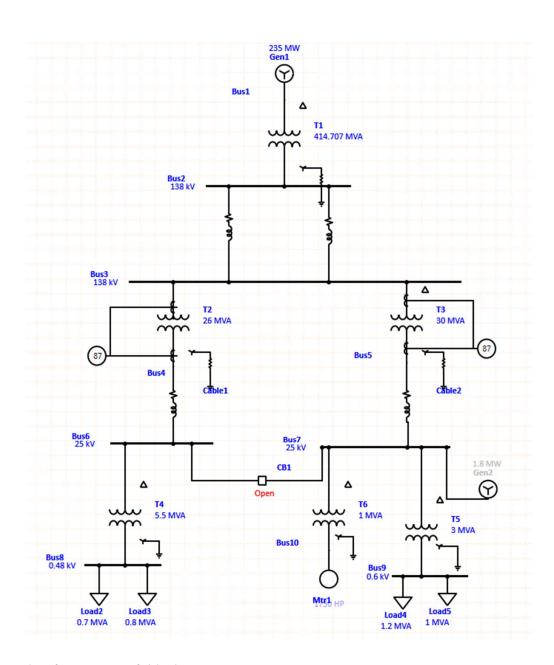
# ENEL 472 Design Project Arpan Dhamane

## **Produce Single Line Diagram – ETAP:**



<sup>\*</sup>Refer to ETAP folder\*

## Calculate Transmission line parameters Pos, Zero Sequence:

Positive Sequence: Z1 = 0.47244 + j0.565496 Ohm per km

Zero Sequence: Zo = 0.65 + j1.59699 Ohm per km

Equations used from Network Protection and Automation Guide

Page 5-17, Eq 5.12:

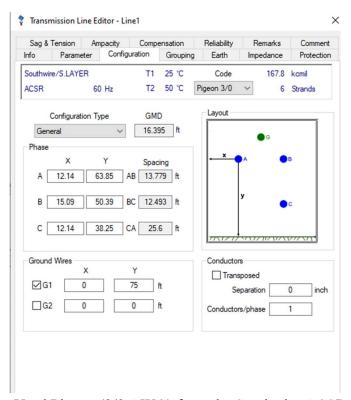
$$Z_1 = Z_2 = R + j0.0029 f \log_{10} \frac{D}{dc}$$

$$Z_0 = R + 0.00296 f + j0.00869 f \log_{10} \frac{D_e}{\sqrt[3]{dcD^2}}$$

Refer to Hand Calculations\*

## Specify Tx Lines L1 and L2:

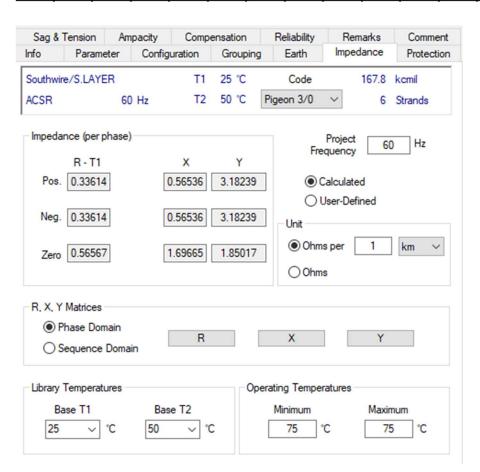
Configuration of Tx Lines was completed from the diagram (Double Circuit 138kV) in the project handout:



Used Pigeon (3/0 AWG) from the Southwire ACSR table (on urcourses).

## \*Refer to Second Last Row\*

Size (AWG or kcmil)	Strand- ing (Al/Stl)	Diameter (ins.)				Weight Per 1000 ft. (lbs.)			Content (%)		Rated Strength	Resistance OHMS/1000 ft.		Allowable Ampacity
		Individual Wires		Steel		Al	StI	Total	AI	StI	(IDS.)	DC @	AC @	(Amps)
		Al	StI	Core	Cable							20°C	75°C	
6	6/1	.0661	.0661	.0661	.198	24	12	36	67.88	32.12	1190	.641	.806	105
4	6/1	.0834	.0834	.0834	.25	39	18	57	67.87	32.12	1860	.403	.515	140
4	7/1	.0772	.103	.103	.257	39	28	67	58.1	41.9	2360	.399	.519	140
2	6/1	.1052	.1052	.1052	.316	62	29	91	67.9	32.1	2850	.254	.332	184
2	7/1	.0974	.1298	.1298	.325	62	45	107	58.12	41.88	3460	.251	.338	184
1	6/1	.1181	.1181	.1181	.354	78	37	115	67.88	32.12	3550	.201	.268	212
1/0	6/1	.1327	.1327	.1327	.398	99	47	145	67.89	32.11	4380	.159	.217	242
2/0	6/1	.1489	.1489	.1489	.447	124	59	183	67.88	32.12	5310	.126	.176	276
3/0	6/1	.1672	.1672	.1672	.502	156	74	230	67.87	32.13	6620	.100	.144	315
4/0	6/1	.1878	.1878	.1878	.563	197	93	291	67.88	32.12	8350	.0795	.119	357
	6 4 4 2 2 1 1/0 2/0 3/0	(AWG or kcmil)  6 6/1  4 6/1  4 7/1  2 6/1  1 6/1  1/0 6/1  2/0 6/1  3/0 6/1	(AWG or kcmil)         ing (Al/Stl)         Individual           6         6/1         .0661           4         6/1         .0834           4         7/1         .0772           2         6/1         .1052           2         7/1         .0974           1         6/1         .1181           1/0         6/1         .1327           2/0         6/1         .1489           3/0         6/1         .1672	(AWG or kcmil)         ing (AVSt)         Individual Wires           AI         StI           6         6/1         .0661         .0661           4         6/1         .0834         .0834           4         7/1         .0772         .103           2         6/1         .1052         .1052           2         7/1         .0974         .1298           1         6/1         .1181         .1181           1/0         6/1         .1327         .1327           2/0         6/1         .1489         .1489           3/0         6/1         .1672         .1672	(AWG or kcmil)         ing (AVStI)         Individual Wires Steel Core           AI         StI         Steel Core           6         6/1         .0661         .0661         .0661           4         6/1         .0834         .0834         .0834           4         7/1         .0772         .103         .103           2         6/1         .1052         .1052         .1052           2         7/1         .0974         .1298         .1298           1         6/1         .1181         .1181         .1181           1/0         6/1         .1327         .1327         .1327           2/0         6/1         .1489         .1489         .1489           3/0         6/1         .1672         .1672         .1672	(AWG or kcmil)         ing (Al/Stl)         Individual Wires Stel Core Cable           AI         Stl         Stell Core Cable         Complete Cable           6         6/1         .0661         .0661         .0661         .198           4         6/1         .0834         .0834         .0834         .25           4         7/1         .0772         .103         .103         .257           2         6/1         .1052         .1052         .1052         .316           2         7/1         .0974         .1298         .1298         .325           1         6/1         .1181         .1181         .1181         .354           1/0         6/1         .1327         .1327         .1327         .398           2/0         6/1         .1489         .1489         .1489         .447           3/0         6/1         .1672         .1672         .1672         .502	(AWG or kcmil)         Individual Wires         Steel Core         Complete Cable         Al           6         6/1         .0661         .0661         .0661         .198         24           4         6/1         .0834         .0834         .0834         .25         39           4         7/1         .0772         .103         .103         .257         39           2         6/1         .1052         .1052         .1052         .316         62           2         7/1         .0974         .1298         .1298         .325         62           1         6/1         .1181         .1181         .1181         .354         78           1/0         6/1         .1327         .1327         .1327         .398         99           2/0         6/1         .1489         .1489         .1489         .447         124           3/0         6/1         .1672         .1672         .1672         .502         156	(AWG or kcmil)         ing (Al/Stl)         Individual Wires         Steel Core         Complete Cable         Al         Stl           6         6/1         .0661         .0661         .0661         .198         24         12           4         6/1         .0834         .0834         .0834         .25         39         18           4         7/1         .0772         .103         .103         .257         39         28           2         6/1         .1052         .1052         .1052         .316         62         29           2         7/1         .0974         .1298         .1298         .325         62         45           1         6/1         .1181         .1181         .1181         .354         78         37           1/0         6/1         .1327         .1327         .1327         .398         99         47           2/0         6/1         .1489         .1489         .1489         .447         124         59           3/0         6/1         .1672         .1672         .1672         .502         156         74	(AWG or kcmil)         Individual Wires         Steel Core Cable         Complete Cable         Al Stl Total           6         6/1         .0661         .0661         .0661         .198         24         12         36           4         6/1         .0834         .0834         .0834         .25         39         18         57           4         7/1         .0772         .103         .103         .257         39         28         67           2         6/1         .1052         .1052         .1052         .316         62         29         91           2         7/1         .0974         .1298         .1298         .325         62         45         107           1         6/1         .1181         .1181         .1181         .354         78         37         115           1/0         6/1         .1327         .1327         .1327         .398         99         47         145           2/0         6/1         .1489         .1489         .447         124         59         183           3/0         6/1         .1672         .1672         .1672         .502 <td>(AWG or kcmil)         ling (AVStI)         Steel Core Cable         Complete Cable         AI         StI         Total         AI           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88           4         6/1         .0834         .0834         .25         39         18         57         67.87           4         7/1         .0772         .103         .103         .257         39         28         67         58.1           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88           1/0         6/1         .1489         .1489         .447         124         59         183         67.88           3/0         6/1         .1672         .1672         .1672         .502</td> <td>(AWG or kcmil)         Individual Wires         Steel Core Cable         Complete Cable         Al Stl         Total Al Stl           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12           4         6/1         .0834         .0834         .0834         .25         39         18         57         67.87         32.12           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12           1/0         6/1         .1489         .1489         .447         124         59         183         67.88         32.12</td> <td>(AWG or kcmill)         ing (Al/Stl)         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         Strength (lbs.)           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12         1190           4         6/1         .0834         .0834         .0834         .25         39         18         57         67.87         32.12         1860           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12         3550           1/0         6/1&lt;</td> <td>(AWG or kcmil)         ing (A/Stl)         Individual Wires         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         DC @ 20°C           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12         1190         .641           4         6/1         .0834         .0834         .25         39         18         57         67.87         32.12         1860         .403           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360         .399           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850         .254           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460         .251           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12         3</td> <td>(AWG or kcmil)         ing (A/Stl)         Individual Wires         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         Stl         Total         Al         Stl         DC @ 20°C         AC @ 20°C         AC @ 20°C         75°C           6         6/1         .0661         .0661         .198         24         12         36         67.88         32.12         1190         .641         .806           4         6/1         .0834         .0834         .25         39         18         57         67.87         32.12         1860         .403         .515           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360         .399         .519           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850         .254         .332           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460         .251         .338</td>	(AWG or kcmil)         ling (AVStI)         Steel Core Cable         Complete Cable         AI         StI         Total         AI           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88           4         6/1         .0834         .0834         .25         39         18         57         67.87           4         7/1         .0772         .103         .103         .257         39         28         67         58.1           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88           1/0         6/1         .1489         .1489         .447         124         59         183         67.88           3/0         6/1         .1672         .1672         .1672         .502	(AWG or kcmil)         Individual Wires         Steel Core Cable         Complete Cable         Al Stl         Total Al Stl           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12           4         6/1         .0834         .0834         .0834         .25         39         18         57         67.87         32.12           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12           1/0         6/1         .1489         .1489         .447         124         59         183         67.88         32.12	(AWG or kcmill)         ing (Al/Stl)         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         Strength (lbs.)           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12         1190           4         6/1         .0834         .0834         .0834         .25         39         18         57         67.87         32.12         1860           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12         3550           1/0         6/1<	(AWG or kcmil)         ing (A/Stl)         Individual Wires         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         DC @ 20°C           6         6/1         .0661         .0661         .0661         .198         24         12         36         67.88         32.12         1190         .641           4         6/1         .0834         .0834         .25         39         18         57         67.87         32.12         1860         .403           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360         .399           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850         .254           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460         .251           1         6/1         .1181         .1181         .1181         .354         78         37         115         67.88         32.12         3	(AWG or kcmil)         ing (A/Stl)         Individual Wires         Steel Core Cable         Complete Cable         Al         Stl         Total         Al         Stl         Stl         Total         Al         Stl         DC @ 20°C         AC @ 20°C         AC @ 20°C         75°C           6         6/1         .0661         .0661         .198         24         12         36         67.88         32.12         1190         .641         .806           4         6/1         .0834         .0834         .25         39         18         57         67.87         32.12         1860         .403         .515           4         7/1         .0772         .103         .103         .257         39         28         67         58.1         41.9         2360         .399         .519           2         6/1         .1052         .1052         .1052         .316         62         29         91         67.9         32.1         2850         .254         .332           2         7/1         .0974         .1298         .1298         .325         62         45         107         58.12         41.88         3460         .251         .338



The ETAP Positive Real value is different from my calculated value because of the temperature at which ETAP has calculated its Resistive values. ETAP used 25 degrees C, while my hand calculations used the ACSR Resistance value is at AC 75 degrees C. The Positive Reactive values are nearly identical when comparing the ETAP value to my hand calculated on.

As for the Zero Impedence, my calculated value does not match the ETAP value because the ground wire has a different conductor core radius than the ASCR wire. Another reason is due to the ground wire being a completely different wire in ETAP than the one used for the hand calculations.

### **Design Differential Protection T2 and T3:**

This task has been postponed for ENEL 482\*

#### **Test Differential Protection T2 or T3:**

This task has been postponed for ENEL 482\*

## **Specify Protection:**

This task has been postponed for ENEL 482\*

#### **Hand verification of Fault Currents:**

\*Refer to Hand Calculations\*

\*All equations and methods were used from ENEL 472 lecture notes 2020\*

```
Bus 2 Fault 3 Phase: IAf = 1.08673 \text{ kA} \angle -67.09 ^{\circ}
Bus 3 Fault 3 Phase: IAf = 30.6613 \text{ kA} \angle -76.109 ^{\circ}
Bus 5 Fault 3 Phase: IAf = 58.46522 \text{ kA} \angle -84.96 ^{\circ}
Bus 6 Fault 3 Phase: IAf = 32.07514 \text{ kA} \angle -86.63 ^{\circ}
```

The fault values above are all hand calculated, and the magnitudes are very similar to the ETAP fault values.

```
*For the next section refer to ETAP Fault Reports* ETAP 3 Phase Bus 2 Fault = 1.034 \text{ kA} \angle -56.6 ^{\circ} ETAP 3 Phase Bus 3 Fault = 3.029 \text{ kA} \angle -69.53 ^{\circ} ETAP 3 Phase Bus 5 Fault = 58.337 \text{ kA} \angle -79.69 ^{\circ} ETAP 3 Phase Bus 6 Fault = 31.155 \text{ kA} \angle -81.12 ^{\circ}
```

#### **Cable Selection:**

The reason why I selected the [KERITE Mag. Code: 350AWG/kcmil 3/C CU] cable for both C1 and C2 was because this cable can handle the total load current if Bus 4 or Bus 3 is faulted.

#### **Protective Measures:**

For the Transmission Lines, I used the 1.5x rule for the allowable ampacity via the combined Primary FLA of Transformers 2 and 3.

For the Cables, I used the 1.5x rule for the allowable ampacity via the 200% Primary FLA as Transformer 4. Further explaining the Cable Selection task; if there is a fault on either Bus 3 or 4, a cable should be able to handle the load from both busses for there to be no stoppage in system operation.

## **Extra Notes:**

The differential protections in my ETAP single line are there for the next class of ENEL 482. This way I can recollect on where I have left off. This also applies to the HV Circuit Breaker between Bus 3 and Bus 4.