Typical Military Base Electrical System
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Introduction

The following report provides a typical electrical system within a military base. A detailed description of a portion of the military base's electrical is described. There is 13.8 kV feeder with an overall demand of 10.7 MW and is connected to the main grid with a series of transformers. This report focused on two building on the feeder: a utility building, (building A), and the combined training facility (building B), Figure 1. The feeder also supplies other loads in the immediate vicinity of buildings under study. Each parameter of the system is found from tables available from the literature.

Each building is configured as a microgrid. During a disturbance building A & B can island and re-connected after the utility is restored. If the disturbance is long term the two buildings can operate as a single microgrid. This requires switches S1, S2 and S3 to be opened. This configuration allows the study of individual microgrids or the combined microgrid.

Figure 2 provides the details of Building A. This provides basic utility services to Building A. Power are provided through transformer, T3 that reduces the 13.8 kV to 480 volts. Inside the building are 100 kVA of loads outside of the microgrid. Within the microgrid there is a 400 hp chiller and 40 hp sweep pump, which are induction motors. The other loads are simple R/L loads. The active sources are three CERTS controlled devices; 2-300 kW generators and a 500 kW battery system. The additional PV and wind systems are constant power sources. The basic operational mode requires the two gen-set be off during grid connection operation. The storage is used for islanding and smoothing the intermittent from the PV and wind sources. During islanding the storage replaces the energy from the grid while the gen-sets come on line.

Figure 3 provides details of Building B. This is a training complex. It includes apartments, offices, training rooms and dinning facilities. Power is provided through transformer, T2 that reduces the 13.8 kV to 480 volts. Inside the building are 200 kVA of loads outside of the microgrid. Within the microgrid there the are both 3-phase 480 volt loads and 120 volt single phase loads. All loads are assume to be basic impedance loads. The active sources are four CERTS controlled devices; 3-300 kW generators and a 1000 kW battery system. The 500 kW PV is modeled as a constant power sources. The basic operational mode requires the three gen-set be off during grid connection operation. The storage is used for islanding and smoothing the intermittent from the PV source. During islanding the storage replaces the energy from the grid while the gen-sets come on line. It would also be useful to look at islanding with the generation operating.

MILATARY BASE MICRGOGRID PROJECT

Figure 1 shows the general overview of the electrical system, detailing the relative location and size of the main buildings: utility building, and training facility. It also provides the location of the transformers and main cables at different voltage levels. This illustrates one a many feeders from a 138 kV substation. The main transformer is rated at 40 MVA feeding 13.8 kV aerial feeder. This project focuses on two buildings each with microgrid features. In addition to the smart switches in both building there are three switches S1, S2 and S3 that enable combining buildings A and B into a single microgrid during long term loss of the utility.

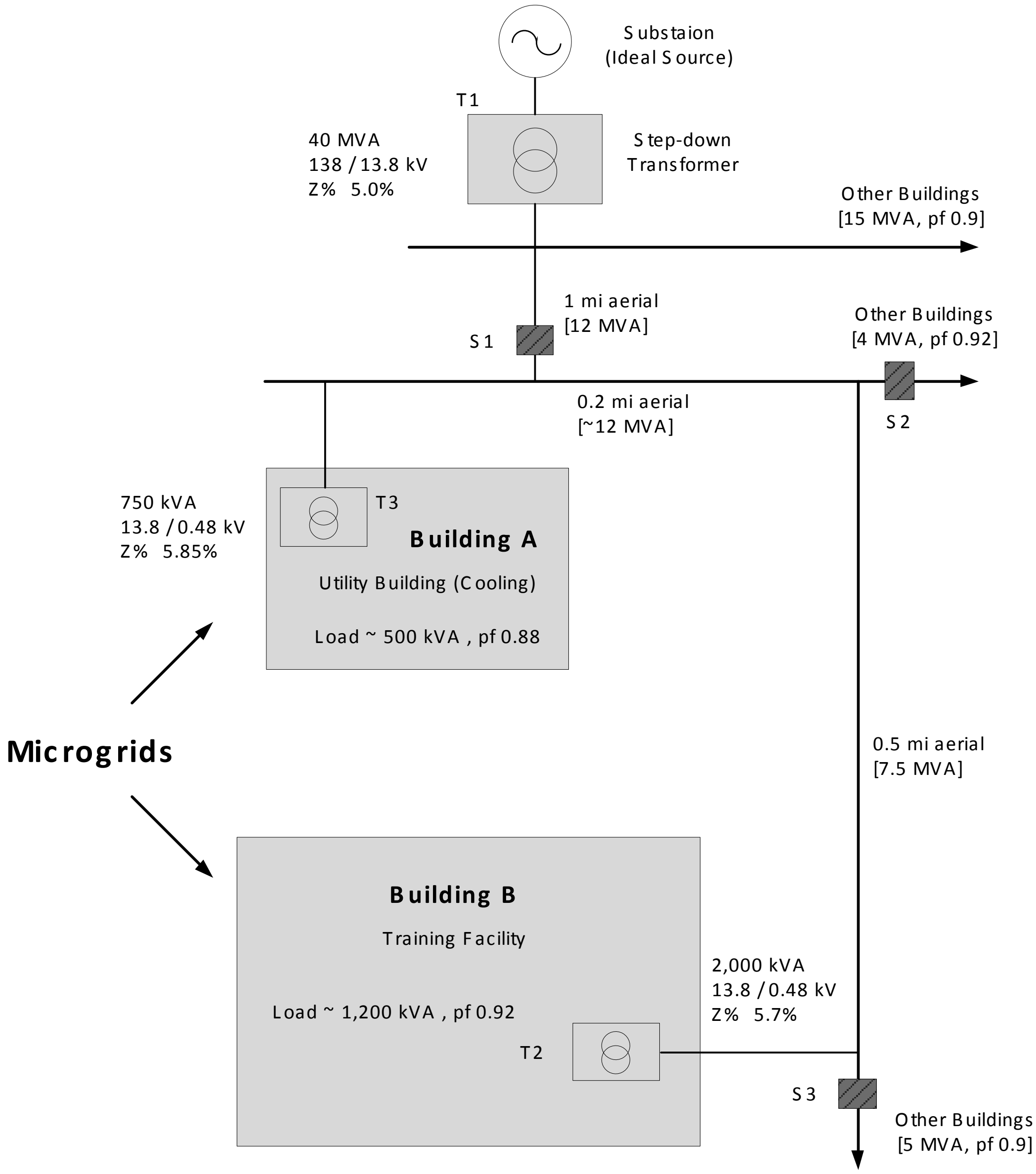

Figure 1. Site Plan

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Figure 2 shows the electrical diagram of the utility building (Building A) with details of load location and bus numerations. This building has a major chiller load, which provides cooling to building B. Building A is configured to islanding all but 100 kVA of load. It also has a 500 kW storage system to handle the load during islanding and two 300 kW NG generators to off load the storage during extended loss of the utility.

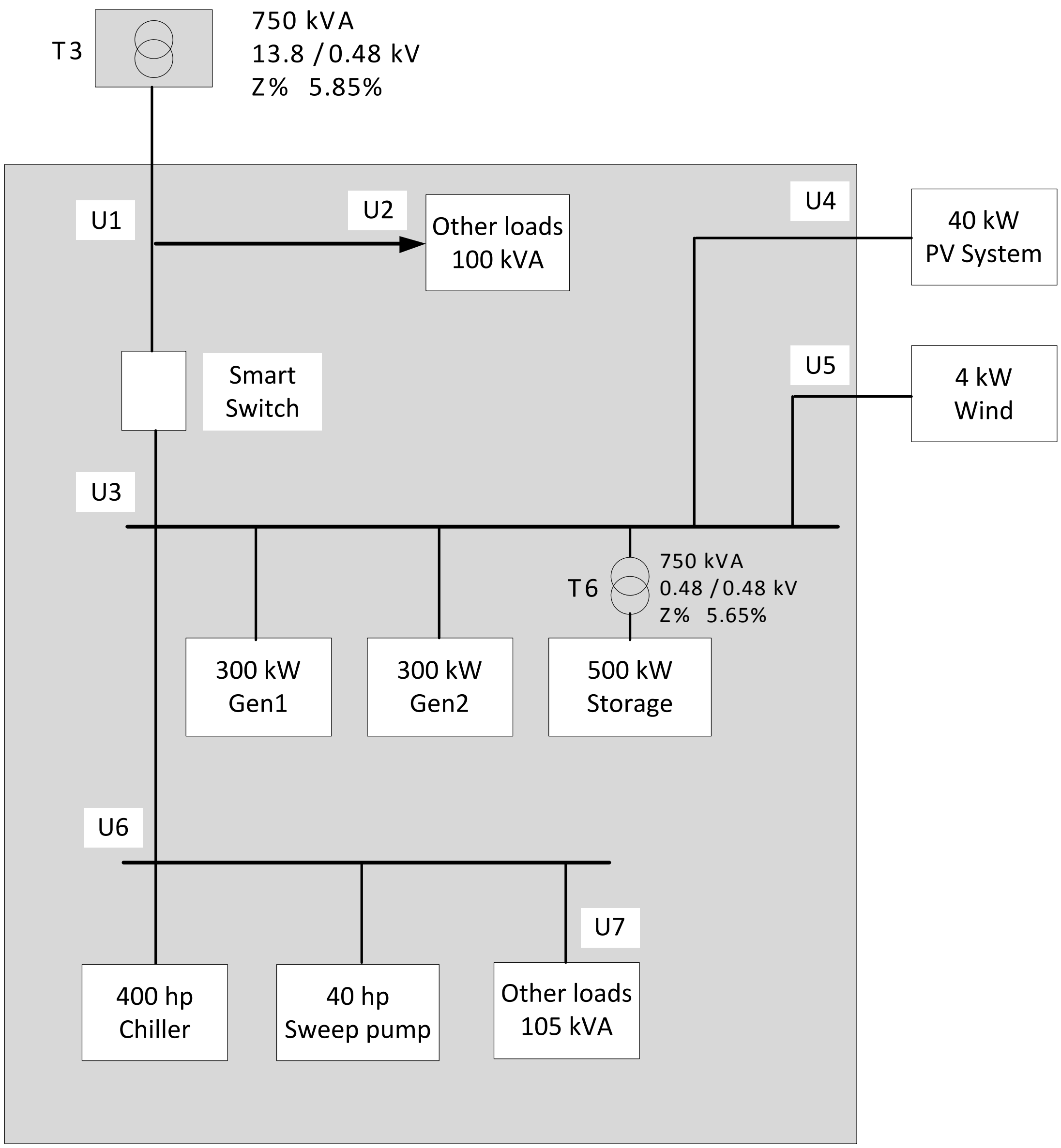


Figure 2. Building A (Utility Building) diagram

Figure 3 illustrates the electrical diagram of the training facilities, (Building B). Building B contains short-term living quarters, training rooms, kitchen and dining facilities, office space and building utilities equipment such as air handling equipment. Within the building there is a 3 phase 480 V feeder supplying 400 kW of loads. There is a 3-phase step down transformer to provide three single-phase 120 V service. The rated 120 V load is 800 kW. This building can also island. The storage is rated at 1,000 kW with three 300 kW ng generators to provide for extended loss of the utility.

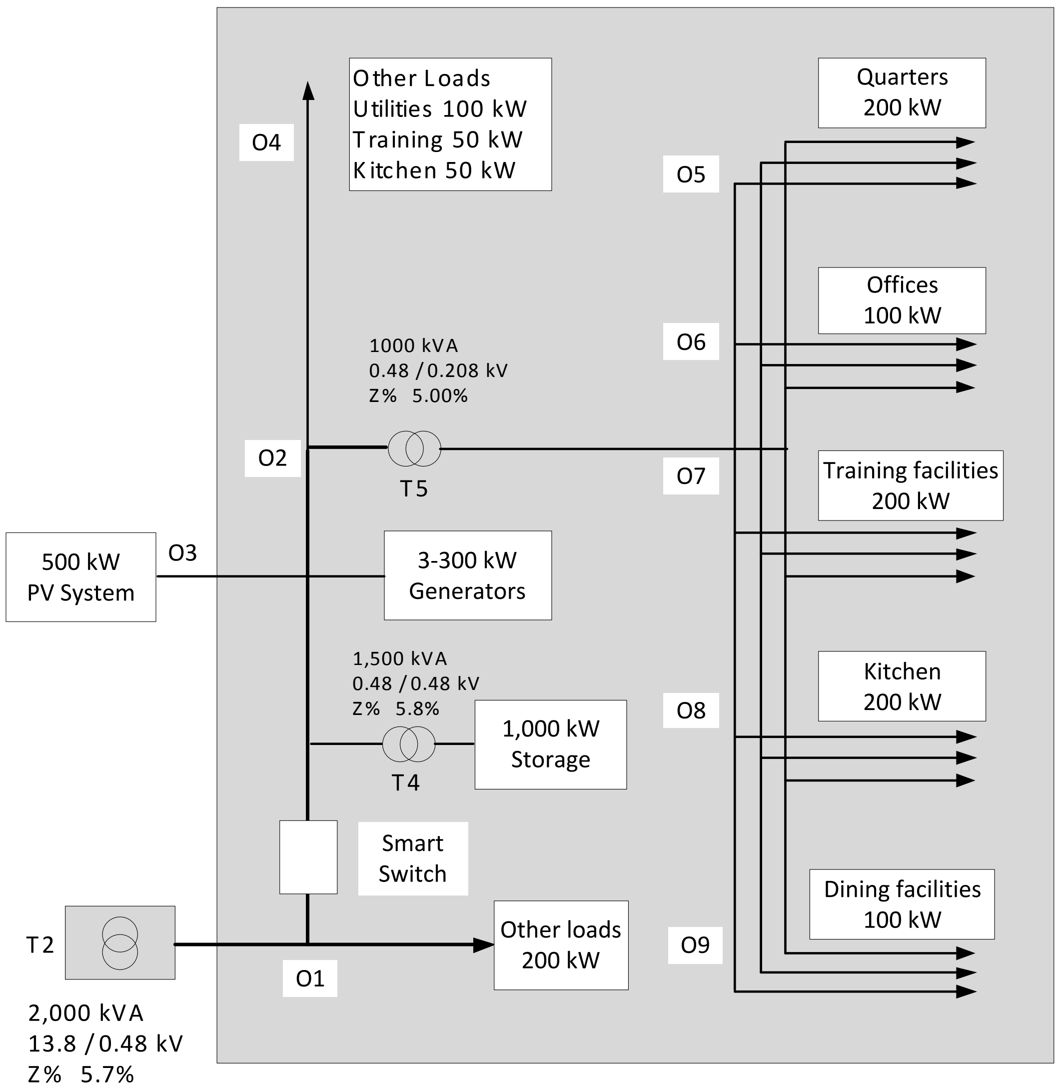


Figure 3. Building B (Training Facility) diagram

Power Flow Analysis

In order to study voltage profile at buses and power flows through buses, load flow analysis is carried out. All loads in the buildings are aggregated and considered as a load clusters. It assumed that all sources are disconnected except the storage. The energy storages is assumed to sink 25% of their ratings (charging mode). Table 1 and 2 show the load ratings for building A and B, respectively.

Table 1. Loading condition of building A

Load	Bus	P [kW]	Q [kVAr]
Other Loads	U2	80	60
Storage (25% charging)	U3	125	0
400 hp Chiller	U6	298.2	106.9
40 hp Sweep Pump	U6	29.8	12.1
Other Loads	U7	84	63
	TOTAL :	**617**	**242**

Table 2. Loading condition of building B

Load	Bus	P [kW]	Q [kVAr]
Other Loads	O1	200	97
Storage (25% charging)	O1	250	0
Other Loads	O4	200	106.8
Quarters	O5	200	65.7
Offices	O6	100	25
Training Facilities	O7	200	96.8
Kitchen	O8	200	107.9
Dining Facilities	O9	100	32.8
	TOTAL :	**1,450**	**532**

Figure 4 shows the results of load flow obtained for the site. This figure is labeled with the real and reactive power flow. At each key bus the voltage in kV and pu is given. On bus B1 the voltage has drooped due to the main transformer to a pu value of 0.9824. The pu voltage at Building B, due to 1.7 mile of aerial line is 0.9261. This represents a voltage droop less than 6% on the 12.8 kV feeder.

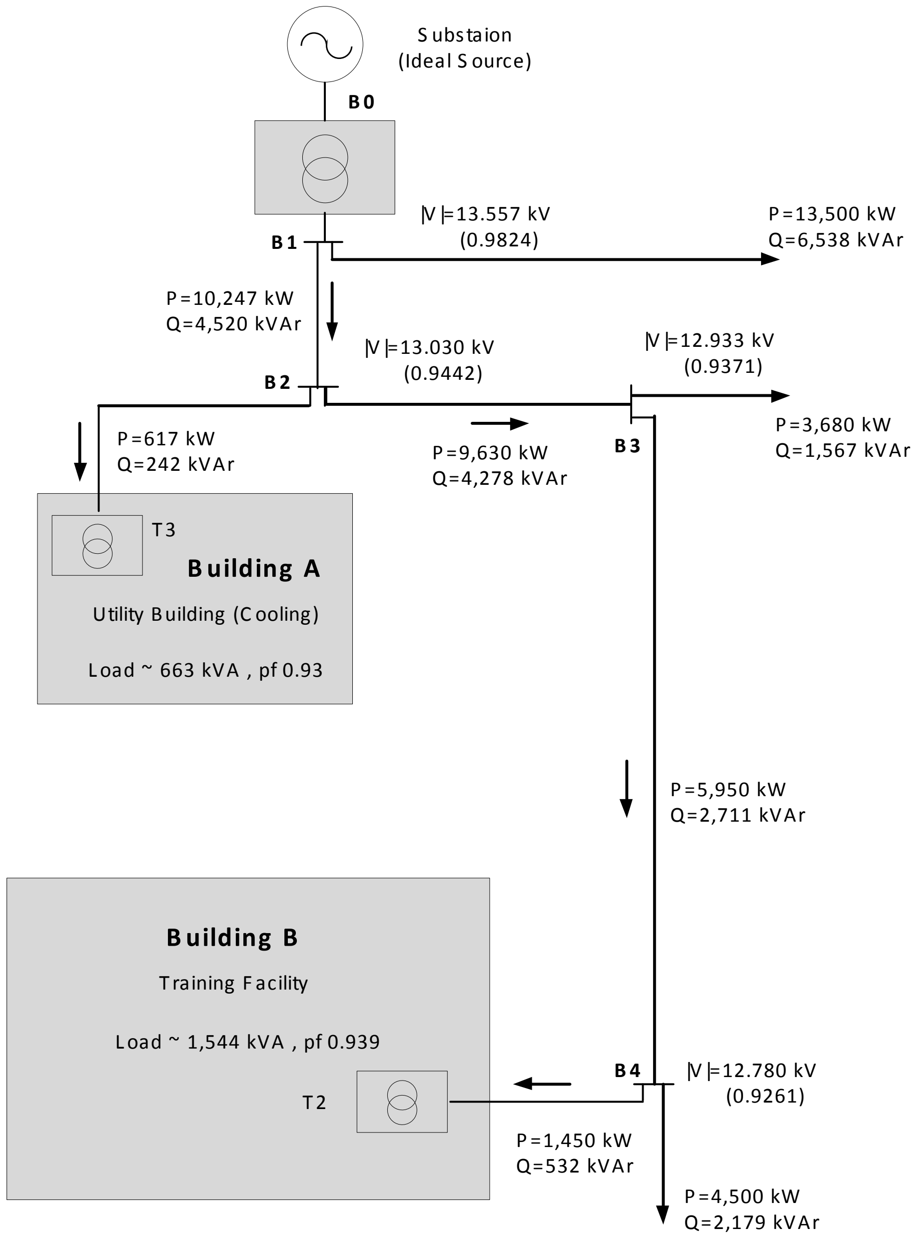


Figure 4. Load flow results for the 13.8 kV feeder

Details of Electrical System

Transformers

There are 6 transformers in total in this system, five of them within the site. The transformer data is summarized in Table 3, where all the voltages, ratings and connection types are listed.

Table 3. Transformer Summary

Transformer #	$V_{primary}$ [kV]	$V_{secondary}$ [kV]	Actual Load [kW]	Rating [kVA]	Connection
1	138	13.8	27,004	40,000	Delta-Delta
2	13.8	0.48	1,104	1,500	Delta-Wye-n
3	13.8	0.48	440	750	Delta-Wye-n
4	0.48	0.48	1,000	1,500	Delta-Wye-n
5	0.48	0.208	800	1,000	Wye-n -Wye-n
6	0.48	0.48	500	750	Delta-Wye-n

Each transformer will be described and the electrical parameters evaluated.

Transformer T1

The primary side busbar is at 138 kV, and the secondary busbar is at 13.8 kV. The secondary busbar is connected to the distribution aerial line of 13.8 kV. This transformer has to carry the full load of the plant, which is of about 27 MW. The size of this transformer is chosen to be 40 MW for standardization. This transformer is delta-wye with neutral solidly grounded on the secondary, and has a variable tap changer. From voltage levels and ratings, this transformer typically will have a percent impedance of 5% and a ratio X/R= 11. With this data in hand it is possible to obtain the transformer data as:

$$X = \frac{V^2 Z\%}{S} = \frac{(138.10^3)^2 0.05}{40.10^6} = 23.805\ \Omega$$

$$R = \frac{X}{11} = 2.164\ \Omega$$

Transformer T2

The primary side at 13.8 kV is connected to a busbar with the underground cable coming from the distribution system. The secondary side, at 480 V, feeds office building which includes barracks, offices, and training rooms. The combined load is 1,200 kW, but redundancy requirements with transformer T2 ask for a much higher capability, such as charging of 1,000 kW storage device. This translates in a 2 MVA rating for transformer T1. This transformer is delta-wye connected and has a solidly grounded neutral at the secondary. The percent impedance of this transformer is 5.7% and X/R=6. The reactance and resistance of the transformer are:

$$X = \frac{(13800)^2 0.0575}{2.10^6} = 5.475\ \Omega$$

$$R = \frac{X}{6} = 0.9125\ \Omega$$

Transformer T3

This transformer is located in the utility building and is needed to feed loads which are cooling characteristic dominantly. The primary side at 13.8 kV is connected to the distribution aerial line. The secondary side is at 480 V. Although the current load is of 492 kW, the rating for this transformer is 750 kVA. The percent impedance of this transformer is 5.85% and the ratio X/R=4.7, which yield:

$$X = \frac{(13800)^2 0.0585}{0.75.10^6} = 14.85\ \Omega$$
$$R = \frac{X}{4.7} = 3.16\ \Omega$$

Transformer T4

This transformer is a connection transformer of energy storage in the office building. The voltage levels of primary and secondary side are 480 V. Storage device is 1,000 kW and the rating for this transformer is chosen as 1,500 kVA. The percent impedance of this transformer is 5.8% and the ratio X/R=6.5, which yield:

$$X = \frac{(480)^2 0.058}{1,5.10^6} = 0.0089\Omega$$
$$R = \frac{X}{5.8} = 0.0014\ \Omega$$

Transformer T5

This transformer is located in the office building and feeds the loads which are mostly single phase. The primary side is at 480 V and the secondary side is at 208 V. The total load is of 800 kW and the rating for this transformer is 1000 kVA. The percent impedance of this transformer is 5% and the ratio X/R=5.1, which yield:

$$X = \frac{(480)^2 0.05}{1.10^6} = 0.0115\Omega$$
$$R = \frac{X}{5.1} = 0.0023\ \Omega$$

Transformer T6

This transformer is another connection transformer used in energy storage located in the utility building. The voltage levels of primary and secondary side are 480 V. Storage device is 500 kW and the rating for this transformer is chosen as 750 kVA. The percent impedance of this transformer is 5.65% and the ratio X/R=4.5, which yield:

$$X = \frac{(480)^2 0.0565}{0.75.10^6} = 0.0174\Omega$$
$$R = \frac{X}{4.5} = 0.0039\ \Omega$$

Lines and Cables

Table 4 shows the current capability for cables in raceways or direct burial and is from [1] on page 196.

Table 4. Current Capability – Raceway and Buried

Size AWG or MCM	Rubber Type R, Type RW / Type RU, Type RUW (14-2) / Type RH-RW / Thermoplastic Type T, Type TW	Rubber Type RH / Type RUH (14-2) / Type RH-RW / Type RHW	Paper / Thermoplastic Asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB / MI Cable / Type RHH**	Asbestos Var-Cam Type AVA, Type AVL	Impregnated Asbestos Type AI (14-8), Type AIA	Asbestos Type A (14-8), Type AA
AMPERES* PER CONDUCTOR						
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
1/0	125	150	155	190	200	225
2/0	145	175	185	215	230	250
3/0	165	200	210	245	265	285
4/0	195	230	235	275	310	340
250	215	255	270	315	335	...
300	240	285	300	345	380	...
350	260	310	325	390	420	...
400	280	335	360	420	450	...
500	320	380	405	470	500	...
600	355	420	455	525	545	...
700	385	460	490	560	600	...
750	400	475	500	580	620	...
800	410	490	515	600	640	...
900	435	520	555	...	...	...
1000	455	545	585	680	730	...
1250	495	590	645	...	...	...
1500	520	625	700	785	...	...
1750	545	650	735	...	...	...
2000	560	665	775	840	...	...
CORRECTION FACTORS FOR ROOM TEMPERATURES OVER 30 C (86 F)						
C F						
40 104	.82	.88	.90	.94	.95	...
45 113	.71	.82	.85	.90	.92	...
50 122	.58	.75	.80	.87	.89	...
55 131	.41	.67	.74	.83	.88	...
60 140	...	.58	.67	.79	.83	.91
70 158	...	.35	.52	.71	.76	.87

Table 5 is used to find the electrical parameters of the cables when the size is known: we are interested only in the first row of data, the one relative to cables below 1KV. Table 5 appears in [2] on page 674.

Table 5. 60 Hz characteristics of three-conductor belted paper-insulated cables

Voltage Class	Insulation Thickness Mils: Conductor	Insulation Thickness Mils: Belt	Circular Mils or AWG (B & S)	Type of (8) Conductor	Weight per 1000 Feet	Diameter or Sector Depth (8) inches	Resistance, Ohms Per Mile (1)	GMR of One Conductor—inches (1)	Positive & Negative Seq: Series Reactance Ohms per Mile	Positive & Negative Seq: Shunt Capacitive Reactance Ohms per Mile (1)	GMR Three Conductors	Zero—Sequence: Series Resistance Ohms per Mile (4)	Zero—Sequence: Series Reactance Ohms per Mile (4)	Zero—Sequence: Shunt Capacitive Reactance Ohms per Mile (4)	Sheath: Thickness Mils	Sheath: Resistance, Ohms per Mile at 50°C.
1 Kv	60	35	6	SR	1 500	0.184	2.50	0.067	0.185	6300	0.184	10.66	0.315	11 900	85	2.69
	60	35	4	SR	1 910	0.232	1.58	0.084	0.175	5400	0.218	8.39	0.293	10 200	90	2.27
	60	35	2	SR	2 390	0.292	0.987	0.106	0.165	4700	0.262	6.99	0.273	9 000	90	2.00
	60	35	1	SR	2 820	0.332	0.786	0.126	0.155	4300	0.295	6.07	0.256	8 400	95	1.78
	60	35	0	SR	3 210	0.373	0.622	0.142	0.152	4000	0.326	5.54	0.246	7 900	95	1.64
	60	35	00	CS	3 160	0.323	0.495	0.151	0.138	2800	0.290	5.96	0.250	5 400	95	1.82
	60	35	000	CS	3 650	0.364	0.392	0.171	0.134	2300	0.320	5.46	0.241	4 500	95	1.69
	60	35	0000	CS	4 390	0.417	0.310	0.191	0.131	2000	0.355	4.72	0.237	4 000	100	1.47
	60	35	250 000	CS	4 900	0.455	0.263	0.210	0.129	1800	0.387	4.46	0.224	3 600	100	1.40
	60	35	300 000	CS	5 660	0.497	0.220	0.230	0.128	1700	0.415	3.97	0.221	3 400	105	1.25
	60	35	350 000	CS	6 310	0.539	0.190	0.249	0.126	1500	0.446	3.73	0.216	3 100	105	1.18
	60	35	400 000	CS	7 080	0.572	0.166	0.265	0.124	1500	0.467	3.41	0.214	2 900	110	1.08
	60	35	500 000	CS	8 310	0.642	0.134	0.297	0.123	1300	0.517	3.11	0.208	2 600	110	0.993
	65	40	600 000	CS	9 800	0.700	0.113	0.327	0.122	1200	0.567	2.74	0.197	2 400	115	0.877
	65	40	750 000	CS	11 800	0.780	0.091	0.366	0.121	1100	0.623	2.40	0.194	2 100	120	0.771
3 Kv	70	40	6	SR	1 680	0.184	2.50	0.067	0.192	6700	0.192	9.67	0.322	12 500	90	2.39
	70	40	4	SR	2 030	0.232	1.58	0.084	0.181	5800	0.227	8.06	0.298	11 200	90	2.16
	70	40	2	SR	2 600	0.292	0.987	0.106	0.171	5100	0.271	6.39	0.278	9 800	95	1.80
	70	40	1	SR	2 930	0.332	0.786	0.126	0.161	4700	0.304	5.83	0.263	9 200	95	1.66
	70	40	0	SR	3 440	0.373	0.622	0.142	0.156	4400	0.335	5.06	0.256	8 600	100	1.48
	70	40	00	CS	3 300	0.323	0.495	0.151	0.142	3500	0.297	5.69	0.259	6 700	95	1.73
	70	40	000	CS	3 890	0.364	0.392	0.171	0.138	2700	0.329	5.28	0.246	5 100	95	1.63
	70	40	0000	CS	4 530	0.417	0.310	0.191	0.135	2400	0.367	4.57	0.237	4 600	100	1.42
	70	40	250 000	CS	5 160	0.455	0.263	0.210	0.132	2100	0.396	4.07	0.231	4 200	105	1.27
	70	40	300 000	CS	5 810	0.497	0.220	0.230	0.130	1900	0.424	3.82	0.228	3 800	105	1.20
	70	40	350 000	CS	6 470	0.539	0.190	0.249	0.129	1800	0.455	3.61	0.219	3 700	105	1.14
	70	40	400 000	CS	7 240	0.572	0.166	0.265	0.128	1700	0.478	3.32	0.218	3 400	110	1.05
	70	40	500 000	CS	8 660	0.642	0.134	0.297	0.126	1500	0.527	2.89	0.214	3 000	115	0.918
	75	40	600 000	CS	9 910	0.700	0.113	0.327	0.125	1400	0.577	2.68	0.210	2 800	115	0.855
	75	40	750 000	CS	11 920	0.780	0.091	0.366	0.123	1300	0.633	2.37	0.204	2 500	120	0.758
5 Kv	105	55	6	SR	2 150	0.184	2.50	0.067	0.215	8500	0.218	8.14	0.342	15 000	95	1.88
	100	55	4	SR	2 470	0.232	1.58	0.084	0.199	7600	0.250	6.86	0.317	13 600	95	1.76
	95	50	2	SR	2 900	0.292	0.987	0.106	0.184	6100	0.291	5.88	0.290	11 300	95	1.63
	90	45	1	SR	3 280	0.332	0.786	0.126	0.171	5400	0.321	5.23	0.270	10 200	100	1.48
	90	45	0	SR	3 660	0.373	0.622	0.142	0.165	5000	0.352	4.79	0.259	9 600	100	1.39
	85	45	00	CS	3 480	0.323	0.495	0.151	0.148	3800	0.312	5.42	0.263	9 300	95	1.64
	85	45	000	CS	4 080	0.364	0.392	0.171	0.143	3200	0.343	4.74	0.254	8 700	100	1.45
	85	45	0000	CS	4 720	0.417	0.310	0.191	0.141	2800	0.380	4.33	0.245	8 300	100	1.34
	85	45	250 000	CS	5 370	0.455	0.263	0.210	0.138	2600	0.410	3.89	0.237	7 800	105	1.21
	85	45	300 000	CS	6 050	0.497	0.220	0.230	0.135	2400	0.438	3.67	0.231	7 400	105	1.15
	85	45	350 000	CS	6 830	0.539	0.190	0.249	0.133	2200	0.470	3.31	0.225	7 000	110	1.04
	85	45	400 000	CS	7 480	0.572	0.166	0.265	0.131	2000	0.493	3.17	0.221	6 700	110	1.00
	85	45	500 000	CS	8 890	0.642	0.134	0.297	0.129	1800	0.542	2.79	0.216	6 200	115	0.885
	85	45	600 000	CS	10 300	0.700	0.113	0.327	0.128	1600	0.587	2.51	0.210	5 800	120	0.798
	85	45	750 000	CS	12 340	0.780	0.091	0.366	0.125	1500	0.643	2.21	0.206	5 400	125	0.707
8 Kv	130	65	6	SR	2 450	0.184	2.50	0.067	0.230	9600	0.236	7.57	0.353	16 300	95	1.69
	125	65	4	SR	2 900	0.232	1.58	0.084	0.212	8300	0.269	6.08	0.329	14 500	100	1.50
	115	60	2	SR	3 260	0.292	0.987	0.106	0.193	6800	0.307	5.25	0.302	12 500	100	1.42
	110	55	1	SR	3 560	0.332	0.786	0.126	0.179	6100	0.338	4.90	0.280	11 400	100	1.37
	110	55	0	SR	4 090	0.373	0.622	0.142	0.174	5700	0.368	4.31	0.272	10 700	105	1.23
	105	55	00	CS	3 870	0.323	0.495	0.151	0.158	4300	0.330	4.79	0.273	8 300	100	1.43
	105	55	000	CS	4 390	0.364	0.392	0.171	0.151	3800	0.362	4.41	0.263	7 400	100	1.34
	105	55	0000	CS	5 150	0.417	0.310	0.191	0.147	3500	0.399	3.88	0.254	6 600	105	1.19
	105	55	250 000	CS	5 830	0.455	0.263	0.210	0.144	3200	0.428	3.50	0.246	6 200	110	1.08
	105	55	300 000	CS	6 500	0.497	0.220	0.230	0.141	2900	0.458	3.31	0.239	5 600	110	1.03
	105	55	350 000	CS	7 160	0.539	0.190	0.249	0.139	2700	0.489	3.12	0.233	5 200	110	0.978
	105	55	400 000	CS	7 980	0.572	0.166	0.265	0.137	2500	0.513	2.86	0.230	4 900	115	0.899
	105	55	500 000	CS	9 430	0.642	0.134	0.297	0.135	2200	0.563	2.53	0.224	4 300	120	0.800
	105	55	600 000	CS	10 680	0.700	0.113	0.327	0.132	2000	0.606	2.39	0.218	3 900	120	0.758
	105	55	750 000	CS	12 740	0.780	0.091	0.366	0.129	1800	0.683	2.11	0.211	3 500	125	0.673
15 Kv	170	85	2	SR	4 350	0.292	0.987	0.106	0.217	8600	0.349	4.20	0.323	15 000	110	1.07
	165	80	1	SR	4 640	0.332	0.786	0.126	0.202	7800	0.381	3.88	0.305	13 800	110	1.03
	160	75	0	SR	4 990	0.373	0.622	0.142	0.193	7100	0.409	3.62	0.288	12 800	110	1.00
	155	75	00	SR	5 600	0.419	0.495	0.159	0.185	6500	0.439	3.25	0.280	12 000	115	0.918
	155	75	000	SR	6 230	0.470	0.392	0.178	0.180	6000	0.476	2.99	0.272	11 300	115	0.867
	155	75	0000	SR	7 180	0.528	0.310	0.200	0.174	5600	0.520	2.64	0.263	10 600	120	0.778
	155	75	250 000	SR	7 840	0.575	0.263	0.218	0.168	5300	0.555	2.50	0.256	10 200	120	0.744
	155	75	300 000	CS	7 480	0.497	0.220	0.230	0.155	5400	0.507	2.79	0.254	7 900	115	0.855
	155	75	350 000	CS	8 340	0.539	0.190	0.249	0.152	5100	0.536	2.54	0.250	7 200	120	0.784
	155	75	400 000	CS	9 030	0.572	0.166	0.265	0.149	4900	0.561	2.44	0.245	6 900	120	0.758
	155	75	500 000	CS	10 550	0.642	0.134	0.297	0.145	4600	0.611	2.26	0.239	6 200	125	0.680
	155	75	600 000	CS	12 030	0.700	0.113	0.327	0.142	4300	0.656	1.97	0.231	5 700	130	0.620
	155	75	750 000	CS	14 190	0.780	0.091	0.366	0.139	4000	0.712	1.77	0.226	5 100	135	0.558

Table 6. Cable Summary

Branch	Voltage [kV]	Actual Load [kW]	Worse pf	Actual [kVA]	Rating [kVA]	Loads Supplied	Current per phase [A]	Cable Type
T3>U1	0.48	495	0.88	562.5	650	All plant	782	3-MCM 300
U1>U2	0.48	80	0.80	100	100	OL	120	AWG 1
U3>U4	0.48	40	0.98	41	41	PV Sys	50	AWG 6
U3>U5	0.48	4	0.96	4.15	4.15	Wind Sys	5	AWG 6
U3>U6	0.48	412	0.91	450.5	500	IM, OL	602	3-MCM 4/0
U6>U7	0.48	84	0.80	105	105	OL	127	AWG 1
T2>O1	0.48	1,200	0.92	1305	1500	All plant	1,805	3-MCM 750
O2>O3	0.48	1,000	1.00	1,000	1,000	Storage	1,204	3-MCM 600
O2>O4	0.48	200	0.90	222	222	OL	267	AWG 300
O2>O5	0.208	200	0.95	210.5	225	Quarters	625	3-MCM 4/0
O2>O6	0.208	100	0.97	103	120	Offices	333	AWG 400
O2>O7	0.208	200	0.90	222	222	Trn. Fac.	616	3-MCM 4/0
O2>O8	0.208	200	0.88	227	227	Kitchen	631	3-MCM 4/0
O2>O9	0.208	100	0.95	105	105	Ding. Fac	291	AWG 350

Table 7: Cable Data

Branch	Cable Size	Length [ft]	R_S [Ω]	X_S [Ω]
T3>U1	3-MCM 300	10	0.00014	0.00008
U1>U2	AWG 1	50	0.0079	0.0016
U3>U4	AWG 6	500	0.2515	0.0186
U3>U5	AWG 6	500	0.0252	0.0019
U3>U6	3-MCM 4/0	80	0.0017	0.0007
U6>U7	AWG 1	50	0.0079	0.0016
T2>O1	3-MCM 750	15	0.00009	0.0006
O2>O3	3-MCM 600	50	0.00038	0.0004
O2>O4	AWG 300	140	0.0062	0.0036
O2>O5	3-MCM 4/0	120	0.0025	0.001
O2>O6	AWG 400	150	0.0050	0.0037
O2>O7	3-MCM 4/0	200	0.0041	0.0017
O2>O8	3-MCM 4/0	170	0.0035	0.0015
O2>O9	AWG 350	250	0.0096	0.0063

Branch at 13.8 kV

Aluminum Conductor Steel Reinforced (ACSR) type cables are used for the branches at the 138 kV.

Branch from Bus 1 to 2

This aerial line starts bus 1 and continues to bus 2 to the plant and other loads are connected. The total load this line feeds is about 11 MVA, so the line is designed to be able to carry 12 MVA. Each phase of the transmission line must be able to carry $20.000/(\sqrt{3}*13.8) = 502$ A. For this current, an ACSR 336.4 (Linnet) fits the need. We can obtain the following data;

Rs'= 0.306 Ω/mile Xs'= 0.7712 Ω /mile

The length of this branch is of 1 mi., therefore the data is:

Rs= 0.306*1= 0.306 Ω   Xs= 0.7712*1= 0.7712 Ω

Branch from Bus 2 to 3

This line is 0.2 mi. long, leaving from bus 2 and reaching the 4 MVA load connection. The total load this line almost the same as previous branch. Therefore the cable size and data is the same, too.
The length of this branch is of 0.2 mi., therefore the data is:

Rs= 0.306*0.2= 0.0612 Ω   Xs= 0.7712*0.2= 0.1542 Ω

Branch from Bus 3 to 4

This aerial line supplies the Building 2 of plant and 5 MVA load. The total load this line feeds is about 6.5 MVA, but the line is designed to be able to carry 7,5 MVA, considering load growth. Each phase of the transmission line must be able to carry $7500/(\sqrt{3}*13.8) = 313$ A. Therefore we can choose the same cable size; ACSR 336.4 (Linnet).

The length of this branch is of 0.5 mi., therefore the data is following:

Rs= 0.306*0.5= 0.1530 Ω   Xs= 0.7712*0.5= 0.3856 Ω

Branch at 0.48 kV

Branch from T3 to U1

This branch is connection between the transformer T3 and bus U1. This branch feeds all loads in the utility building containing about 495 kW load with 400 hp alone of induction motors. If the power factor is assumed as 0.88, then the apparent power requirement for this part of the network is: 495/0.88 = 650 kVA. The current requirement per phase for cable is: $650/(\sqrt{3}*0.48) = 782$ A. From Table 4, it is possible to see that we need three parallel connected wires of size MCM 300 choosing insulation RHW type. From Table 5, we obtain the following data:

Rs'= 0.220/3= 0.0733 Ω/mile   Xs'= 0.128/3= 0.0427 Ω /mile

The length of this branch is of 10 ft, therefore the data is:

Rs= 0.0733*10/4970= 0.00014 Ω   Xs= 0.0427*10/4970= 0.00008 Ω

Branch from U1 to U2

This branch feeds the some other 480V loads of the factory. This is a short cable that starts from the smart switch panel to panel which feeds the total 100 kVA load. The current requirement per phase for cable is: $100/(\sqrt{3}*0.48) = 120$ A. From Table 4, we see that a cable size AWG 1 fits our needs when insulation RHW is chosen. From Table 5, we obtain:

Rs'= 0.786 Ω/mile   Xs'=0.156 Ω /mile

The length of this branch is of 50 ft, therefore the data is:

Rs= 0.786*50/4970= 0.0079 Ω   Xs=0.156*50/4970= 0.0016 Ω

Branch from U3 to U4

This branch starts from bus U3 and reaches the cabin where 40 kW PV system is connected. Considering the pf 0.99, the apparent power is about 41 kVA.The current requirement per phase for cable is: 41/($\sqrt{3}$*0.48) = 50 A. From Table 4, we need cable size AWG 6. From Table 5, we obtain:

Rs'= 2.5 Ω/mile Xs'=0.185 Ω /mile

The length of this branch is of 500 ft, the data is:

Rs= 2.5*500/4970= 0.2515 Ω Xs=0.185*500/4970= 0.0186 Ω

Branch from U3 to U5

This branch connects the bus U3 to 4 kW wind microsource system. Assuming the apparent power 4.15 kVA, the current requirement per phase for cable is: 4.15/($\sqrt{3}$*0.48) = 5 A. From Table 4, we need cable size AWG 6. The length of this branch is of 500 ft, therefore the data is:

Rs= 2.5*500/4970= 0.0252 Ω Xs= 0.185 *500/4970= 0.0019 Ω

Branch from U3 to U6

This branch feeds the bus U6 which two induction motors and other loads are connected. The total load is 450 kVA, but considered as 500 kVA. The current requirement per phase for cable is: 500/($\sqrt{3}$*0.48) = 602 A. From Table 4, we see that three parallel connected cables which are size of MCM 4/0 fit our needs when insulation RHW is chosen. From Table 5, we obtain:

Rs'= 0.310/3= 0.103 Ω/mile Xs'= 0.130= 0.043 Ω /mile

The length of this branch is of 80 ft, the data is:

Rs= 0.103*80/4970= 0.0017 Ω Xs= 0.043*80/4970= 0.0007 Ω

Branch from U6 to U7

This branch feeds other 480V loads of the factory which is connected to bus U6. This short cable feeds the total 105 kVA load. The current requirement per phase for cable is: 105/($\sqrt{3}$*0.48) = 127 A. From Table 4, we need cable size AWG 1. The length of this branch is of 50 ft, therefore the data is:

Rs= 0.786*50/4970= 0.0079 Ω Xs=0.156*50/4970= 0.0016 Ω

Branch from T2 to O1

This branch is connection between the transformer T2 and O1 bus. This branch feeds all loads in the office building. If the power factor is assumed as 0.92, then the apparent power requirement for this part of the network is: 1200/0.92 = 1305 kVA. Cable is designed to carry 1500 kVA by considering future needs. The current requirement per phase for cable is: 1500/($\sqrt{3}$*0.48) = 1,805 A. From Table 4, it is possible to see that we need three parallel wires of size MCM 750 choosing insulation AIA type. From Table 5, we obtain the following data:

Rs'= 0.091/3= 0.0303 Ω/mile   Xs'= 0.623= 0.2077 Ω /mile

The length of this branch is of 15 ft, therefore the data is:

Rs= 0.0303*15/4970= 0.00009Ω   Xs= 0.2077*15/4970= 0.0006 Ω

Branch from O2 to O3

This branch connects bus O2 and 1000 kW storage device. The current requirement per phase for cable is: 1000/($\sqrt{3}$*0.48) =1204 A. From Table 4 we need three parallel cables sized MCM 600 choosing insulation RHW type From Table 5:

Rs'= 0.113/3= 0.0377 Ω/mile   Xs'= 0.122/3= 0.0407 Ω /mile

The length of this branch is of 50 ft, the data is:

Rs= 0.0377*50/4970= 0.00038Ω   Xs=0.0407*50/4970= 0.0004 Ω

Branch from O2 to O4

This branch is connection between bus O2 and other 200 kW loads including training and kitchen. If the power factor is assumed as 0.90, then the apparent power requirement for this part of the network is: 200/0.90 = 222 kVA. The current requirement per phase for cable is: 222/($\sqrt{3}$*0.48) = 267 A. From Table 4, it is possible to see that we need a wire of size AWG 300 choosing insulation AVL type. The length of this branch is of 140 ft, therefore the data is:

Rs= 0.0733*140/4970= 0.0021 Ω   Xs= 0.0427*140/4970= 0.0012 Ω

Branch at 0.208 kV

Branch from O2 to O5

This branch provides connection between transformer T4 and quarters loads which is 200 kW. Considering the pf 0.95, the apparent power is about 210.5 kVA. The cable is designed to carry 225 kVA for potential extension. The current requirement per phase for cable is: 225/($\sqrt{3}$*0.208) = 625 A. From Table 4, we need three cables sized of MCM 4/0 choosing insulation RHW type. The length of this branch is of 120 ft, therefore the data is:

Rs= 0.103*120/4970= 0.0025 Ω   Xs= 0.043*120/4970= 0.001 Ω

Branch from O2 to O6

This branch feeds the 100 kW office loads. Assuming pf to be 0.97, the apparent power is about 103 kVA. The cable is designed to carry 120 kVA for some adding in the future. The current requirement per phase for cable is: 120/($\sqrt{3}$*0.208) = 333 A. From Table 4, we need a cable size of AWG 400. From Table 5, we obtain the following data:

Rs'= 0.166 Ω/mile   Xs'= 0.124 Ω /mile

The length of this branch is of 150 ft, the data is:

Rs= 0.166 *150/4970 = 0.005 Ω   Xs=0.124 *150/4970 = 0.0037 Ω

Branch from O2 to O7
This branch starts from transformer T4 and feeds 200 kW facilities load. Considering the pf 0.90, the apparent power is about 222 kVA. The current requirement per phase for cable is: $222/(\sqrt{3}*0.208) = 616$ A. From Table 4, three cables sizes of MCM 4/0 fit our needs when insulation RHW is chosen. The length of this branch is of 200 ft, therefore the data is:

Rs= 0.103*200/4970= 0.0041 Ω   Xs= 0.043*200/4970= 0.0017 Ω

Branch from O2 to O8
This branch connects transformer T4 to 200 kW kitchen load. Assuming pf to be 0.88, the apparent power is about 227 kVA. The current requirement per phase for cable is: $227/(\sqrt{3}*0.208) = 631$ A. From Table 4, we need three cables which are sized of MCM 4/0. The length of this branch is of 170 ft, therefore the data is:

Rs= 0.103*170/4970= 0.0035 Ω   Xs= 0.043*170/4970= 0.0015 Ω

Branch from O2 to O9
This branch feeds the 100 kW dining facilities. Considering the pf 0.95, the apparent power is about 105 kVA. The current requirement per phase for cable is: $105/(\sqrt{3}*0.208) = 291$ A. From Table 4, we need a cable size of AWG 350. From Table 5, we obtain the following data:

Rs'= 0.190 Ω/mile   Xs'= 0.126 Ω /mile

The length of this branch is of 250 ft, the data is:

Rs= 0.190 *250/4970 = 0.0096 Ω   Xs=0.126 *250/4970 = 0.0063 Ω

Loads
The following section describes the loads in detail: each load is defined by where it is located, what ratings it has and by the connections with the distribution system. Every load has its own model and a brief explanation describes how to obtain the electrical parameters for all loads in the plant.

Induction Motors
There are 2 induction motors in the utility building. One is for chiller and the other is for sweep pump. These motors will be represented with a series equivalent impedance model. The data required to find the parameters of the induction motors are terminal voltage, active power and the pole pairs of the machine. In this case we assume that each machine has two poles. Our goal is to obtain the five parameters that fully define the single phase equivalent circuit of an induction machine as represented in Figure 5.

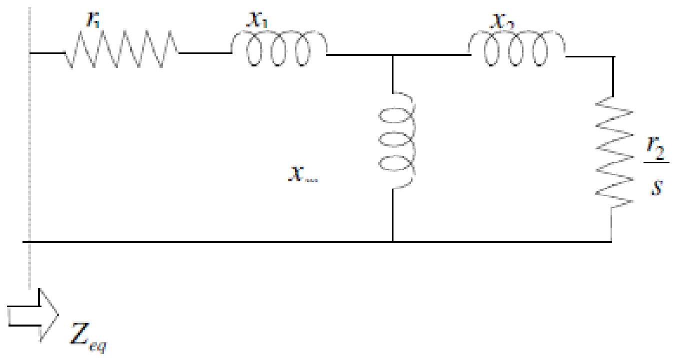


Figure 5. Single phase diagram of and induction machine

Resistances r_1 and r_2 are respectively the stator and rotor winding resistance, while s is the slip at which the machine is operating. Reactances x_1 and x_2 represent the leakage part of the flux in the machine, respectively on the stator and on the rotor windings. Reactance x_m represents the magnetizing inductance, responsible for creating the main magnetic field of the machine.

When expressed in per unit of the machine, due to design constraints, the leakage inductance is always about 0.2 in per unit, traditionally split in equal amounts on the rotor and stator circuits. Therefore:
x_1=0.1 pu
x_2=0.1 pu

To obtain the values for the resistance terms, it is necessary to calculate the pole pitch term. We have two induction motors rated 400 hp and 40 hp. Remembering that P=2, then the pole pitch results from:

$$\tau_P = 0.095\left(\frac{hp}{\frac{P}{2}}\right)^{\frac{6}{23}}$$

Now it is possible to calculate the resistive terms as:

$$r_1 = 0.0033(\tau_P)^{-1}$$
$$r_2 = 0.004(\tau_P)^{-1}$$

The numerical values for the resistances are expressed in pu of the machine ratings. Figure 6 shows the values of the resistances versus the machine size.

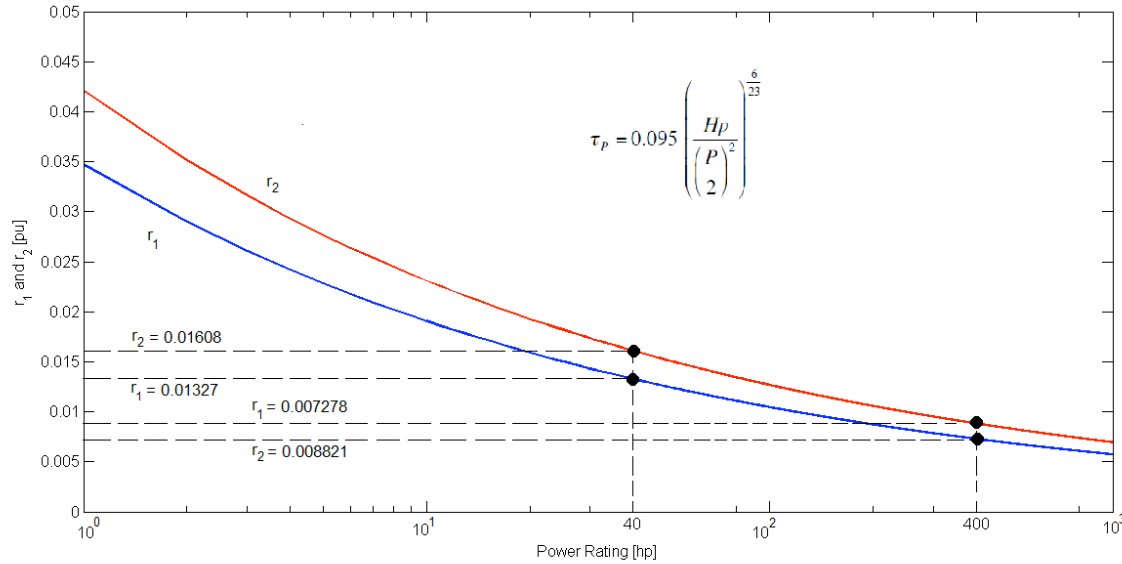


Figure 6. Per Unit Values of Resistance Versus Machine Size

Therefore we have following values:

For 40 hp machine;
$r_1 = 0.01327$ pu
$r_2 = 0.01608$ pu

For 400 hp machine;
$r_1 = 0.007278$ pu
$r_2 = 0.008821$ pu
The value for the magnetizing inductance can be found with a similar process, involving the pole pitch previously calculated:

Figure 7 shows the plot of magnetizing inductance versus the size of the machine, and it results that:
$x_m = 4.987$ pu (for 40 hp machine)
$x_m = 6.734$ pu (for 400 hp machine)

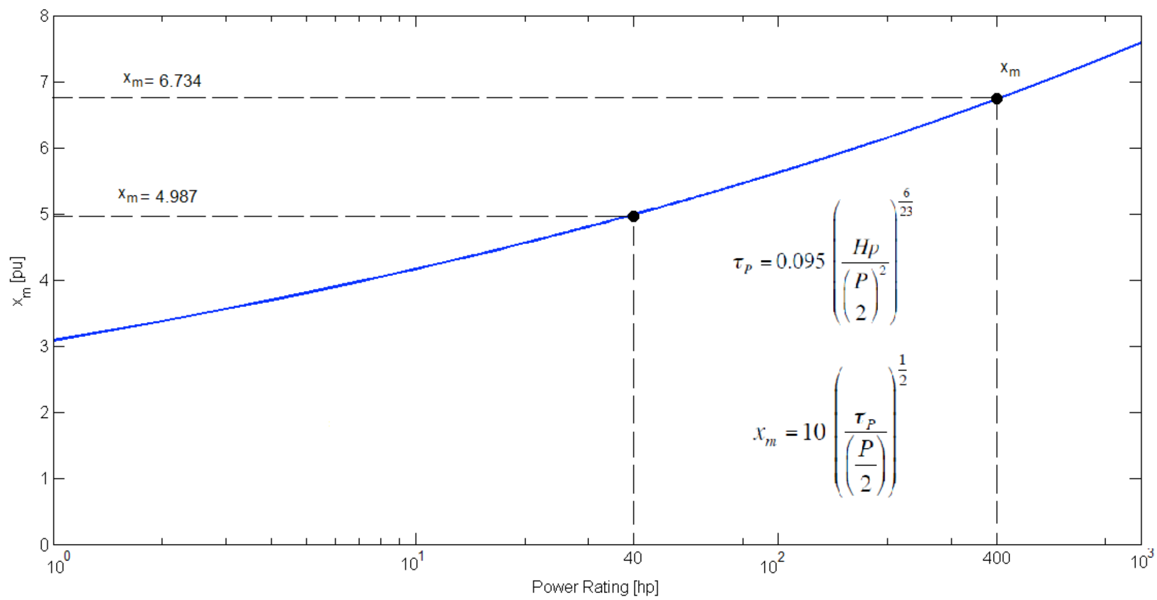


Figure 7. Per Unit Magnetizing Inductance Versus Machine Size

We need to convert these per unit values in actual units of Ohms, operation that we can do by defining the base of the machine as:

$$Z_B = \frac{{V_B}^2}{S_B}$$

V_B=480 V
S_B=40*0.7457=29.828 kW
S_B=400*0.7457=298.28 kW
Z_B = 7.720 Ω (for 40 hp machine)
Z_B = 0.772 Ω (for 400 hp machine)

Notice that the base power is taken to be the three phase active power rating of the machine, rather than the apparent power. This convention is used following the guidelines that brought to the formulas to calculate the values of the parameters in per unit. It is possible to find the values of the parameters in actual units as in Table 8.

Table 8. Induction machine parameters

40 hP machine	400 hP machine
x_1 = 0.7720 Ω	x_1 = 0.0772 Ω
x_2 = 0.7720 Ω	x_2 = 0.0772 Ω
r_1 = 0.1024 Ω	r_1 = 0.0056 Ω
r_2 =0.1241 Ω	r_2 = 0.0068 Ω
x_m = 38.5 Ω	x_m = 5.1986 Ω

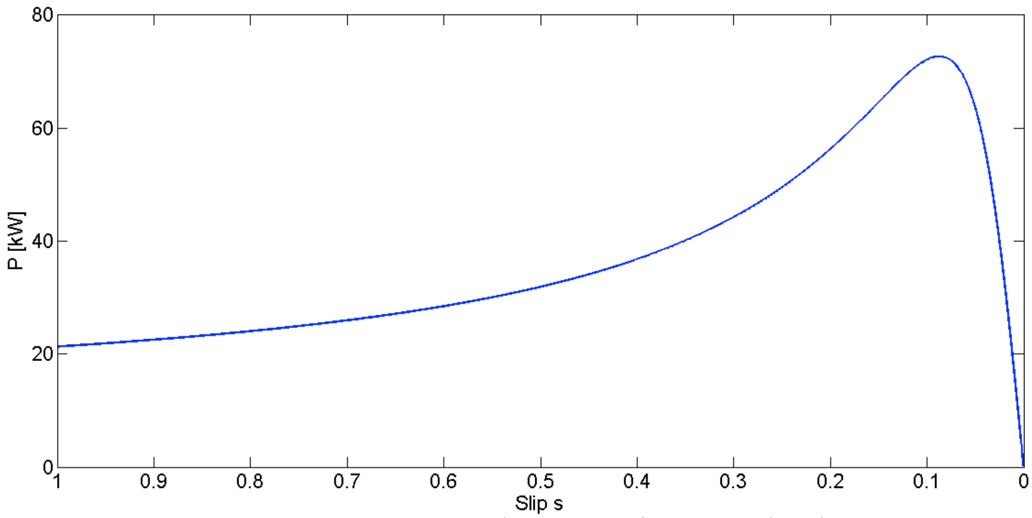
We now have five out of the six parameters that fully describe the induction machine as represented in Figure 5, we still miss the numerical value of the slip. This value depends on the operating point of the machine. The equivalent impedance of the circuit as seen from the terminals is given by:

$$Z_{eq} = r_1 + jx_1 + \frac{jx_m \frac{r_2}{s} - x_m x_2}{\frac{r_2}{s} + j(x_m + x_2)}$$

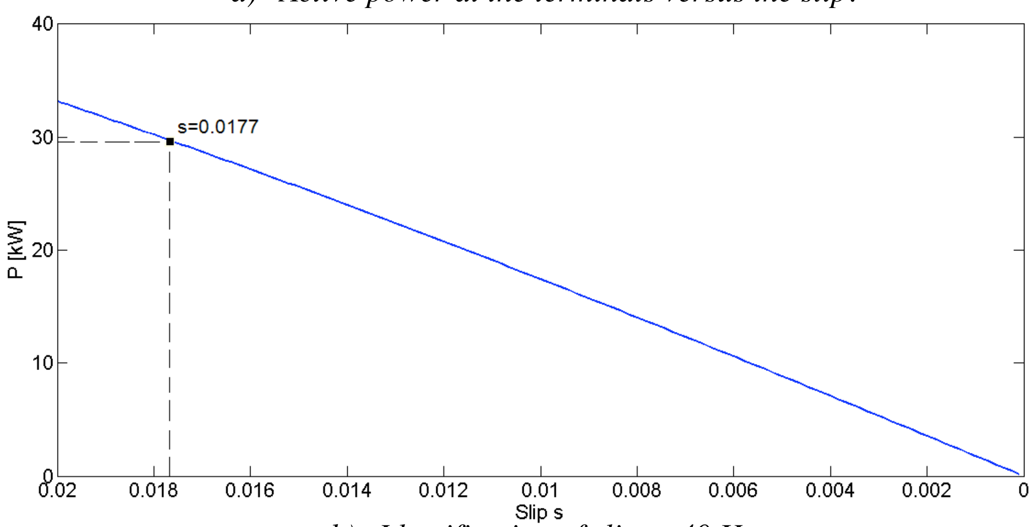
The power at the terminal is:

$$P = Re\left(\frac{V^2}{Z_{eq}}\right)$$

Figure 8a shows the plot of the active power as a function of the slip: there are two solutions for the slip when a power of 29.828 KW (40 Hp) is demanded at the terminals, but induction machine theory says that the only stable operating point is on the right side of the maximum reached by the characteristic. Figure 8b shows the magnification of this part of the curve, allowing for the identification of the value of the slip as the machine is outputting rated power.



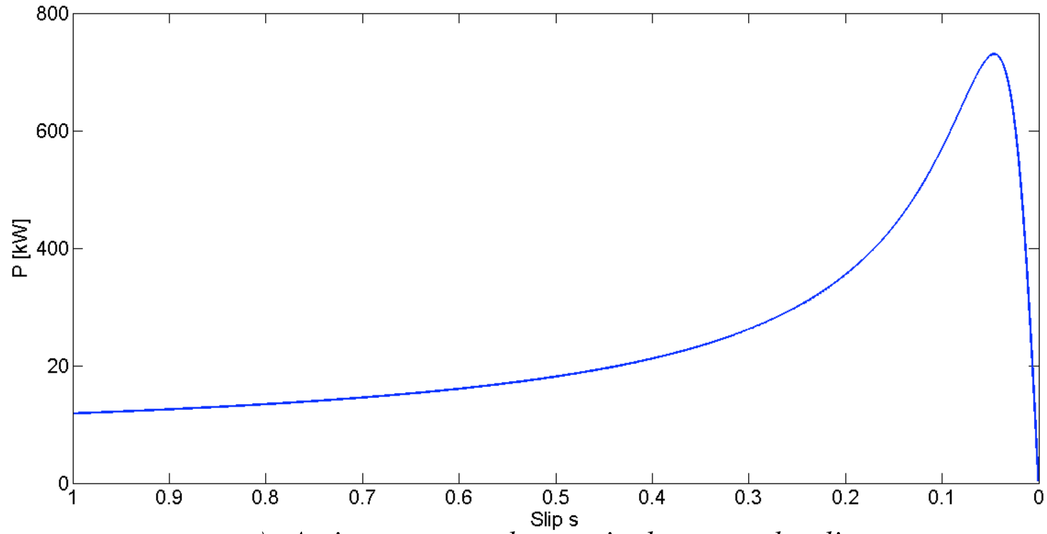
a) Active power at the terminals versus the slip.



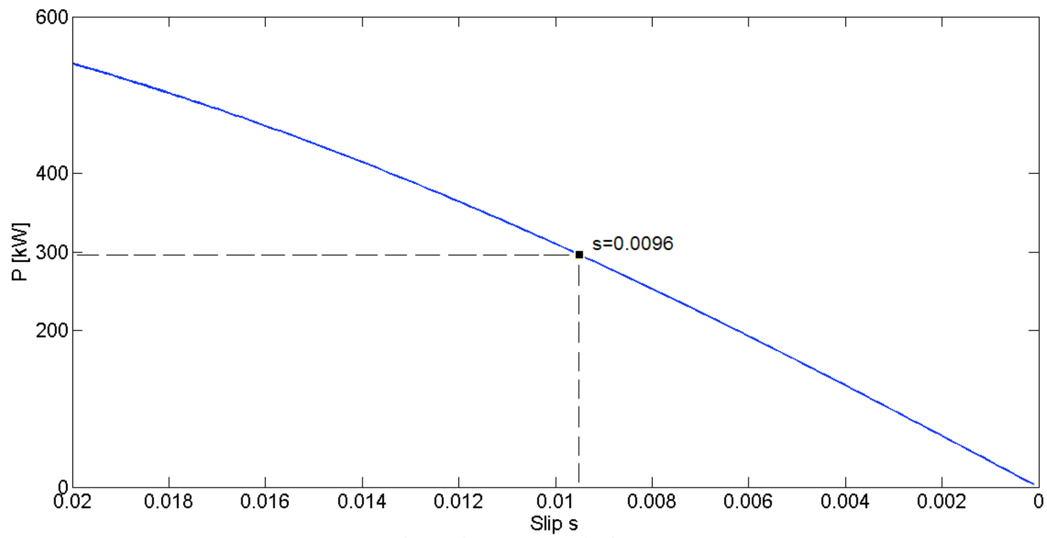
b) Identification of slip at 40 Hp

Figure 8. Variation of active power as a function of slip (40 Hp)

Figure 9 shows the active power as a function of slip for the 400 Hp machine.



a) Active power at the terminals versus the slip.



a) Identification of slip at 400 Hp

Figure 9. Variation of active power as a function of slip (400 Hp)

The values of the slip are: s = 0.0177 (40 Hp) and s = 0.0096 (400 Hp). Now we can convert the circuit of Figure 5 to the equivalent circuit represented in Figure 10.

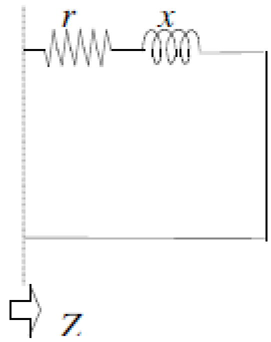


Figure 10. Equivalent circuit of the induction machine

In numerical terms it is possible to find the equivalent terms as:

$$r_{eq} = Re\{Z_{eq}\}$$
$$x_{eq} = Im\{Z_{eq}\}$$

For 40 hp machine;
r_{eq} = 6.6399 Ω
x_{eq} = 2.6975 Ω

For 400 hp machine;
r_{eq} = 0.6825 Ω
x_{eq} = 0.2444 Ω

The resulting power factor of the induction machine represented by these parameters is given by:

$$\cos(\varphi) = cos\left[tan^{-1}\left(\frac{x_{eq}}{r_{eq}}\right)\right]$$

$\cos(\varphi)$ = 0.9265 (for 40 hp machine)
$\cos(\varphi)$ = 0.9416 (for 400 hp machine)

Now it is possible to find reactive power;

$Q = P \tan(\varphi)$

Q = 12.118 kVAr (for 40 hp machine)
Q = 106.7956 kVAr (for 400 hp machine)

The machines are fed from a 480V busbar, therefore the parallel conductance and susceptance is:

$$G_{LN} = \frac{P}{V^2} \qquad B_{LN} = \frac{Q}{V^2}$$

G_{LN} = 0.1295 ohm^{-1} B_{LN} = 0.0526 ohm^{-1} (for 40 hp machine)
G_{LN} = 1.295 ohm^{-1} B_{LN} = 0.4635 ohm^{-1} (for 400 hp machine)

To better reflect the IM design, we represent it with a delta configuration rather than a wye connection as it is now. Indeed, a delta configuration guarantees that no ground path is given from this terminal, which is what happens with IM.

The equivalent conductance and susceptance when connected in delta is calculated dividing by 3:

$G_D = 0.0432$ ohm^{-1} $B_D = 0.0175$ ohm^{-1} (for 40 hp machine)
$G_D = 0.4315$ ohm^{-1} $B_D = 0.1545$ ohm^{-1} (for 400 hp machine)

The magnitude of the admittance is:

$$Y_D^2 = G_D^2 + B_D^2$$

Then, the parallel resistance and reactance connected at delta are:

$$R = \frac{G_D}{Y_D^2} \qquad X = \frac{B_D}{Y_D^2}$$

$R = 19.89\ \Omega$ $X = 8.0806\ \Omega$ (for 40 hp machine)
$R = 2.054\ \Omega$ $X = 0.7354\ \Omega$ (for 400 hp machine)

Other Loads

Besides the induction motors, there are several other loads in both utility and office buildings. These are considered as load clusters rated different power level.
To represent the load cluster with a series equivalent impedance, we only need to specify a representative power angle. The impedances for those loads are calculated as following by considering their power and power factors:

480 V loads

100 kVA load (bus U2 in utility building)

$$P = Scos(pf) = 100 * 0.8 = 80\ kW$$
$$Q = \sqrt{S^2 - P^2} = \sqrt{100^2 - 80^2} = 60\ kVAr$$
$$G = \frac{P}{V^2} = 0.3472\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 0.2604\ \text{ohm}^{-1}$$
$$Y^2 = G^2 + B^2 = 0.1884\ \text{ohm}^{-2}$$
$$R = \frac{G}{Y^2} = 1.8433\ \text{ohm} \qquad X = \frac{B}{Y^2} = 1.3822\ \text{ohm}$$

105 kVA load (bus U7 in utility building)

$$P = Scos(pf) = 105 * 0.8 = 84\ kW$$
$$Q = \sqrt{S^2 - P^2} = \sqrt{105^2 - 84^2} = 63\ kVAr$$
$$G = \frac{P}{V^2} = 0.3646\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 0.2734\ \text{ohm}^{-1}$$
$$Y^2 = G^2 + B^2 = 0.2077\ \text{ohm}^{-2}$$
$$R = \frac{G}{Y^2} = 1.7554\ \text{ohm} \qquad X = \frac{B}{Y^2} = 1.3163\ \text{ohm}$$

200 kW load (bus O1 in office building)

$$Q = Ptan\big(acos(pf)\big) = 200 * tan\big(acos(0.9)\big) = 97\ kVAr$$

$G = \frac{P}{V^2} = 0.8681 \text{ ohm}^{-1}$ $B = \frac{Q}{V^2} = 0.4204 \text{ ohm}^{-1}$

$Y^2 = G^2 + B^2 = 0.9303 \text{ ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.9331 \text{ ohm}$ $X = \frac{B}{Y^2} = 0.4519 \text{ ohm}$

100 kW load (bus O4 in office building, utilities)

$Q = Ptan\big(acos(pf)\big) = 100 * tan\big(acos(0.9)\big) = 48.5\ kVAr$

$G = \frac{P}{V^2} = 0.4340 \text{ ohm}^{-1}$ $B = \frac{Q}{V^2} = 0.2102 \text{ ohm}^{-1}$

$Y^2 = G^2 + B^2 = 0.2326 \text{ ohm}^{-2}$

$R = \frac{G}{Y^2} = 1.8662 \text{ ohm}$ $X = \frac{B}{Y^2} = 0.9039 \text{ ohm}$

50 kW load (bus O4 in office building, training)

$Q = Ptan\big(acos(pf)\big) = 50 * tan\big(acos(0.92)\big) = 21.3\ kVAr$

$G = \frac{P}{V^2} = 0.2170 \text{ ohm}^{-1}$ $B = \frac{Q}{V^2} = 0.0924 \text{ ohm}^{-1}$

$Y^2 = G^2 + B^2 = 0.0556 \text{ ohm}^{-2}$

$R = \frac{G}{Y^2} = 3.9002 \text{ ohm}$ $X = \frac{B}{Y^2} = 1.6615 \text{ ohm}$

50 kW load (bus O4 in office building, kitchen)

$Q = Ptan\big(acos(pf)\big) = 50 * tan\big(acos(0.88)\big) = 27\ kVAr$

$G = \frac{P}{V^2} = 0.2170 \text{ ohm}^{-1}$ $B = \frac{Q}{V^2} = 0.1171 \text{ ohm}^{-1}$

$Y^2 = G^2 + B^2 = 0.0608 \text{ ohm}^{-2}$

$R = \frac{G}{Y^2} = 3.5684 \text{ ohm}$ $X = \frac{B}{Y^2} = 1.9260\text{ohm}$

208 V loads

200 kW load (bus O5 in utility building)

$Q = Ptan\big(acos(pf)\big) = 200 * tan\big(acos(0.95)\big) = 65.7\ kVAr$

$G = \frac{P}{V^2} = 4.6228 \text{ ohm}^{-1}$ $B = \frac{Q}{V^2} = 1.5194 \text{ ohm}^{-1}$

$Y^2 = G^2 + B^2 = 23.6788 \text{ ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.1952 \text{ ohm}$ $X = \frac{B}{Y^2} = 0.0642 \text{ ohm}$

100 kW load (bus O6 in utility building)

$Q = Ptan\big(acos(pf)\big) = 100 * tan\big(acos(0.97)\big) = 25\ kVAr$

$G = \frac{P}{V^2} = 2.3114\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 0.5793\ \text{ohm}^{-1}$

$Y^2 = G^2 + B^2 = 5.6781\ \text{ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.4071\ \text{ohm} \qquad X = \frac{B}{Y^2} = 0.1020\ \text{ohm}$

200 kW load (bus O7 in utility building)

$Q = Ptan\left(acos(pf)\right) = 200 * tan\left(acos(0.90)\right) = 96.8\ kVAr$

$G = \frac{P}{V^2} = 4.6228\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 2.2389\ \text{ohm}^{-1}$

$Y^2 = G^2 + B^2 = 26.3828\ \text{ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.1752\ \text{ohm} \qquad X = \frac{B}{Y^2} = 0.0849\ \text{ohm}$

200 kW load (bus O8 in utility building)

$Q = Ptan\left(acos(pf)\right) = 200 * tan\left(acos(0.88)\right) = 107.9\ kVAr$

$G = \frac{P}{V^2} = 4.6228\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 2.4951\ \text{ohm}^{-1}$

$Y^2 = G^2 + B^2 = 27.5957\ \text{ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.1675\ \text{ohm} \qquad X = \frac{B}{Y^2} = 0.0904\ \text{ohm}$

100 kW load (bus O9 in utility building)

$Q = Ptan\left(acos(pf)\right) = 100 * tan\left(acos(0.95)\right) = 32.8\ kVAr$

$G = \frac{P}{V^2} = 2.3114\ \text{ohm}^{-1} \qquad B = \frac{Q}{V^2} = 0.7597\ \text{ohm}^{-1}$

$Y^2 = G^2 + B^2 = 5.9197\ \text{ohm}^{-2}$

$R = \frac{G}{Y^2} = 0.3905\ \text{ohm} \qquad X = \frac{B}{Y^2} = 0.1283\ \text{ohm}$

Power Sources

The following section describes the power sources installed in plant. These sources are synchronous generator, PV system, wind turbine and energy storage.

Synchronous Generators

There are two synchronous generators, rated 300 kW each, in the utility building. They were assumed diesel gensets with wound filed synchronous machine. Three 300 kW synchronous generators are located in office building. The part of engine was designed same as that in UW-Madison laboratory except power rating.

The parameters for the synchronous machines were obtained from Uljanik Tesu catalogue and are given in Table 9. We can use the following data for those generators from the data sheet of a generator manufacturer:

Table 9: Synchronous generator parameter

V_{base}	480 V
S_{base}	300 kVA
x_d	212.3 %
x_d'	32.9 %
x_d''	19.6 %
x_q	105.2 %
x_q''	14.7 %

x_2	17.2 %
T_{d0}'	313.4 ms
T_{d0}''	1.9 ms
T_a	26.0 ms
R_s	0.0084 Ω
J / H	6 kgm2 / 0.3553 s
p	2 (pairs of pole)

Photovoltaic (PV) System

There are two PV systems, one which is 40 kW is located in utility building and the other, 500 kW, is in office building. Since they operates unity power factor, they are designed as constant power sources which produces 40 kW and 500 kW active power and no reactive power. For simplicity they are modeled as voltage controlled current source as shown in Figure 11. Therefore they can produce same power at their outputs in every voltage level.

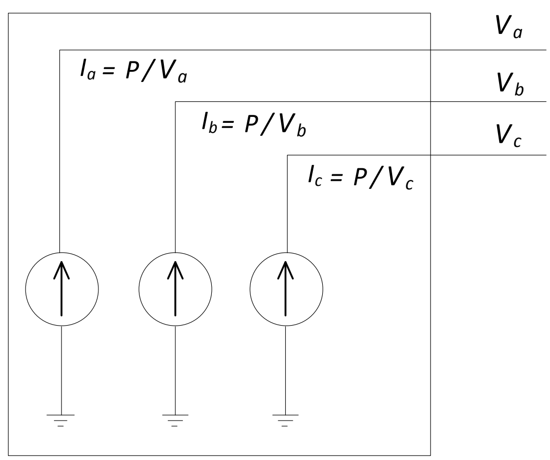


Figure 11. Constant power source model for PV systems

Wind System

Wind system in the utility building is same exactly as PV systems except power rating which is 4 kW.

Energy Storage

Energy storage system consists of battery storage units and inverter. This inverter based system is assumed that there is a battery on the DC bus coupled to the AC system through an inverter as shown in Figure 12. There are two storage system; 500 kw storage device is in utility building and 1000 kW one is in office building. Connection transformers are chosen to be 750 kVA and 1,500 kVA. Inductance L_{pv} with 0.15 mH and 0.08 mH are used between inverter and grid considering instability criteria.

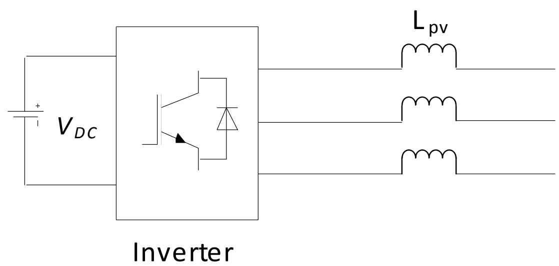


Figure 12. Interface inverter system

For 500 kW and 1000 kW energy storage systems, parameters are tabulated in Table 10 and 11, respectively.

Table 10: Inverter parameters for 500 kW energy storage

V_{DC}	750 V	V_{req}	1
S_{BASE}	500 kVA	K_{pp}	3
ω_{base}	376.9911 ($2\pi 60$)	K_{pi}	30
$\Delta\omega$	3.1416 ($2\pi 0.5$)	K_{vp}	0.01
P_{max}	500 kW	K_{vi}	5
P_{min}	-500 kW	m_Q	0.05
P_{req}	450 kW	m_P	1.5708

Table 11: Inverter parameters for 1000 kW energy storage

V_{DC}	750 V	V_{req}	1
S_{BASE}	1000 kVA	K_{pp}	3
ω_{base}	376.9911 ($2\pi 60$)	K_{pi}	30
$\Delta\omega$	3.1416 ($2\pi 0.5$)	K_{vp}	0.01
P_{max}	1000 kW	K_{vi}	5
P_{min}	-1000 kW	m_Q	0.05
P_{req}	950 kW	m_P	1.5708