the BAN substation to control the transformer OLTC. The Rset and Xset values of the LDCs and their settings were extracted from the following documents provided by Powercor:

- BAN ZSS VRR1 (AVR)
- Bungaree P160A
- Millbrook P50
- Muskvale (P190 Barkstead)

It is worth noting, the LDC settings within the PSS SINCAL model differed from the documentation provided by Powercor. DNV GL have modelled both settings to identify most reasonable results that would closely match the voltage profiles provided by the Powercor shown in Figure 2-1. During a meeting with Powercor on 18/10/2019, new regulator settings were proposed to address the voltage deviation issues. The proposed settings for Bungaree regulator along with the other regulators are shown in the table below:

Table 3 LDC setting comparison

	SINCAL model			Data sheet		
Name	**R (ohm)**	**X (ohm)**	**X/R ratio**	**R (Volts)**	**X (Volts)**	**X/R ratio**
Bungaree Reg	2.32	3.25	1.401	6.5	9.1	1.4
Millbrook	NA	NA	NA	10	2.1	0.211
Muskvale	2.877	1.726	0.601	5.4	3.3	0.611

The parameters from the SINCAL model column were used for simulation purposes. The LDC have been modelled with 'continuous' tapping, to align with Powercor modelling techniques and voltage profile. The voltage setpoints were supplied by Powercor via email [3].

To ensure the model used for this study aligns with Powercor's model, DNV GL performed a data validation by matching the voltage profiles as close as possible with Powercor's provided ones.

DNV GL have used Sincal software to generate the voltage profiles. The data are presented in the following pages in Figures 2-1 to 2-3.

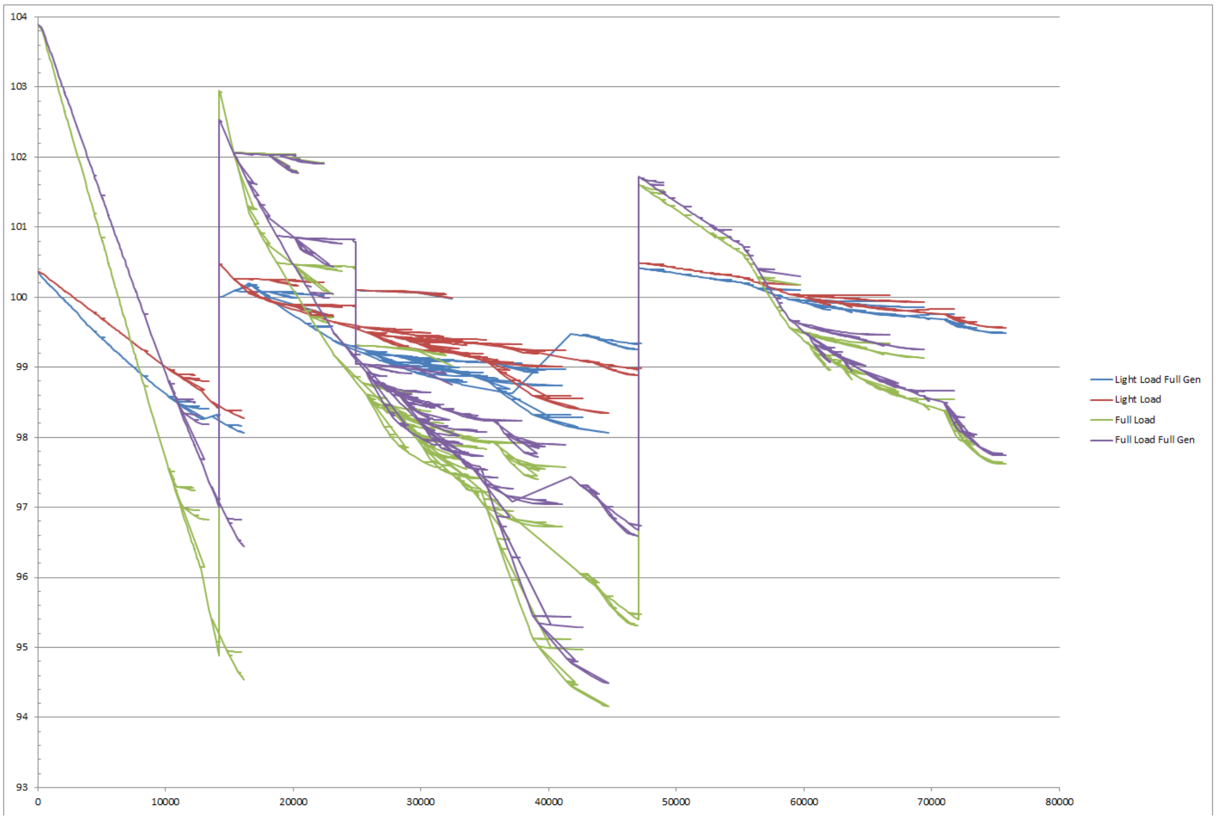


Figure 2-1 Powercor BAN011 voltage profile

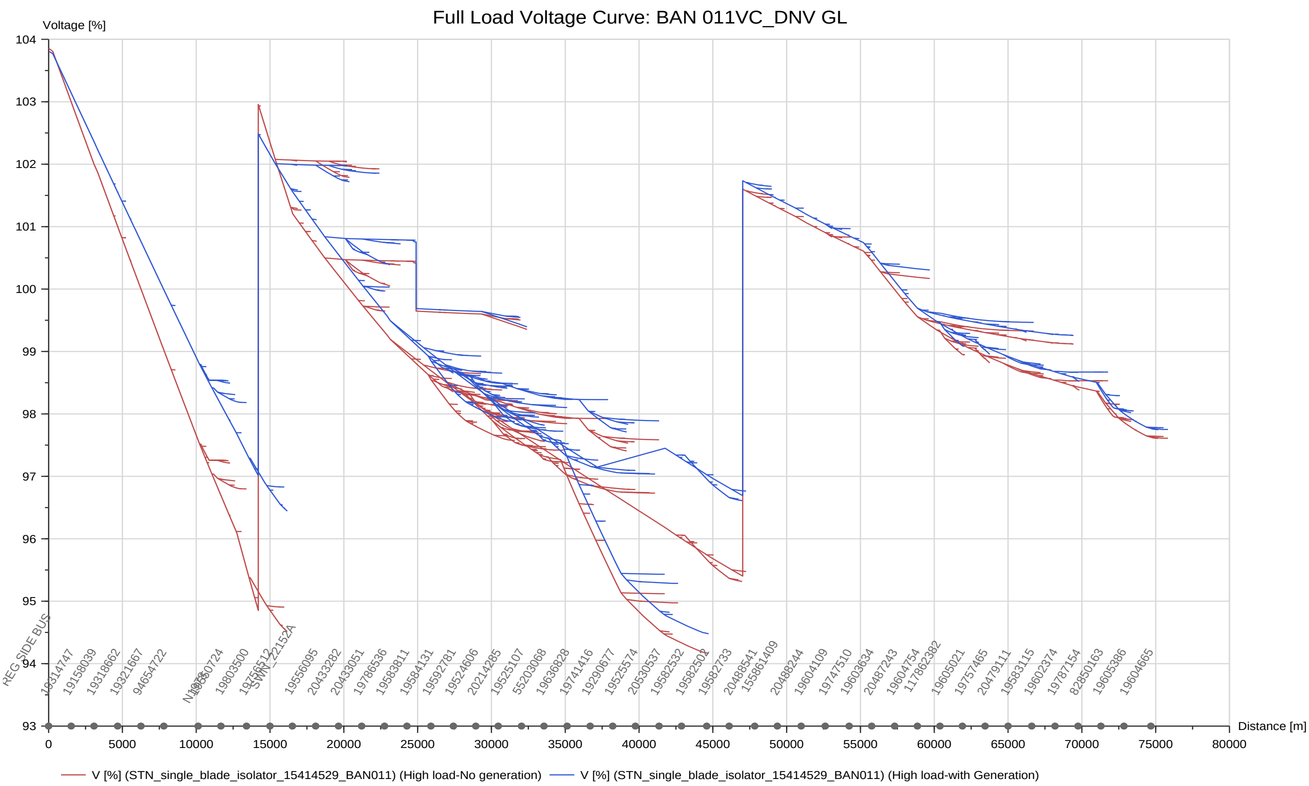


Figure 2-2 DNV GL BAN011 Full load voltage profile

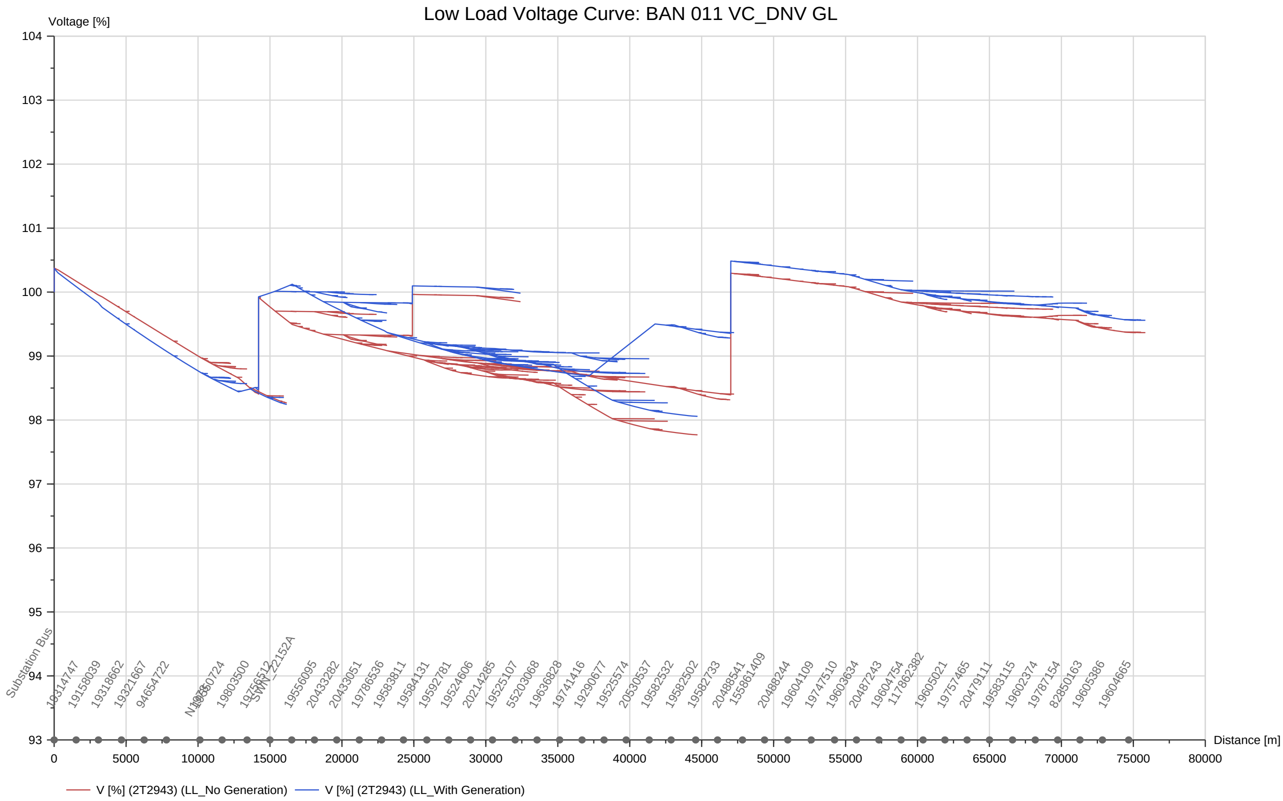


Figure 2-3 DNV GL BAN011 Low load voltage profile

2.3 Plant model

The existing plant system specification received from Hepburn Wind Farm are used for this study.

The plant consists of two wind turbines with a dedicated transformer and a STATCOM system.

As per Senergy's report [4] after considering the reactive capability of the turbines, both wind turbines can provide up to 1.66MVar of reactive power at POC.

To meet Powercor's requirement, additional 993kVar of external reactive power was calculated by Repower to meet the leading PF of 0.85 at POC at 1p.u voltage. The additional reactive power in the current configuration is provided by the STATCOM

The existing plant layout and specification of such equipment is shown in the following figures 2-5 to Figure 2-8, whilst Figure 2-9 presents the specifications of the future central solar inverters which may be installed (2 x 3000 kVA units).

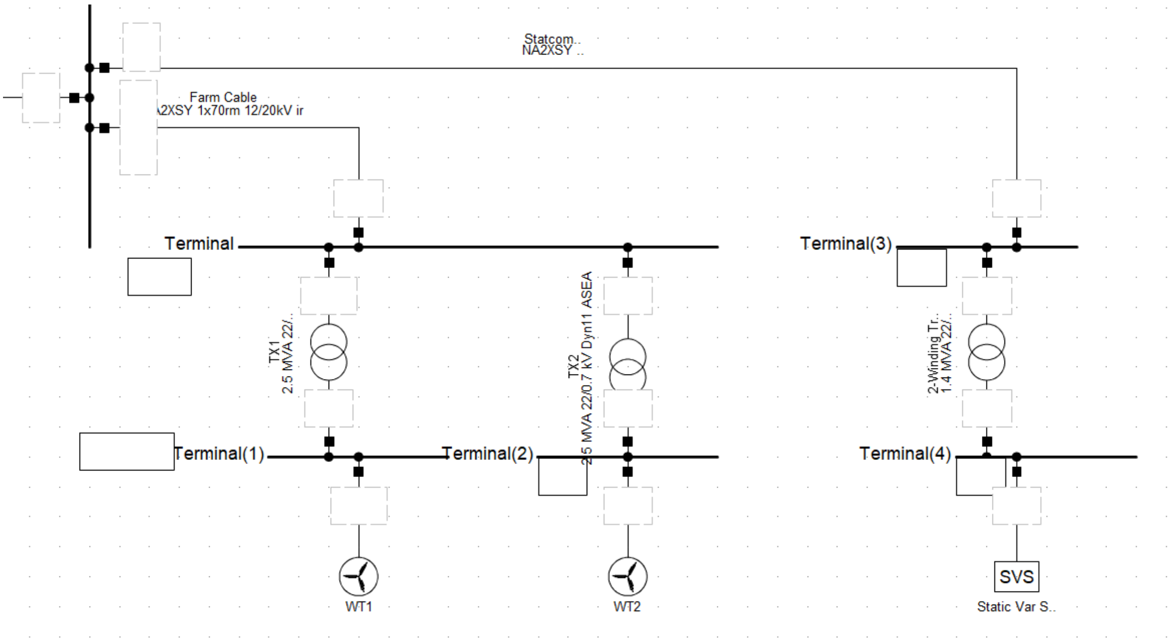


Figure 2-4 Existing plant model represented in PowerFactory

Parameter	Value
Nominal power (nominal active power)	P_N = 2050 kW
Power factor	cos phi = ~ 1
Nominal voltage	U_N = 690 V
Voltage range (at LV terminals) [1] of the WEC (cos phi = ~ 1)	90% ≤ U_N ≤110%
Rated frequency	f_N = 50 Hz
nominal current (cos phi= ~ 1)	I_N = 1715 A
Rated generator speed	n = 1800 RPM

Figure 2-5 Wind turbine specification [5]

Manufacturer	Schneider Electric
Serial No.	T080564
Transformer Spec	22kV/0.690kV 2.5MVA Dyn11
Standard	AS 60076 - 2005
Year of Manufacture	2008
Impedance	6.28%
Cooling Method	ONAN

Figure 2-6 Wind turbine transformer Specification [5]

Manufacturer	Trasfor
Serial No.	CZ1002111/01
Transformer Spec	22kV/0.480kV 1.4MVA Dyn11
Standard	IEC 60076 - 11
Year of Manufacture	2011
Impedance	6.0%
Cooling Method	AN

Figure 2-7 STATCOM transformer specification [5]

The reactive power capability that the wind farm is able to supply at POC is 1.666Mvar [6] [4]. Calculated PQ curve by Repower is shown in Figure 2-8

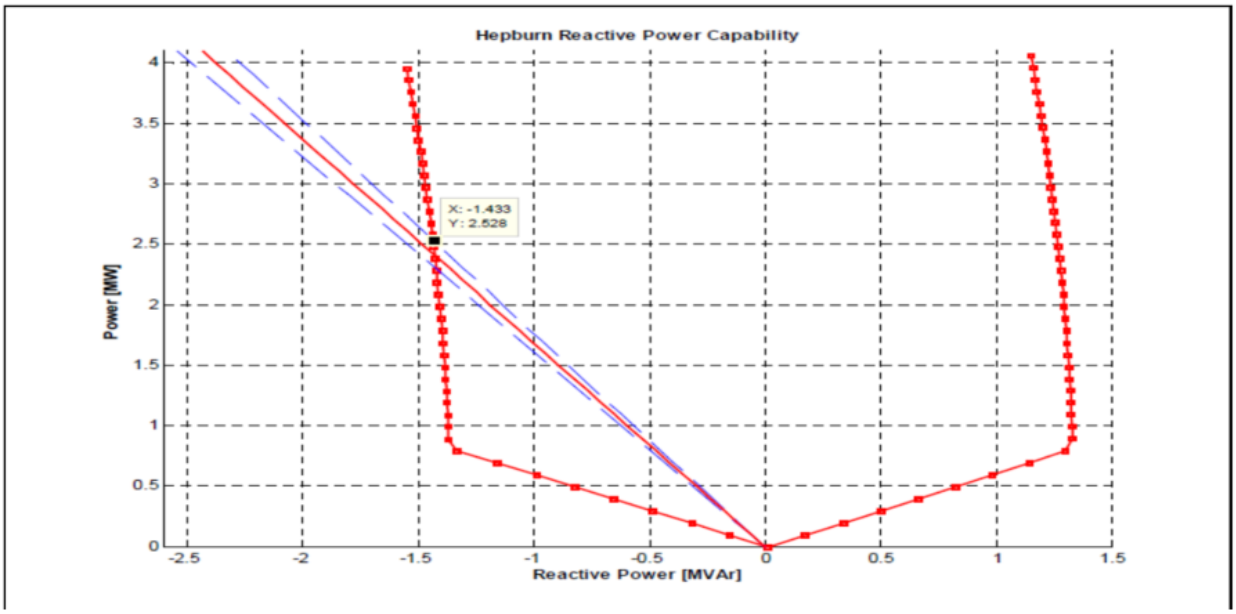


Figure 2-8 Reactive power capability with the Powercor requirements superimposed [4]

Figure 2-9 shows the final model used by DNV GL which incorporates the additional solar generation.

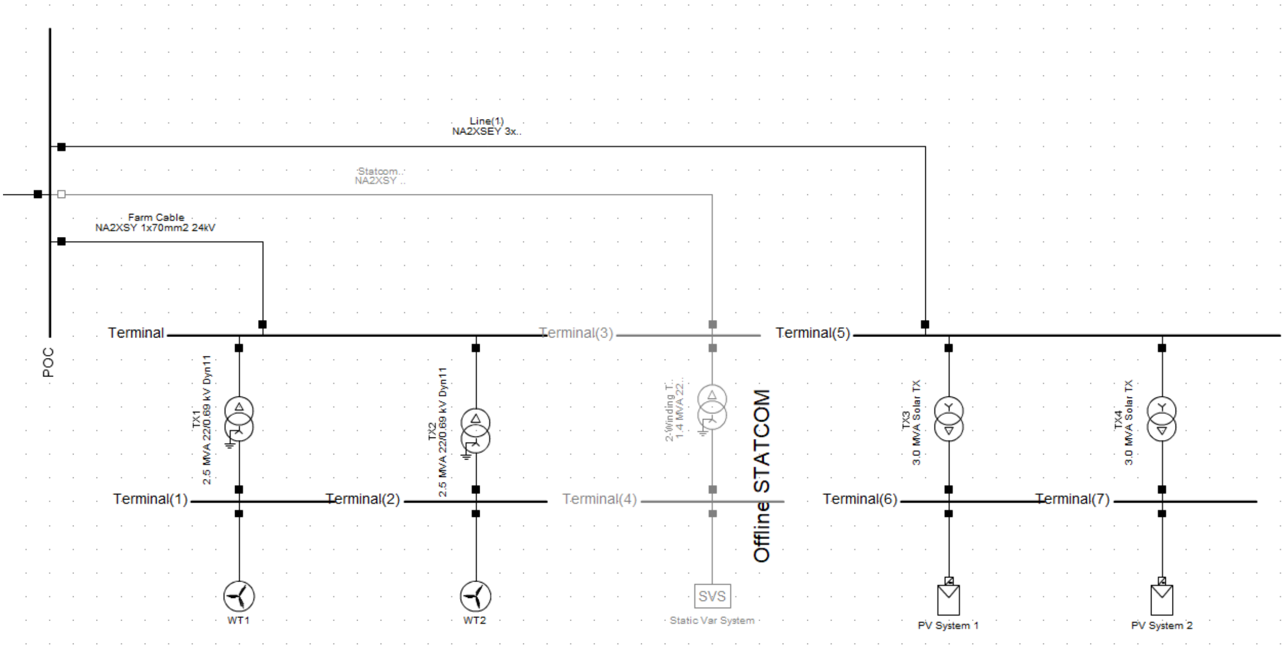


Figure 2-9 The proposed plant layout

Detailed specification of the SMA SC3000-EV inverter is shown in APPENDIX C – SMA SOLAR INVERTER SPECIFICATION. The brief datasheet is shown below:

Technical Data	Sunny Central 2500-EV	Sunny Central 2750-EV	Sunny Central 3000-EV
Input (DC)			
MPP voltage range V_{DC} (at 25°C / at 35°C / at 50°C)	850 V to 1425 V / 1200 V / 1200 V	875 V to 1425 V / 1200 V / 1200 V	956 V to 1425 V / 1200 V / 1200 V
Min. input voltage $V_{DC, min}$ / Start voltage $V_{DC, Start}$	778 V / 928 V	849 V / 999 V	927 V / 1077 V
Max. input voltage $V_{DC, max}$	1500 V	1500 V	1500 V
Max. input current $I_{DC, max}$ (at 35°C / at 50°C)	3200 A / 2956 A	3200 A / 2956 A	3200 A / 2970 A
Max. short-circuit current rating	6400 A	6400 A	6400 A
Number of DC inputs	24 double pole fused (32 single pole fused) for PV		
Number of DC inputs with optional DC battery coupling	18 double pole fused (36 single pole fused) for PV and 6 double pole fused for batteries		
Max. number of DC cables per DC input (for each polarity)	2 x 800 kcmil, 2 x 400 mm²		
Integrated zone monitoring	○		
Available DC fuse sizes (per input)	200 A, 250 A, 315 A, 350 A, 400 A, 450 A, 500 A		
Output (AC)			
Nominal AC power at cos φ =1 (at 35°C / at 50°C)	2500 kVA / 2250 kVA	2750 kVA / 2500 kVA	3000 kVA / 2700 kVA
Nominal AC power at cos φ =0.8 (at 35°C / at 50°C)	2000 kW / 1800 kW	2200 kW / 2000 kW	2400 kW / 2160 kW
Nominal AC current $I_{AC, nom}$ = Max. output current $I_{AC, max}$	2624 A	2646 A	2646 A
Max. total harmonic distortion	< 3% at nominal power	< 3% at nominal power	< 3% at nominal power
Nominal AC voltage / nominal AC voltage range[1) 8)]	550 V / 440 V to 660 V	600 V / 480 V to 690 V	655 V / 524 V to 721 V[9)]
AC power frequency	50 Hz / 47 Hz to 53 Hz 60 Hz / 57 Hz to 63 Hz		
Min. short-circuit ratio at the AC terminals[10)]	> 2		
Power factor at rated power / displacement power factor adjustable[8) 11)]	● 1 / 0.8 overexcited to 0.8 underexcited ○ 1 / 0.0 overexcited to 0.0 underexcited		
Efficiency			
Max. efficiency[2)] / European efficiency[2)] / CEC efficiency[3)]	98.6% / 98.3% / 98.0%	98.7% / 98.5% / 98.5%	98.8% / 98.6% / 98.5%

Figure 2-10 PV Central inverter specification Sunny Central 3000-EV for future solar equipment [7]

2.4 Plant control mode

The existing wind farm is operating in power factor control mode in range of 0.85-0.89 leading [4]. As per the original proposed [4] control scheme by Senergy and PWE the reactive power is supplied by both the STATCOM and wind turbines. DNV GL is aware the STATCOM has been responsible for multiple spurious protection trips on site in recent years, and therefore methods to remove it from service were part of the analysis performed.

DNV GL has assumed maintaining a power factor control mode for the proposed additional generation as the optimum solution to meeting compliance targets.

In Power Factor control mode, the plant (existing and proposed) is set to control its net power factor. This is achieved by implementing a fixed power factor at each generator within the model. Note a Power Plant Controller is needed at a cubicle connecting the farm to the POC Busbar. The power factor set point has been changed to accommodate the requirement set by Powercor and Victorian Electricity Distribution Code.

The additional capacity provided uses two SMA central inverters rated at 3.0MVA each. Simulations were performed iteratively to select the optimum Power Factor (PF) of the entire plant at the POC.

The selection of the PF setting was required to meet the 4.4% and 5% voltage variation criteria and the generator trip conditions.

The results presented in Section 3 of this report are based on DNV GL’s findings of the following optimum control configuration:

1. Wind turbines were configured with fixed power factor of 0.93 leading
2. Solar farm was configured with fixed power factor of 0.83 leading
3. STATCOM switched off

The result of the combination of factors 1 to 3 above is a net Power Factor of the entire plant at the POC of 0.87 leading.

3 RESULTS

3.1 Steady State Voltage Variation

3.1.1 Normal operation

This section of the study investigates steady state voltage variations within the feeder created by the inclusion of the entire plant into the grid. Network simulations were conducted for the various loading levels and inclusion of Hepburn Wind Farm.

The acceptable levels for voltage variations are detailed within clause 4.2.2 of the VIC EDC which references Table 1.

STANDARD NOMINAL VOLTAGE VARIATIONS				
Voltage Level in kV	**Voltage Range for Time Periods**			**Impulse Voltage**
	Steady State	**Less than 1 minute**	**Less than 10 seconds**	
< 1.0	+10% - 6%	+14% - 10%	Phase to Earth +50%-100% Phase to Phase +20%-100%	6 kV peak
1-6.6	± 6 % (± 10 % Rural Areas)	± 10%	Phase to Earth +80%-100% Phase to Phase +20%-100%	60 kV peak
11				95 kV peak
22				150 kV peak
66	± 10%	± 15%	Phase to Earth +50%-100% Phase to Phase +20%-100%	325 kV peak

Figure 3-1 - Replication of Table 1 from Clause 4.2.2 of Vic EDC

Referencing the above table, to comply with the Victorian EDC the proposed plant shall not cause voltage variation of more than ±10% on the 22kV (MV) terminals within the BAN011 feeder.

Powercor requires **Planning Limit of 4.4%** in Steady State Voltage Variation. This was assessed for the 4 key voltage profiles described by Powercor [8] .

The 4 key voltage profiles in the analysis of the BAN011 feeder are:

1. Case 1: Low Load and No Generation
2. Case 2: High Load and No Generation
3. Case 3: Low Load and Full Generation
4. Case 4: High Load and Full Generation

Considering the planning limits are significantly lower that EDC limits, DNV GL has used the 4.4% as the main assessment criteria for voltage deviation limit, in addition to maintaining the voltages on the BAN011 feeder at all times between 0.9 to 1.1 p.u.

Voltages across all terminal points were monitored while comparing:

- Case 1 and 3
- Case 2 and 4
- Case 1 and 2
- Case 2 and 3

After running the simulation, all terminal points voltages remained below the **voltage deviation limit of 4.4%.** All results are shown in APPENDIX A – NORMAL OPERATION RESULTS .

The following terms are used for the graphs:

FLNG Full Load No Generation **FLFG** Full Load Full Generation

LLNG Low Load No Generation **LLFG** Low Load Full Generation

3.1.2 Trip Scenario

This section of the study analyses voltage fluctuations within the feeder created by the very rare case of a wind farm trip event.

As discussed with Powercor, the maximum voltage change following the sudden trip of the entire plant ***shall not exceed 5%*** [9]***.*** In the trip event, the voltage of all terminals during sudden loss of both WT and Solar inverter systems for both low and high load scenarios are investigated.

The following steps are used to model a trip event:

1. Entire plant trip under Full Generation
    1.1. Taps unlocked on all voltage regulation elements
    1.2. Load flow conducted with the plant 100% generation (fixed PF control mode)
    1.3. Taps locked on all voltage regulation elements
    1.4. Load flow conducted with the entire plant tripped

After running the simulation, all terminal points voltages remained below the **voltage deviation limit of 5%.** Results are shown in the figures overleaf.

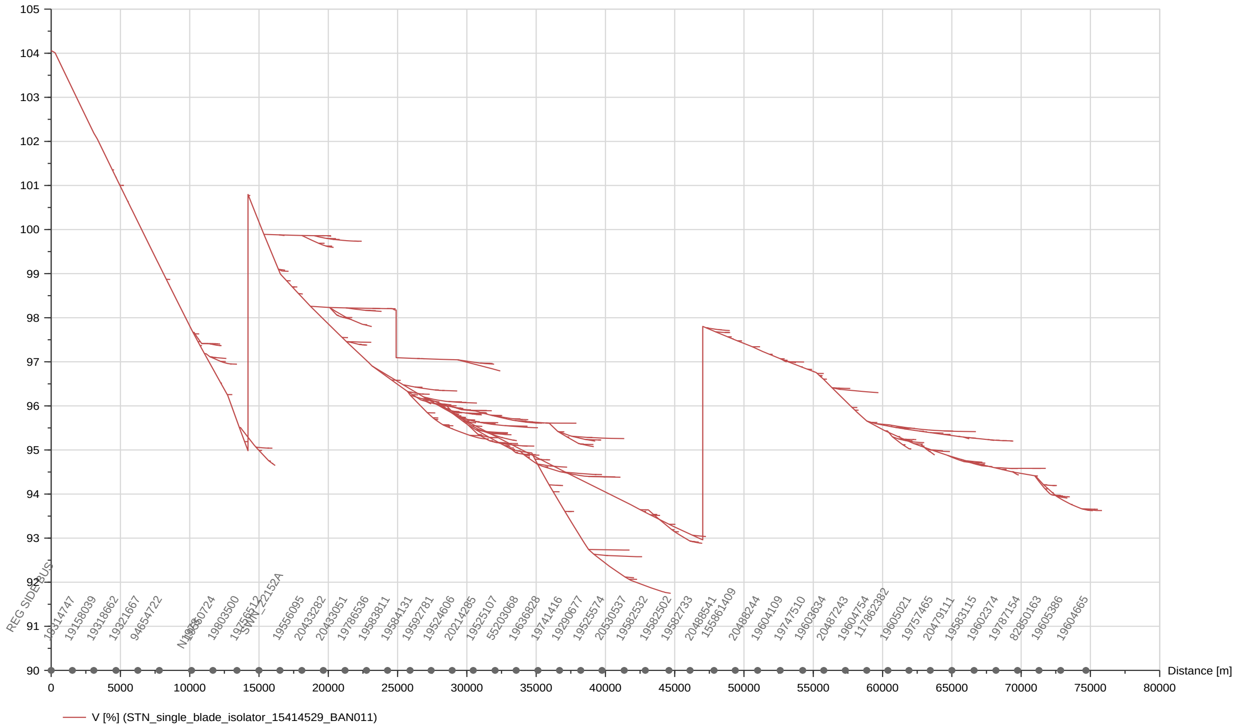


Figure 3-2 Full Load trip voltage profile

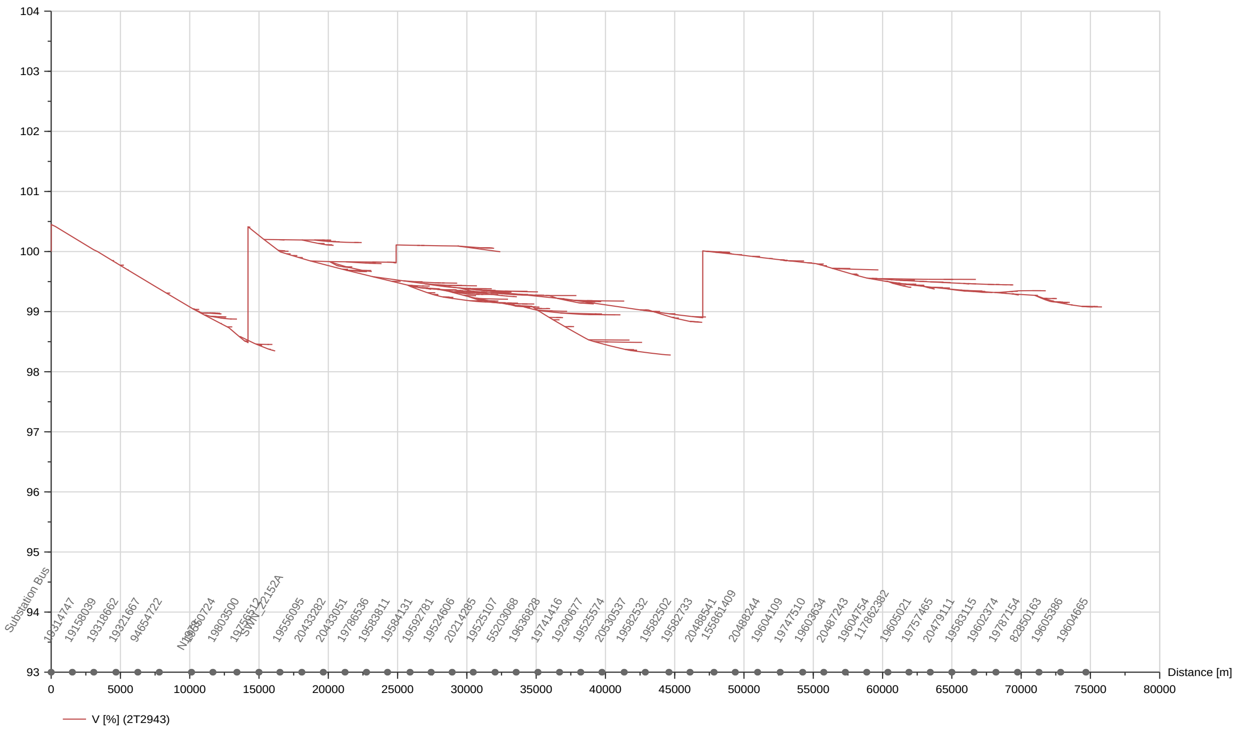


Figure 3-3 Low Load Trip voltage profile

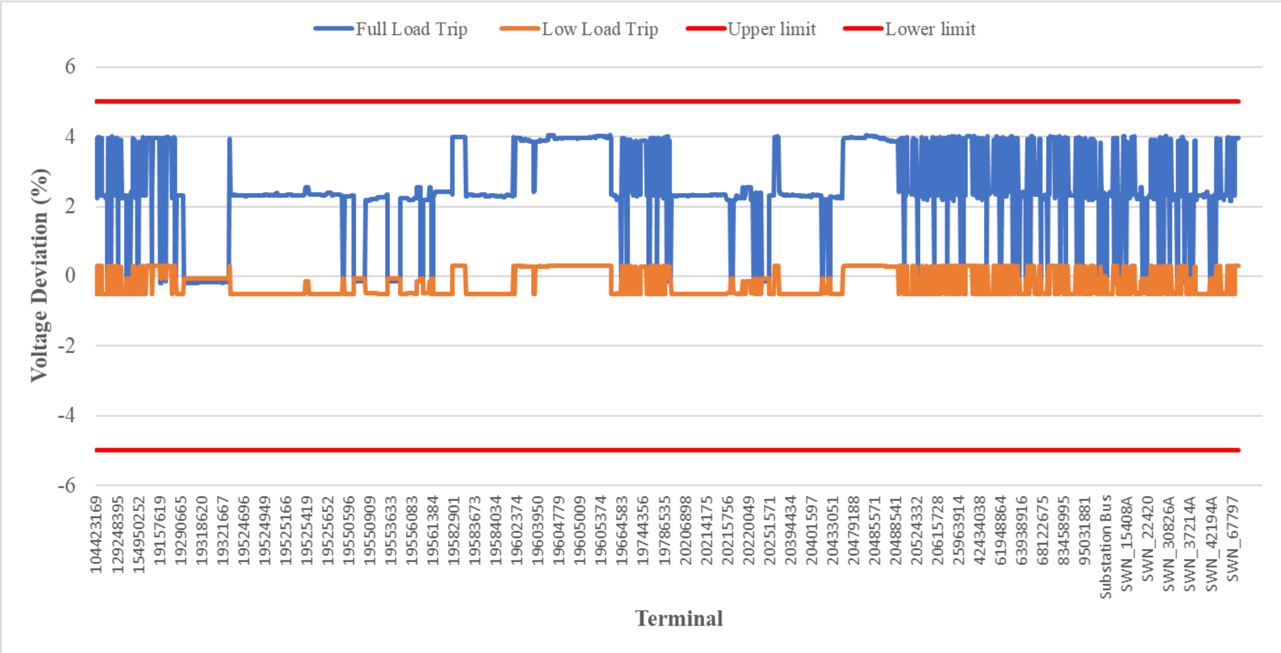


Figure 3-4 Trip voltage deviation

3.1.3 Cloud Cover Scenario

DNV GL has used a number of historical datasets to identify how to best represent a cloud cover event. By observing the amount and number of sudden generation changes, it is concluded to use a generation change of 100% to 40% to represent a cloud cover.

System setup:

Initial condition:

Wind turbines in full service: 4.1MVA @0.93 leading PF

PV inverters in full service: 3.8MVA @0.83 leading PF

Cloud cover event:

Wind turbines in full service: 4.1MVA @0.93 leading PF

Lock transformer tap

PV inverters instantaneous ramp down to 40%

Load flow analysis has been conducted on the network model in PowerFactory to ascertain the voltage variation for the various loading levels and due to cloud cover affecting the output of the PV system (40% Generation).

The voltage change across the feeder is monitored both at high and low load scenario. All terminal point voltages remained below the **voltage deviation limit of 5%.**

Results are shown in APPENDIX B – CLOUD COVER RESULT

3.2 Thermal Ratings of Network Equipment

This section of the study assesses the impact of the HWF on the thermal loading of network elements within the BAN011 feeder.

The maximum thermal loading limit for the feeder's lines is 100% as provided in the network model. Based on discussion with Powercor it is understood that elements within the network model must remain below 100% without requiring replacement or augmentation of these elements. This requirement will form the basis of assessment for this study

Load flow study of feeder without any generation (at Full Load scenario) shows several lines are already overloaded. DNV GL has corresponded with Powercor on this matter and Powercor have confirmed this is the case.

Table 4 Overloaded lines at full load scenario

Line Name	Loading %	Irated kA
67134052 HV_Line(_BAN011_RWB_6/1/.144_AC	110.6576	0.175
129344643 HV_Line(_BAN011_RWB_6/1/.144_A	110.6572	0.175
67134053 HV_Line(_BAN011_RWB_6/1/.144_AC	110.5886	0.175
62752048 HV_Line(_BAN011_RWB_6/1/.144_AC	102.4358	0.175
83837000 HV_Line(_BAN011_RWB_6/1/.144_AC	102.3721	0.175
83836999 HV_Line(_BAN011_RWB_6/1/.144_AC	102.3089	0.175
83836998 HV_Line(_BAN011_RWB_6/1/.144_AC	102.0516	0.175
83836997 HV_Line(_BAN011_RWB_6/1/.144_AC	101.7937	0.175

As the embedded generation of Hepburn Wind Farm is changing the flow of power, all conductors remained below 100% their current rating at Full load as well as Low Load.

If Powercor plans to upgrade the overloaded lines in future HWF may be able to increase its generation capacity accordingly.

3.3 Fault Level Studies

This section of study assesses the fault level contributions of the proposed plant to the Powercor' distribution system fault levels. According to the standard in VIC EDC/IEC Short-Circuit calculations, the static generators are normally disregarded. For the purpose of this study, the short circuit factor K used for the wind turbine is 1.1 and for the PV inverter K factor of 1.34 as per SMA recommendation [10]. The K factor is used on their nominal AC current output to calculate the fault current.

The acceptable limits of fault levels are detailed in clause 7.3 of the Victorian Electricity Distribution Code, this is shown in Figure below.

Table 5

DISTRIBUTION SYSTEM FAULT LEVELS		
Voltage Level kV	**System Fault Level MVA**	**Short Circuit Level kA**
66	2500	21.9
22	500	13.1
11	350	18.4
6.6	250	21.9
<1	36	50.0

Figure 3-5 Maximum distribution system fault levels under Vic EDC

To calculate the maximum three phase short circuit IEC 60909 2016 version with break time of 0.3 seconds and clearing time of 1 second is used.

Referencing the above table, the plant must not cause fault levels in the distribution system to exceed 13.1kA for the 22kV network as specified in table 5 of clause 7.3 of the Vic EDC. The proceeding methodology and results will demonstrate the plant compliance with this.

.

Table 5 Full load - Short circuit fault contribution

Terminal	**Plant offline**		**Plant Online**		**Change ∆**	
	Sk'' (MVA)	Ik'' (kA)	Sk'' (MVA)	Ik'' (kA)	Sk'' (MVA)	Ik'' (kA)
84343815	30.31	0.795	42.62	1.11	12.31	0.315
Two Phase Short circuit fault contribution						
84343815	8.75	0.68	12.06	0.94	3.31	0.26
Single Phase to ground Short circuit fault contribution						
84343815	0.614	0.048	0.917	0.072	0.303	0.024

Table 6 Low load - Short circuit fault contribution

Terminal	**Plant offline**		**Plant Online**		**Change ∆**	
	Sk'' (MVA)	Ik'' (kA)	Sk'' (MVA)	Ik'' (kA)	Sk'' (MVA)	Ik'' (kA)
84343815	29.39	0.753	40.09	1.07	10.7	0.317
Two Phase Short circuit fault contribution						
84343815	8.48	0.66	11.79	0.92	3.31	0.26
Single Phase to ground Short circuit fault contribution						
84343815	0.63	0.049	0.95	0.074	0.32	0.025

As shown by the above table, fault currents in the distribution system with the inclusion of the combined wind farm and solar farm are within the limits defined by the Victorian Electricity Distribution Code and is therefore compliant with Powercor’s requirements.

4 Conclusions

A detailed analysis of the Hepburn Wind Farm (HWF) with additional solar capacity was carried out with numerous iterations of simulations conducted.

Power Factor control setting was selected to be 0.87 leading at the POC as described in Section 2.4 of this report. This setting was observed to provide the best performance, with the LDC settings and network configuration of BAN011.

From the power system studies the effect of the HWF on the distribution network and point of connection is as follows:

Thermal Loading

- With the HWF disconnected, a number of lines were already overloaded. With HWF connected in Full and Low load scenario all lines were below the 100% limit.

Steady State Voltage Studies

- For all generation conditions the Power System did not exceed the ±10% requirements of the Victorian EDC.
- For the 4 key cases analysed the wind farm was compliant with the 4.4% requirement.
- Trip events were modelled for low load and high load cases. Voltage variation stayed below 5% limit
- Cloud cover event was simulated with satisfactory results i.e. voltage variation stayed below 2%

Fault Level Studies

- The maximum fault contribution by the entire plant was within the limits outlined in the Vic EDC.

The results presented in this report show that the combined wind and solar farm installation was compliant with all criteria assessed using the control mode proposed.

It is noted that the configuration above allows the STATCOM presently in service to be removed from service, which will introduce a benefit to the Customer as the STATCOM is known to have caused multiple spurious trips of the site resulting in project downtime.

However, it should be noted that operating the wind turbines in the proposed power factor will mean a maximum generation at each WTG of 1.9 MW. The effect of this reduced maximum MW output from the wind turbines compared to business as usual should be considered by the Customer in relation to the financial model for the project.

5 References

[1] E. S. Commission, “ELECTRICITY DISTRIBUTION CODE,” 2018.

[2] D. H. C. D. Manager, “ HWF update,” CitiPower Pty, Powercor Australia Ltd , Mon 20/05/2019 5:15 PM.

[3] D. H. C. D. Manager, “ Hepburn Community Wind Farm,” CitiPower Pty, Powercor Australia , 08/05/2019.

[4] Senergy, “Leonard Hill Wind Farm Reactive Power Solution Due Diligence Assessment,” 29 / 04 / 2010.

[5] M. Group, “RAPID EARTH FAULT CURRENT IMPACT ASSESSMENT REPORT,” 10/01/2019.

[6] T. R. Hill, “Hepburn Community Wind Farm Ban11 Voltage Profile Report,” Repower Systems AG Uberseering 10/Oval Office D-22297 Hamburg. Received , 7th April.

[7] SMA, “SUNNY CENTRAL 2200 / 2475 / 2500-EV / 2750-EV / 3000-EV”.

[8] S. C. P. Australia, “Leonards Hill wind farm soalr request,” 2019.

[9] D. H. Powercor, “email FW: Hepburn Community Wind Farm,” Mon 6/05/2019 9:53 AM.

[10] SMA, “Short-circuit behavior of SMA Sunny Central,” September 12th 2018.

[11] D. Holroyd, “Email RE: FW: HWF update,” Wed 22/05/2019 3:15 PM.

Appendix A – Normal Operation Results

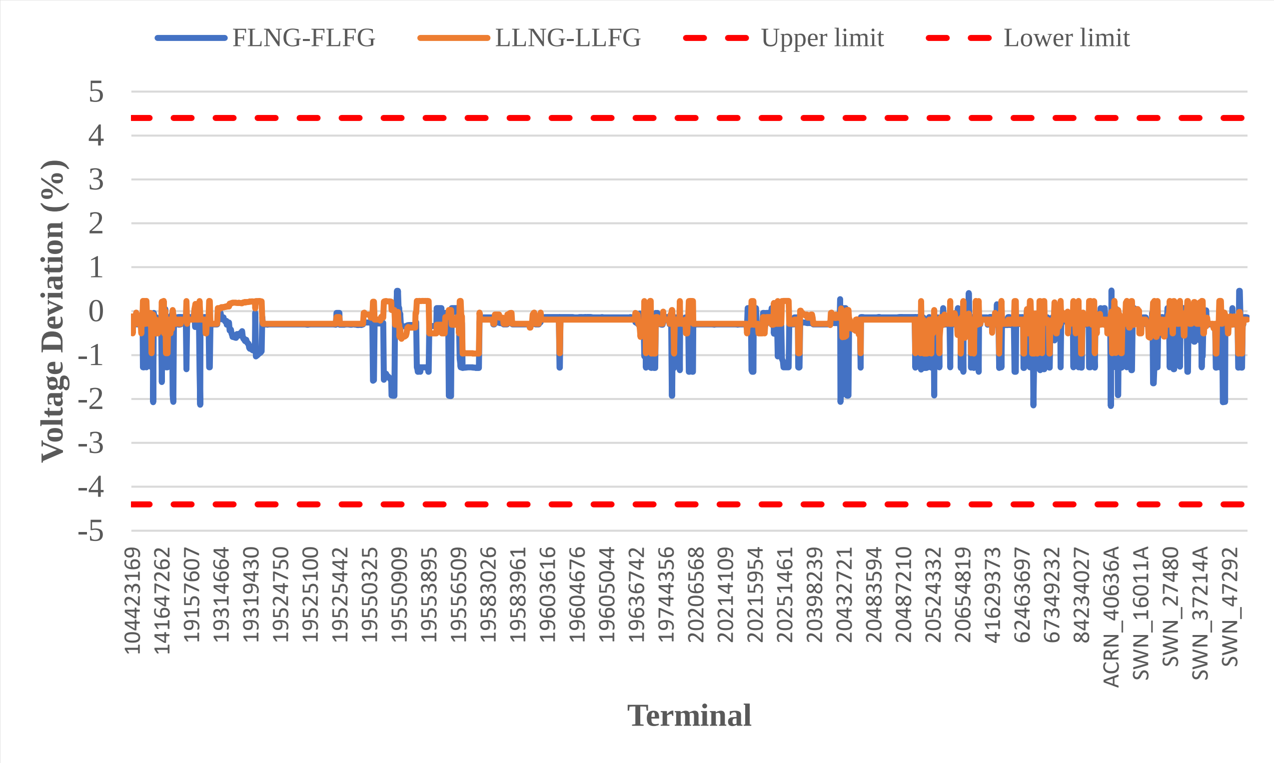


Figure 0-1 Case 1 and 3, Case 2 and 4

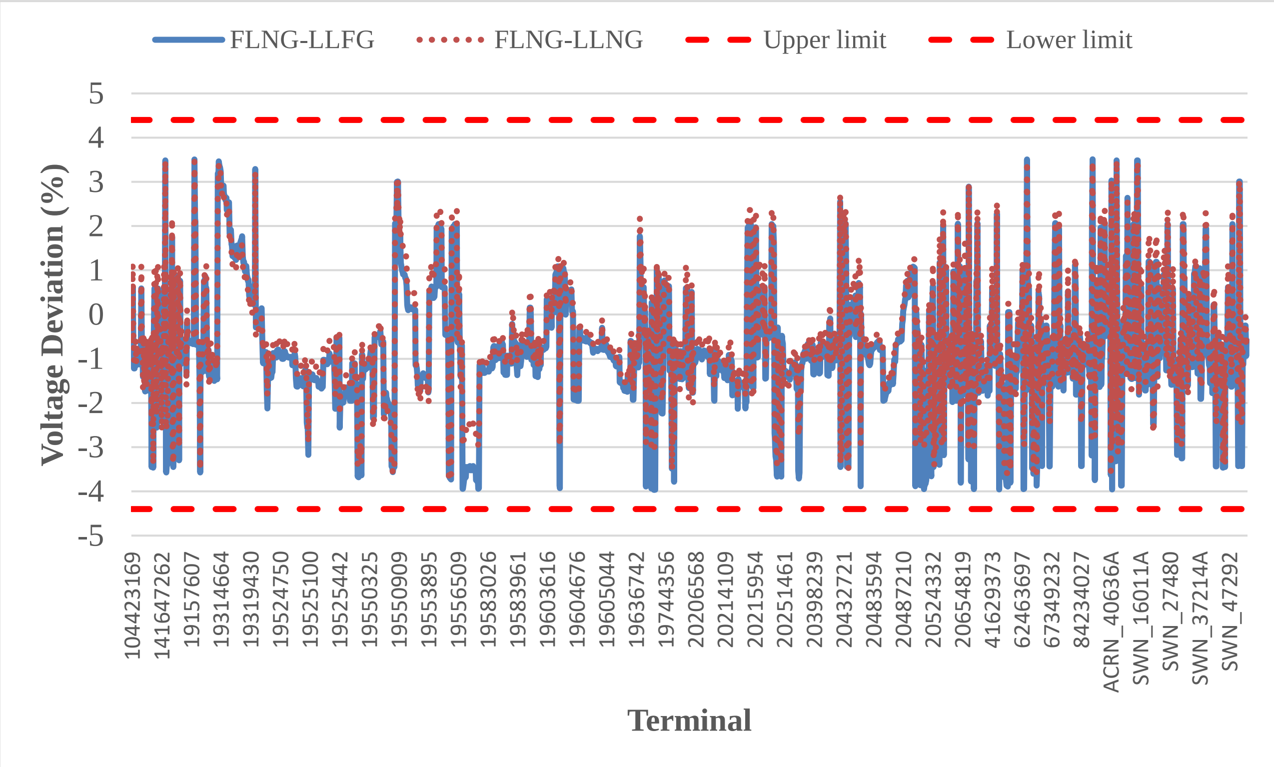


Figure 0-2 Case 1 and 2, Case 2 and 3

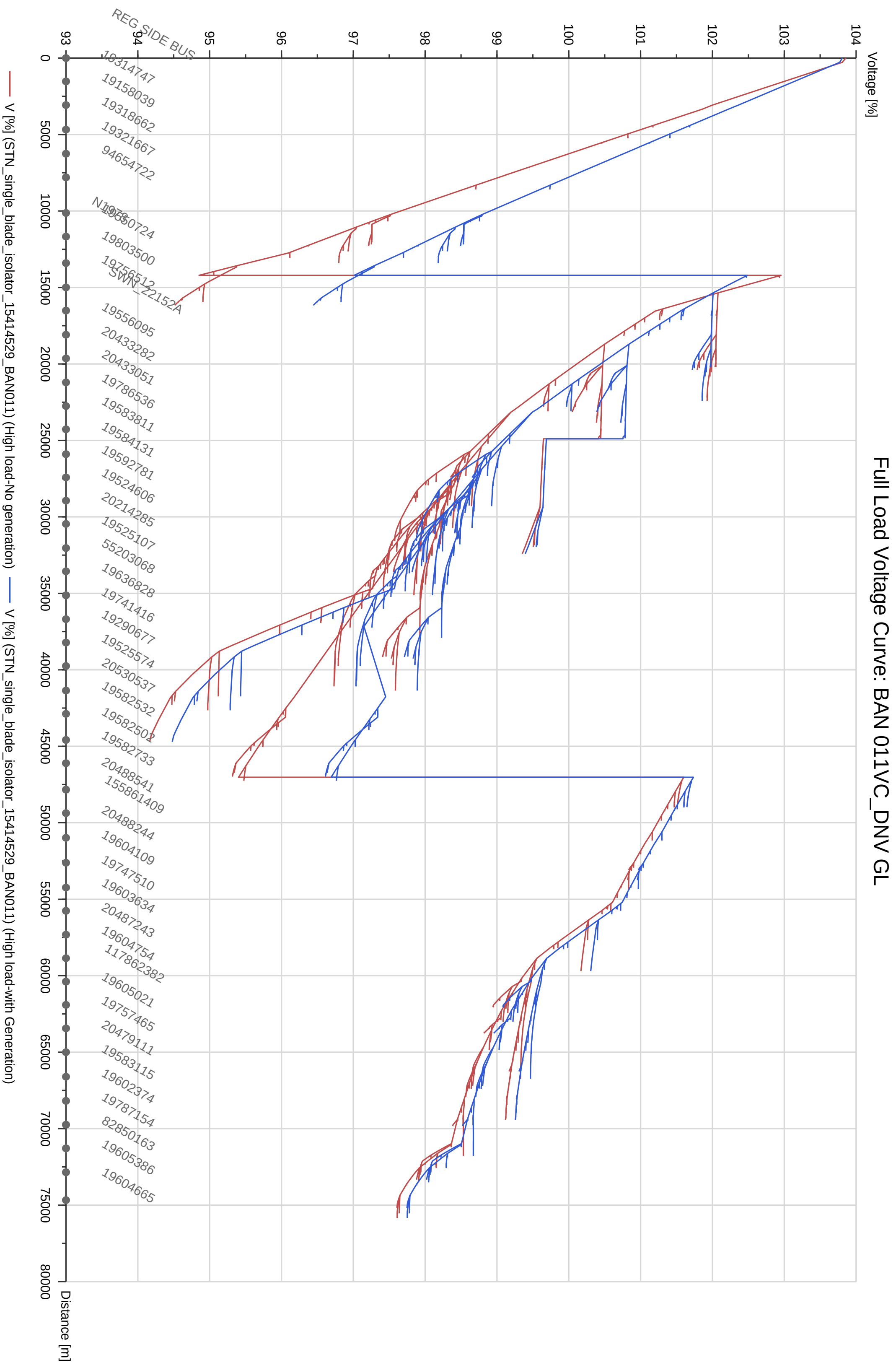


Figure 0-3 FLFG

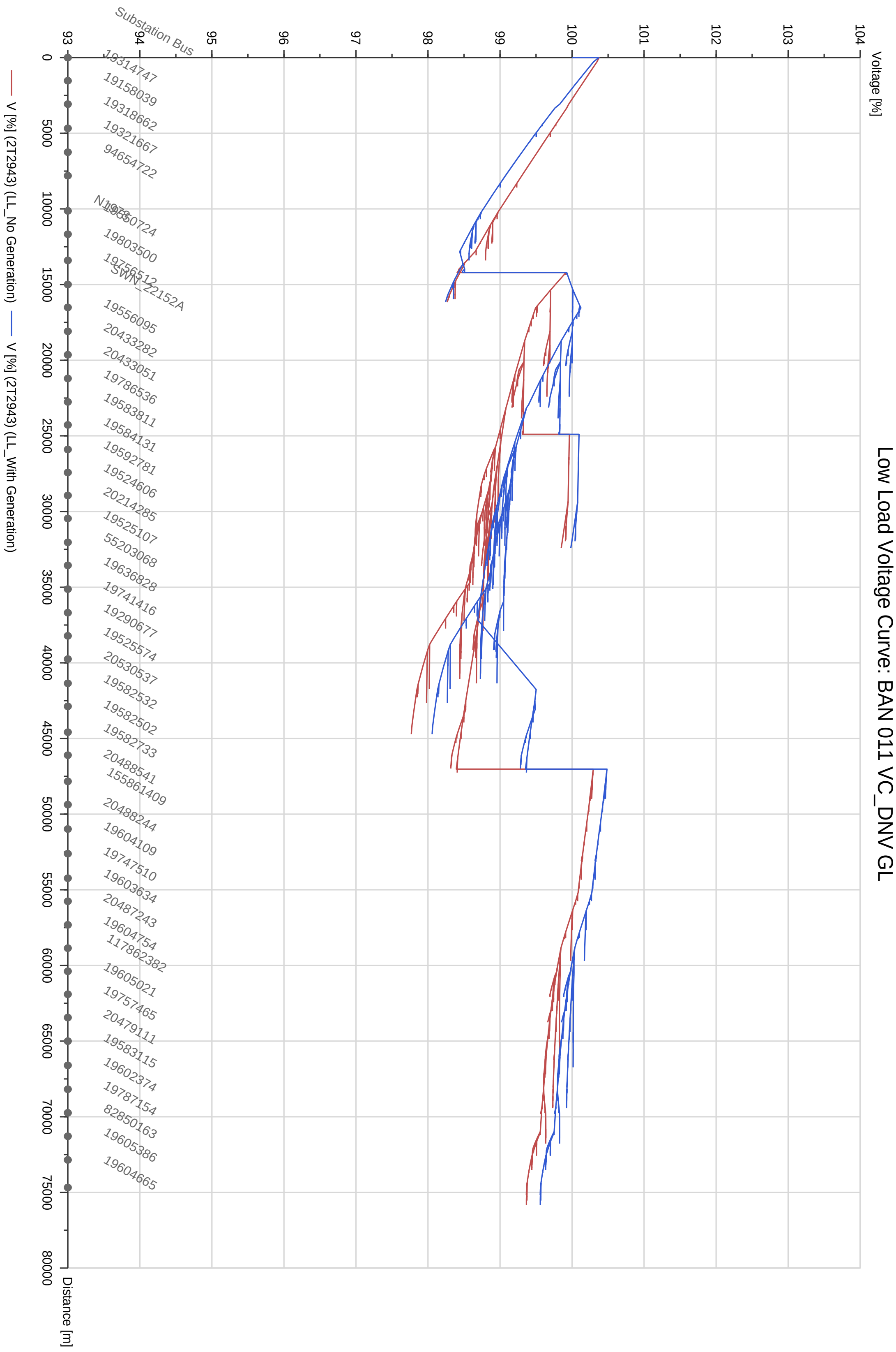
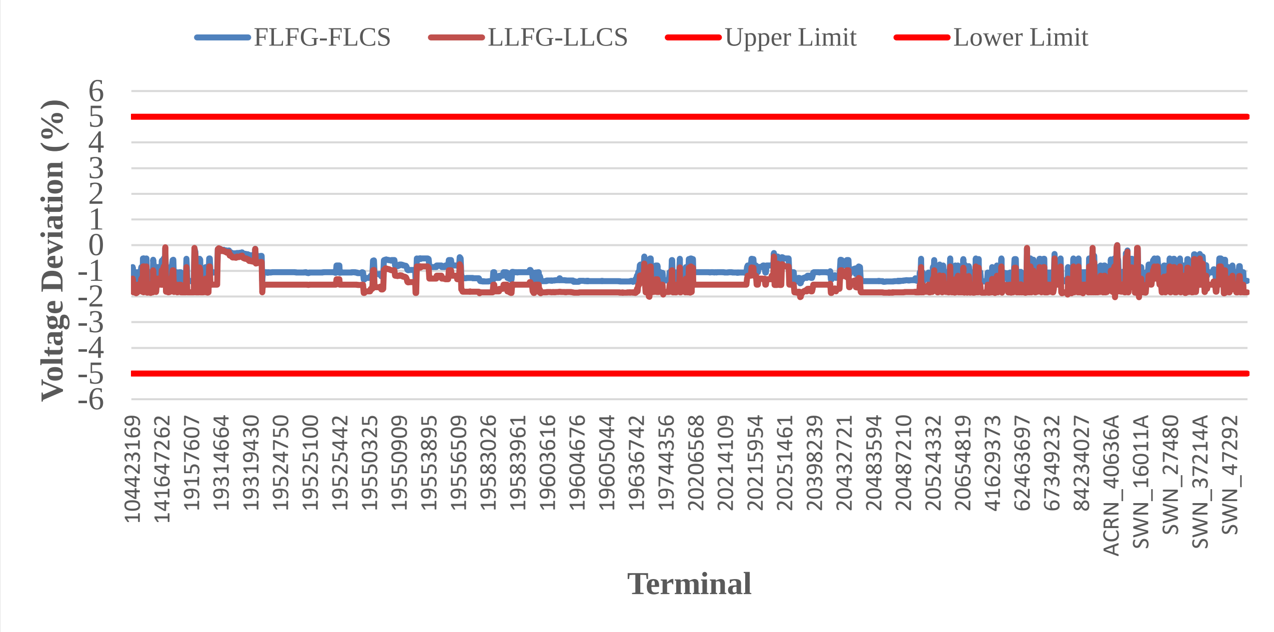


Figure 0-4 LLFG

Appendix B – Cloud Cover Result



Appendix C – SMA Solar Inverter Specification

Technical Information Document

Sunny Central SC 3000-EV

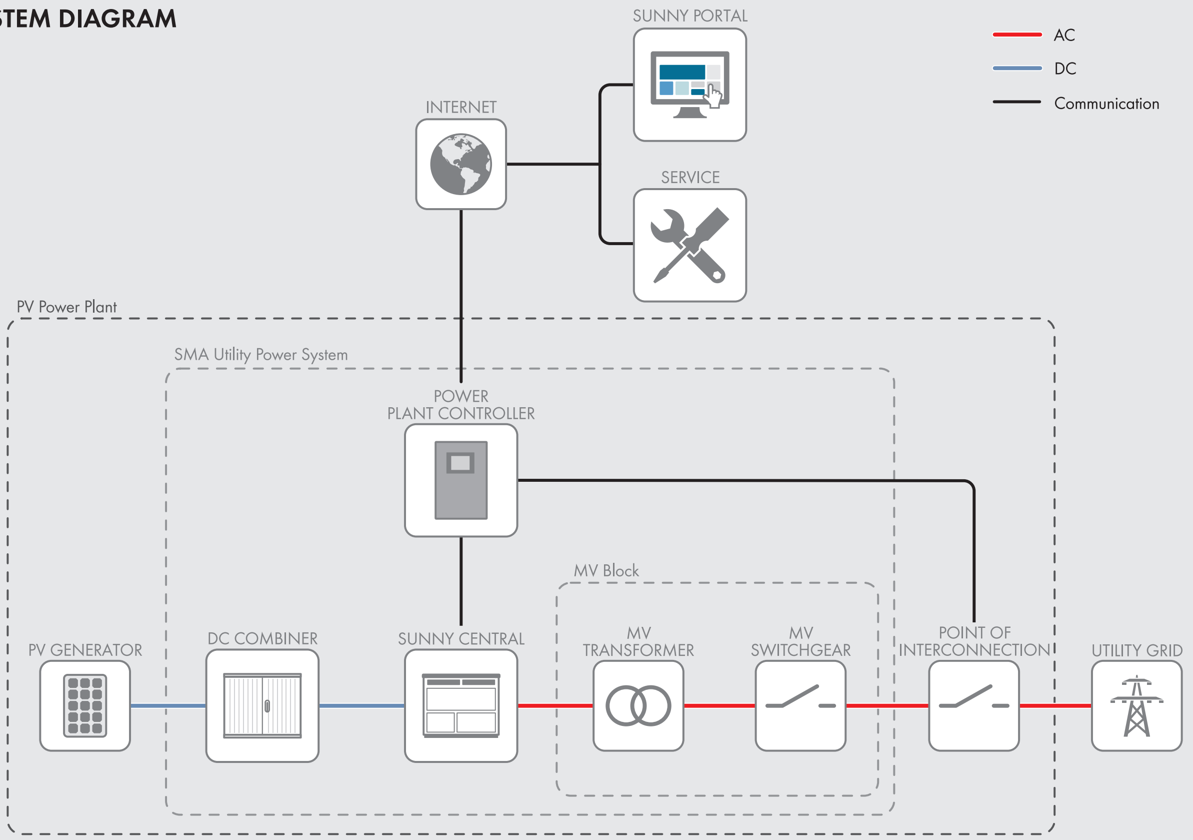
Revision 5.2

SUNNY CENTRAL 1500 V

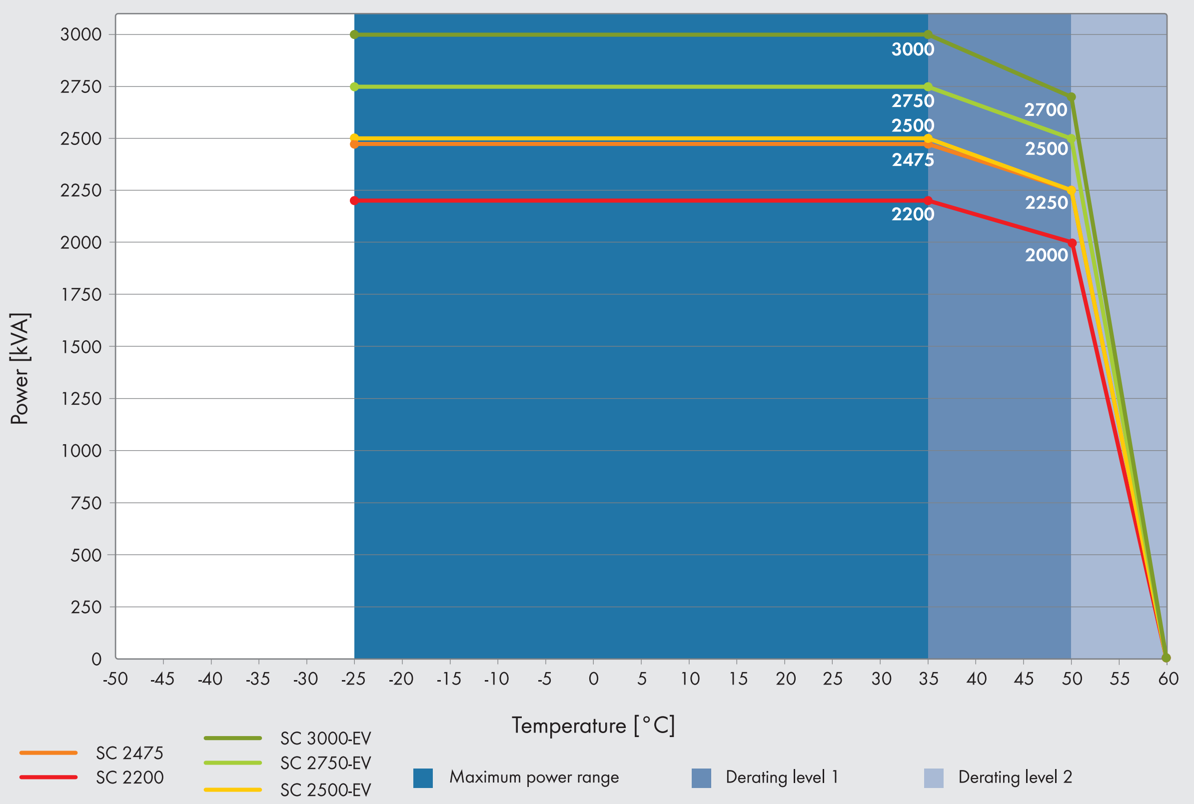
Technical Data	Sunny Central 2500-EV	Sunny Central 2750-EV	Sunny Central 3000-EV
Input (DC)			
MPP voltage range V_{DC} (at 25 °C / at 35 °C / at 50 °C)	850 V to 1425 V / 1200 V / 1200 V	875 V to 1425 V / 1200 V / 1200 V	956 V to 1425 V / 1200 V / 1200 V
Min. input voltage $V_{DC, min}$ / Start voltage $V_{DC, Start}$	778 V / 928 V	849 V / 999 V	927 V / 1077 V
Max. input voltage $V_{DC, max}$	1500 V	1500 V	1500 V
Max. input current $I_{DC, max}$ (at 35 °C / at 50 °C)	3200 A / 2956 A	3200 A / 2956 A	3200 A / 2970 A
Max. short-circuit current rating	6400 A	6400 A	6400 A
Number of DC inputs	24 double pole fused (32 single pole fused) for PV		
Number of DC inputs with optional DC battery coupling	18 double pole fused (36 single pole fused) for PV and 6 double pole fused for batteries		
Max. number of DC cables per DC input (for each polarity)	2 x 800 kcmil, 2 x 400 mm²		
Integrated zone monitoring	○		
Available DC fuse sizes (per input)	200 A, 250 A, 315 A, 350 A, 400 A, 450 A, 500 A		
Output (AC)			
Nominal AC power at cos φ =1 (at 35 °C / at 50 °C)	2500 kVA / 2250 kVA	2750 kVA / 2500 kVA	3000 kVA / 2700 kVA
Nominal AC power at cos φ =0.8 (at 35 °C / at 50 °C)	2000 kW / 1800 kW	2200 kW / 2000 kW	2400 kW / 2160 kW
Nominal AC current $I_{AC, nom}$ = Max. output current $I_{AC, max}$	2624 A	2646 A	2646 A
Max. total harmonic distortion	< 3% at nominal power	< 3% at nominal power	< 3% at nominal power
Nominal AC voltage / nominal AC voltage range[1) 8)]	550 V / 440 V to 660 V	600 V / 480 V to 690 V	655 V / 524 V to 721 V[9)]
AC power frequency	50 Hz / 47 Hz to 53 Hz 60 Hz / 57 Hz to 63 Hz		
Min. short-circuit ratio at the AC terminals[10)]	> 2		
Power factor at rated power / displacement power factor adjustable[8) 11)]	● 1 / 0.8 overexcited to 0.8 underexcited ○ 1 / 0.0 overexcited to 0.0 underexcited		
Efficiency			
Max. efficiency[2)] / European efficiency[2)] / CEC efficiency[3)]	98.6% / 98.3% / 98.0%	98.7% / 98.5% / 98.5%	98.8% / 98.6% / 98.5%
Protective Devices			
Input-side disconnection point	DC load-break switch		
Output-side disconnection point	AC circuit breaker		
DC overvoltage protection	Surge arrester, type I		
AC overvoltage protection (optional)	Surge arrester, class I		
Lightning protection (according to IEC 62305-1)	Lightning Protection Level III		
Ground-fault monitoring / remote ground-fault monitoring	○ / ○		
Insulation monitoring	○		
Degree of protection: electronics / air duct / connection area (as per IEC 60529)	IP65 / IP34 / IP34		
General Data			
Dimensions (W / H / D)	2780 / 2318 / 1588 mm (109.4 / 91.3 / 62.5 inch)		
Weight	< 3400 kg / < 7496 lb		
Self-consumption (max.[4)] / partial load[5)] / average[6)])	< 8100 W / < 1800 W / < 2000 W		
Self-consumption (standby)	< 370 W		
Internal auxiliary power supply	Integrated 8.4 kVA transformer		
Operating temperature range[8)]	−25 to 60 °C / −13 to 140 °F		
Noise emission[7)]	67.8 dB(A)		
Temperature range (standby)	−40 to 60 °C / −40 to 140 °F		
Temperature range (storage)	−40 to 70 °C / −40 to 158 °F		
Max. permissible value for relative humidity (condensing / non-condensing)	95% to 100% (2 month / year) / 0 % to 95%		
Maximum operating altitude above MSL[8)] 1000 m / 2000 m[12)] / 3000 m[12)]	● / ○ / –	● / ○ / –	● / ○ / –
Fresh air consumption	6500 m³/h		
Features			
DC connection	Terminal lug on each input (without fuse)		
AC connection	With busbar system (three busbars, one per line conductor)		
Communication	Ethernet, Modbus Master, Modbus Slave		
Communication with SMA string monitor (transmission medium)	Modbus TCP / Ethernet (FO MM, Cat-5)		
Enclosure / roof color	RAL 9016 / RAL 7004		
Supply transformer for external loads	○ (2.5 kVA)		
Standards and directives complied with	CE, IEC / EN 62109-1, IEC / EN 62109-2, BDEW-MSRL, IEEE1547, Arrêté du 23/04/08		
EMC standards	CISPR 11, CISPR 22, EN55011:2017, EN 55022, IEC/EN 61000-6-4, IEC/EN 61000-6-2, IEC 62920, FCC Part 15 Class A	CISPR 11, CISPR 22, EN55011:2017, EN 55022, IEC 62920, FCC Part 15 Class A	
Quality standards and directives complied with	VDI/VDE 2862 page 2, DIN EN ISO 9001		
● Standard features ○ Optional – not available			
Type designation	SC-2500-EV-10	SC-2750-EV-10	SC-3000-EV-10

1) At nominal AC voltage, nominal AC power decreases in the same proportion
2) Efficiency measured without internal power supply
3) Efficiency measured with internal power supply
4) Self-consumption at rated operation
5) Self-consumption at < 75% Pn at 25 °C
6) Self-consumption averaged out from 5% to 100% Pn at 35 °C
7) Sound pressure level at a distance of 10 m
8) Values apply only to inverters. Permissible values for SMA MV solutions from SMA can be found in the corresponding data sheets.
9) AC voltage range can be extended to 753V for 50Hz grids only (option „Aux power supply: external" must be selected, option "housekeeping" not combinable).
10) A short-circuit ratio of < 2 requires a special approval from SMA
11) Depending on the DC voltage
12) Available as a special version, earlier temperature-dependent de-rating and reduction of DC open-circuit voltage

SYSTEM DIAGRAM



TEMPERATURE BEHAVIOR (at cos φ =1 and installation altitudes of up to 1,000 m[1])



1) For the temperature behavior for installations at above 1,000 m see the Technical Information document.

Agenda

1. Efficiency

The conversion efficiency of the inverter is defined by the ratio of AC output power to DC input power. The main losses occur as waste heat due to switching and conducting losses inside the IGBT's of the inverter and due to the inductance of the sine filter choke. Depending on the methodology of measuring the efficiency, the self-consumption of the inverter can also be integrated into the efficiency calculation as it is done with the CEC efficiency rating.
The conversion efficiency strongly depends on the DC voltage with the highest efficiency being experienced at the lowest possible DC voltage for this type of inverter bridge topology.

a) Efficiency without auxiliary losses

Max Efficiency = 98.8% / Euro Eta= 98.6%

Efficiency measurement conditions test results											
SC3000-EV-10											
Input voltage [Vdc]		Power in [kW] (nom. 3000kW)									
		5%	10%	20%	25%	30%	40%	50%	60%	75%	100%
		150 kW	300 kW	600 kW	750 kW	900 kW	1200 kW	1500 kW	1800 kW	2250 kW	3000 kW
		η in [%]									
V_{MPPmin}	955	97,11	98,19	98,63	98,70	98,72	98,75	98,71	98,66	98,57	98,35
$V_{MPPnom1}$	1190	95,46	97,43	98,22	98,36	98,42	98,47	98,49	98,47	98,39	98,18
$V_{MPPnom2}$	1283	94,79	97,13	98,10	98,21	98,29	98,36	98,39	98,39	98,32	98,11
V_{MPPmax}	1425	93,85	96,65	97,87	97,98	98,10	98,24	98,28	98,27	98,21	98,00

Table 1: Efficiencies without aux. losses at 25°C measured according to IEC 61683

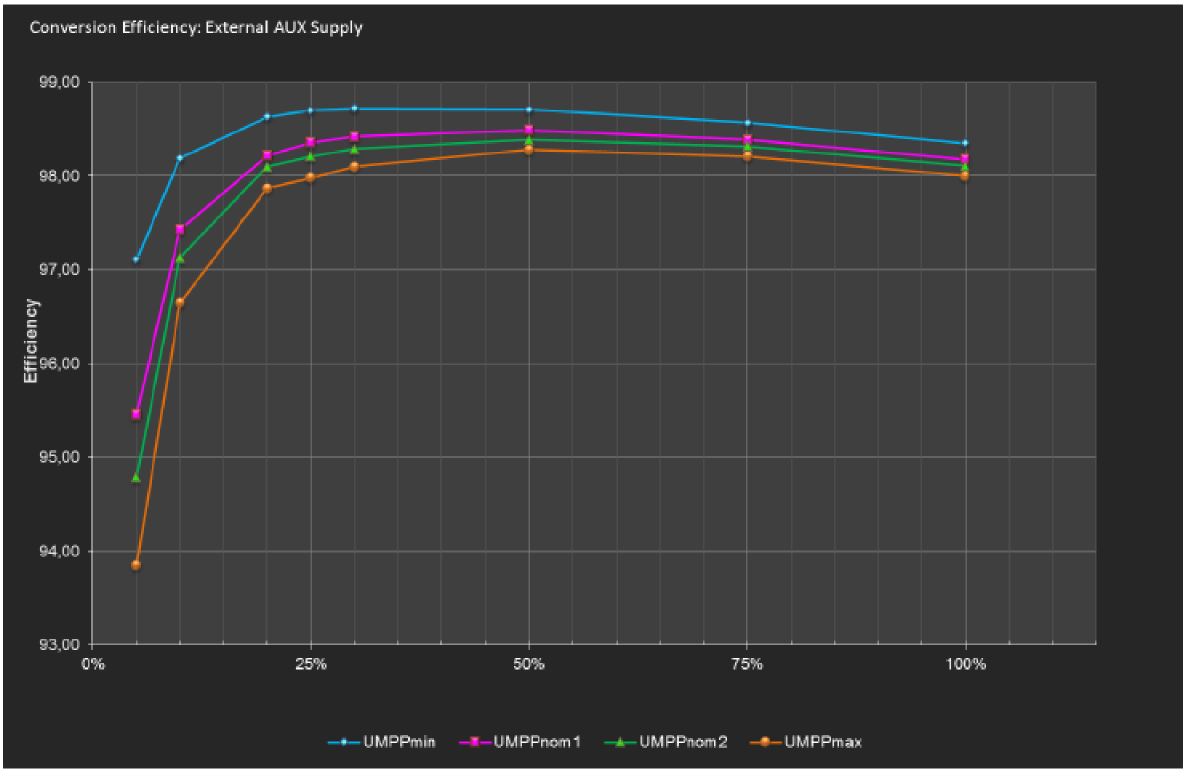


Figure 1: Efficiencies without aux. losses at 25°C measured according to IEC 61683

b) Efficiency with auxiliary losses (CEC)

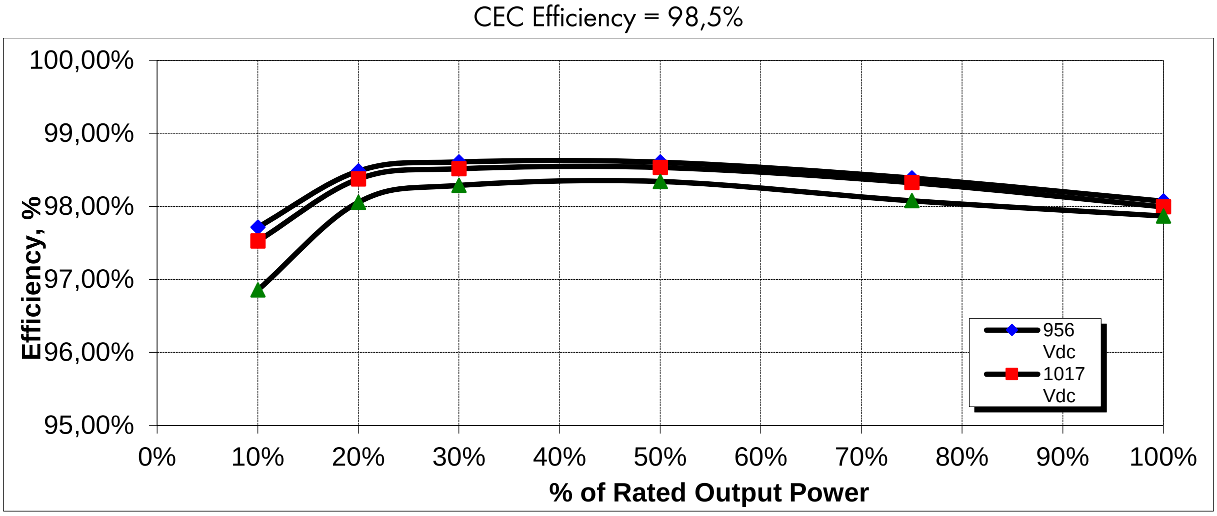


Figure 2: Efficiencies with aux. losses at 25 °C (CEC)

CEC-Eta

Vmin @956Vdc: 98.42%

Vnom @1017Vdc: 98.35%

Vmax @1200Vdc: 98.10%

c) Efficiency in dependence of DC voltage and temperature

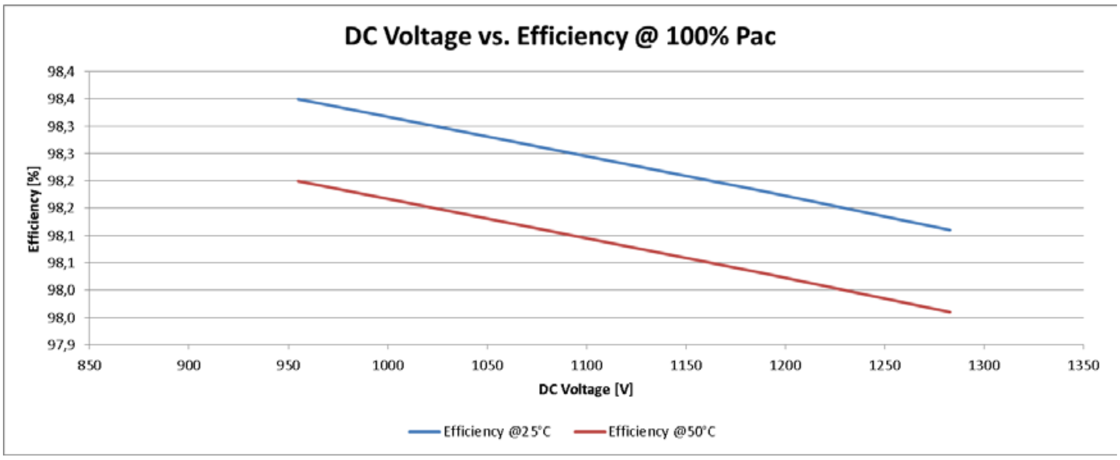


Figure 3: Efficiency in dependence of DC voltage and temperature (incl. Aux losses)

2. Auxiliary Consumption

The inverter converts DC to AC power which requires some auxiliary power for the control, communication and cooling system. The amount of auxiliary power depends on the ambient temperature and on the produced output power. The auxiliary power is drawn from the AC side at the inverter terminals.
If the available PV power exceeds 100% of the DC power which can be converted by the inverter per nameplate rating, the inverter produces some more AC power in order to compensate for its internal losses. That way the effective auxiliary consumption of the inverter is 0 kVA as soon as the DC power exceeds 100%.

a) Auxiliary consumption on a sunny day

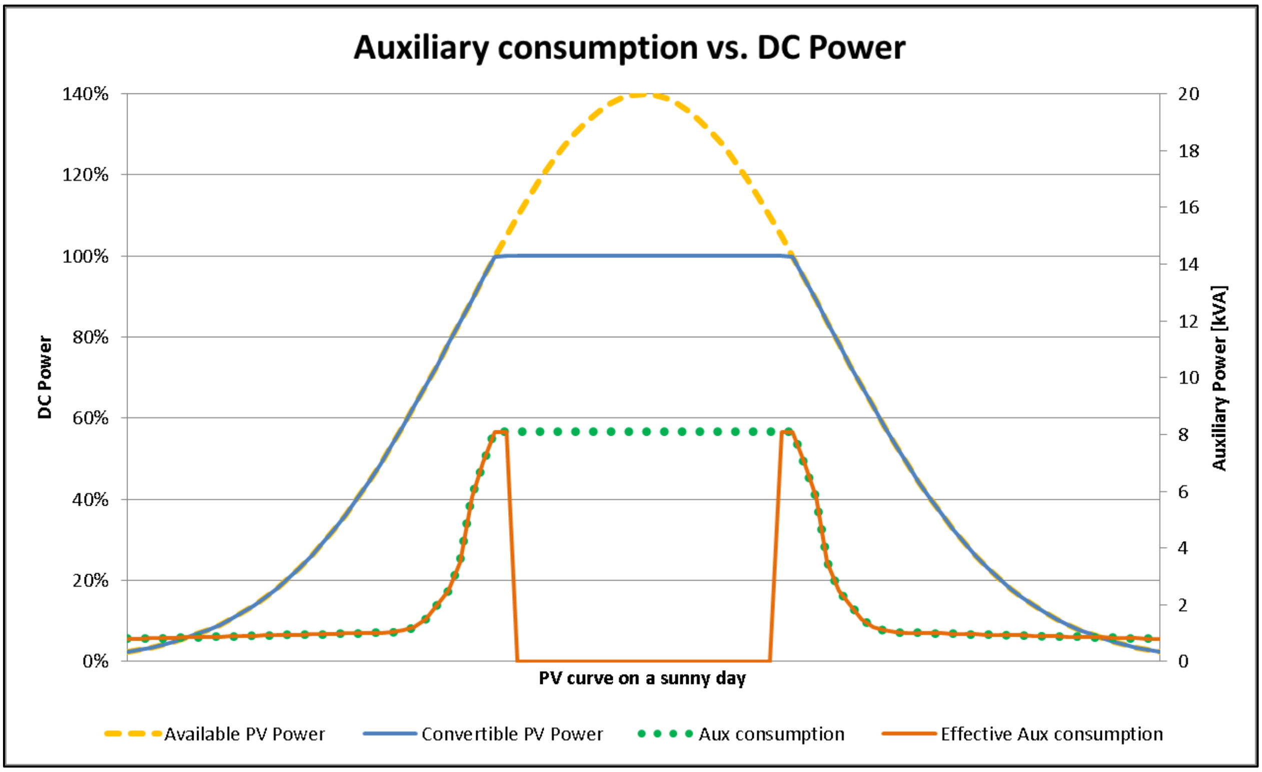


Figure 4: Auxiliary power consumption on a sunny day at 25 °C

b) Auxiliary consumption on a cloudy day

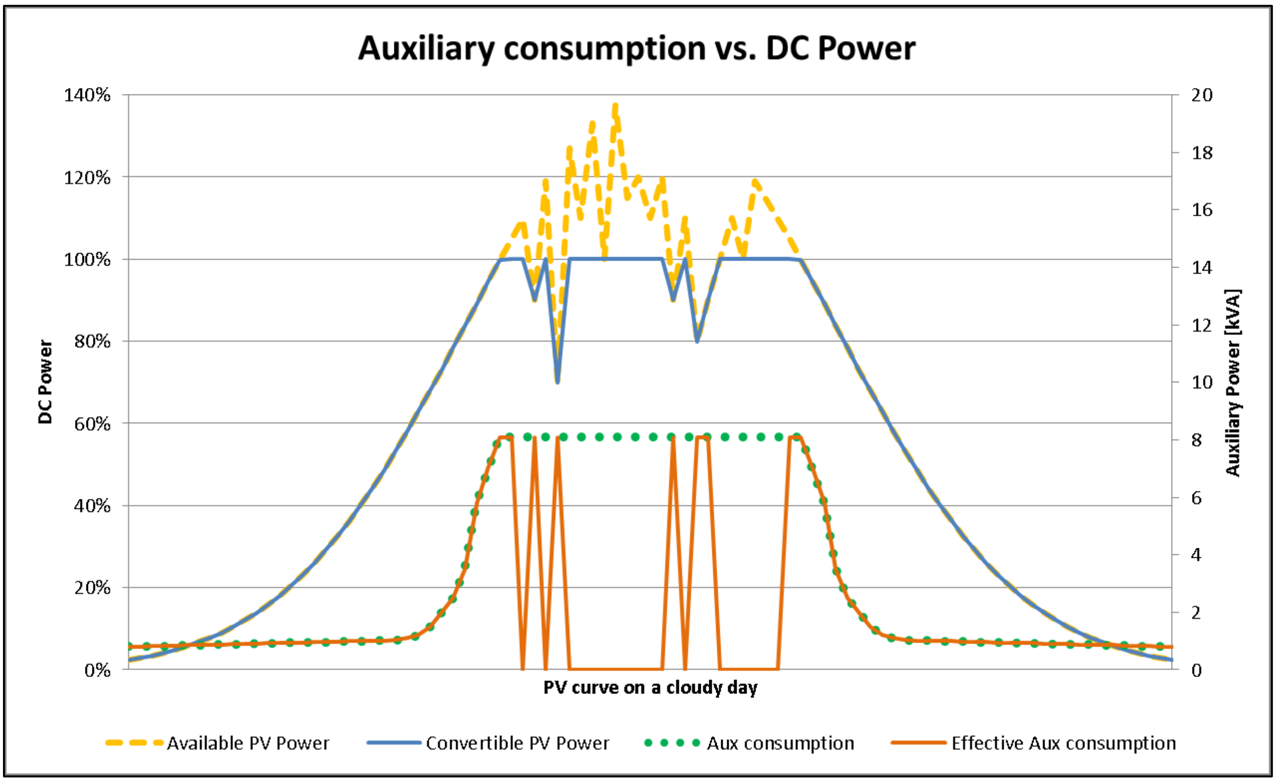


Figure 5: Auxiliary power consumption on a cloudy day at 25 °C

3. Harmonics

Harmonics occur as integer multiples of the fundamental frequency which is typically 50 Hz or 60 Hz in electronic power grids. Harmonic currents cause voltage drops which superimpose the nominal grid voltage resulting in distortion of the sine wave of the grid voltage. Harmonics can be generated by non-linear loads or from power electronic means with high frequent switching transistors (for example by an inverter).
The inverter control and the filter design have a big impact on the harmonics generated by the inverter. The measured harmonics will also vary with the grid frequency, the grid impedance and the initial level of harmonic stress in the grid.
The system solution which uses a Dy transformer for the connection to the MV grid has a different harmonic spectrum as the Delta winding of the transformer does not allow a zero sequence system to develop. Thus the corresponding harmonics (all multiples of the 3rd order) equal zero on the MV side. This effect is shown in Figure 9. Additionally the SC SC 3000-EV actively compensates harmonics up to the 7th order by its internal control, thus producing a total harmonic current (THC) of less than 1%.

a) Measurements according to BDEW (50Hz)

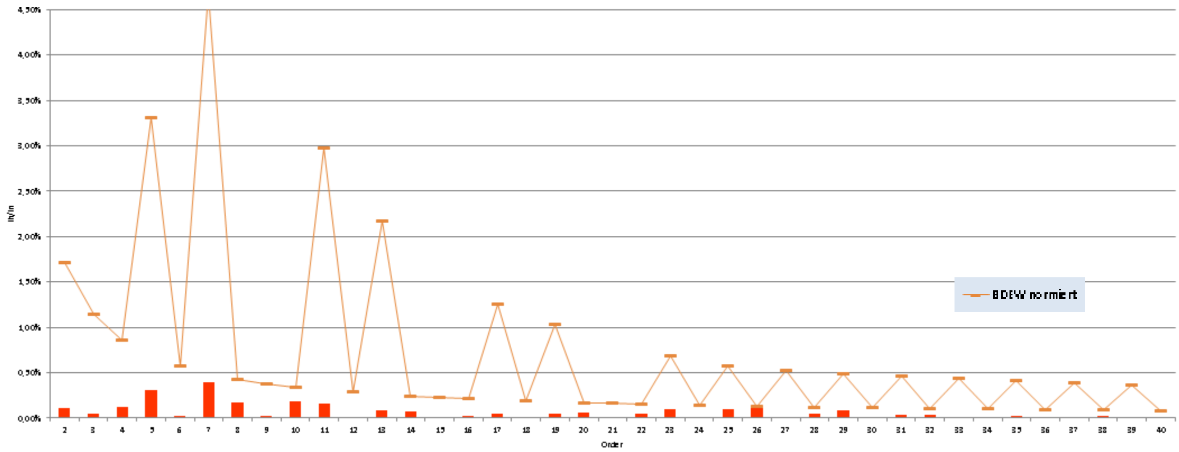


Figure 6: Total Harmonic distortion at 100% P_{AC} (50 Hz)

	Order	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	Lv/In[%]	0,11%	0,05%	0,12%	0,31%	0,03%	0,40%	0,17%	0,02%	0,19%
Order	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Lv/In[%]	0,16%	0,01%	0,09%	0,07%	0,01%	0,03%	0,05%	0,01%	0,06%	0,01%
Order	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Lv/In[%]	0,10%	0,01%	0,11%	0,01%	0,08%	0,01%	0,04%	0,04%	0,01%	0,01%
Order	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Lv/In[%]	0,04%	0,04%	0,01%	0,01%	0,03%	0,01%	0,01%	0,03%	0,01%	0,01%
									THDC	
									0,63%	

Table 2: Total Harmonic distortion at 100% P_{AC} (50 Hz)

b) Measurements according to IEEE 1547 (60Hz)

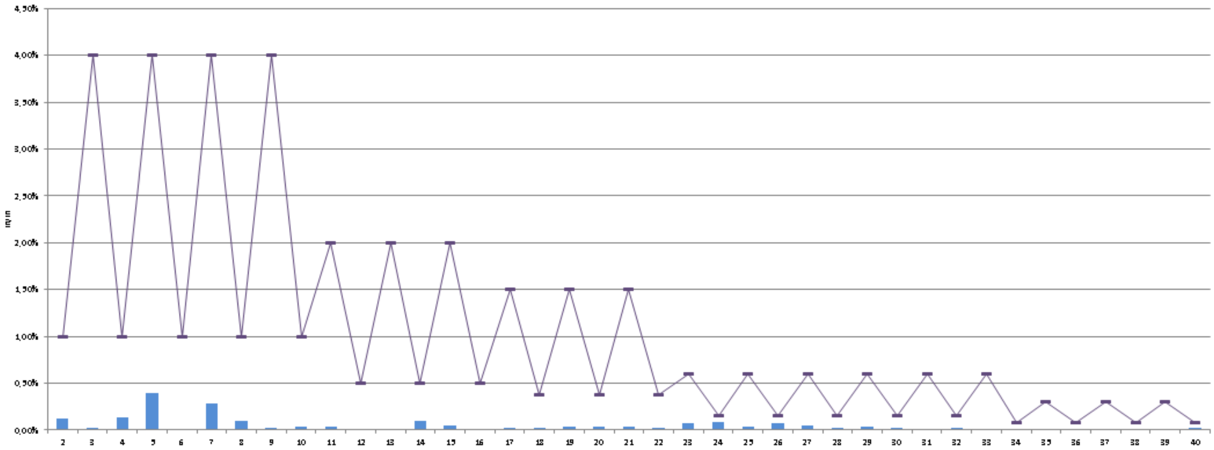


Figure 7: Harmonic distortion compared to the limits defined by IEEE 1547 and IEEE 519

	Order	2	3	4	5	6	7	8	9	10
	Lv/In[%]	0,12%	0,03%	0,14%	0,40%	0,01%	0,29%	0,10%	0,02%	0,04%
Order	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Lv/In[%]	0,04%	0,01%	0,01%	0,10%	0,05%	0,01%	0,03%	0,03%	0,04%	0,04%
Order	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**
Lv/In[%]	0,07%	0,08%	0,07%	0,04%	0,03%	0,01%	0,02%	0,01%	0,01%	0,03%
Order	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**
Lv/In[%]	0,01%	0,02%	0,01%	0,01%	0,01%	0,01%	0,01%	0,01%	0,00%	0,02%
									THDC	
									0,57%	

Table 3: Harmonic distortion per phase at 1425 V_{DC} and 100% P_{AC} (60 Hz)

4. Reactive Power

The inverter can provide reactive power in addition to the active power which is produced by conversion of incoming DC power. The resulting apparent power which is defined by the inverter's nameplate rating is calculated by geometric addition of reactive and active power.
The reactive power provision can be defined either via Power Factor (max. cosφ=0.8 as standard, optional extended up to cosφ=0.0) or as a fix Q value. Since the reactive power is independent of the active power provision of the inverter, it is possible to provide the max. reactive power at any time respecting the limits defined by the apparent power value of the inverter at different ambient temperatures. The inverter can provide up to 60% (100% optional) of its nameplate rating as reactive power disconnecting only when the active power drops below 2 kW.
Reactive power has an impact on the frequency-dependent voltage drop at the sinus filter choke so that the minimum MPP voltage depends on the applied power factor. This effect is illustrated in the below pictures.

Please note the extended power setting range is not available for:

- UL-Listed inverters
- SMA Medium voltage solutions e.g. MVPS, MV-Block, UPR

To enable the extended reactive power range please contact an SMA Application Engineer.

a) P/Q diagram SC 3000-EV @35 °C

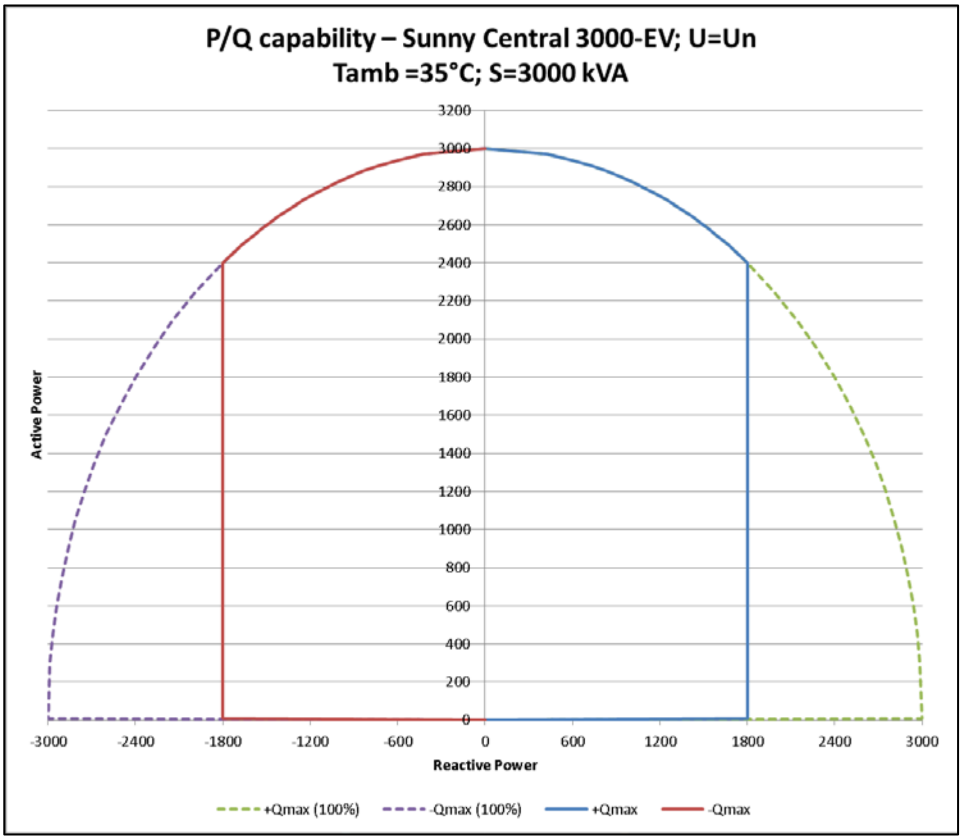


Figure 8: P/Q diagram at 35 °C and grid voltage U ≥Un

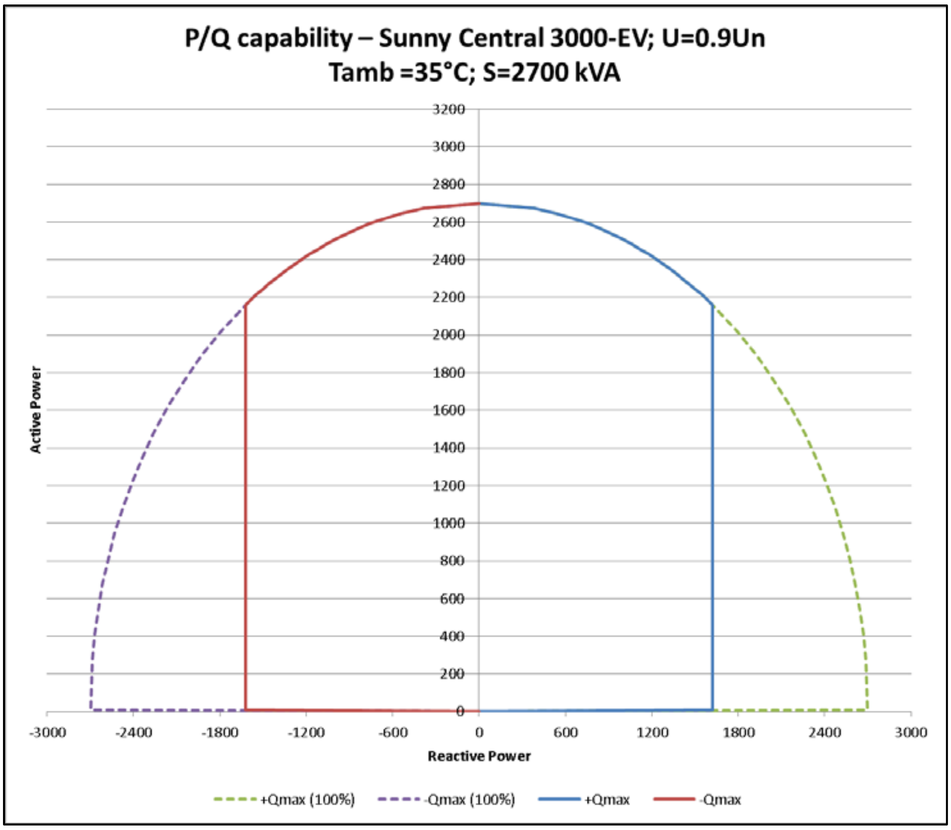


Figure 9: P/Q diagram at 35°C and U=0.9Un

b) P/Q diagram SC 3000-EV @50°C

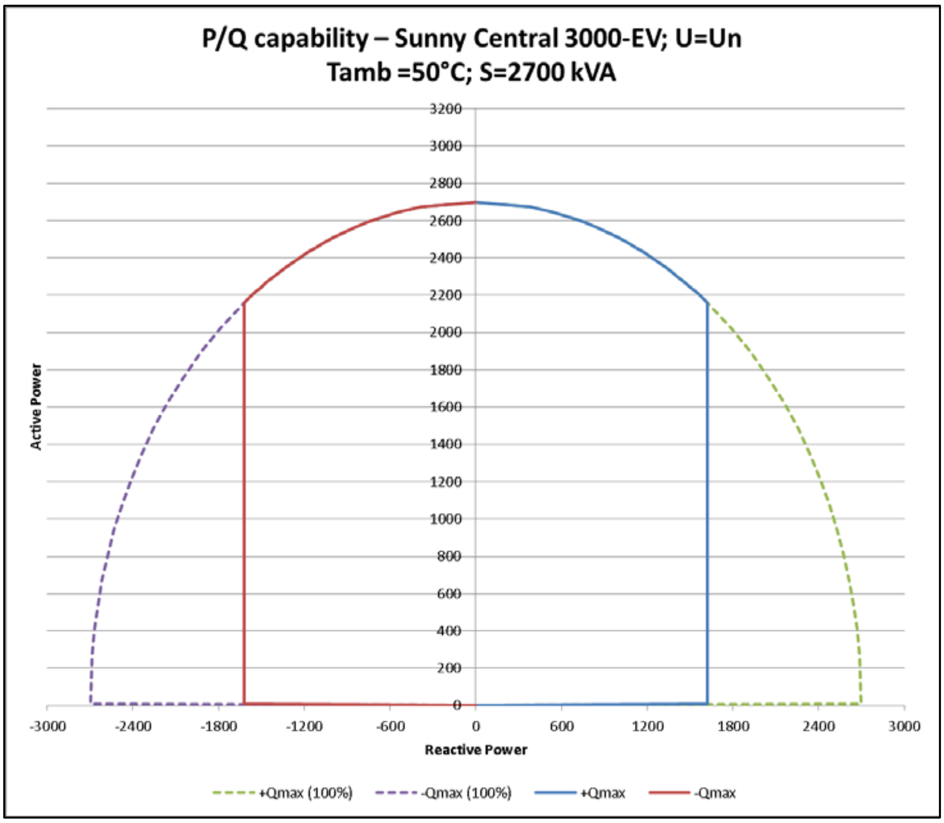


Figure 10: P/Q diagram at 50°C and grid voltage U ≥Un

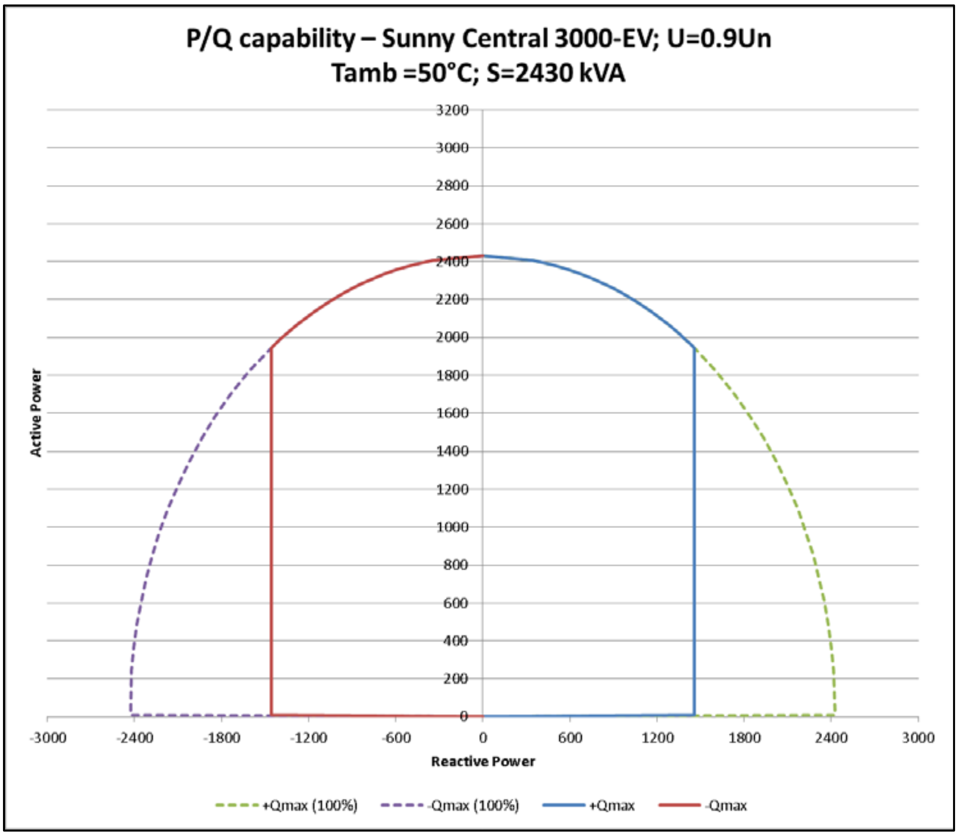


Figure 11: P/Q diagram at 50°C and U=0.9Un

c) Minimum MPP Voltage with reactive power @60 Hz

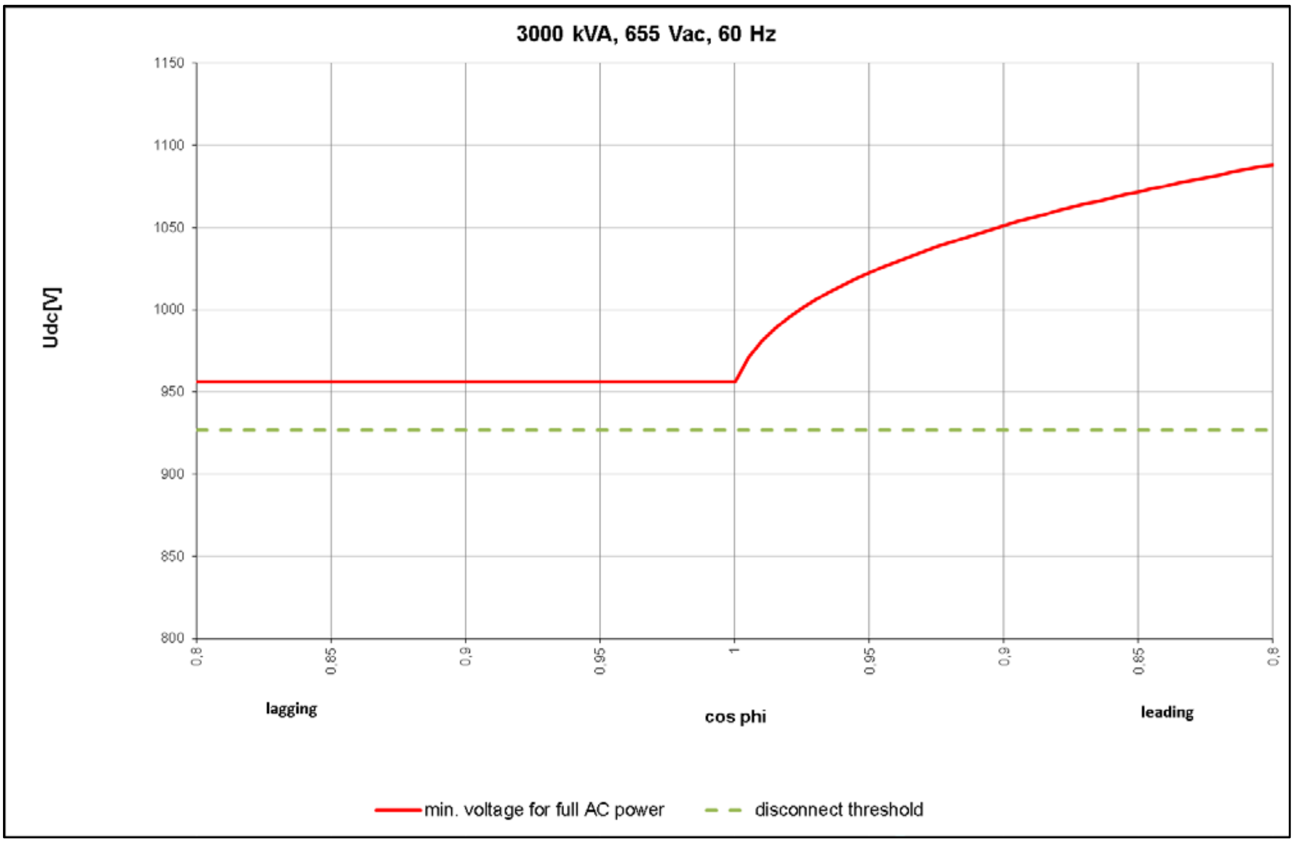


Figure 12: Minimum MPP Voltage at 60 Hz and 35°C

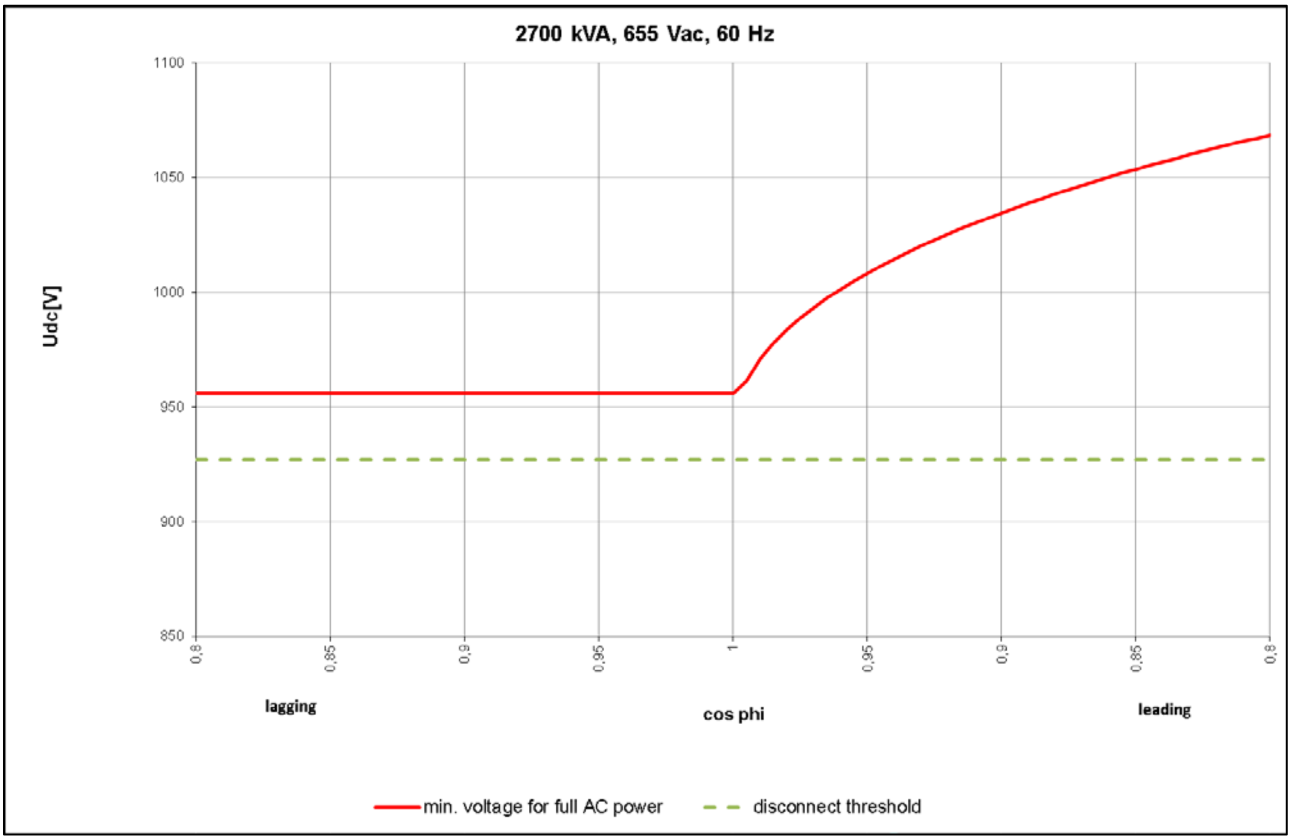


Figure 13: Minimum MPP Voltage at 60 Hz and 50°C

d) Minimum MPP Voltage with reactive power @50 Hz

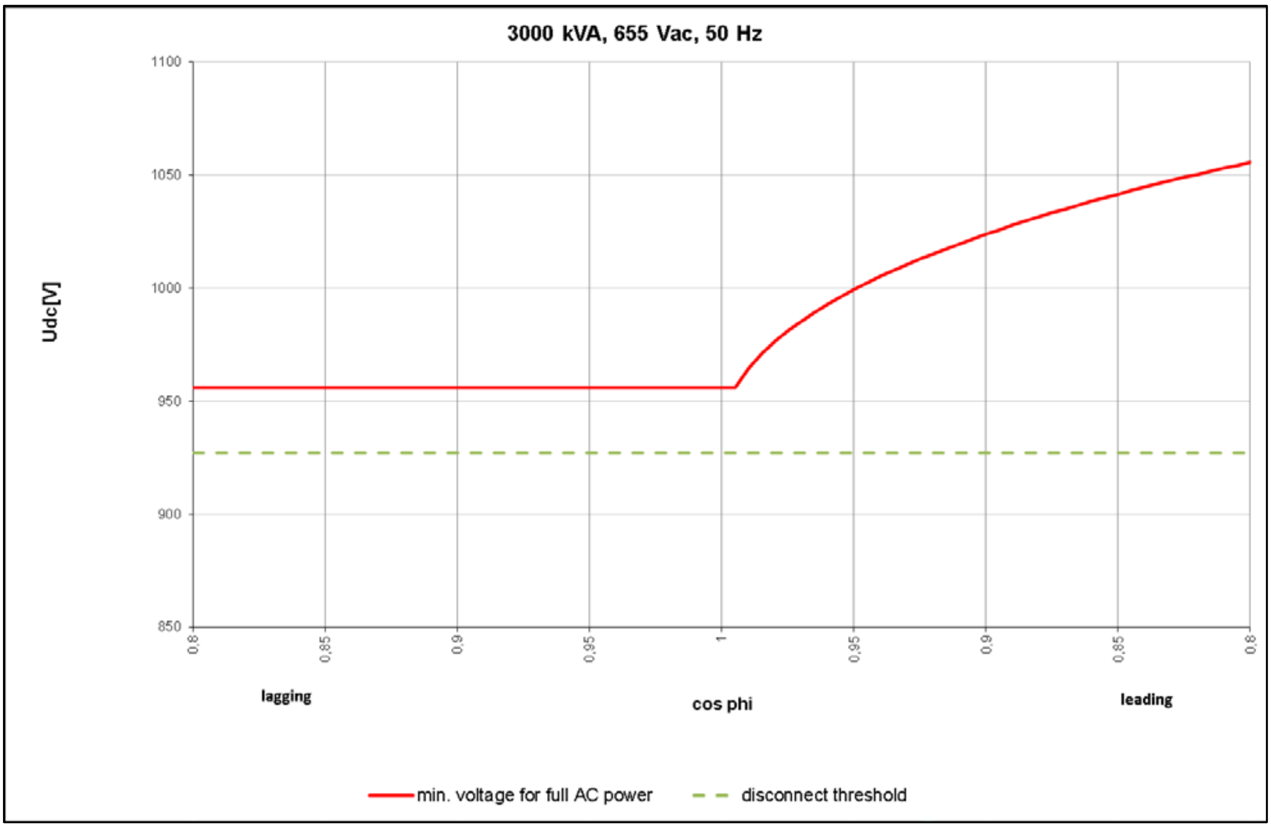


Figure 14: Minimum MPP Voltage at 50 Hz and 35°C

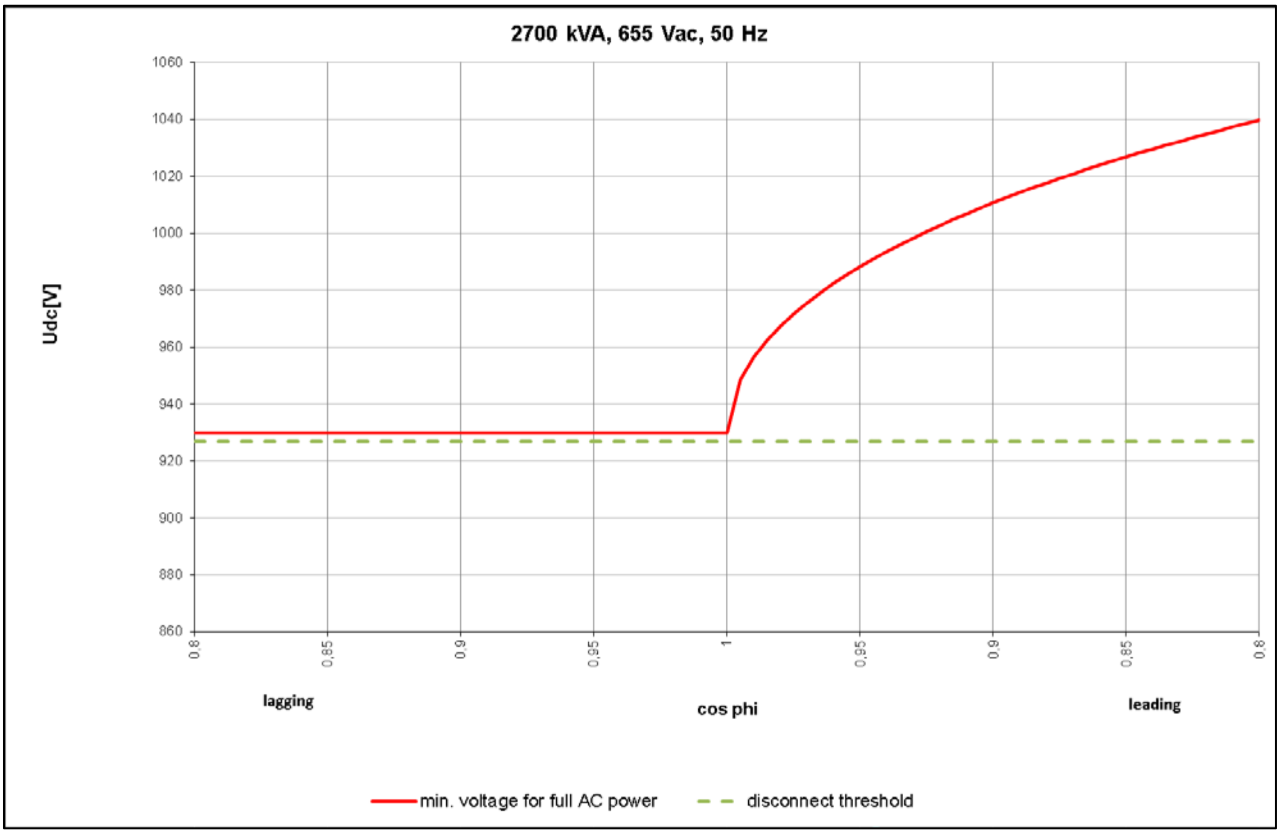


Figure 15: Minimum MPP Voltage at 50 Hz and 50°C

The thermal management of the inverter decides about de-rating conditions in dependence of ambient temperature, DC voltage and altitude.
Above 35°C the output power of the inverter has to be reduced. High DC voltage causes switching losses at the IGBTs which significantly contribute to the heat rise inside the inverter. With rising ambient temperature the maximum operation DC voltage with full load needs to be reduced between 25°C and 50°C in order to support the inverter's thermal management.
The lower density of air with rising altitude reduces the cooling effect. The inverter can produce its full power output at altitudes up to 2,000m with only reducing slightly the max. temperature for operation with nominal power. An adaptation starts above 1,000m and results in a linear shift to lower max. temperature also aligned with the temperature drop at high altitudes.

a) De-rating due to DC voltage

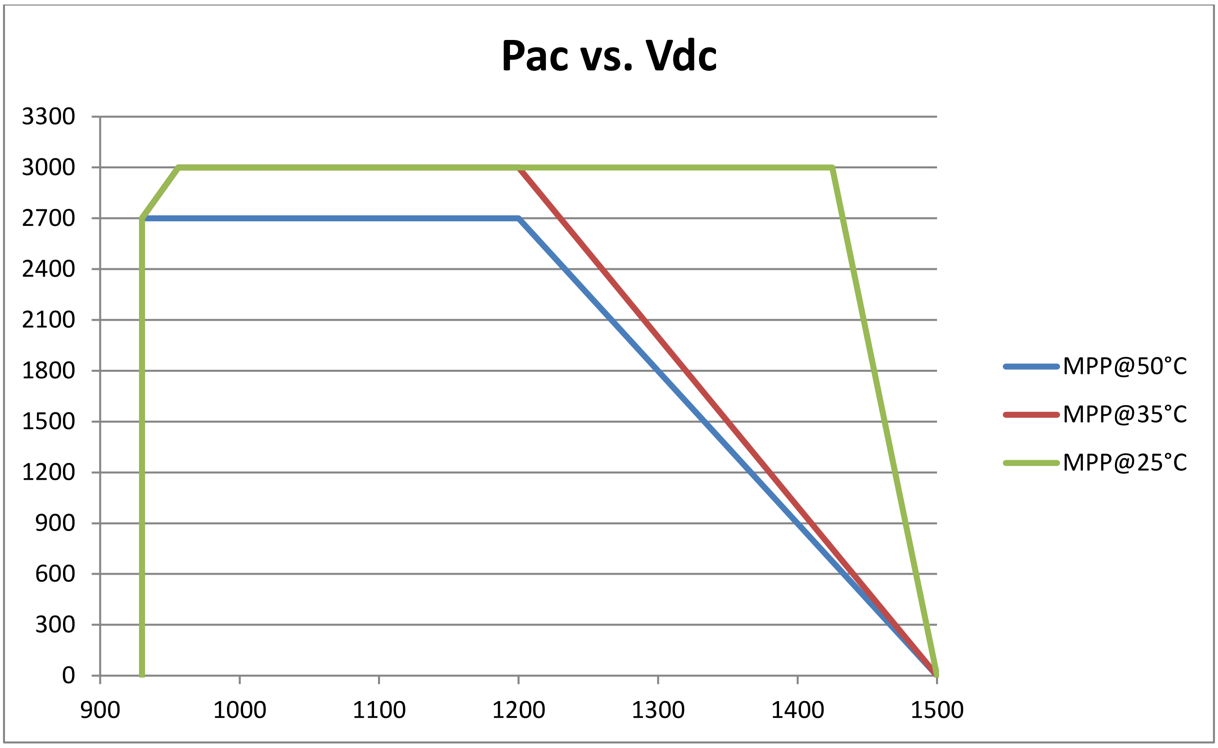


Figure 16: De-rating depending on DC voltage

b) De-rating at high Altitudes

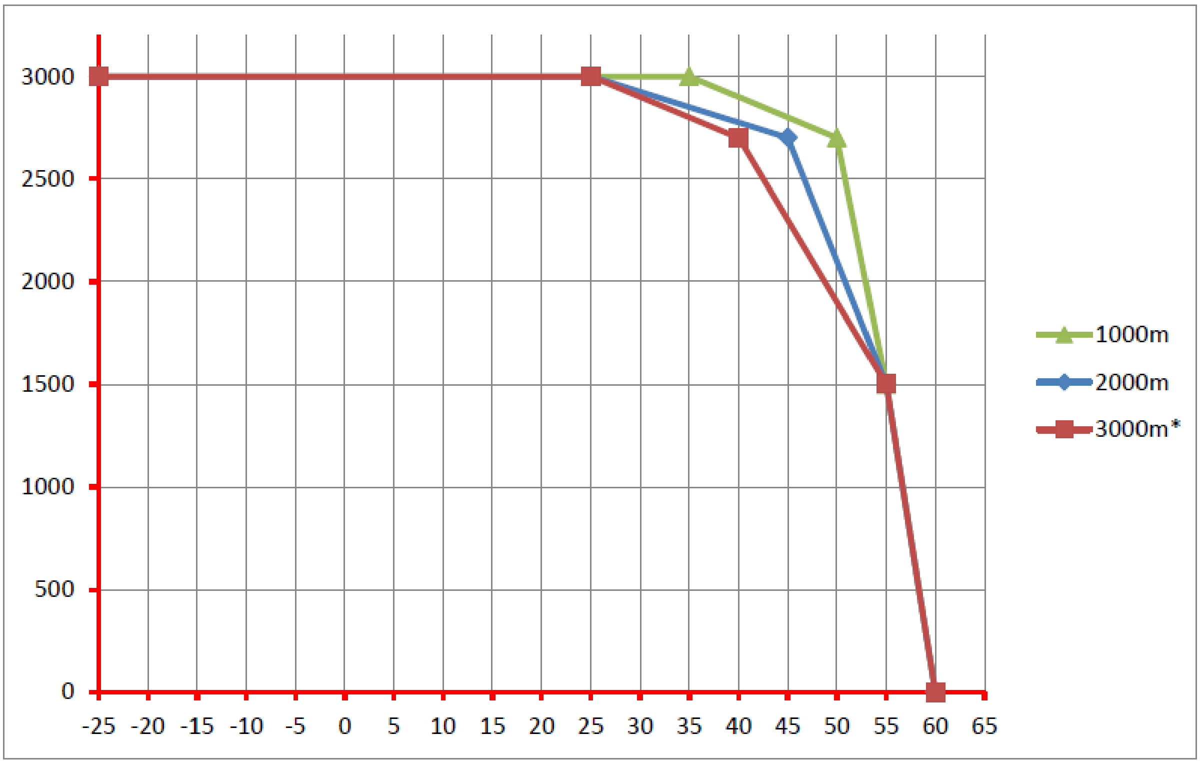


Figure 17: Linear de-rating at high altitudes

*Projects at a higher altitude between 2001m and 3000m asl. are possible to order via special version.

The following performance restrictions must be considered for installations in such altitudes:

- Open circuit voltage derating **18Voc/100m**
- Only available with the option **'Auxiliary Power External'** (Brown Power)
- Additional AC voltage and power derating with **60Hz** applications

5. Ride Through capabilities

The inverter has the capability to support the grid by remaining online or by reactive power feed-in during a temporary change of the grid voltage beyond preset low voltage (LV) and high voltage (HV) thresholds. The below figure describes the max. voltage ride-through (VRT) capabilities of the SC SC 3000-EV. If the max. disconnecting delay time at specific voltage levels is exceeded, the inverter switches off and reconnects to the grid when the voltage returns to the preset nominal operation window.

A project specific VRT window can be defined with the parameters described in the inverter's operation manual.

The inverter will also ride through abnormal frequency events with the capability of reducing the output power at high frequency scenarios. The ride-through capabilities are described below with similar possibilities to adjust the window as for the voltage ride-through.

a) Voltage Ride Through

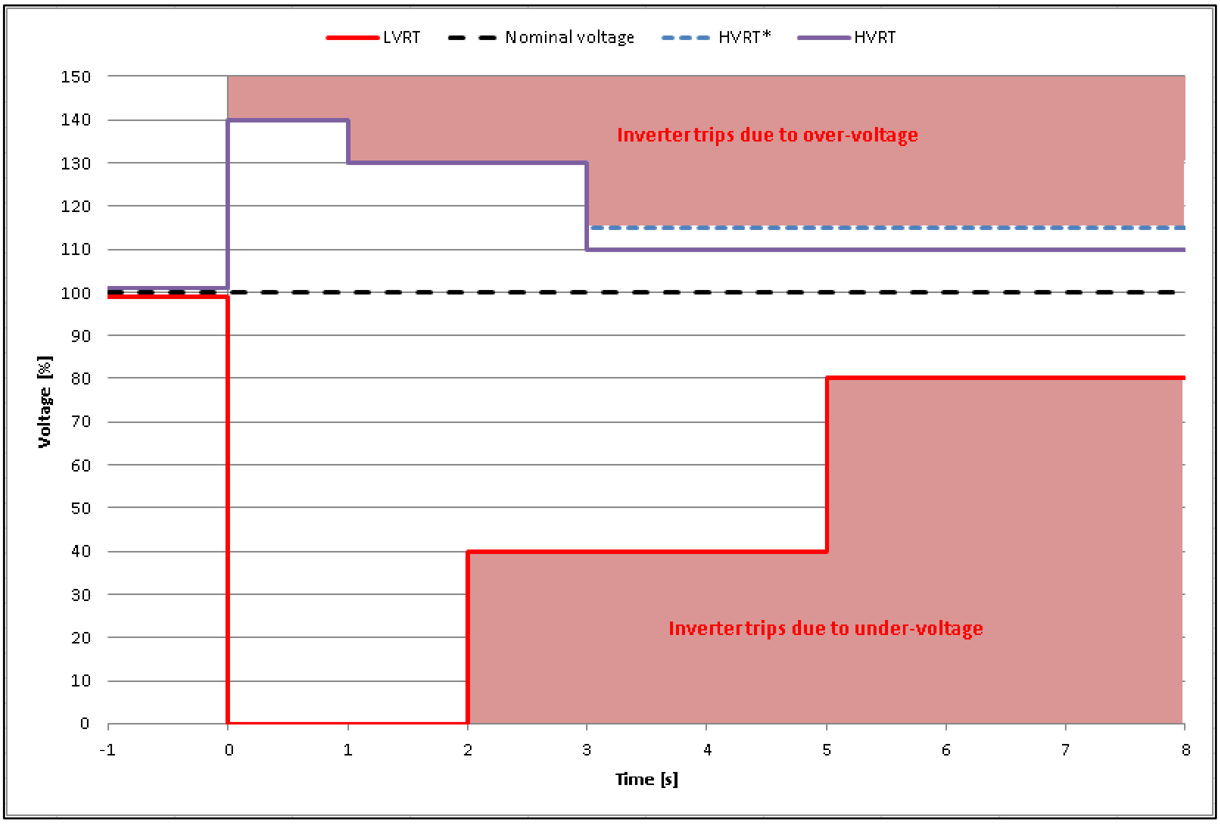


Figure 18: LVRT/HVRT capabilities

*115% of nominal voltage only with option "Aux power supply: external"

b) Frequency Ride Through

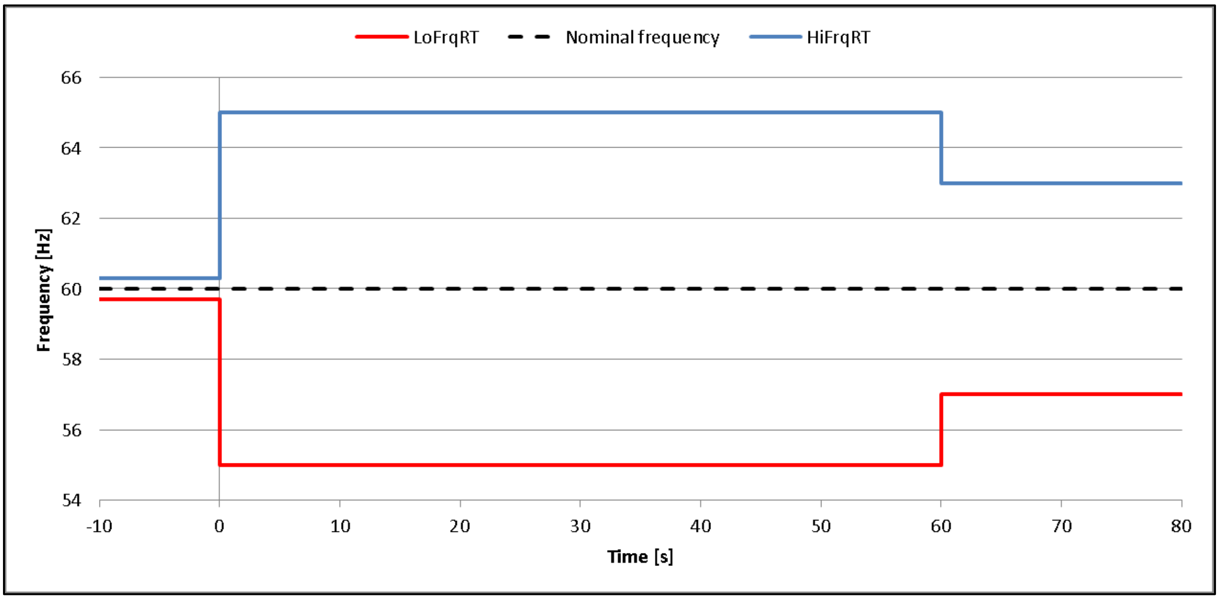


Figure 19: LoFrqRT/HiFrqRT capabilities (60 Hz)

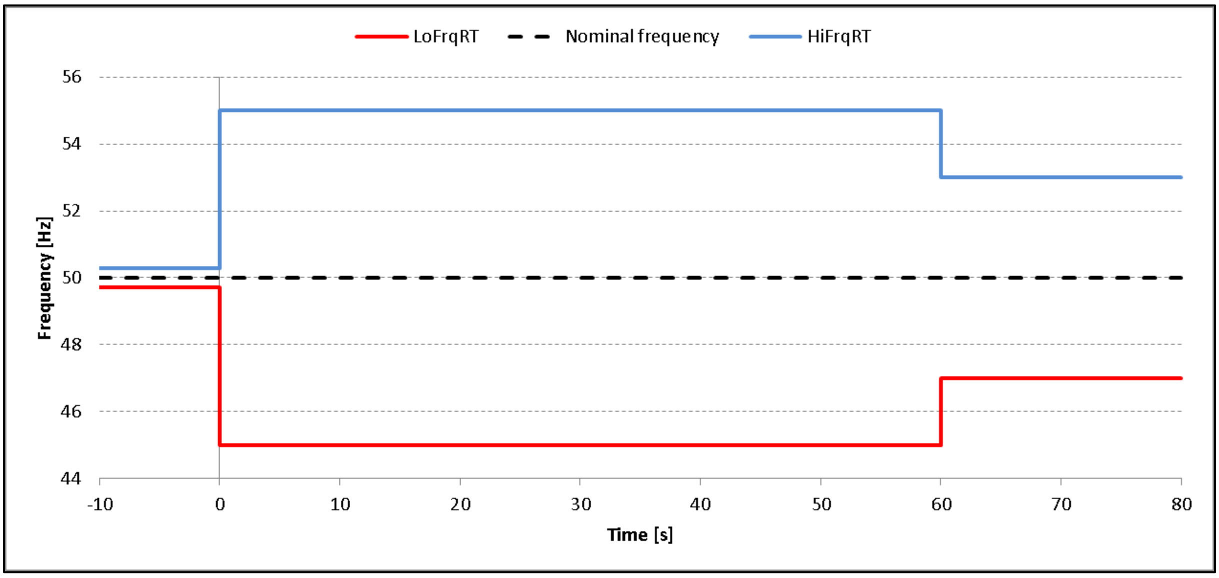


Figure 20: LoFrqRT/HiFrqRT capabilities (50 Hz)

6. AC Voltage Range

Standardly the SC 3000-EV has an AC Voltage Range of -20% to +10% (524V to 720V) for 50Hz and 60Hz grids.

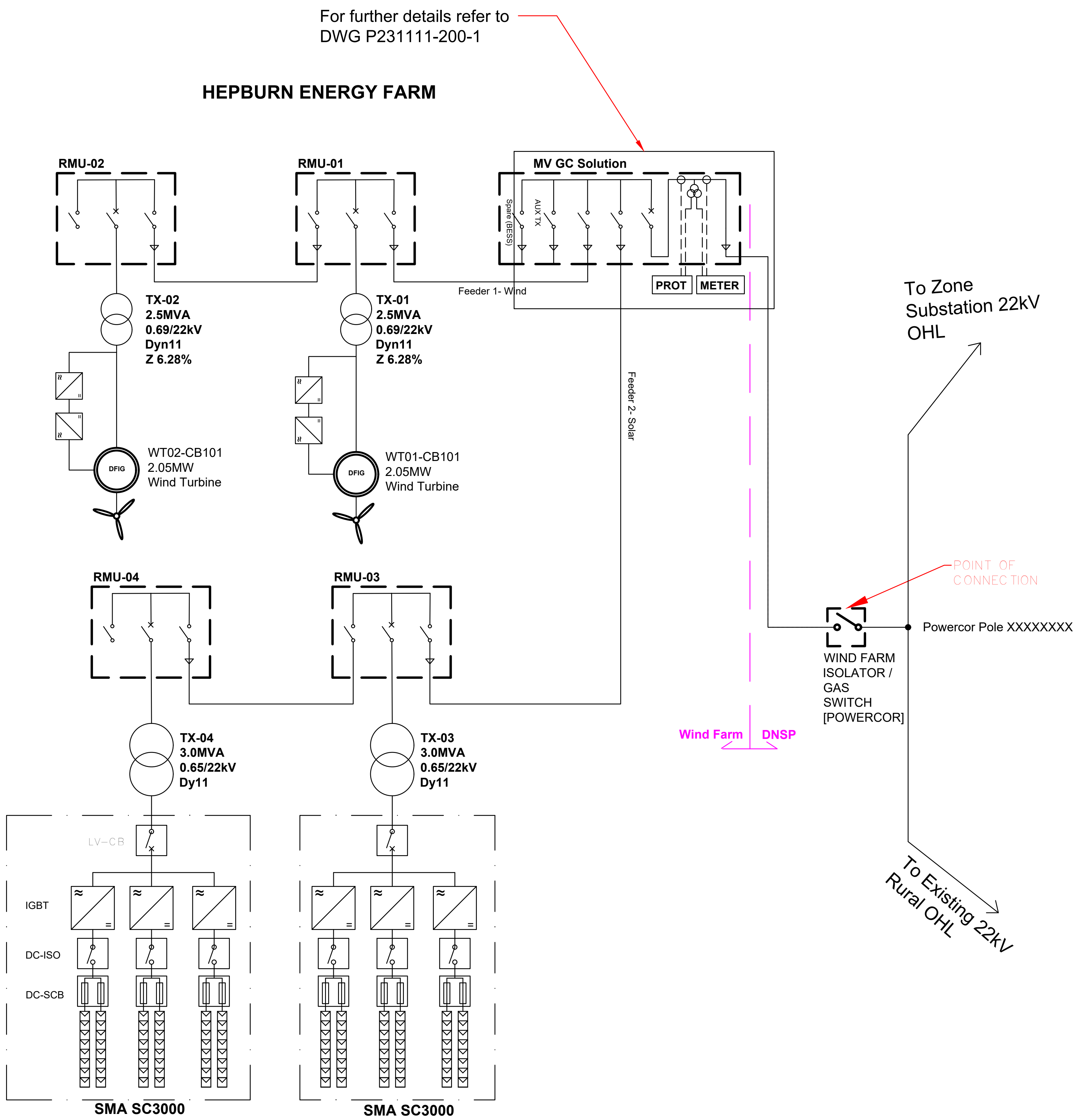
An AC Voltage Range of +15% Uac can be achieved for 50Hz grids only in combination of the inverter option 'brown power' (without SMA 'auxiliary transformer' and without option 'housekeeping'). Please contact an SMA Application Engineer for further support.

Niestetal, December 14th, 2018

SMA Solar Technology AG
Sonnenallee 1
34266 Niestetal/ Germany

i. A. Andreas Tügel
i. A. Daniel Greger
Product Manager

Appendix D – Site Layout and Electrical Schematics



DNV·GL

ABN: 14 154 635 319 T: +613 8615 1515
Level 12/350 Queen St, Melbourne VIC 3000

Client:

Notes:

1. Some details omitted for clarity. Drawing intends to show general connection arrangement only.

PRELIMINARY

Project: Hepburn Wind Farm

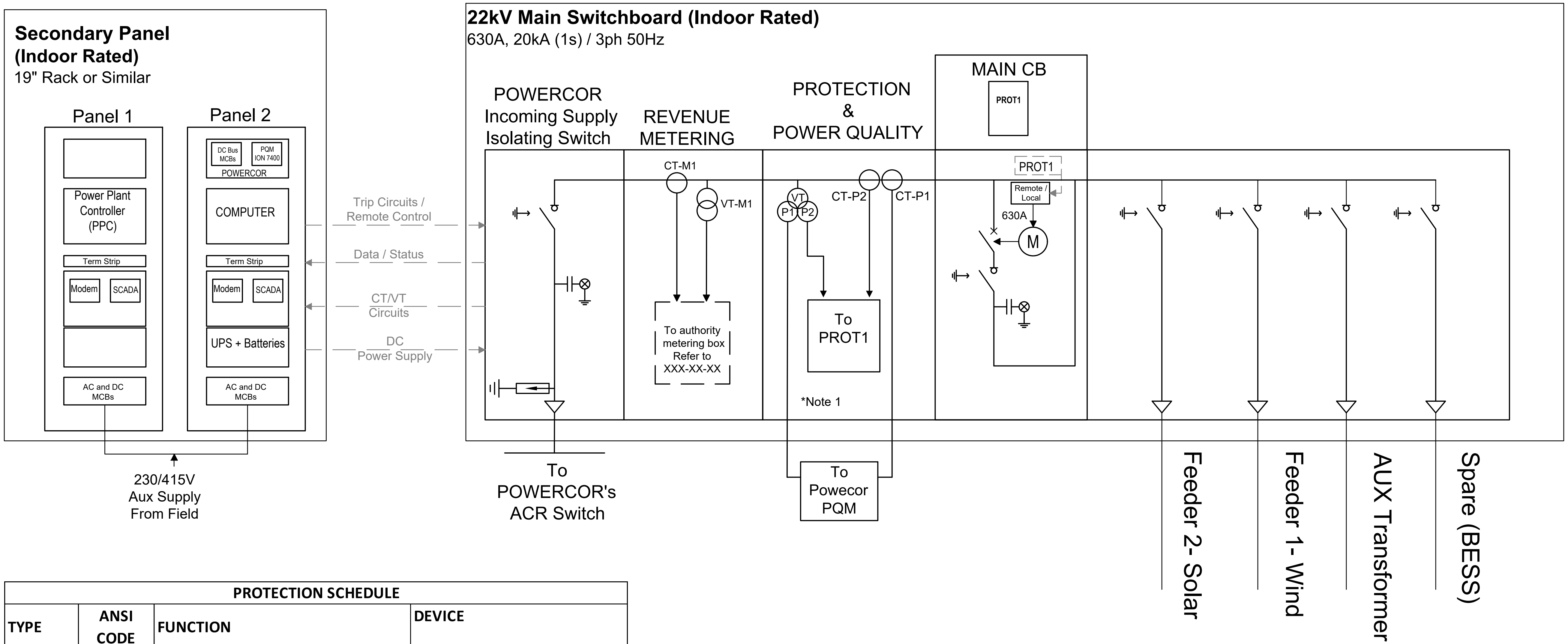
Title: Overall Electrical Schematic MV AC

Dwg No: P231111–100–1 Rev: A

Rev	Date	Comments	Dwn	Chkd

Dwn: FM Chkd: AG Date: 14/11/19

Job No: P23111 Scale: NTS@A3



PROTECTION SCHEDULE			
TYPE	ANSI CODE	FUNCTION	DEVICE
PROT 1 (22kV)	50/51	INSTANTANEOUS OVERCURRENT	Siemens 7SJ62
	50N	EARTH FAULT	
	79	TRIPPING RELAY	
	50BF	BREAKER FAILURE	
	81O	OVER FRERQUENCY	
	81U	UNDER FREQUENCY	
	27	UNDER VOLTAGE	
	81R	ROCOF (TBC)	
	59	OVER VOLTAGE	
PROT 2 (INV)	81O	OVER FRERQUENCY	SMA SC3000 INVERTER
	81U	UNDER FREQUENCY	
	27	UNDER VOLTAGE	
	59	OVER VOLTAGE	
	25	SYNCHRONISM-CHECK DEVICE	
	-	ACTIVE ANTI-ISLANDING	
PROT 3	50/51	INSTANTANEOUS OVERCURRENT	Transformer

ID	TYPE	RATIO	CLASS	BURDEN (VA)
CT-P1	PROTECTION CT	300:1A	5P20	25
VT-P1	PROTECTION VT	22/0.11kV	CL0.5M	15
CT-P2	PROTECTION CT	300:5A	5P10	10
VT-P2	PROTECTION VT	22/0.11kV	CL0.5	TBA
CT-M1	METERING CT	300:5A	CL0.5S	15
VT-M1	METERING VT	22/0.11kV	CL0.5M	TBA

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ABN: 14 154 635 319 T: +613 8615 1515
Level 12/350 Queen St, Melbourne VIC 3000

Client:

Notes:

1. Details show proposed indoor connection cubicle consisting of MV switchgear and secondary panels. Subject to further discussion with Powercor.
2.

PRELIMINARY

Project: Hepburn Wind Farm

Title: MV Connection Solution SLD

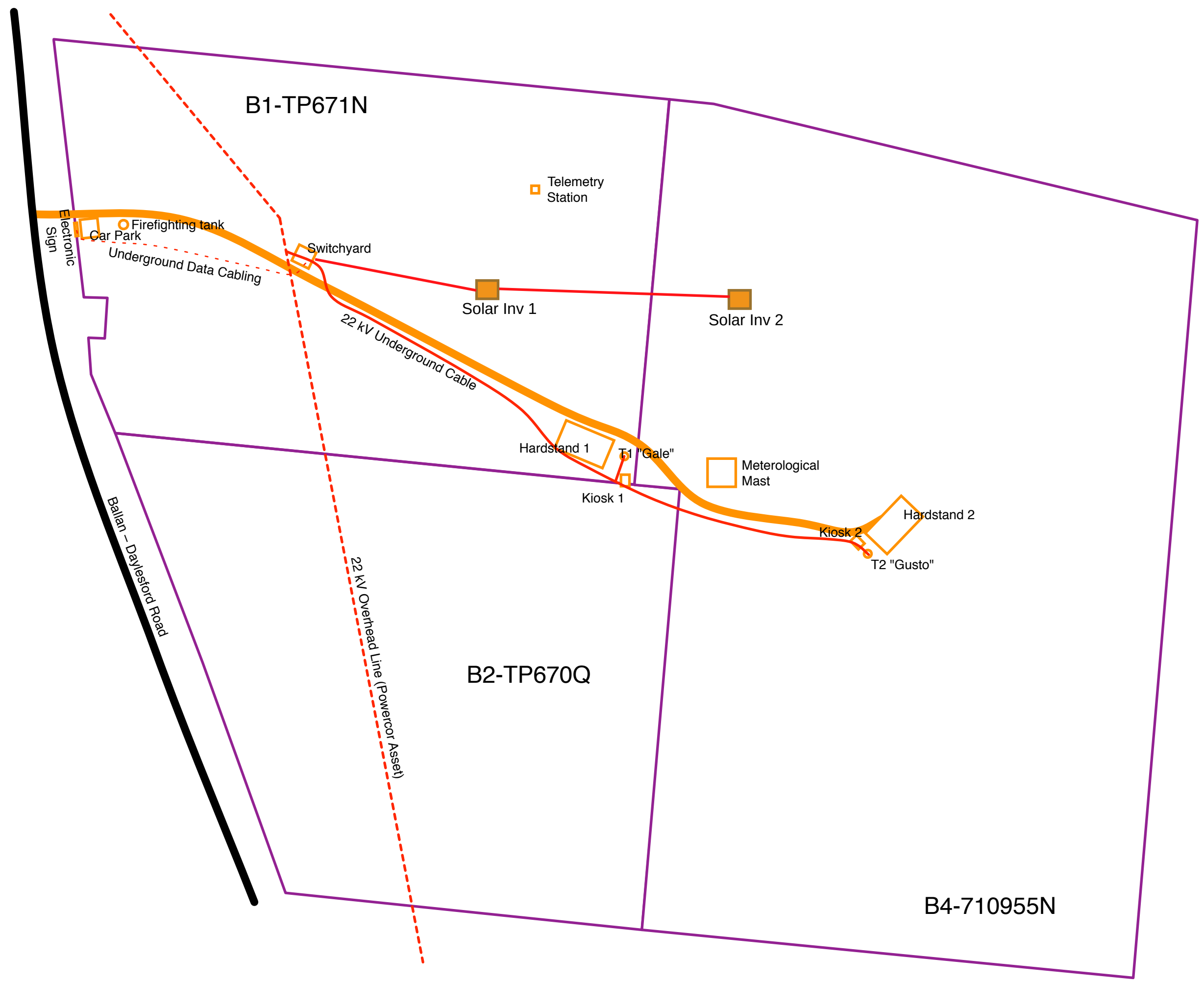
Dwg No: P231111-200-1 Rev: A1

Rev Date Comments Dwn Chkd

Dwn: FM Chkd: AG Date: 14/11/19

Job No: P231111 Scale: NTS@A3

Hepburn Community Wind Farm Site Plan



Author: Simon Holmes à Court
Date: 7 February 2014
Version: 2014.2
Note: Layout is not to scale. Positions are indicative. Consult a surveyor and "Dial Before You Dig" prior to any excavation or construction activities.

Not To Scale
Not For Construction or Excavation

About DNV GL

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