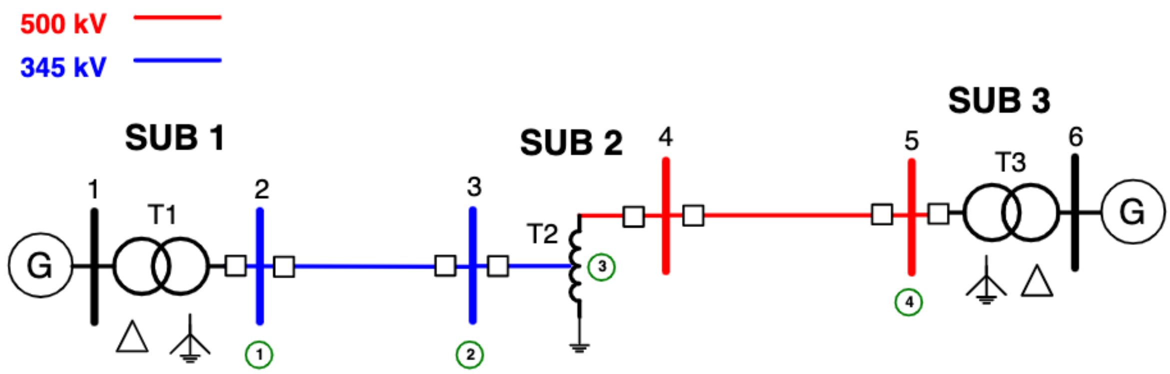
Appendix II – Example of GIC Calculations

The following section describes the steps that can be taken to compute GIC flow in a power system. The example six-bus system that will be analyzed is shown in Figure B-1. Bus numbers are shown at bus locations. Encircled numbers refer to circuit nodes that will be used later in the calculation of GIC.

Figure B-1: Example system used to compute GIC



Required system data are provided in Tables B-1 through B-3.

Table B-1: Substation location and ground grid resistance

Name	Latitude	Longitude	Grounding Resistance (Ohms)
Sub 1	33.613499	-87.373673	0.2
Sub 2	34.310437	-86.365765	0.2
Sub 3	33.955058	-84.679354	0.2

Table B-2: Transmission line information

Line	From Bus	To Bus	Length (km)	Resistance (Ohms/phase)
1	2	3	121.06	3.525
2	4	5	160.47	4.665

Table B-3: Transformer and autotransformer winding resistance values

Name	Resistance W1 (ohm/phase)	Resistance W2 (ohm/phase)
T1	0.5	N/A
T2	0.2 (series)	0.2 (common)
T3	0.5	N/A

For these calculations we use the geomagnetic coordinate system with x axis in the northward direction, y axis in the eastward direction, and z axis vertically downward. The procedure described in Appendix I can be used to compute northward and eastward distances and are shown in Table B-4.

Table B-4: Eastward and northward distance calculation results

Line	From Bus	To Bus	Northward Distance (km)	Eastward Distance (km)
1	2	3	77.306	93.157
2	4	5	-39.421	155.556

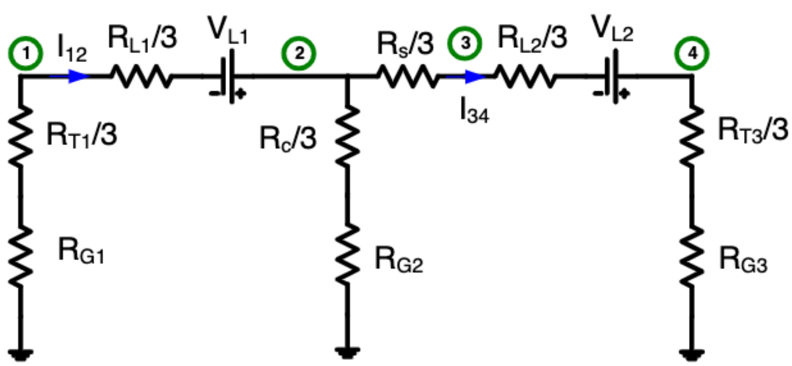
Assuming an electric field magnitude of 10 V/km with Eastward direction, the resulting induced voltages were computed using (28) and found to be as shown in Table B-5.

Table B-5: Induced voltage calculation results

Line	From Bus	To Bus	Induced Voltage (Volts)
1	2	3	931.6
2	4	5	1555.6

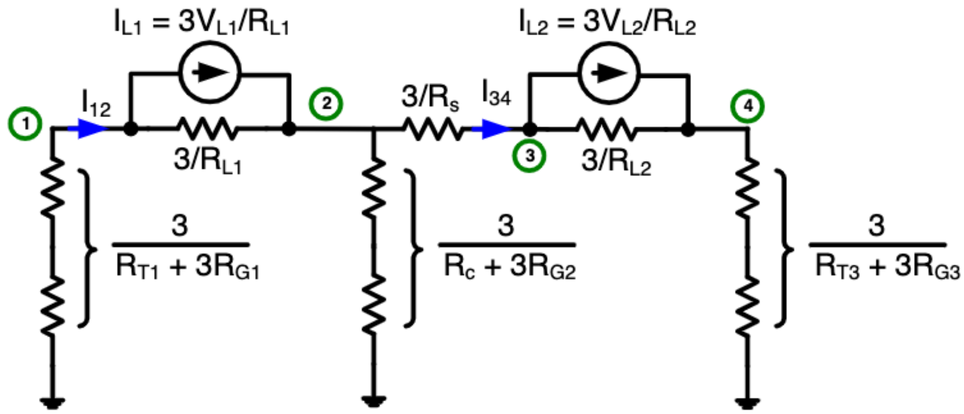
The next step is to construct an equivalent circuit of the system. An equivalent circuit of the system shown in Figure B-1 is provided in Figure B-2. Note the node names correspond to the locations indicated in Figure B-1.

Figure B-2: Equivalent circuit of example system



Although the equivalent circuit shown in Figure B-2 can be solved directly, it is more convenient to perform the calculations using nodal analysis where the voltage sources are converted to current sources, and all impedance elements are converted to their equivalent admittances. The resulting equivalent circuit is shown in Figure B-3.

Figure B-3: Equivalent circuit of example system in nodal form



The admittance matrix of the circuit shown in Figure B-3 can be readily constructed, and is shown in general form in (B.1):

$$Y = \begin{bmatrix} \frac{3}{R_{T1}+3R_{G1}} + \frac{3}{R_{L1}} & -\frac{3}{R_{L1}} & 0 & 0 \\ -\frac{3}{R_{L1}} & \frac{3}{R_s} + \frac{3}{R_{L1}} + \frac{3}{R_c+3R_{G2}} & -\frac{3}{R_s} & 0 \\ 0 & -\frac{3}{R_s} & \frac{3}{R_s} + \frac{3}{R_{L2}} & -\frac{3}{R_{L2}} \\ 0 & 0 & -\frac{3}{R_{L2}} & \frac{3}{R_{L2}} + \frac{3}{R_{T3}+3R_{G3}} \end{bmatrix} \quad \text{(B.1)}$$

Substituting the appropriate values into (B.1) results in (B.2):

$$Y = \begin{bmatrix} 3.578 & -0.851 & 0 & 0 \\ -0.851 & 19.601 & -15 & 0 \\ 0 & -15 & 15.643 & -0.643 \\ 0 & 0 & -0.643 & 3.37 \end{bmatrix} mhos \quad \text{(B.2)}$$

The resulting nodal current injections were found to be:

$$I_{L1} = \frac{3V_{L1}}{R_{L1}} = -792.83\ amps \qquad I_{L2} = \frac{3V_{L2}}{R_{L2}} = -1000.39\ amps$$

The current vector can be constructed using the nodal currents as shown in (B.3):

$$I = \begin{bmatrix} -I_{L1} \\ I_{L1} \\ -I_{L2} \\ I_{L2} \end{bmatrix} \quad \text{(B.3)}$$

The resulting node voltages are computed using Ohms Law

$$V = [Y]^{-1} I = \begin{bmatrix} 230.23 \\ 36.34 \\ 87.28 \\ -280.20 \end{bmatrix} \quad \text{(B.4)}$$

The GIC flows (all three phases combined) are computed using various relationships derived from the circuit. The results are as follows:

$$I_{T1} = V_1 \left(\frac{3}{R_{T1}+3R_{G1}}\right) = 626.5\ amps \quad \text{(B.5);}$$

$$I_{12} = I_{L1} + (V_1 - V_2)\frac{3}{R_{L1}} = -626.5\ amps \quad \text{(B.6);}$$

$$I_s = (V_2 - V_3)\frac{3}{R_s} = -762.45\ amps \quad \text{(B.7);}$$

$$I_c = V_2 \left(\frac{3}{R_c+3R_{G2}}\right) = 135.95\ amps \quad \text{(B.8);}$$

$$I_{34} = I_{L2} + (V_3 - V_4)\frac{3}{R_{L2}} = -762.45\ amps \quad \text{(B.9);}$$

$$I_{T3} = V_4 \left(\frac{3}{R_{T3}+3R_{G3}}\right) = -762.45\ amps \quad \text{(B.10).}$$

The per-phase GIC values can be determined from the results provided in (B.5)-(B.10) by dividing by 3.

Similar calculations were performed with varying orientations of the electric field. A neutral blocking device was also considered in the neutral of the autotransformer by setting the corresponding substation ground grid resistance to a very large value (1MΩ). The results of these calculations are provided in Tables B-6 and B-7. The per-phase GIC values can be determined from the results provided in Tables B-6 and B-7 by dividing the values shown by 3.

Table B-6: Results without neutral blocking device

|E| (V/km)	Orientation (degrees)	I_{T1} (amps)	I_{12} (amps)	I_s (amps)	I_c (amps)	I_{34} (amps)	I_{T3} (amps)
10	0	-408.8	408.8	-126.5	535.3	-126.5	-126.5
10	30	-667.9	667.9	272.5	395.4	272.5	272.5
10	60	-748.1	748.1	598.5	149.6	598.5	598.5
10	90	-627.8	627.8	764.1	-136.3	764.1	764.1
10	120	-339.3	339.3	724.0	-385.7	724.0	724.0
10	150	40.2	-40.2	491.6	-531.7	491.6	491.6
10	180	408.8	-408.8	126.5	-535.3	126.5	126.5

Table B-7: Results with neutral blocking device installed in the neutral of the autotransformer

|E| (V/km)	Orientation (degrees)	I_{T1} (amps)	I_{12} (amps)	I_s (amps)	I_c (amps)	I_{34} (amps)	I_{T3} (amps)
10	0	-107.3	107.3	107.3	0.00	107.3	107.3
10	30	-445.2	445.2	445.2	0.00	445.2	445.2
10	60	-663.8	663.8	663.8	0.00	663.8	663.8
10	90	-704.6	704.6	704.6	0.00	704.6	704.6
10	120	-556.5	556.5	556.5	0.00	556.5	556.5
10	150	-259.4	259.4	259.4	0.00	259.4	259.4
10	180	107.34	-107.34	-107.31	0.00	-107.31	-107.31