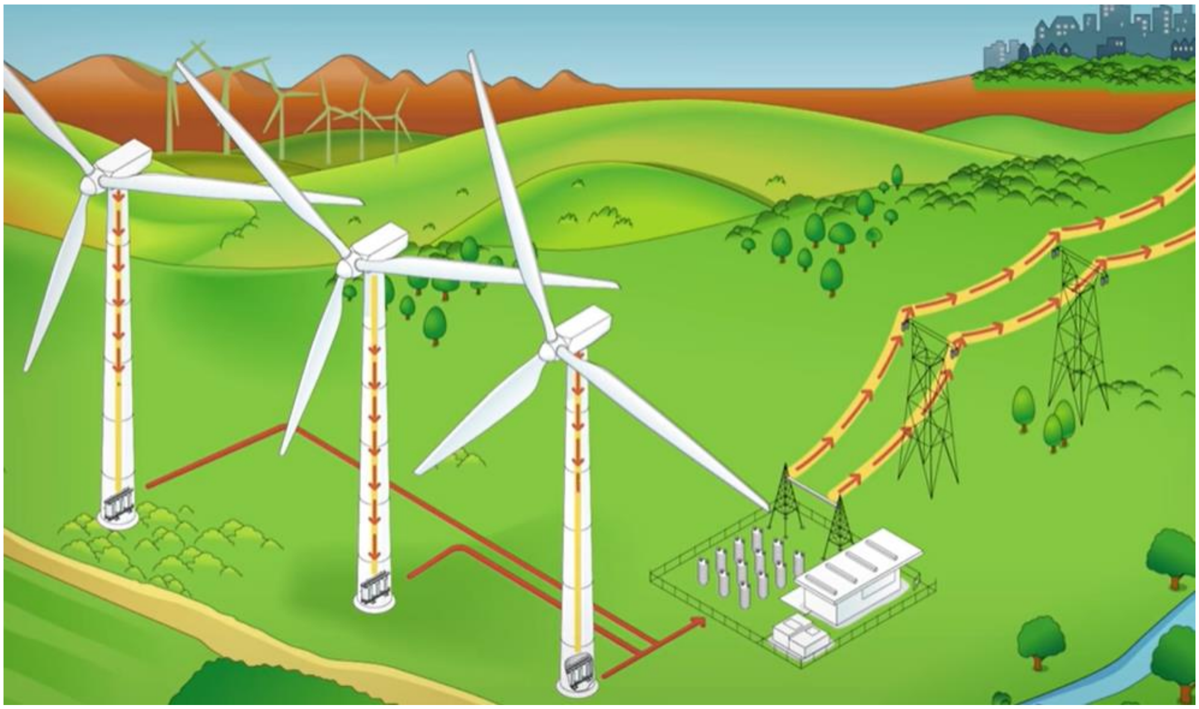
Wind Power Plant



Project Overview

Wind energy is one of the fastest-growing energy sources. Wind power is a renewable and clean energy source. The objective of this project is to design a utility-scale 500MW wind power plant that delivers power to the city of Ottawa via a transmission line system with a voltage of 100kV. The power plant is 100km away from the city and it is required to transmit the power over the 100km. The voltage is transformed through the system twice before reaching the University of Ottawa. The total amount of wind turbines required to deliver 500MW is 175. The major characteristics of the wind turbine that was manufactured by Siemens are indicated in the tables.

Specifications of the Wind Turbine

Rated Power	2.9MW
IED class	S
Control	Pitch and Variable Speed
Standard Operating Temperature	Range from –20 C to 45 C

Table 1: General Details

Diameter	129m
Swept Area	13070 m^2
Power Density	221.88 W/m^2

Table 2: Rotor

Length	63.5m
Airfoils	Siemens Gamesa
Material	Fiberglass reinforced with epoxy

Table 3: Blades

Type	Tubular steel tower
Height	87 m and site-specific

Table 4: Tower

Type	3 stages

Table 5: Gearbox

Type	Full scale converter
Voltage	690 V AC
Frequency	60 Hz
Protection class	IP 54
Power	0.9 CAP-0.9 IND throughout the power range

Table 6: Generator

Estimation & Specifications

The number of wind turbines needed:

500MW/2.9MW = 174 rounded up

We will use 174 wind turbines in parallel to deliver 500MW power.

We don't need DC/DC, DC/AC converters because we are using wind turbines.

Transformer Ratings

30 MVA 138 kV D - 12.47kV Wye, 3 Phase 60 HZ Oil Filled Station Type

Type	Oil Filled Station
Voltage	138k V
Frequency	60 Hz
Phase	3 Phase
Power	30MVA

Table 7: Transformer Ratings

Transformer Specifications

The voltage produced at the output of the wind turbine is 690* sqrt(2) = 975.807358 volts (peak). We need to step up the voltage to 100kV so the primary to secondary turns ratio for the three-phase transformer (connected Y-Y with the generator) is 100000/975.80. The secondary transformer needs to be a primary to secondary turns ratio of 33000/100000. The tertiary transformer needs to be a single-phase transformer at a turns ratio of 120/ 33000.

Electrical Calculation

Output Voltage of each string	975.807358Vp
Output current of each string	11 A

Table 7: Output Voltage and Current of Each String

DC Output Power Calculation

Output power of each string	9.2MW

Table 8: Output Power of Each String

Land Required Calculations

The width and length of required land use is about half a kilometer. The area of the wind turbine use would be about 0.25 km^2. When this is multiplied by 174 wind turbines this would give a total square capacity of 43.5 square kilometers. The land use would have to be low-density farmland.

Financial Analysis and Feasibility

Component	Price (USD)	Quantity	Total Cost
Wind Turbine	2000000	175	350000000
Transformers	100000	35	3500000
Wires	300 000	-	300000
Circuit Protector	50 000	-	50000
Construction Work	1 000 000	-	1000000
Grand Total			354850000

Table 9: Financial Analysis and Feasibility of the Project

Financial Estimation

The wind farm will produce about 500MW. Over the year this will translate into about 15,770,000,000,000,000 J of energy. This is approximately 4380555555.5555553436 KWh of energy. If the electricity is sold at the amount of 0.15 cents per KWh then that would produce a revenue of 657083333.33 dollars. Assuming an operations cost of 1000 000 this would produce a profit of 301233333.33 dollars within the first year.

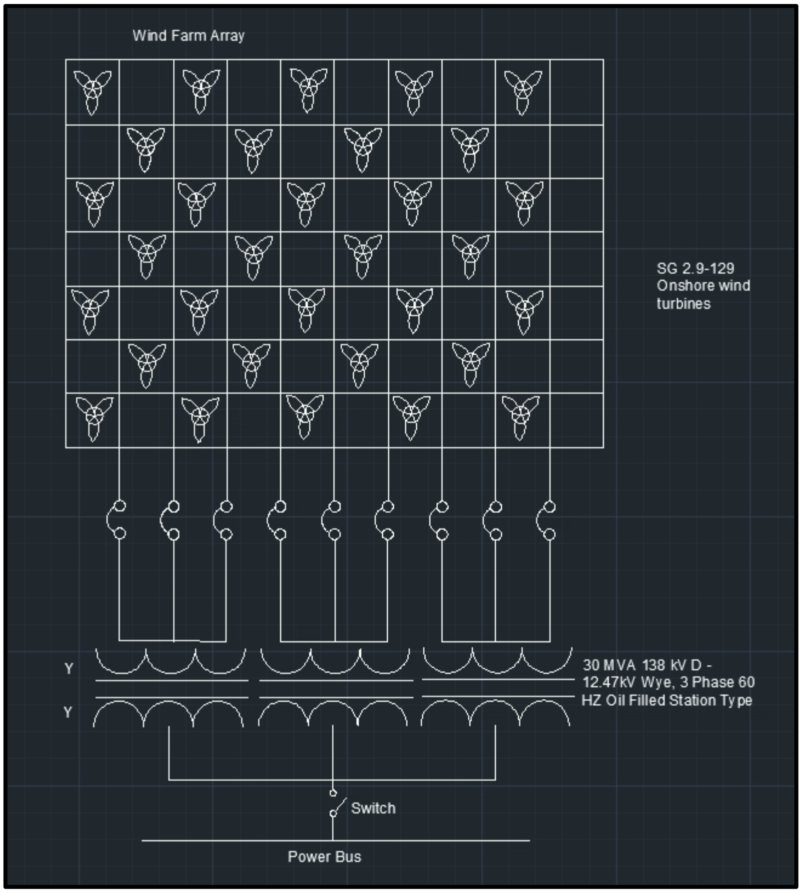


Figure 1: Block Diagram of the Design Protocol

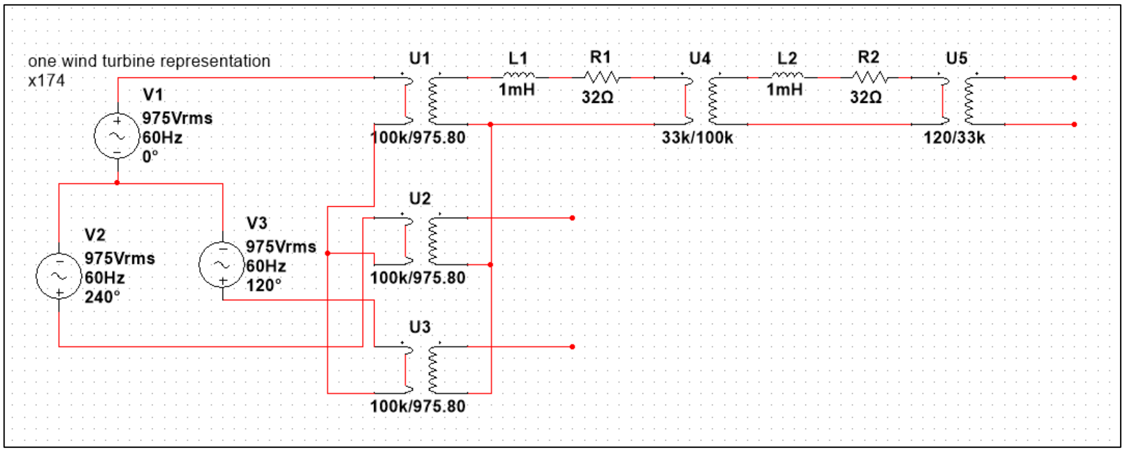


Figure 2: Wind Power Plant Substation

AMERICAN WIRE GAUGE (AWG) SIZES AND PROPERTIES TABLE

Table lists the AWG sizes for electrical cables / conductors. In addition to wire size, the table provides values load (current) carrying capacity, resistance and skin effects. The resistances and skin depth noted are for copper conductors. A detailed description of each conductor property is described below.

AWG	Diameter (inches)	Diameter (mm)	Area (mm^2)	Resistance (Ohms / 1000 ft)	Resistance (Ohms / km)	Max Current (Amperes)	Max Frequency for 100% skin Depth
0000 (4/0)	0.46	11.684	107	0.049	0.16072	302	125 Hz
000 (3/0)	0.4096	10.40384	85	0.0618	0.202704	239	160 Hz
00 (2/0)	0.3648	9.26592	67.4	0.0779	0.255512	190	200 Hz
0 (1/0)	0.3249	8.25246	53.5	0.0983	0.322424	150	250 Hz
1	0.2893	7.34822	42.4	0.1239	0.406392	119	325 Hz
2	0.2576	6.54304	33.6	0.1563	0.512664	94	410 Hz
3	0.2294	5.82676	26.7	0.197	0.64616	75	500 Hz
4	0.2043	5.18922	21.2	0.2485	0.81508	60	650 Hz
5	0.1819	4.62026	16.8	0.3133	1.027624	47	810 Hz
6	0.162	4.1148	13.3	0.3951	1.295928	37	1100 Hz
7	0.1443	3.66522	10.5	0.4982	1.634096	30	1300 Hz
8	0.1285	3.2639	8.37	0.6282	2.060496	24	1650 Hz
9	0.1144	2.90576	6.63	0.7921	2.598088	19	2050 Hz
10	0.1019	2.58826	5.26	0.9989	3.276392	15	2600 Hz
11	0.0907	2.30378	4.17	1.26	4.1328	12	3200 Hz
12	0.0808	2.05232	3.31	1.588	5.20864	9.3	4150 Hz
13	0.072	1.8288	2.62	2.003	6.56984	7.4	5300 Hz
14	0.0641	1.62814	2.08	2.525	8.282	5.9	6700 Hz
15	0.0571	1.45034	1.65	3.184	10.44352	4.7	8250 Hz
16	0.0508	1.29032	1.31	4.016	13.17248	3.7	11 k Hz
17	0.0453	1.15062	1.04	5.064	16.60992	2.9	13 k Hz
18	0.0403	1.02362	0.823	6.385	20.9428	2.3	17 kHz
19	0.0359	0.91186	0.653	8.051	26.40728	1.8	21 kHz
20	0.032	0.8128	0.518	10.15	33.292	1.5	27 kHz
21	0.0285	0.7239	0.41	12.8	41.984	1.2	33 kHz
22	0.0254	0.64516	0.326	16.14	52.9392	0.92	42 kHz
23	0.0226	0.57404	0.258	20.36	66.7808	0.729	53 kHz
24	0.0201	0.51054	0.205	25.67	84.1976	0.577	68 kHz
25	0.0179	0.45466	0.162	32.37	106.1736	0.457	85 kHz
26	0.0159	0.40386	0.129	40.81	133.8568	0.361	107 kHz
27	0.0142	0.36068	0.102	51.47	168.8216	0.288	130 kHz
28	0.0126	0.32004	0.081	64.9	212.872	0.226	170 kHz
29	0.0113	0.28702	0.0642	81.83	268.4024	0.182	210 kHz
30	0.01	0.254	0.0509	103.2	338.496	0.142	270 kHz
31	0.0089	0.22606	0.0404	130.1	426.728	0.113	340 kHz
32	0.008	0.2032	0.032	164.1	538.248	0.091	430 kHz
33	0.0071	0.18034	0.0254	206.9	678.632	0.072	540 kHz
34	0.0063	0.16002	0.0201	260.9	855.752	0.056	690 kHz
35	0.0056	0.14224	0.016	329	1079.12	0.044	870 kHz
36	0.005	0.127	0.0127	414.8	1360	0.035	1100 kHz
37	0.0045	0.1143	0.01	523.1	1715	0.0289	1350 kHz
38	0.004	0.1016	0.00797	659.6	2163	0.0228	1750 kHz
39	0.0035	0.0889	0.00632	831.8	2728	0.0175	2250 kHz
40	0.0031	0.07874	0.00501	1049	3440	0.0137	2900 kHz

Figure 3: Wire Gauges

The gauge of the wires used to transmit the electricity from the power plant to the city transformer is 0. As seen in the above table, the gauge of the wire is optimal for high voltage power transmission since the max current is 150A.

High Voltage Transmission Line

The Selected Conductor and its Specifications:

Conductor Type	AAC
Current Carrying Capacity	2024 A
Outside Diameter	0.0548132 meters
Rated Voltage	100kV
Resistance	1.657 ohms
Series Inductive Reactance	0.000001534 H/m
Shunt Capacitive Reactance	1.55086 * 10^-11 F/m
Frequency	60 Hz

Table 1: Specifications of the AAC Conductor

For the conductor type, we have chosen the AAC type. The reason for this is because it is the cheapest to manufacture for the medium distance that it needs to be transported (approximately 100km).

CODE	SIZE AWG or kcmil	STRANDING No. of cores	STRANDING Class	DIAMETER ins Individual Wire	DIAMETER ins Complete Cable	CROSS SECTIONAL AREA sq ins	WEIGHT PER 1000FT lbs	RATED STRENGTH lbs	RESISTANCE ohms/1000ft DC at 20°C	RESISTANCE ohms/1000ft DC at 75°C	ALLOWABLE AMPACITY Amps
FLAG	700	61	A	0.1071	0.964	0.5499	656	12400	0.0247	0.0305	812
VIOLET	715.5	37	AA	0.1391	0.974	0.562	671	12800	0.0242	0.0299	823
NASTURTIUM	715.5	61	A	0.1083	0.975	0.5621	671	13100	0.0242	0.0299	823
PETUNNIA	750	37	AA	0.1424	0.997	0.5891	703	13100	0.023	0.0286	847
CATTAIL	750	61	A	0.1109	0.998	0.5891	703	13500	0.023	0.0286	847
ARBUTUS	795	37	AA	0.1466	1.026	0.6244	745	13900	0.0217	0.027	878
ULAC	795	61	A	0.1142	1.028	0.6244	746	14300	0.0217	0.027	879
COCKCOMB	900	37	AA	0.156	1.093	0.7069	844	15400	0.0192	0.0239	948
SNAPDRAGON	900	61	A	0.1215	1.094	0.7069	844	15900	0.0192	0.0239	948
MAGNOLIA	954	37	AA	0.1606	1.124	0.7493	895	16400	0.0181	0.0226	982
GOLDENROD	954	61	A	0.1251	1.126	0.7493	895	16900	0.0181	0.0226	983
HAWKWEED	1000	37	AA	0.1644	1.15	0.7854	937	17200	0.0173	0.0216	1010
CAMELIA	1000	61	A	0.128	1.152	0.7854	937	17700	0.0173	0.0216	1011
BLUEBELL	1033.5	37	AA	0.1671	1.17	0.8117	968	17700	0.0167	0.021	1031
LARKSPUR	1033.5	61	A	0.1302	1.172	0.8117	969	18300	0.0167	0.021	1032
MARIGOLD	1113	61	AA.A	0.1351	1.216	0.8742	1044	19700	0.0155	0.0195	1079
HAWTHORN	1192.5	61	AA.A	0.1398	1.258	0.9366	1117	21100	0.0145	0.0183	1124
NARCISSUS	1272	61	AA.A	0.1444	1.3	0.999	1192	22000	0.0136	0.0173	1169
COLUMBINE	1351.5	61	AA.A	0.1489	1.34	1.061	1266	23400	0.0128	0.0163	1212
CARNATION	1431	61	AA.A	0.1532	1.379	1.124	1342	24300	0.0121	0.0155	1253
GLADIOLUS	1510.5	61	AA.A	0.1574	1.417	1.186	1416	25600	0.0144	0.0147	1294
COREOPSIS	1590	61	AA	0.1614	1.454	1.249	1489	27000	0.0109	0.0141	1333
JESSAMINE	1750	61	AA	0.1694	1.525	1.374	1641	29700	0.0988	0.0129	1408
COWSLIP	2000	91	A	0.1482	1.63	1.571	1873	34200	0.00864	0.0115	1518
SAGEBRUSH	2250	91	A	0.1572	1.729	1.767	2128	37500	0.00776	0.0105	1612
LUPINE	2500	91	A	0.1657	1.823	1.964	2365	41900	0.00698	0.00969	1706
BITTERROOT	2750	91	A	0.1739	1.913	2.16	2602	46100	0.00635	0.009	1793
TRILLIUM	3000	127	A	0.1537	1.996	2.356	2687	50300	0.00582	0.00834	1874
BLUEBONNET	3500	127	A	0.166	2.158	2.749	3344	58700	0.00499	0.00756	2024

Figure 1: Bluebonnet AAC Conductor Specifications

Calculations of Conductor Parameters:

Series Inductive Reactance:

The series inductance can be calculated using the following formula:

$$L = 4 \times 10^{-7} ln \frac{D}{r'}$$

Figure 2: Formula to Calculate the Inductance

With the distance between the phases being 990mm and the radius found to be 0.0274m we can find that the total inductance is 0.000001534 H/km. This translates into an inductive reactance of j*0.000578304 Ohms/km.

Shunt Capacitive Reactance:

The shunt capacitive reactance can be calculated using the following formula:

$$C_{ab} = \frac{q}{V} = \frac{q}{\frac{q}{\pi\varepsilon} ln \frac{D}{r}} = \frac{2\pi\varepsilon}{ln \frac{D}{r}}$$

Figure 3: Formula to Calculate the Capacitance

With the distance between the phases being 990mm and the radius found to be 0.0274m we can find the capacitance to be 1.55086 * 10^-11 F/m. This translates into a shunt capacitive reactance of -j/0.000000005 Ohms/m.

The Selected Tower Specifications:

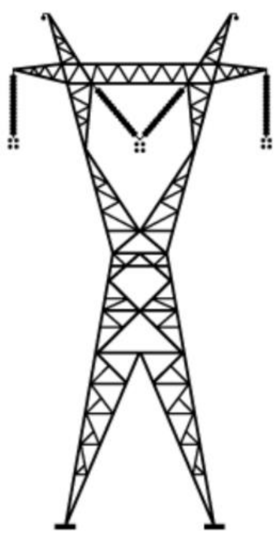


Figure 4: Diagram of the Waist-Type Transmission Line

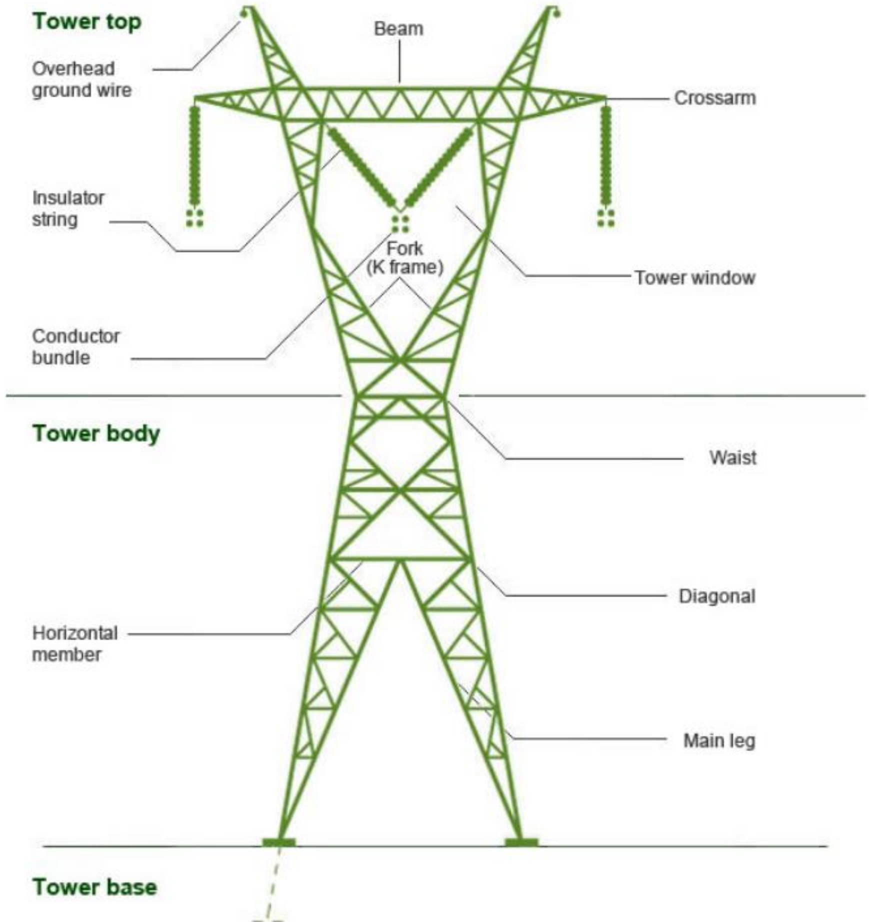


Figure 5: Detailed Diagram of Waist-type Tower

Tower type	Waist-Type
Number of three phase circuits	3
Number of conductors per phase	1
Configuration type	Star
Type and details of insulators	Type: Suspension type Number of insulators per string: 7
Voltage Range	20 kV – 100 kV
Phase to phase clearance	990.6 mm
Number of conductors per phase	1

Table 2: Specifications of the Selected Tower

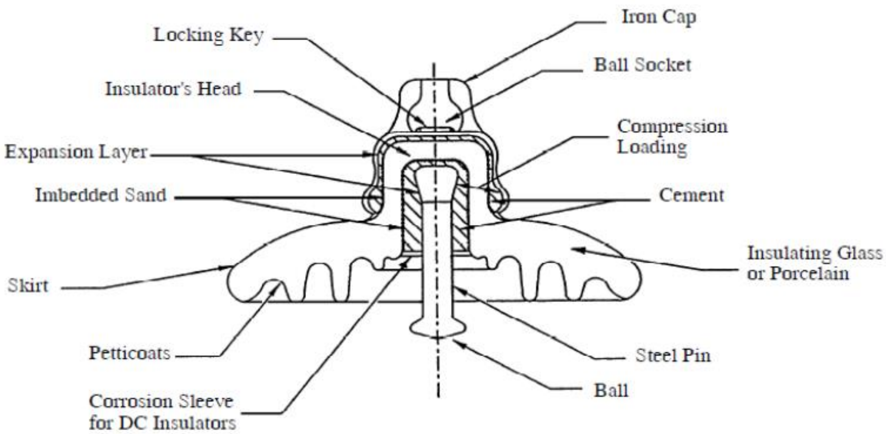


Figure 6: Suspension Type Insulator

Minimum Electrical Clearance As Per BS:162.

OUTDOOR		
Voltage in KV	Phase to earth in mm	Phase to phase in mm
6.6	139.7	177.8
11	177.8	228.6
22	279.4	330.2
33	381	431.8
66	685.8	787.4
110	863.6	990.6
132	1066.8	1219.2
220	1778	2057.4

Figure 7: Phase to Phase Clearance of 110kV Transmission Line

Transmission Line Model:

$$A = \frac{ZY}{2} + 1$$

$$B = Z$$

$$C = Y\left(\frac{ZY}{4} + 1\right)$$

$$D = \frac{ZY}{2} + 1$$

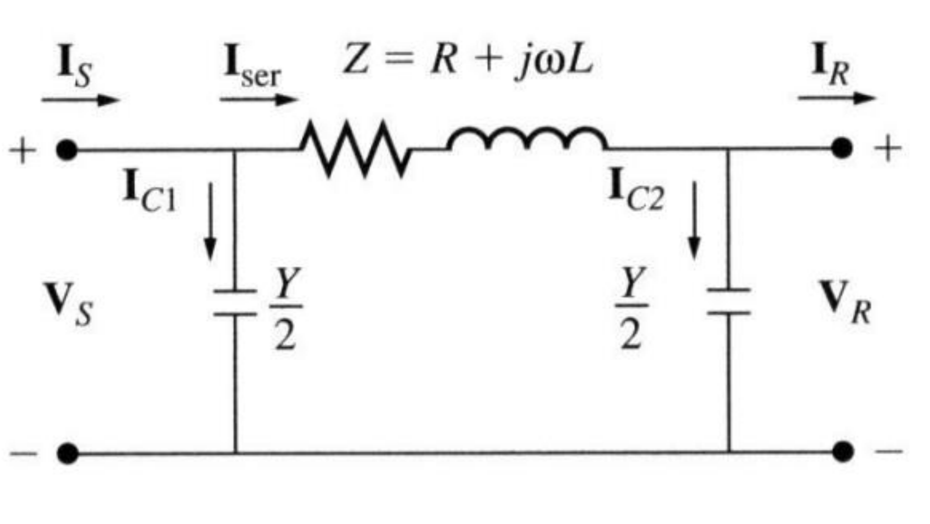


Figure 8: Model of a Transmission Line of Medium Length

$$Vs \ = \ \left(\frac{YZ}{2} + 1\right) V_R \ + Z I_R$$

$$Is \ = \ Y\left(\frac{ZY}{4} + 1\right) V_R \ + \left(\frac{ZY}{2} + 1\right) I_R$$

The power factor of the load is 0.95.

R = rd = 1.657 ohms

X = xd = j*0.000578304 Ohms/km * 100km = j*0.057 ohms

Y = yd = j*0.000000005 Ohms/m * 100000 = j*0.0005 ohms

Z = R + X

Z = (1.657 + j*57.83) ohms

V_R= (100,000)/√3 = 57735V

$|I_R|$= 500MW/(√3*100kV*0.95) = 3038.69 A

I_R= 3038.69∠-0. 317560 A

cos(θ) = 0.95

θ = -0. 317560 rad

$$Vs \ = \ \left(\frac{YZ}{2} + 1\right) V_R \ + Z I_R$$

$$Is \ = \ Y\left(\frac{ZY}{4} + 1\right) V_R \ + \left(\frac{ZY}{2} + 1\right) I_R$$

Vs = 62571.61508 - j1383.748521

Vs = 62586.91376∠-0.02211

Is = 2887.101837 - j918.7527553

Is = 3029.762968∠-0.30809

Voltage Regulation

$$VR = \frac{Vnl - Vfl}{Vfl} \times 100\%$$

VR = ((62586- 57735)/57735) * 100%=8.4

Efficiency

$$\eta = \frac{Pout}{Pin} \times 100\%$$

= 500MW/ (3*Is*Vs*cos (-0.02211 -0.30809)) *100%

=88%

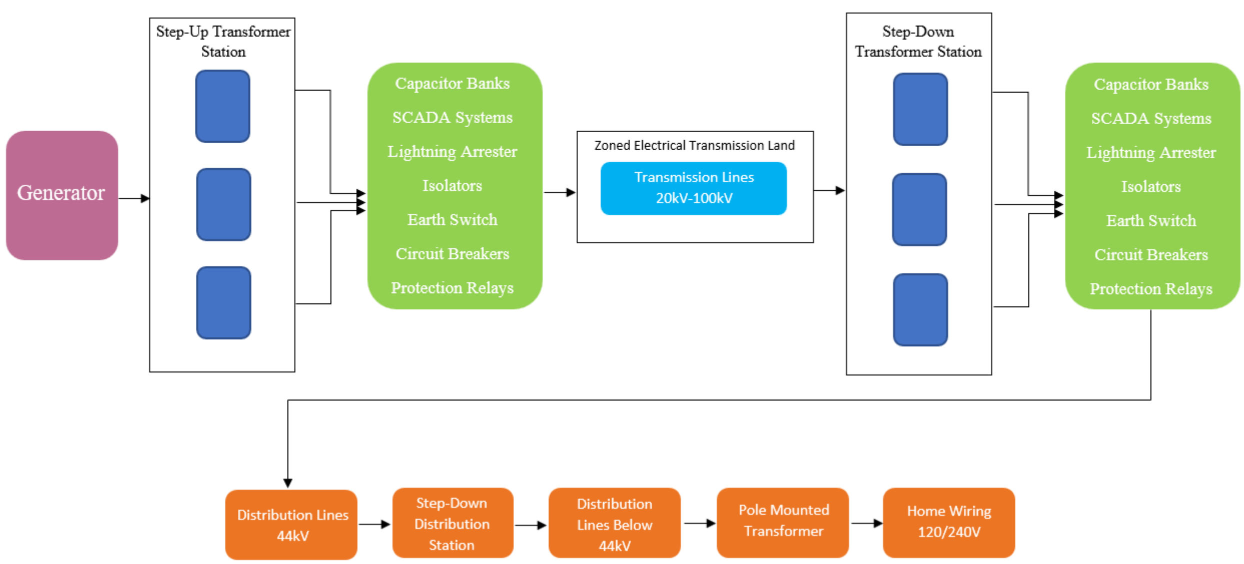


Figure 9: Block Diagram of Power Plant, Substation, and the Transmission Line

The width of the zoned electrical transmission land can be found using the following formula:

$$B = (\mu_o * I) * 10000/4*\pi*r = 2.5mG$$

Figure 10: Formula for Calculating the Width of Zone Electrical Transmission Land

Solving this using the rated current for the line gives us 1619.2m as the safe width from any type of commercial or residential land.

Protection System (Lightning)

- Protection Zones

For the protection of the transmission line, we are going to use protection zones where each zone is protected using an appropriate circuit breaker or fuse. The zones will be categorized as follows. There will be the unit generator, the transformer, the bus, the line, and the residential/ commercial zone. In addition to this we are going to use some redundancy in the transmission line as well as the transformers section that is modulated by a relay system. This will ensure that the power will not go out provided that one of the transformers goes out. A diagram of the system is shown in the following diagram.

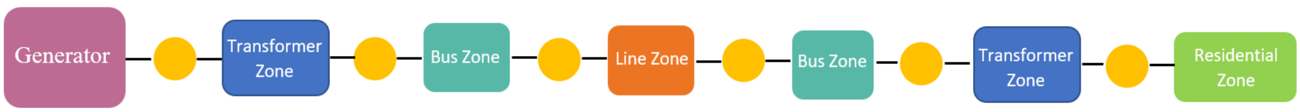


Figure 11: Protection System (Yellow Circles are Circuit Breaker or Fuse)

- Fuses

For the fuses in the system, we are going to adopt the IEEE standard C37.40 fuses. In particular, for the residential and generator we are going to adopt the E rating which will melt in about 300s if the current goes beyond that of 100A. For the transmission line we must use more heavy-duty fuses. Therefore, we are going to use the R rating. For the relay system, we will adopt the standard setup as illustrated in the NERC technical paper on protection system reliability.

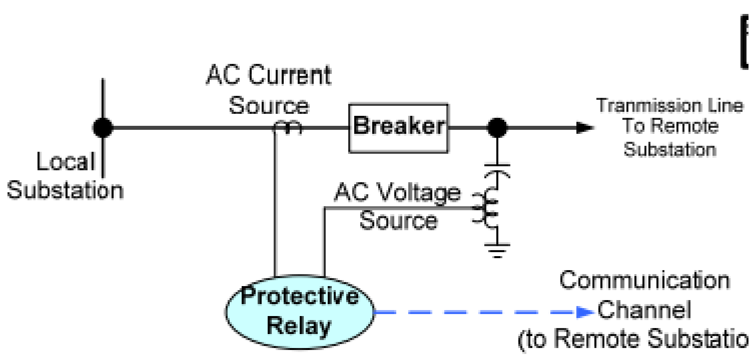


Figure 12: NERC Simplified One Line Relay Input/Output

- Lightning Arresters

Table 1

System Application Voltages	3-400 kV
Rated Arrester Voltages, U_r	3-360 kV
Power System Frequency	50 or 60 Hz
Applicable Design and Test Standard	IEC 99-4
Nominal Discharge Current	20 kA
Line Discharge Class	4
High Current Withstand	100 kA
Pressure Relief Class	63 kA rms sym
Rated Discharge Energy	8.9 kJ/kV of U_c or 7.2 kJ/kV of U_r

Figure 13: VariSTAR Type AZG4 Surge 400kV Lightning Arrester Specifications

Table 2. Arrester ratings commonly used on 3-phase systems

System Voltages L-L (kV)		Arrester Ratings (kV)	
Nominal	Max	Grounded Circuits	High-Impedance/ Ungrounded Circuits
3.3	3.7	3	–
6.6	7.3	6	9
10.0	11.5	9	12-15
11.0	12.0	9-10	12-15
16.4	18.0	15	18-21
22.0	24.0	18-21	24-27
33.0	36.3	27-30	36-39
47.0	52.0	39-48	54-60
66.0	72.0	54-60	66-84
91.0	100	78-84	90-96
110	123	96-108	120-138
132	145	108-120	132-144
155	170	132-144	162-172
220	245	180-198	204-240
275	300	216-240	258-294
330	362	258-288	294-360
400	420	312-360	-

Figure 14: VariSTAR Type AZG4 Surge 400kV Lightning Arrester Commonly Used on 3 Phase Systems

- Transformer Relay System

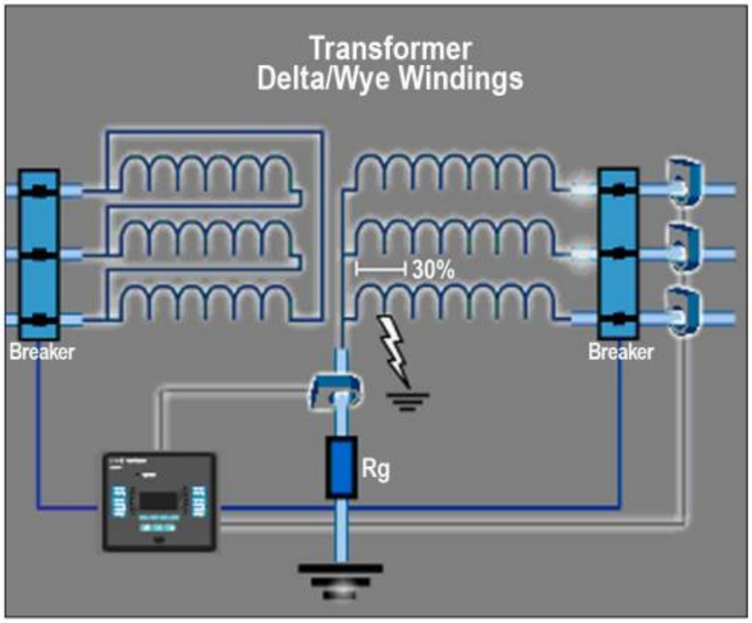


Figure 15: Restricted Ground Fault for the Transformer

Relay Outputs

Continuous Current:	5 A ac / dc
Max. Make Current:	25 A ac / 25 A dc up to 30 V for 4 s 30 A / 230 Vac according to ANSI IEEE Std C37.90-2005 30 A / 250 Vdc according to ANSI IEEE Std C37.90-2005
Max. Breaking Current:	5 A ac up to 125 Vac 5 A dc up to 30 V (resistive) 0.3 A dc at 300 V
Max. Switching Voltage:	250 Vac / 250 Vdc
Switching Capacity:	1,250 VA
Contact Type:	changeover contact or normally open contact
Terminals:	Screw-type terminals

Figure 16: ETR-4000 Transformer Protection Relay Output Specifications

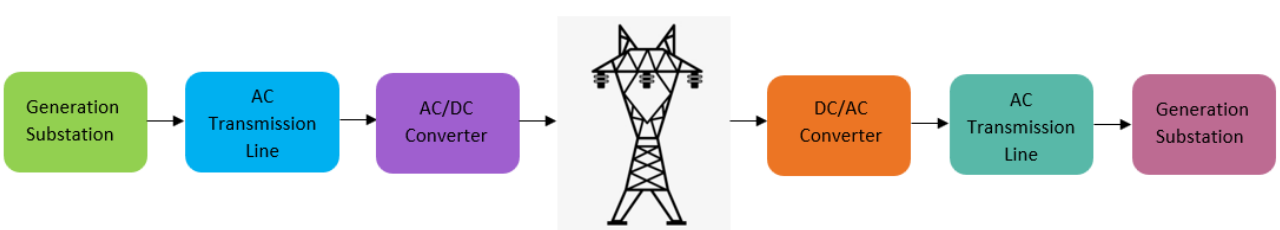


Figure 17: HVAC Conversion of Transmission Line

Distribution System

Configuration type	Delta-delta
Rated power	500MW
Rated primary voltage	100kV
Rated secondary voltage	33kV
Normal loading	1.28*500MW = 640MW
2-hour emergency loading	1.70*500MW = 850MW
30-day emergency loading	1.55*500MW = 775MW

Table 1: Transformer Specifications for Primary Transmission Substation

Conductor Type	AAC
Current Carrying Capacity	2024 A
Outside Diameter	0.0548132 meters
Rated Voltage	100kV
Resistance DC at 20°C	0.00499 ohms/1000ft
Resistance DC at 75°C	0.00756 ohms/1000ft
Resistance	1.657 ohms
Series Inductive Reactance	0.000001534 H/m
Shunt Capacitive Reactance	1.55086 * 10^-11 F/m
Frequency	60 Hz

Table 2: Conductor (Bluebonnet) Specifications

For the conductor characteristics for the primary substation, we are going to use a primary side switchgear-transformer as the link type. The selection of conductor for the primary side will be two strands of Bluebonnet, which has an AWG of 3500. For the system, we are going to utilize a safety factor of 1.25. The total ampacity can be calculated using the following formula:

$$I = \frac{P}{\sqrt{3}\, V_L\, Cos\,(\theta)}$$

$$I = \frac{(0.6)(500 \times 10^6)}{\sqrt{3}\,(100 \times 10^3)\,(0.95)}$$

$$I = 1823\,A$$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(850 \times 10^6)}{\sqrt{3}\,(100 \times 10^3)(0.95)}$$

$$I = 3099\,A$$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(775 \times 10^6)}{\sqrt{3}\,(100 \times 10^3)(0.95)}$$

$I = 2826\,A$

Given the safety factor the rated current will be:

$(3099)(1.25) = 3874\,A$

For the conductor characteristics for the primary substation, we are going to use a secondary side switchgear-transformer as the link type. The selection of conductor for the secondary side will be 6 strands of Bluebonnet, which has an AWG of 3500. For the system we are going to utilize a safety factor of 1.25. The total ampacity can be calculated using the following formula:

$$I = \frac{(0.6)(500 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$I = 5525\,A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(850 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$I = 9392\,A$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(775 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$I = 8564\,A$

Given the safety factor the rated current will be:

$(9392)(1.25) = 11740A$

We are going to divide the 500MW transmission into 5 substations which will handle 100MW each.

Configuration type	Delta-delta
Rated power	500MW/5 = 100MW
Rated primary voltage	33kV
Rated secondary voltage	13.8kV
Normal loading	1.28*100MW = 128MW
2-hour emergency loading	1.70*100MW = 170MW
30-day emergency loading	1.55*100MW = 155MW

Table 3: Transformer Specifications for Secondary Transmission Substation

For the conductor characteristics for the secondary substation, we are going to use a primary side switchgear-transformer as the link type. The selection of conductor for the primary side will be two strands of Bluebonnet, which has an AWG of 3500. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(100 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$I = 1105\,A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(170 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$$I = 1878\ A$$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(155 \times 10^6)}{\sqrt{3}\,(33 \times 10^3)\,(0.95)}$$

$$I = 1713\ A$$

Given the safety factor the rated current will be:

$$(1878)(1.25) = 2348\ A$$

For the conductor characteristics for the secondary substation, we are going to use a secondary side switchgear-transformer as the link type. The selection of conductor for the secondary side will be 6 strands of Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(100 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 2642\ A$$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(170 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 4492\ A$$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(155 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 4096\ A$$

Given the safety factor the rated current will be:

$$(4492)(1.25) = 5615\ A$$

Conductor Type	ACSR
Current Carrying Capacity	1010 A
Outside Diameter	0.0303784 meters
Rated Voltage	13.8kV
Resistance DC at 25°C	0.0979 ohms/mile
Resistance DC at 50°C	0.1078 ohms/mile
Series Inductive Reactance	0.390 ohms/mile
Shunt Capacitive Reactance	0.0890 ohms/mile
Frequency	60 Hz

Table 4: Conductor (Cardinal) Specifications

We are going to divide the 100MW transmission into 20 substations which will handle 5MW each.

Configuration type	Delta-Star
Rated power	5MW
Rated primary voltage	13.8kV
Rated secondary voltage	400V
Normal loading	1.28*5MW = 6.4MW
2-hour emergency loading	1.70*5MW = 8.5MW
30-day emergency loading	1.55*5MW = 7.75MW

Table 5: Transformer Specifications for Tertiary Transmission Substation

For the conductor characteristics for the tertiary substation, we are going to use a primary side switchgear-transformer as the link type. The selection of conductor for the primary side will a strand of Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(5 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 132\ A$$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(8.5 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 225\ A$$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(7.75 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$$I = 205\ A$$

Given the safety factor the rated current will be:

$$(225)(1.25) = 281\ A$$

For the conductor characteristics for the tertiary substation, we are going to use a secondary side switchgear-transformer as the link type. The selection of conductor for the secondary side will be 8 strands of Falcon, which has an AWG of 1000. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(5 \times 10^6)}{\sqrt{3}\,(400)\,(0.95)}$$

$$I = 4558\ A$$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(8.5 \times 10^6)}{\sqrt{3}\,(400)\,(0.95)}$$

$$I = 7749\ A$$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(7.75 \times 10^6)}{\sqrt{3}\,(400)\,(0.95)}$$

$I = 7065\ A$

Given the safety factor the rated current will be:

$(7749)(1.25) = 9686\ A$

Conductor Type	ACSR
Current Carrying Capacity	1380 A
Outside Diameter	0.039243 meters
Rated Voltage	400V
Resistance DC at 25°C	0.0587 ohms/mile
Resistance DC at 50°C	0.0646 ohms/mile
Series Inductive Reactance	0.359 ohms/mile
Shunt Capacitive Reactance	0.0814 ohms/mile
Frequency	60 Hz

Table 6: Conductor (Falcon) Specifications

Configuration type	Delta-Star
Rated power	2.5MW
Rated primary voltage	13.8kV
Rated secondary voltage	600V
Normal loading	1.28*2.5MW = 3.2MW
2-hour emergency loading	1.70*2.5MW = 4.25MW
30-day emergency loading	1.55*2.5MW = 3.875MW

Table 7: Transformer Specifications for uOttawa Substation

For the conductor characteristics for the uOttawa substation, we are going to use a primary side switchgear-transformer as the link type. The selection of conductor for the primary side will be Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(2.5 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 66\ A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(4.25 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 112\ A$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(3.875 \times 10^6)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 102\ A$

Given the safety factor the rated current will be:

$(112)(1.25) = 140\ A$

For the conductor characteristics for the uOttawa substation, we are going to use a secondary side switchgear-transformer as the link type. The selection of conductor for the secondary side will be 4 strands of Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(2.5 \times 10^6)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 1519\ A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(4.25 \times 10^6)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 2583\ A$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(3.875 \times 10^6)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 2355\ A$

Given the safety factor the rated current will be:

$(2583)(1.25) = 3229\ A$

Configuration type	Delta-Star
Rated power	360kW
Rated primary voltage	13.8kV
Rated secondary voltage	600V
Normal loading	1.28*360kW = 460.8kW
2-hour emergency loading	1.70*360kW = 612kW
30-day emergency loading	1.55*360kW = 558kW

Table 8: Transformer Specifications for Meat Plant

For the conductor characteristics for the meat plant substation, we are going to use a primary side switchgear-transformer as the link type. The selection of conductor for the primary side will be Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(360 \times 10^3)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 10\ A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(612 \times 10^3)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 16\ A$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(558 \times 10^3)}{\sqrt{3}\,(13.8 \times 10^3)\,(0.95)}$$

$I = 15\ A$

Given the safety factor the rated current will be:

$(16)(1.25) = 20\ A$

For the conductor characteristics for the meat plant substation, we are going to use a secondary side switchgear-transformer as the link type. The selection of conductor for the secondary side will be 4 strands of Cardinal, which has an AWG of 954. For the system we are going to utilize a safety factor of 1.25. The total ampacity is calculated below:

$$I = \frac{(0.6)(360 \times 10^3)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 219\ A$

For 2-hour emergency load the expected ampacity is:

$$I = \frac{(0.6)(612 \times 10^3)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 372\ A$

For 30-day emergency load the expected ampacity is:

$$I = \frac{(0.6)(558 \times 10^3)}{\sqrt{3}\,(600)\,(0.95)}$$

$I = 339\ A$

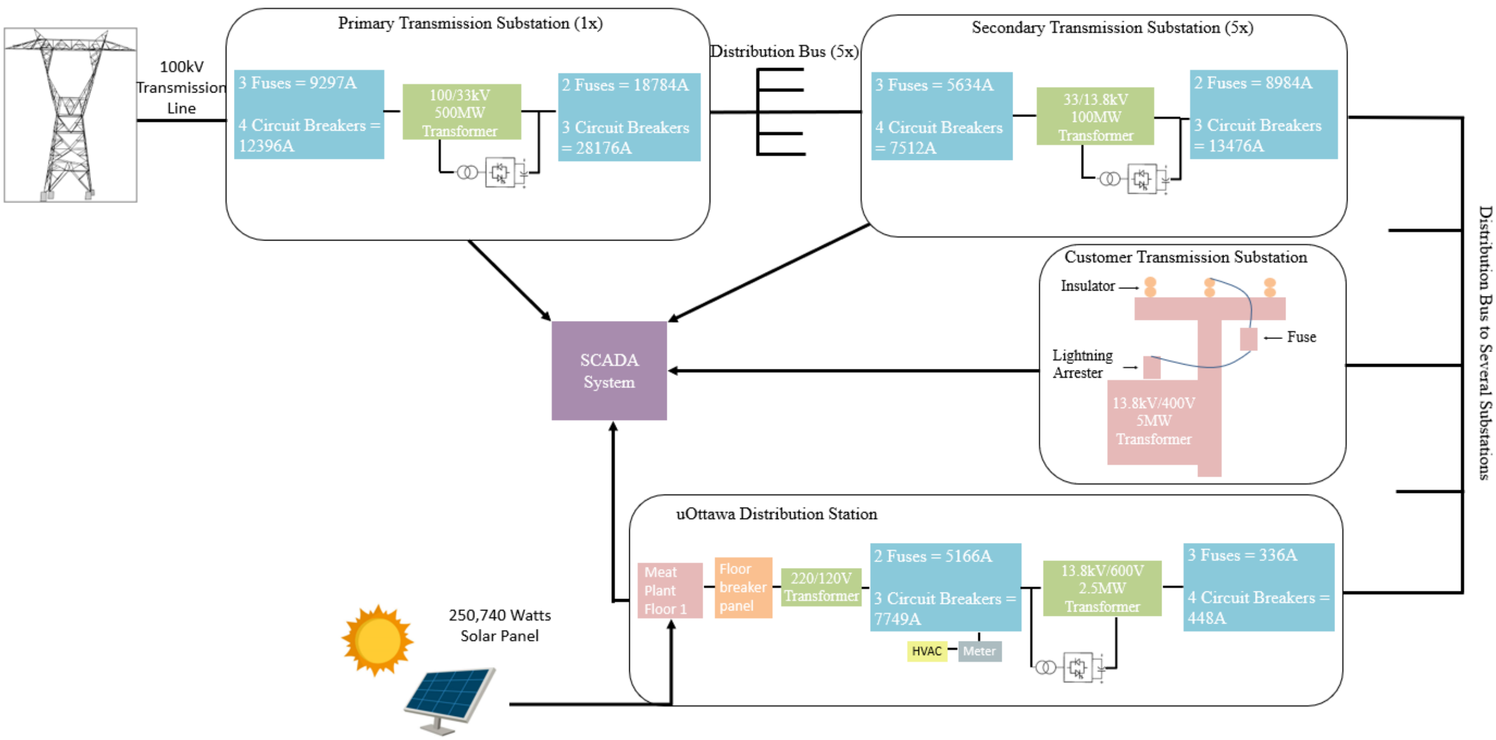
Given the safety factor the rated current will be:

$(372)(1.25) = 465\ A$

	Fuse	Circuit Breaker
Primary Transmission Substation Primary Voltage Side	3099*3 = 9297A	3099*4 = 12396A
Primary Transmission Substation Secondary Voltage Side	9392*2 = 18784A	9392*3 = 28176A
Secondary Transmission Substation Primary Voltage Side	1878*3 = 5634A	1878*4 = 7512A
Secondary Transmission Substation Secondary Voltage Side	4492*2 = 8984A	4492*3 = 13476A
Customer Transmission Substation Primary Voltage Side	225*3 = 675A	225*4 = 900A
Customer Transmission Substation Secondary Voltage Side	7749*2 = 15498A	7749*3 = 23247A
uOttawa Transmission Primary Voltage Side	112*3 = 336A	112*4 = 448A
uOttawa Transmission Secondary Voltage Side	2583*2 = 5166A	2583*3 = 7749A

Table 9: System Protection Specifications

Block Diagram of the Power System



Power World Simulation of the Power System