3 Model of Typical Substation

3.1 General Model

To test the model of the RSS, a generic substation and power system is modeled in EMTP. The selected substation is a 500 kV/345 kV transmission switching station, with four 500 kV transmission lines, two 500/345/34.5 kV transformers, and two 345 kV transmission lines, arranged in a breaker-and-a-half scheme. The power system is modeled to 2 busses away from the substation. This allows the testing of the region of vulnerability for all relays in the substation. Also included in the EMTP model are the necessary current transformers (CT), potential transformers (PT), and anti-aliasing filters.

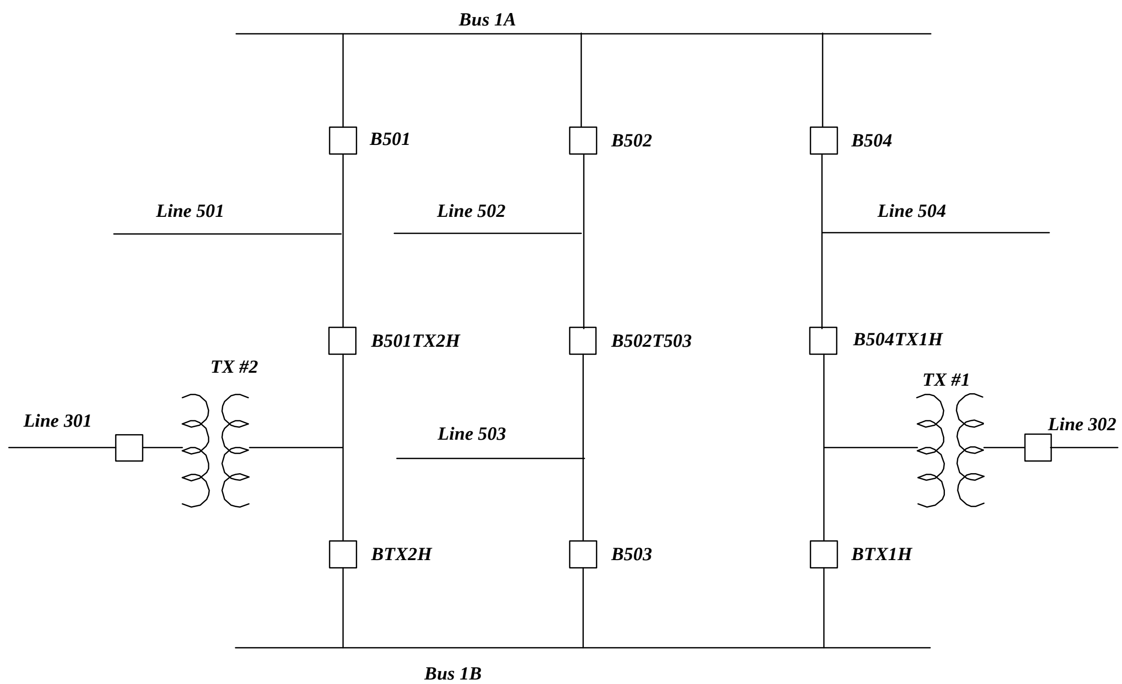

Figure 6: Substation Layout

Ideal sources with an associated equivalent impedance represent the rest of the power system. The generators have identical per-unit constants on their own base. The system is designed with the phase angles of the generaotrs lagging or leading each other to provide some pre-fault load flow.

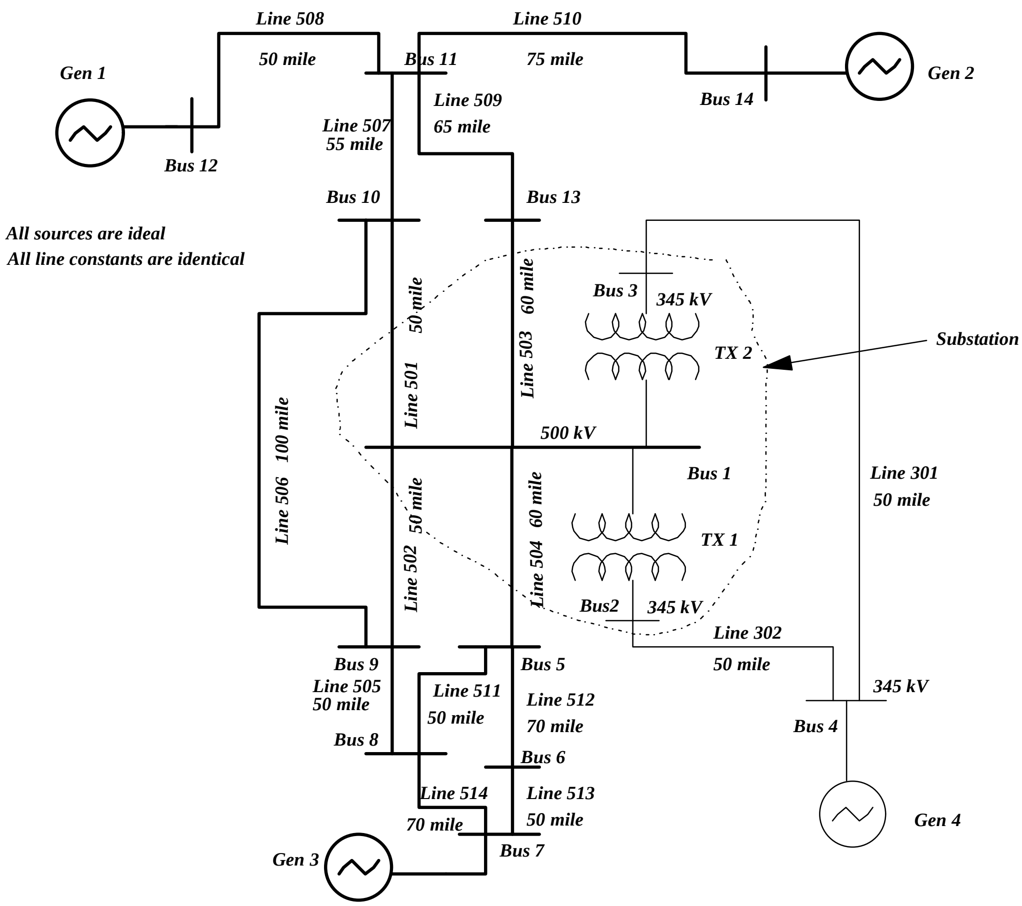

Figure 7: Power System Diagram

3.2 Substation/Power System Model in EMTP

The voltage level of all ideal sources is adjusted so the steady state pre-fault voltage at Bus 1 equal to 1 p.u. To equal a sampling rate of 12 times per cycle, samples are taken every 1.389 milliseconds. The test cases are 0.60 seconds long, which is long enough to illustrate relay operations.

3.2.1 Transmission Line Model

All the 500 kV transmission lines have identical impedance values per unit length. All the 345 kV transmission lines have identical impedance values per unit length. The lines are modeled as π-equivalent circuit sections connected in series. The π-equivalent circuit provides accurate transient information for system faults. The use of sections allows the easy placement of faults at a variety of points along the line. Most sections are 10 miles long, with a few 5 mile sections.

The line impedance and admittance values are typical values for a 800 kV flat line, used for the 500 kV lines, and a 362 kV flat line, used for the 345 kV lines.[12] The line values are transposed and converted to sequence components. The sequence components are then converted to π-equivalents using the following two equations.

$$Z_S = \frac{1}{3}(Z_0 + 2Z_1)$$

$$Z_M = \frac{1}{3}(Z_0 - Z_1)$$

The resulting π-equivalent impedance and admittance are show in Table 2 and Table 3.

Table 2: Transmission Line Impedance

	Series Impedance		π-Equivalent Impedance	
	Z_1 (Ω/mile)	Z_0 (Ω/mile)	Z_S (Ω/mile)	Z_M (Ω/mile)
345 kV	0.1019 + j0.5912	0.6160 + j1.8151	0.2733 + j0.9991	0.1714 + j0.4080
500 kV	0.1073 + j0.5350	0.1361 + j1.3485	0.1169 + j0.8061	0.0096 + j0.2712

Table 3: Transmission Line Admittance

	Shunt Admittance		π-Equivalent Admittance	
	Y_1 (μ-mhos/mile)	Y_0 (μ-mhos/mile)	Y_S (μ-mhos/mile)	Y_M (μ-mhos/mile)
345 kV	j7.2720	j4.7090	j6.4177	-j0.8543
500 kV	j8.0363	j5.4863	j7.1863	-j0.8500

3.2.2 Transformer Model

The transformers are modeled as 3 winding, Y-Δ-Y transformers, using the saturable transformer model in EMTP for harmonic restraint. Typical impedance values for a 500/345/34.5 kV, three winding transformer, are used. The leakage reactance is 12.2%, 57%, and 37.6% between 500/345, 500/34.5, 345/34.5. The magnetizing current at rated voltage is 0.058%. The saturation characteristic is defined by two additional points: a current of 0.015% at a voltage of 80%, and a current of 0.29% at a voltage of 115%.[3] Values for the saturation characteristic and winding impedance are shown in Table 4 and Table 5.

Table 4: Saturation Characteristic Data

Voltage	Current (A peak)	Flux (Vs)
80%	0.184	866.330
100%	0.710	1082.912
115%	3.552	1245.349

Table 5: Winding Impedance Data

	Impedance (%)	Base Impedance (Ω)	Impedance (Ω)
Zp	15.80 %	333.33	52.667
Zs	-3.60 %	333.33	-12.000
Zt	41.20 %	158.710	65.384

3.2.3 Ideal Source Model

The ideal sources are modeled assuming the impedance is pure inductance, the negative sequence equals the positive sequence, and that the zero sequence is ½ the positive sequence. All the generators have the same per-unit impedance. The generator voltages are adjusted until the voltage at Bus 1 (the main substation bus) is approximately 1 p.u. for normal conditions. For all sources: Z_1 = 0.15 p.u. Z_0 = 0.075 p.u. The source impedances are shown in Table 6.

Table 6: Ideal Source Impedance

			Series Impedance		π-Equivalent Impedance	
	kV Base	MVA Base	Z_1 (Ω)	Z_0 (Ω)	Z_S (Ω)	Z_M (Ω)
Generator 1	500	800	j46.87	j23.44	j39.06	-j7.81
Generator 2	500	800	j46.87	j23.44	j39.06	-j7.81
Generator 3	500	1000	j37.50	j18.75	j31.25	-j6.25
Generator 4	345	1000	j17.85	j8.93	j14.88	-j2.98

To provide some pre-fault load flow, the phase angles of the ideal sources are varied. The phase angles used are shown in Table 7.

Table 7: Ideal Source Phase Angles

Source	Relative Phase Angle (degrees)
Generator 1	-5
Generator 2	0
Generator 3	20
Generator 4	15

3.2.4 CT/PT Models

Current transformers (CT) and potential transformers (PT) are modeled as ideal transformers, with an anti-aliasing circuit added in the secondary burden circuit. CT and PT ratios are not specifically considered. This project does not concern itself with the practical relaying effects of CT saturation, and therefore can use actual current and voltage values for operation. The CT model includes a 50 ohm burden. EMTP provides secondary currents and voltages to the RSS model.

3.2.5 Anti-Aliasing Filter Model

The anti-aliasing filter is a two stage RC filter. The model is designed to work with a sampling rate of 12 times per cycle, or 720 Hz. The filter bandlimits the frequency to 350 Hz.

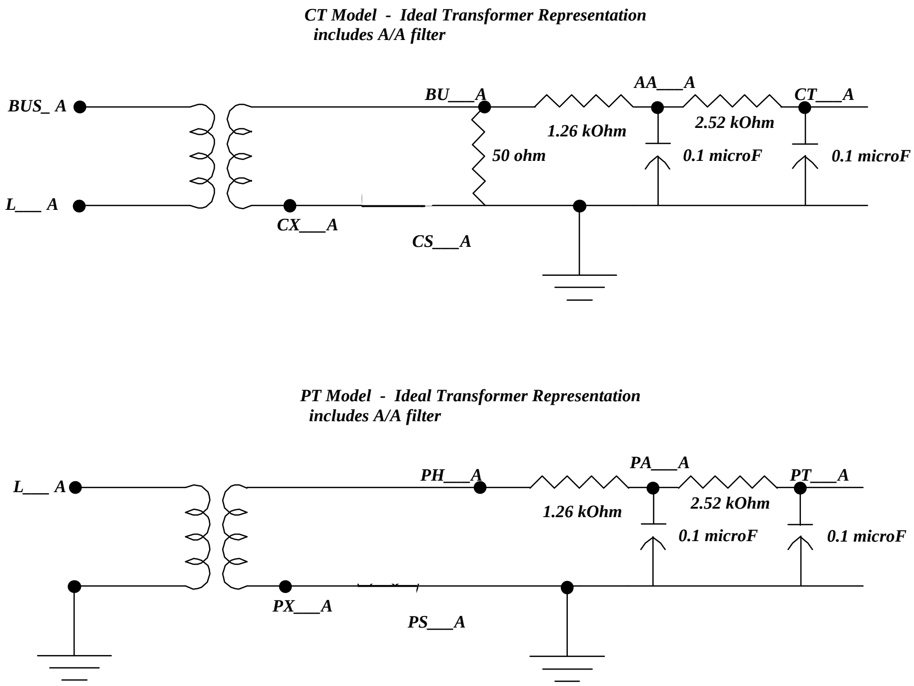

Figure 8: CT/PT Models with Anti-Aliasing Filter