Cable Thermal Studies

Technical Documentation for Ames BESS

Cable Thermal Studies

Technical Documentation for Cable Thermal Analysis results for Ames BESS

Table Of Contents

Executive Summary

Cable thermal analysis plays a critical role in system design. Cable thermal analysis is important for overheating, safety, cable efficiency, and extending cable lifespan. Cable thermal analysis is a module in ETAP which uses a U/G Thermal Neher-McGrath calculation method to determine the cable temperature and ampacity ratings. It employs a thermal circuit model to represent heat flow situations. For this module, it is assumed that the cables have been carrying a load long enough that the heat flow has reached its steady-state.

To run a cable thermal analysis in ETAP, we need to know cable sizes, lengths, insulation type, minimum coverage for cables buried in a conduit, and we need to know the type of soil and temperature it will be buried in. Once this information is obtained from the one-line, cable schedule and with assumptions given from our client, we can create a study case for each cable we are testing. Once we have these, we can add the cables into the conduit and test the cables using the Neher-McGrath calculation method in ETAP.

The cable thermal analysis module in ETAP was used to simulate a cable raceway system that can be tested at specified load conditions. The module calculations determined the temperature of all the cable conductors involved in a raceway system. The calculation method used to test the Ames BESS system used the U/G Thermal Neher-McGrath approach. It was assumed that the cables had been carrying the specified load long enough that the heat flow had reached its steady state. The simulation assumes worst-case scenarios in its calculations. This approach calculates the cables based on user-defined load factors, thermal resistivity, power factor, loss factor, and dialectical constants.

Standards

U/G Thermal Neher McGrath

NEC 310.16 (Low Voltage)

NEC 310.15 (Low Voltage Ambient Temperature Correction Factor)

NEC 311.60 (Medium Voltage)

NEC 300.50 (Minimal coverage)

Methodology

For the cable thermal analysis on the Ames Battery Energy Storage System (BESS), four main groups of cables were analyzed: cables between PCS skids one through six, home run cables, auxiliary cables, and the auxiliary equipment pad cables. All raceways were placed underground in conduit. NEC Article 300.50 was used to determine minimum coverage depths which were 36 inches and 30 inches for medium-voltage and low-multiple cables respectively. The resistivity of the soil (rho) was 108 Ω/m. Additionally, the client, Burns & McDonnell, required that only aluminum conductors be used, and have a maximum size of 1000 kcmil.

The system was modeled using ETAP software. To avoid mutual heating[1], six case studies were simulated, one for each of the following groups of cables: PCS1-2, PCS2-3, PCS4-5, PCS5-6, auxiliary equipment pad cables, and auxiliary switchboard cables. For preliminary analyses, the cable schedule created in the previous semester was used. This cable schedule included conductors' sizes, insulation types, lengths, and number of conductors per phase. These initial analyses indicated that all four groups of cables needed to be upsized. To recalculate the cables sizes Equation 1 was used, and the cable schedule was updated to reflect these changes.

$$I = \frac{\frac{XFMR\ (VA)}{Voltage\ (V)}}{\sqrt{3}}$$

Equation 1

For this project, cables may not be placed in a triplexed placement, thus "random lie" was used to place the cables in a raceway.

System Data

For our initial cable analyses input data for our system was obtained from

- Previous semester calculation
- One line diagram
- Cable schedule

[1] Phenomenon where cable(s) under load heat adjacent cables

Assumptions

Conductor Material & Configuration

- Medium-voltage (MW) cables are triplexed and directly buried
- Raceways may be at least 5 feet apart to minimize heat transfer between cables
- Medium-voltage (MW) cables are buried at least 36 inches
- Low-voltage (LV) cables are buried at least 30 inches

Cable and Insulation Specifications

- Medium-voltage (MW) cables' insulation withstand 105°C
- Low-voltage (LV) cables' insulation withstand 95°C
- Cables are in separate raceways
- Studies were calculated for 5 hours
- XLPE and RHW2 insulation are used

Environmental Conditions

- Ambient temperature of 40°C

Study Cases

Table 1: Study Cases

Cable	Size (kc mil)	Ampacity (A)	Insulation	Length (ft)	Conductors/ Phase	Min. Coverage (in)
PCS1-2	1/0	98.016	XLPE	53.02	1	36
PCS2-3	3/0	175.112	XLPE	53.02	1	36
PCS4-5	2/0	154.194	XLPE	53.02	1	36
PCS5-6	1/0	77.097	XLPE	53.02	1	36
Home Run	350	483.500 (total)	XLPE	572.05	1	36
Aux Pad	1000	1820	RHW2	40	4	36
Aux SWBRD	1/0	57.134	XLPE	15	1	30

Results

Initial Cable Sizing and Performance

Using the previous semester's cable schedule, the simulations indicated that all of the cables required upsizing. However, the auxiliary cables were already at the maximum allowable size of 1000 kcmil aluminum.

Design Modifications

All of the cables were upsized to a minimum of 1/0 aluminum. For the auxiliary cables two parallel runs of 1000 kcmil copper were used to meet thermal requirements. This redesign adhered to NEC Article 300.50 for burial depths.

Thermal Performance

Following the design modifications, simulations confirmed that the new design met steady-state temperature requirements. By using separated raceways mutual heating was mitigated and opting for "random lie" ensured simulations accounted for sufficient thermal dissipation.

Case Study Results

Home Run Cables: These runs were upsized to 350kcmil aluminum, achieving sufficient performance over 572 feet.

PCS Cables: All sections PSC1 through PS6 were resized and met thermal requirements.

Auxiliary Equipment Pad Cables: By using two parallel runs of 1000 kcmil copper with RHW2 insulation the cables were within their thermal insulation ratings.

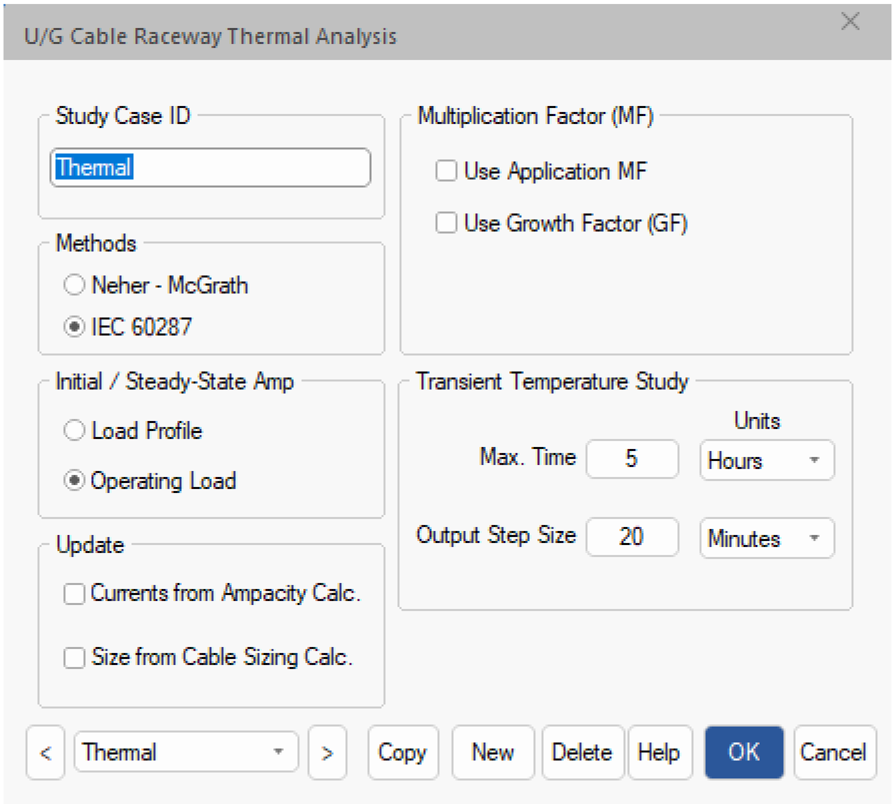
Auxiliary Switchboard Cables: Reconfigured with 1/0 aluminum cables to meet temperature ratings.

Conclusion

Cable thermal studies play a critical role in many applications from everyday technologies to system design. This paper examined key considerations in cable selection, methods, and materials. This paper takes into account the importance of heat transfer, soil types, spacing, material properties and more. By utilizing computational tools such as ETAP we are able to confirm design selection will be sufficient in real-world applications.

Appendix A: Settings Information

ETAP setting screenshot



Appendix B: Study Results

Auxiliary Cable Thermal Results

Project:	ETAP	Page: 1
Location:	24.0.0E	Date: 11-20-2024
Contract:		SN: IASTATEPL
Engineer:	Study Case: Thermal	Revision: Base
Filename: AMES_BESS		Study: Steady-State Temperature

Summary (RW9)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 33-1A	Loc4	1/0	54.84	48.79
2	Cable ID: 33-1B	Loc4	1/0	54.84	48.79
3	Cable ID: 33-1C	Loc4	1/0	54.84	48.79
4	Cable ID: 34-1A	Loc32	1/0	54.84	48.59
5	Cable ID: 34-1B	Loc32	1/0	54.84	48.59
6	Cable ID: 34-1C	Loc32	1/0	54.84	48.59
7	Cable ID: 35-1A	Loc33	1/0	54.84	49.70
8	Cable ID: 35-1B	Loc33	1/0	54.84	49.70
9	Cable ID: 35-1C	Loc33	1/0	54.84	49.70
10	Cable ID: 36-1A	Loc34	1/0	54.84	50.59
11	Cable ID: 36-1B	Loc34	1/0	54.84	50.59
12	Cable ID: 36-1C	Loc34	1/0	54.84	50.59
13	Cable ID: 37-1A	Loc35	1/0	54.84	51.37
14	Cable ID: 37-1B	Loc35	1/0	54.84	51.37
15	Cable ID: 37-1C	Loc35	1/0	54.84	51.37
16	Cable ID: 38-1A	Loc36	1/0	54.84	52.04
17	Cable ID: 38-1B	Loc36	1/0	54.84	52.04
18	Cable ID: 38-1C	Loc36	1/0	54.84	52.04
19	Cable ID: 39-1A	Loc37	1/0	54.84	52.60
20	Cable ID: 39-1B	Loc37	1/0	54.84	52.60
21	Cable ID: 39-1C	Loc37	1/0	54.84	52.60
22	Cable ID: 40-1A	Loc38	1/0	54.84	53.05
23	Cable ID: 40-1B	Loc38	1/0	54.84	53.05
24	Cable ID: 40-1C	Loc38	1/0	54.84	53.05
25	Cable ID: 41-1A	Loc39	1/0	54.84	53.40
26	Cable ID: 41-1B	Loc39	1/0	54.84	53.40
27	Cable ID: 41-1C	Loc39	1/0	54.84	53.40
28	Cable ID: 42-1A	Loc40	1/0	54.84	53.66
29	Cable ID: 42-1B	Loc40	1/0	54.84	53.66
30	Cable ID: 42-1C	Loc40	1/0	54.84	53.66
31	Cable ID: 43-1A	Loc41	1/0	54.84	53.83
32	Cable ID: 43-1B	Loc41	1/0	54.84	53.83
33	Cable ID: 43-1C	Loc41	1/0	54.84	53.83
34	Cable ID: 44-1A	Loc42	1/0	54.84	53.91
35	Cable ID: 44-1B	Loc42	1/0	54.84	53.91
36	Cable ID: 44-1C	Loc42	1/0	54.84	53.91

Project:	ETAP	Page:	2
Location:	24.0.0E	Date:	11-20-2024
Contract:		SN:	IASTATEPL
Engineer:	Study Case: Thermal	Revision:	Base
Filename: AMES_BESS		Study:	Steady-State Temperature

Summary (RW9)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
37	Cable ID: 45-1A	Loc43	1/0	54.84	53.90
38	Cable ID: 45-1B	Loc43	1/0	54.84	53.90
39	Cable ID: 45-1C	Loc43	1/0	54.84	53.90
40	Cable ID: 46-1A	Loc53	1/0	54.84	53.81
41	Cable ID: 46-1B	Loc53	1/0	54.84	53.81
42	Cable ID: 46-1C	Loc53	1/0	54.84	53.81
43	Cable ID: 47-1A	Loc44	1/0	54.84	53.63
44	Cable ID: 47-1B	Loc44	1/0	54.84	53.63
45	Cable ID: 47-1C	Loc44	1/0	54.84	53.63
46	Cable ID: 48-1A	Loc45	1/0	54.84	53.35
47	Cable ID: 48-1B	Loc45	1/0	54.84	53.35
48	Cable ID: 48-1C	Loc45	1/0	54.84	53.35
49	Cable ID: 49-1A	Loc46	1/0	54.84	52.98
50	Cable ID: 49-1B	Loc46	1/0	54.84	52.98
51	Cable ID: 49-1C	Loc46	1/0	54.84	52.98
52	Cable ID: 50-1A	Loc47	1/0	54.84	52.51
53	Cable ID: 50-1B	Loc47	1/0	54.84	52.51
54	Cable ID: 50-1C	Loc47	1/0	54.84	52.51
55	Cable ID: 51-1A	Loc48	1/0	54.84	51.93
56	Cable ID: 51-1B	Loc48	1/0	54.84	51.93
57	Cable ID: 51-1C	Loc48	1/0	54.84	51.93
58	Cable ID: 52-1A	Loc49	1/0	54.84	51.21
59	Cable ID: 52-1B	Loc49	1/0	54.84	51.21
60	Cable ID: 52-1C	Loc49	1/0	54.84	51.21
61	Cable ID: 53-1A	Loc50	1/0	54.84	50.35
62	Cable ID: 53-1B	Loc50	1/0	54.84	50.35
63	Cable ID: 53-1C	Loc50	1/0	54.84	50.35
64	Cable ID: 54-1A	Loc51	1/0	54.84	49.31
65	Cable ID: 54-1B	Loc51	1/0	54.84	49.31
66	Cable ID: 54-1C	Loc51	1/0	54.84	49.31
67	Cable ID: 55-1A	Loc52	1/0	54.84	48.02
68	Cable ID: 55-1B	Loc52	1/0	54.84	48.02
69	Cable ID: 55-1C	Loc52	1/0	54.84	48.02
70	Cable ID: 56-1A	Loc30	1/0	54.84	46.33
71	Cable ID: 56-1B	Loc30	1/0	54.84	46.33
72	Cable ID: 56-1C	Loc30	1/0	54.84	46.33

Project:	**ETAP**	Page:	3
Location:	24.0.0E	Date:	11-20-2024
Contract:		SN:	IASTATEPL
Engineer:	Study Case: Thermal	Revision:	Base
Filename: AMES_BESS		Study:	Steady-State Temperature

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation

* Indicates a cable temperature exceeding its limit

\# Indicates a cable temperature exceeding its marginal limit

Auxiliary Pad Cable Thermal Results

Project:		ETAP	Page:	1
Location:		24.0.0E	Date:	11-21-2024
Contract:			SN:	IASTATEPL
Engineer:		Study Case: Thermal	Revision:	Base
Filename:	AMES_BESS		Study:	Steady-State Temperature

Summary (RW1)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 32-1C	Loc1	1000	455.00	82.78
2	Cable ID: 32-1B	Loc1	1000	455.00	82.78
3	Cable ID: 32-1A	Loc1	1000	455.00	82.78
4	Cable ID: 32-2C	Loc1	1000	455.00	82.78
5	Cable ID: 32-2B	Loc1	1000	455.00	82.78
6	Cable ID: 32-2A	Loc1	1000	455.00	82.78
7	Cable ID: 32-3C	Loc5	1000	455.00	82.78
8	Cable ID: 32-3B	Loc5	1000	455.00	82.78
9	Cable ID: 32-3A	Loc5	1000	455.00	82.78
10	Cable ID: 32-4C	Loc5	1000	455.00	82.78
11	Cable ID: 32-4B	Loc5	1000	455.00	82.78
12	Cable ID: 32-4A	Loc5	1000	455.00	82.78

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

Home Run Cable Thermal Results

Project:		ETAP	Page:	1
Location:		24.0.0E	Date:	11-20-2024
Contract:			SN:	IASTATEPL
Engineer:		Study Case: Thermal	Revision:	Base
Filename:	AMES_BESS		Study:	Steady-State Temperature

Summary (RW15)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 4-1A	Loc2	350	252.20	67.30
2	Cable ID: 4-1B	Loc2	350	252.20	67.30
3	Cable ID: 4-1C	Loc2	350	252.20	67.30
4	Cable ID: 5-1A	Loc3	350	231.30	61.77
5	Cable ID: 5-1B	Loc3	350	231.30	61.77
6	Cable ID: 5-1C	Loc3	350	231.30	61.77

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
# Indicates a cable temperature exceeding its marginal limit

PCS 1 – 2 Cable Thermal Results

Project:		ETAP	Page: 1
Location:		24.0.0E	Date: 11-20-2024
Contract:			SN: IASTATEPL
Engineer:		Study Case: Thermal	Revision: Base
Filename:	AMES_BESS		Study: Steady-State Temperature

Summary (RW19)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 2-1A	Loc25	1/0	98.02	43.29
2	Cable ID: 2-1B	Loc25	1/0	98.02	43.29
3	Cable ID: 2-1C	Loc25	1/0	98.02	43.29

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
# Indicates a cable temperature exceeding its marginal limit

PCS 2 – 3 Cable Thermal Results

Project:		ETAP	Page:	1
Location:		24.0.0E	Date:	11-20-2024
Contract:			SN:	IASTATEPL
Engineer:		Study Case: Thermal	Revision:	Base
Filename:	AMES_BESS		Study:	Steady-State Temperature

Summary (RW8)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 3-1C	Loc29	3/0	175.10	62.38
2	Cable ID: 3-1B	Loc29	3/0	175.10	62.38
3	Cable ID: 3-1A	Loc29	3/0	175.10	62.38

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
\# Indicates a cable temperature exceeding its marginal limit

PCS 4 – 5 Cable Thermal Results

Project:	ETAP	Page:	1
Location:	24.0.0E	Date:	11-20-2024
Contract:		SN:	IASTATEPL
Engineer:	Study Case: Thermal	Revision:	Base
Filename: AMES_BESS		Study:	Steady-State Temperature

Summary (RW20)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 6-1A	Loc26	2/0	154.20	60.31
2	Cable ID: 6-1B	Loc26	2/0	154.20	60.31
3	Cable ID: 6-1C	Loc26	2/0	154.20	60.31

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
# Indicates a cable temperature exceeding its marginal limit

PCS 5 – 6 Cable Thermal Results

Project:	**ETAP**	Page: 1
Location:	24.0.0E	Date: 11-20-2024
Contract:		SN: IASTATEPL
Engineer:	Study Case: Thermal	Revision: Base
Filename: AMES_BESS		Study: Steady-State Temperature

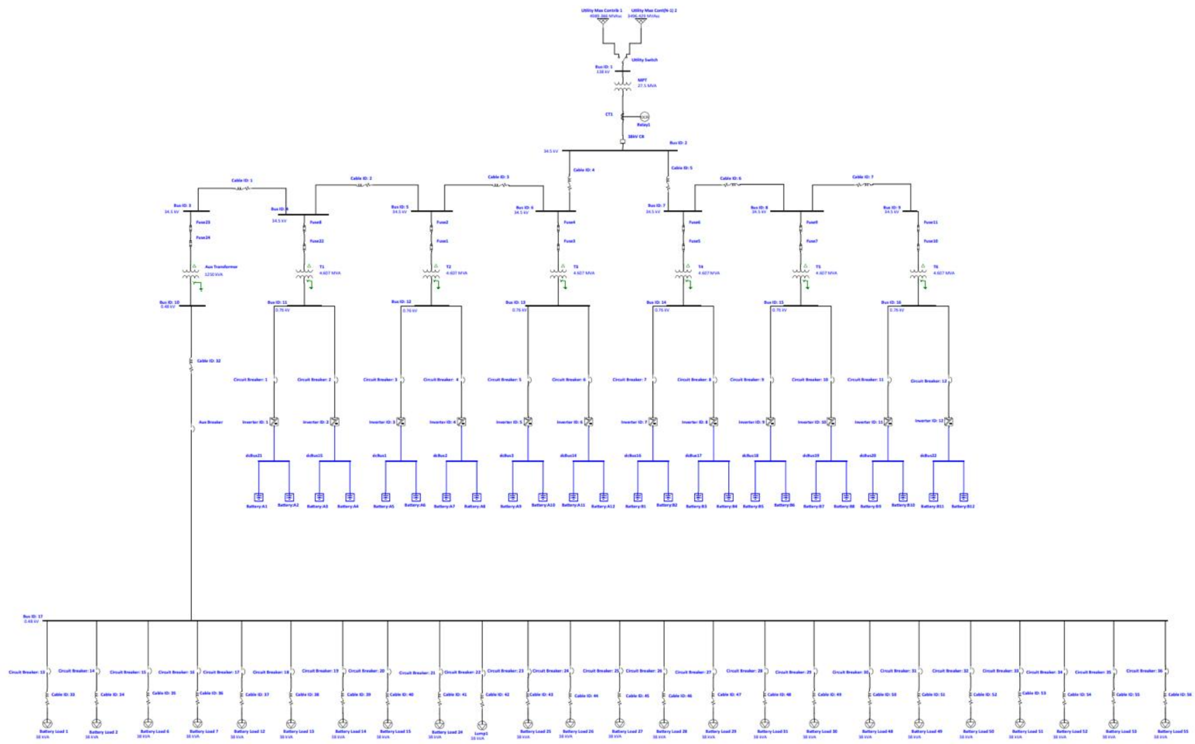
Summary (RW21)

No.	Cable ID	Conduit/Location ID	Size	Current Amp	Temp. °C
1	Cable ID: 7-1A	Loc88	1/0	77.10	35.82
2	Cable ID: 7-1B	Loc88	1/0	77.10	35.82
3	Cable ID: 7-1C	Loc88	1/0	77.10	35.82

F Indicates fixed cable size in cable sizing calculations or fixed cable ampacity in uniform ampacity calculation
* Indicates a cable temperature exceeding its limit
# Indicates a cable temperature exceeding its marginal limit

Appendix C: One-Line

One-Line Diagram - Ames BESS | Load Flow Analysis | LF

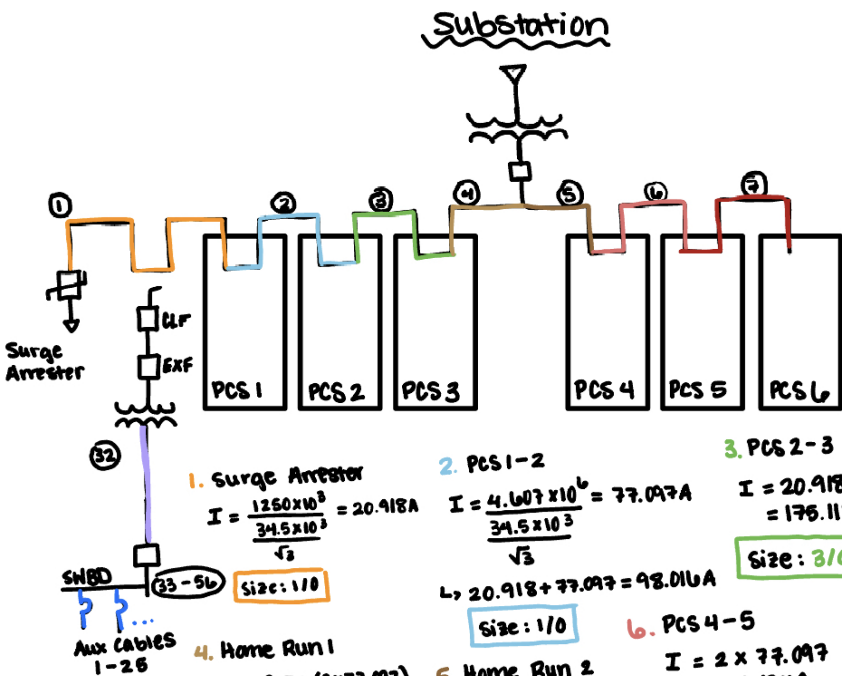


Appendix D: Supporting Documents

Cable Schedule

Cable ID	Current flow	From	To	Description	Conductor Size	Length	Conductors per phase	Qty	Raceway Length
1	20.918 A	Surge Arrestor	PCS1	Fuse/ Surge Arrestor	1/0	45.57 ft	1	3	29.57 ft
2	98.016 A	PCS1	PCS2	inveter cable	1/0	53.02 ft	1	3	37.02 ft
3	175.112 A	PCS2	PCS3	inverter cable	3/0	53.02 ft	1	3	37.02 ft
4	252.209 A	PCS3	Substation Breaker	Home Run 1	350 kcmil	563.99 ft	1	3	547.99 ft
5	231.291 A	Substaion Breaker	PCS 4	Home Run 2	350 kcmil	572.05 ft	1	3	556.05 ft
6	154.194 A	PCS4	PCS5	PCS4	2/0	53.02 ft	1	3	37.02 ft
7	77.097 A	PCS5	PCS6	PCS5	1/0	53.02 ft	1	3	37.02 ft
8	1274A	Inverter	Battery B12	DC Battery B12	500 Kcmil	30.86 ft	4	4	16.86 ft
9	1274A	Inverter	Battery B11	DC Battery B11	500 Kcmil	74.19 ft	4	4	60.19 ft
10	1274A	Inverter	Battery B10	DC Battery B10	500 Kcmil	72.62 ft	4	4	58.62 ft
11	1274A	Inverter	Battery B09	DC Battery B09	500 Kcmil	24.03 ft	4	4	10.03 ft
12	1274A	Inverter	Battery B08	DC Battery B08	500 Kcmil	30.86 ft	4	4	16.86 ft
13	1274A	Inverter	Battery B07	DC Battery B07	500 Kcmil	74.19 ft	4	4	60.19 ft
14	1274A	Inverter	Battery B06	DC Battery B06	500 Kcmil	72.62 ft	4	4	58.62 ft
15	1274A	Inverter	Battery B05	DC Battery B05	500 Kcmil	24.03 ft	4	4	10.03 ft
16	1274A	Inverter	Battery B04	DC Battery B04	500 Kcmil	30.86 ft	4	4	16.86 ft
17	1274A	Inverter	Battery B03	DC battery B03	500 Kcmil	74.19 ft	4	4	60.19 ft
18	1274A	Inverter	Battery B02	DC Battery B02	500 Kcmil	72.62 ft	4	4	58.62 ft
19	1274A	Inverter	Battery B01	DC Battery B01	500 Kcmil	24.03 ft	4	4	10.03 ft
20	1274A	Inverter	Battery A12	DC Battery A12	500 Kcmil	30.86 ft	4	4	16.86 ft
21	1274A	Inverter	Battery A11	DC Battery A11	500 Kcmil	74.19 ft	4	4	60.19 ft
22	1274A	Inverter	Battery A10	DC Battery A10	500 Kcmil	72.62 ft	4	4	58.62 ft
23	1274A	Inverter	Battery A09	DC Battery A09	500 Kcmil	24.03 ft	4	4	10.03 ft
24	1274A	Inverter	Battery A08	DC Battery A08	500 Kcmil	30.86 ft	4	4	16.86 ft
25	1274A	Inverter	Battery A07	DC Battery A07	500 Kcmil	74.19 ft	4	4	60.19 ft
26	1274A	Inverter	Battery A06	DC Battery A06	500 Kcmil	72.62 ft	4	4	58.62 ft
27	1274A	Inverter	Battery A05	DC Battery A05	500 Kcmil	24.03 ft	4	4	10.03 ft
28	1274A	Inverter	Battery A04	DC Battery A04	500 Kcmil	30.86 ft	4	4	16.86 ft
29	1274A	Inverter	Battery A03	DC Battery A03	500 Kcmil	74.19 ft	4	4	60.19 ft
30	1274A	Inverter	Battery A02	DC Battery A02	500 Kcmil	72.62 ft	4	4	58.62 ft
31	1274A	Inverter	Battery A01	DC Battery A01	500 Kcmil	24.03 ft	4	4	10.03 ft
32	1820A	Aux Transformer	Aux Equipment pad	Auxilary Equipment pad	1000 Kcmil	40 ft	4	4	24 ft
33	54.84A	Aux Cable C1	Battery A01	Aux Power Cabinet C1	1/0		4	1	
34	54.84A	Aux Cable C2	Battery A02	Aux Power Cabinet C2	1/0		1	1	
35	54.84A	Aux Cable C3	Battery A03	Aux Power Cabinet C3	1/0		1	1	
36	54.84A	Aux Cable C4	Battery A04	Aux Power Cabinet C4	1/0		1	1	
37	54.84A	Aux Cable C6	Battery A05	Aux Power Cabinet C6	1/0		1	1	
38	54.84A	Aux Cable C7	Battery A06	Aux Power Cabinet C7	1/0		1	1	
39	54.84A	Aux Cable C8	Battery A07	Aux Power Cabinet C8	1/0		1	1	
40	54.84A	Aux Cable C9	Battery A08	Aux Power Cabinet C9	1/0		1	1	
41	54.84A	Aux Cable C11	Battery A09	Aux Power Cabinet C11	1/0		1	1	
42	54.84A	Aux Cable C12	Battery A10	Aux Power Cabinet C12	1/0		1	1	
43	54.84A	Aux Cable C13	Battery A11	Aux Power Cabinet C13	1/0		1	1	
44	54.84A	Aux Cable C14	Battery A12	Aux Power Cabinet C14	1/0		1	1	
45	54.84A	Aux Cable C16	Battery B01	Aux Power Cabinet C15	1/0		1	1	
46	54.84A	Aux Cable C17	Battery B02	Aux Power Cabinet C17	1/0		1	1	
47	54.84A	Aux Cable C18	Battery B03	Aux Power Cabinet C18	1/0		1	1	
48	54.84A	Aux Cable C19	Battery B04	Aux Power Cabinet C19	1/0		1	1	
49	54.84A	Aux Cable C21	Battery B05	Aux Power Cabinet C21	1/0		1	1	
50	54.84A	Aux Cable C22	Battery B06	Aux Power Cabinet C22	1/0		1	1	
51	54.84A	Aux Cable C23	Battery B07	Aux Power Cabinet C23	1/0		1	1	
52	54.84A	Aux Cable C24	Battery B08	Aux Power Cabinet C24	1/0		1	1	
53	54.84A	Aux Cable C26	Battery B09	Aux Power Cabinet C26	1/0		1	1	
54	54.84A	Aux Cable C27	Battery B10	Aux Power Cabinet C27	1/0		1	1	
55	54.84A	Aux Cable C28	Battery B11	Aux Power Cabinet C28	1/0		1	1	
56	54.84A	Aux Cable C29	Battery B12	Aux Power Cabinet C29	1/0		1	1	

Cable Ampacity Calculations



1. Surge Arrester

$I = \frac{1250\times10^3}{\frac{34.5\times10^3}{\sqrt{3}}} = 20.918A$

$\boxed{\text{Size: 1/0}}$

2. PCS 1-2

$I = \frac{4.607\times10^6}{\frac{34.5\times10^3}{\sqrt{3}}} = 77.097A$

↳ $20.918 + 77.097 = 98.016A$

$\boxed{\text{Size: 1/0}}$

3. PCS 2-3

$I = 20.918 + (2\times77.097)$
$= 175.112A$

$\boxed{\text{Size: 3/0}}$

4. Home Run 1

$I = 20.918 + (3\times77.097)$
$= 252.209A$

$\boxed{\text{Size: 350 kcmil}}$

5. Home Run 2

$I = 3\times77.097$
$= 231.291A$

$\boxed{\text{Size: 350 kcmil}}$

6. PCS 4-5

$I = 2\times77.097$
$= 154.194A$

$\boxed{\text{Size: 2/0}}$

7. PCS 5-6

$I = \frac{4.607\times10^6}{\frac{34.5\times10^3}{\sqrt{3}}}$
$= 77.097A$

$\boxed{\text{Size: 1/0}}$

32. Aux Equip Pad

$I = \frac{1250\times10^3}{\frac{480}{\sqrt{3}}} = 1503A$

↳ choose 1000 kcmil → 500A
↳ use Ambient correction factor
$T = 0.91$

$I = 500\times4\times0.91$
$= 1820A$

$\boxed{\text{Size: 1000 kcmil with 4 cond / phase}}$

33-56: Aux Cables

$I = \frac{38\times10^3}{\frac{480}{\sqrt{3}}} = 45.707A$

↳ 45.707×1.25 (rated current)
$= 57.134A$

$\boxed{\text{Size: 1/0}}$

NEC Article 311 for Medium Voltage

Table 311.60(C)(85) Ampacities of Three Triplexed Single Insulated Copper Conductors Directly Buried in Earth

	Temperature Rating of Conductor			
	2001–5000 Volts Ampacity		5001–35,000 Volts Ampacity	
Conductor Size (AWG or kcmil)	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105
One Circuit, Three Conductors [See Figure 311.60(D)(3), Detail 7.]				
8	90	95	—	—
6	120	130	115	120
4	150	165	150	160
2	195	205	190	205
1	225	240	215	230
1/0	255	270	245	260
2/0	290	310	275	295
3/0	330	360	315	340
4/0	375	405	360	385
250	410	445	390	410
350	490	580	470	505
500	590	635	565	605
750	725	780	685	740
1000	825	885	770	830
Two Circuits, Six Conductors [See Figure 311.60(D)(3), Detail 8.]				
8	85	90	—	—
6	110	115	105	115
4	140	150	140	150
2	180	195	175	190
1	205	220	200	215
1/0	235	250	225	240
2/0	265	285	255	275
3/0	300	320	290	315
4/0	340	365	325	350
250	370	395	355	380
350	445	480	425	455
500	535	575	510	545
750	650	700	615	660
1000	740	795	690	745

Note: Refer to 311.60(F) for basis of ampacities and Table 311.10(A) for the temperature rating of the conductor.

Table 311.60(C)(86) Ampacities of Three Triplexed Single Insulated Aluminum Conductors Directly Buried in Earth

	Temperature Rating of Conductor			
	2001–5000 Volts Ampacity		5001–35,000 Volts Ampacity	
Conductor Size (AWG or kcmil)	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105	90°C (194°F) Type MV-90	105°C (221°F) Type MV-105
One Circuit, Three Conductors [See Figure 311.60(D)(3), Detail 7.]				
8	70	75	—	—
6	90	100	90	95
4	120	130	115	125
2	155	165	145	155
1	175	190	165	175
1/0	200	210	190	205
2/0	225	240	215	230
3/0	255	275	245	265
4/0	290	310	280	305
250	320	350	305	325
350	385	420	370	400
500	465	500	445	480
750	580	625	550	590
1000	670	725	635	680
Two Circuits, Six Conductors [See Figure 311.60(D)(3), Detail 8.]				
8	65	70	—	—
6	85	95	85	90
4	110	120	105	115
2	140	150	135	145
1	160	170	155	170
1/0	180	195	175	190
2/0	205	220	200	215
3/0	235	250	225	245
4/0	265	285	255	275
250	290	310	280	300
350	350	375	335	360
500	420	455	405	435
750	520	560	485	525
1000	600	645	565	605

Note: Refer to 311.60(F) for basis of ampacities and Table 311.10(A) for the temperature rating of the conductor.

NEC Article 310 for Low Voltage

Table 310.16 Ampacities of Insulated Conductors with Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried)

	Temperature Rating of Conductor [See Table 310.4(A)]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, XHWN, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, PFA, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, XHWN, XHWN-2, XHHN, Z, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, XHWN, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, XHWN, XHWN-2, XHHN	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18*	—	—	14	—	—	—	—
16*	—	—	18	—	—	—	—
14*	15	20	25	—	—	—	—
12*	20	25	30	15	20	25	12*
10*	30	35	40	25	30	35	10*
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

Notes:

1. Section 310.15(B) shall be referenced for ampacity correction factors where the ambient temperature is other than 30°C (86°F).
2. Section 310.15(C)(1) shall be referenced for more than three current-carrying conductors.
3. Section 310.16 shall be referenced for conditions of use.

*Section 240.4(D) shall be referenced for conductor overcurrent protection limitations, except as modified elsewhere in the *Code*.

NEC Article 310 for Ambient Temperature Correction Factor

Table 310.15(B)(2) Ambient Temperature Correction Factors Based on 40°C (104°F)

For ambient temperatures other than 40°C (104°F), multiply the ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor						Ambient Temperature (°F)
	60°C	75°C	90°C	150°C	200°C	250°C	
10 or less	1.58	1.36	1.26	1.13	1.09	1.07	50 or less
11–15	1.50	1.31	1.22	1.11	1.08	1.06	51–59
16–20	1.41	1.25	1.18	1.09	1.06	1.05	60–68
21–25	1.32	1.2	1.14	1.07	1.05	1.04	69–77
26–30	1.22	1.13	1.10	1.04	1.03	1.02	78–86
31–35	1.12	1.07	1.05	1.02	1.02	1.01	87–95
36–40	1.00	1.00	1.00	1.00	1.00	1.00	96–104
41–45	0.87	0.93	0.95	0.98	0.98	0.99	105–113
46–50	0.71	0.85	0.89	0.95	0.97	0.98	114–122
51–55	0.50	0.76	0.84	0.93	0.95	0.96	123–131
56–60	—	0.65	0.77	0.90	0.94	0.95	132–140
61–65	—	0.53	0.71	0.88	0.92	0.94	141–149
66–70	—	0.38	0.63	0.85	0.90	0.93	150–158
71–75	—	—	0.55	0.83	0.88	0.91	159–167
76–80	—	—	0.45	0.80	0.87	0.90	168–176
81–90	—	—	—	0.74	0.83	0.87	177–194
91–100	—	—	—	0.67	0.79	0.85	195–212
101–110	—	—	—	0.60	0.75	0.82	213–230
111–120	—	—	—	0.52	0.71	0.79	231–248
121–130	—	—	—	0.43	0.66	0.76	249–266
131–140	—	—	—	0.30	0.61	0.72	267–284
141–160	—	—	—	—	0.50	0.65	285–320
161–180	—	—	—	—	0.35	0.58	321–356
181–200	—	—	—	—	—	0.49	357–392
201–225	—	—	—	—	—	0.35	393–437

2020 Edition NATIONAL ELECTRICAL CODE **70**–159

NEC Article 300 for Minimum Coverage

Table 300.50 Minimum Cover[a] Requirements

	General Conditions (not otherwise specified)						Special Conditions (use if applicable)					
	Column 1		Column 2		Column 3		Column 4		Column 5		Column 6	
	Direct-Buried Cables[b]		RTRC, PVC, and HDPE Conduit[c]		Rigid Metal Conduit and Intermediate Metal Conduit		Raceways Under Buildings or Exterior Concrete Slabs, 100 mm (4 in.) Minimum Thickness[d]		Cables in Airport Runways or Adjacent Areas Where Trespass Is Prohibited		Areas Subject to Vehicular Traffic, Such as Thoroughfares and Commercial Parking Areas	
Circuit Voltage	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.	mm	in.
Over 1000 V through 22 kV	750	30	450	18	150	6	100	4	450	18	600	24
Over 22 kV through 40 kV	900	36	600	24	150	6	100	4	450	18	600	24
Over 40 kV	1000	42	750	30	150	6	100	4	450	18	600	24

General Notes:
1. Lesser depths shall be permitted where cables and conductors rise for terminations or splices or where access is otherwise required.
2. Where solid rock prevents compliance with the cover depths specified in this table, the wiring shall be installed in a metal or nonmetallic raceway permitted for direct burial. The raceways shall be covered by a minimum of 50 mm (2 in.) of concrete extending down to rock.
3. In industrial establishments, where conditions of maintenance and supervision ensure that qualified persons will service the installation, the minimum cover requirements, for other than rigid metal conduit and intermediate metal conduit, shall be permitted to be reduced 150 mm (6 in.) for each 50 mm (2 in.) of concrete or equivalent placed entirely within the trench over the underground installation.

Specific Footnotes:

[a]Cover is defined as the shortest distance in millimeters (inches) measured between a point on the top surface of any direct-buried conductor, cable, conduit, or other raceway and the top surface of finished grade, concrete, or similar cover.

[b]Underground direct-buried cables that are not encased or protected by concrete and are buried 750 mm (30 in.) or more below grade shall have their location identified by a warning ribbon that is placed in the trench at least 300 mm (12 in.) above the cables.

[c]Listed by a qualified testing agency as suitable for direct burial without encasement. All other nonmetallic systems shall require 50 mm (2 in.) of concrete or equivalent above conduit in addition to the table depth.

[d]The slab shall extend a minimum of 150 mm (6 in.) beyond the underground installation, and a warning ribbon or other effective means suitable for the conditions shall be placed above the underground installation.

Battery Datasheet Specification

System Parameter

System Type	MC10C-B5365-U-R4M01	MC10C-B4659-U-R2M01
DC Data		
Cell type	LFP	LFP
Pack type	1P416S	1P416S
System configuration	10 × 1P416S	10 × 1P416S
Battery capacity (BOL)	5365kWh	4659kWh
DC usable energy (BOL)@FAT	5099kWh	4382kWh
DC usable energy (BOL)@SAT	4946kWh	4251kWh
Battery voltage range	1081.6 ~ 1497.6	1081.6 ~ 1497.6
Nominal power	1236kW	2125kW
General Data		
Dimensions (W×D×H)	6058×2438×2896mm	6058×2438×2896mm
Weight	≤42252kg	≤42252kg
IP rating	IP55	IP55
Ambient operating temperature range	-30℃ ~ +55℃【1】	-30℃ ~ +55℃【1】
Relative humidity	5% ~ 100%	5% ~ 100%
Max. working altitude	＜2000m【2】	＜2000m【2】
Cooling concept	Smart air cooling	Liquid cooling
Noise	≤75dBA	≤75dBA
Fire suppression system	With fire alarm system (Aerosol)	With fire alarm system (Aerosol)
Auxiliary power interface	AC480V/60Hz, 3 Phase 4 wire	AC480V/60Hz, 3 Phase 4 wire
Auxiliary system peak power requirement @45℃, PF0.8	38kVA	75kVA
Communication interfaces	Ethernet	Ethernet
Communication protocols	Modbus TCP/IP	Modbus TCP/IP
Standard color	RAL 9003	RAL 9003
Compliance	UN3536, UL9540A, UL9540	

Note:
【1】Power derating is performed when the ambient temperature is below -15℃ or above +45℃.
【2】Power derating is performed when the altitude is between 2000-3000m.

Inverter Datasheet Specifications

	Proteus PCS-E Battery Inverters				
	Gamesa Electric Proteus PCS 4180E	Gamesa Electric Proteus PCS 4360E	Gamesa Electric Proteus PCS 4600E	Gamesa Electric Proteus PCS 4910E	Gamesa Electric Proteus PCS 5150E
DC Input					
DC Minimum Voltage for grid tied mode[1]	976 V	1018 V	1075 V	1146 V	1202 V
DC Maximum Voltage	1500 V				
Number of Independent Power Modules per PCS	2, not galvanically isolated				
Max. DC Current	2 x 2227 A				
Number of Fused DC Inputs per Power Module/Total[2]	Up to 3+ & 3- / 6+ & 6-				
Max. DC short-circuit withstanding capability	2 x 250kA, 3ms Double DC bus configuration 1 x 250kA, 3ms Single DC bus configuration				
AC Output					
Number of Phases	Three-phase w/o neutral point				
Nominal AC Power Total @25°C [77°F], 1500VDC	4446 kVA	4639 kVA	4897 kVA	5219 kVA	5477 kVA
Nominal AC Power Total @40°C [104°F], 1500VDC	4183 kVA	4365 kVA	4607 kVA	4910 kVA	5153 kVA
Nominal AC Power Total @40°C [104°F], 1300VDC	4541 kVA	4739 kVA	5002 kVA	5331 kVA	5595 kVA
Nominal AC Voltage[2]	690 Vrms	720 Vrms	760 Vrms	810 Vrms	850 Vrms
Nominal Voltage Allowance Range[2]	+/-10%				
Frequency Range[2]	47.5-53 Hz // 57-63 Hz				
THD of AC Current	<1% @Sn				
Power Factor Range[3]	0 (lagging) - 1- 0 (leading)				
Performance					
Efficiency	99,00%				
Stand-by Power Consumption	< 200 W				
General Data					
Temperature Range - Operation	-20°C / +60°C [-4°F / +140°F]				
Maximum Altitude[4]	< 2,000 m [6,561 ft] (w/o derating)				
Cooling System	Liquid & forced air				
Relative Humidity	4% – 100% (w/o condensation)				
Seismic[2]	Zone 4 IBC 2012				
Max. wind speed[2]	288 km/h (179 mph)				
Snow load[2]	2,5 kN/m²				
Protection Class	IP55 class 1, NEMA3R				
Dimensions (W/H/D)	4,325 x 2,255 x 1,022 mm [170.3" x 88.5" x 40.2"]				
Weight	4,535 kg [10,000 lb]				
AC Protections					
AC Side Disconnection & Short-circuit Current Protection	Two motorized AC circuit breakers - one per each power module				
AC Overvoltage Protection	Type 1 + 2 SPD				
Anti-islanding	Included (SW)				
Grid Voltage Fluctuations (LVRT, HVRT)[2]	Included (SW)				
Frequency Failure	Included (SW)				
DC Protections					
DC Disconnections	Two motorized DC switches (on-load) - one per each power module				
DC Short-circuit Protection	DC fast fuses (optional)				
DC Over-voltage Protection	Type 1 + 2 SPD				
Reverse Polarity Detection	Included				
DC Ground Fault and Insulation Detection	Included				
Other Protections					
Over-temperature Protection	Included				
Emergency Push Button	Included				
Communications					
Control[2]	Modbus TCP/IP				
Monitoring[2]	Modbus TCP/IP				
Webserver	Included				

Optionals
Low Temperature Kit to up to -30°C [-22°F]
Factory-fitted DC fuses
Factory-fitted joint DC inputs
Enhanced corrosion protection

Standards/Directives[5]			
IEC 62109-1	IEC 62920	IEC 60529	NEC 2020
IEC 62109-2	UL 62109-1	IEC 61727	CEA 2007
IEC 61000-6-2/4	IEC 62116	NTS 631 v1.1 SENP, v2.1 SEPE	Rule 14, Rule 21
IEEE 1547	IEC 61683	UL 1741-SA	PRC 024
EN 55011	IEEE 519	CSA C22.2	

(1) At nominal AC voltage. Consult Gamesa Electric for other options

(2) Consult Gamesa Electric for a especific configuration

(3) Consult P-Q chart

(4) Up to 4,000m [13,123 ft] with derating as optional

(5) Consult Gamesa Electric for more details

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