Military Institute of Science and Technology (MIST)

Dept. of Electrical, Electronic and Communication Engineering

EECE 306: Power System Laboratory

<u>Group – 3</u>

Open Ended Lab Project

Simulation and Load Flow Study of a 5-bus power system

Group no - 3

Group Members

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Question: Fig. 1 shows a 5-bus power system. Table 1 and Table-2 are the bus data and transmission line data based on 10 kV base. Consider Bus-1 as the swing bus.

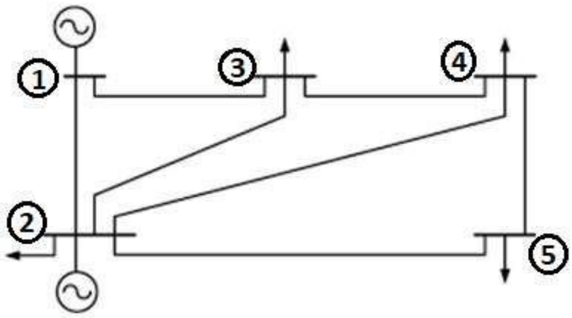

Table-1: Bus Data

Bus No	Bus Voltage	Generation		Load	
		MW	MVar	MW	MVar
1	1.06+j0.0	0	0	0	0
2	1.0+j0.0	40	30	20	10
3	1.0+j0.0	0	0	45	15
4	1.0+j0.0	0	0	40	5
5	1.0+j0.0	0	0	60	10

Table-2: Transmission Line Data

Line	Line Impedance		Line Charging
	R per unit	X per unit	
1-2	0.02	0.06	0.0+j0.03
1-3	0.08	0.24	0.0+j0.025
2-3	0.06	0.25	0.0+j0.02
2-4	0.06	0.18	0.0+j0.02
2-5	0.04	0.12	0.0+j0.015
3-4	0.01	0.03	0.0+j0.01
4-5	0.08	0.24	0.0+j0.025

Tasks:

1. Perform load flow studies of the power system of Fig. 1 to identify slack bus (Bus no. 1) power and bus voltages (Bus no. 2 to Bus no. 3). Compute line flows and line losses also. [Use **ETAP** simulation software]
2. Verify the results obtained in Task no. 1 by writing a Matlab code adopting any load flow analysis method.
3. Make an under voltage event in Bus-4 and apply any technique to overcome the under voltage problem of the system. (Consider, below 85% to be undervoltage for any bus) .
4. Initiate an unsymmetrical fault (L-G, L-L-G, L-L) in the transmission lines. Group-1 initiate fault in line 1-3, Group-2 initiate fault in line 2-3, Group-3 initiate fault in line 2-4 and Group-4 initiate fault in line 2-5. Observe the change in the results of the load flow studies after the fault initiation.

Solution :

1. Perform load flow studies of the power system of Fig. 1 to identify slack bus (Bus no. 1) power and bus voltages (Bus no. 2 to Bus no. 3). Compute line flows and line losses also. [Use ETAP simulation software]

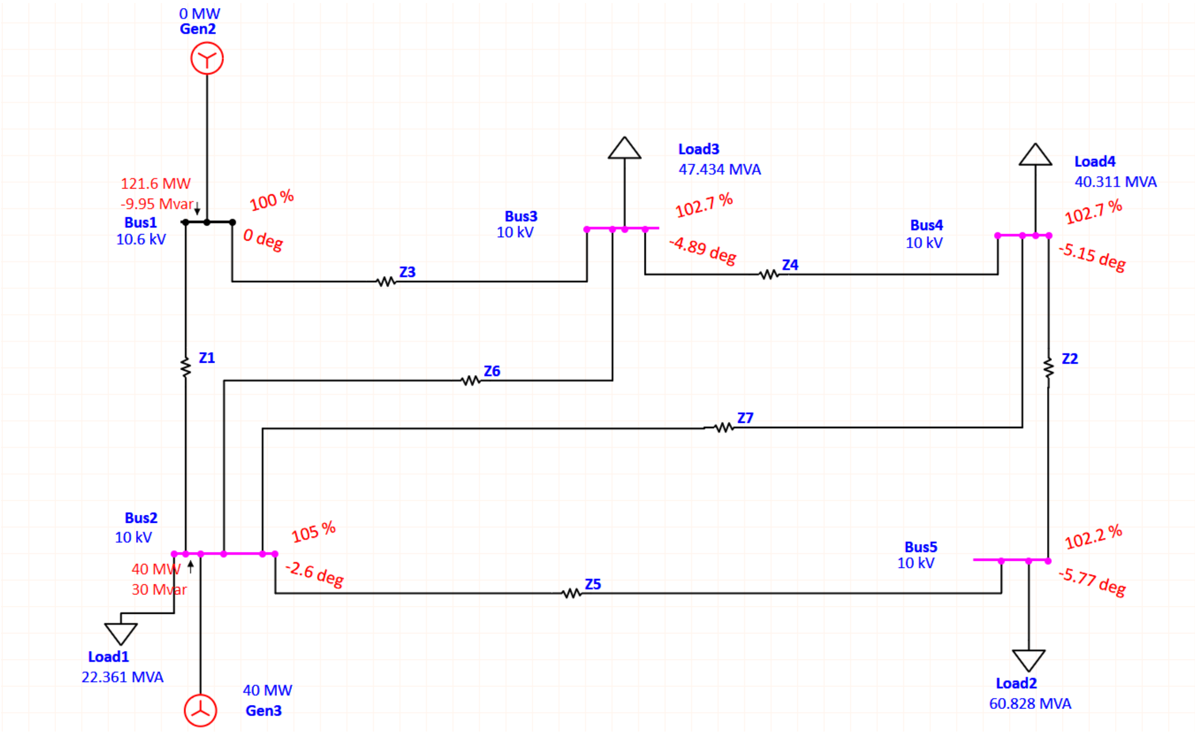

Figure 2: Identification of Generation Power & Bus Voltages

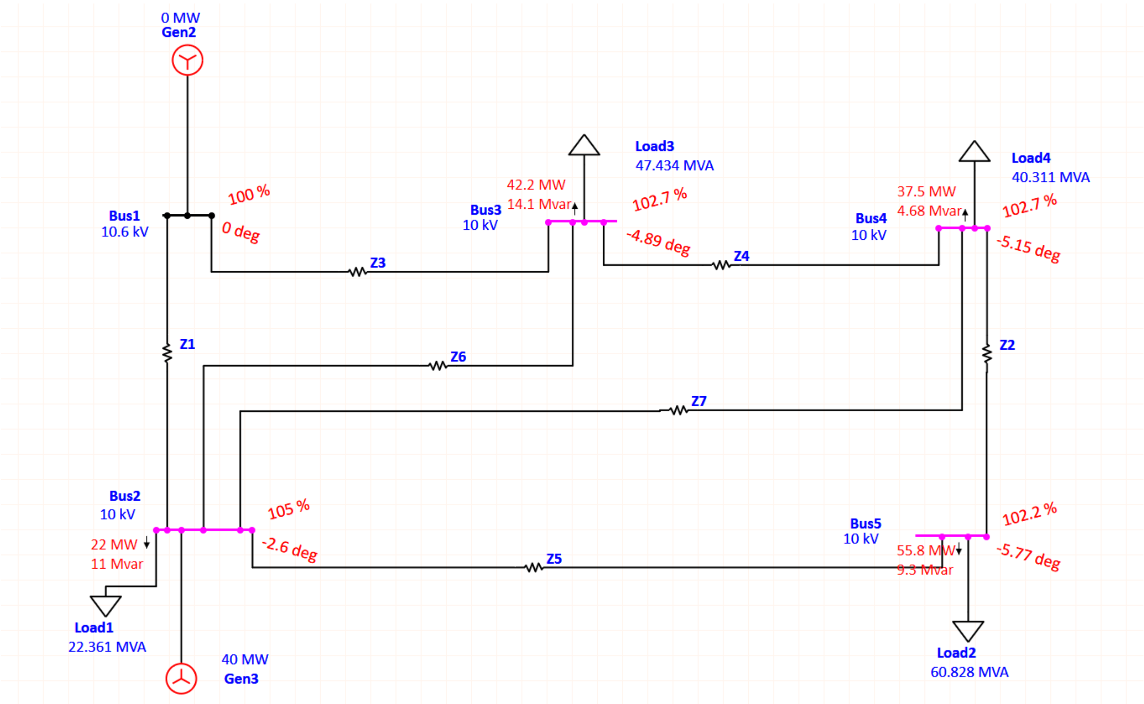

Figure 1: Identification of Load Power & Bus Voltages

Table 1: Identification of Generation Power , Load Power & Bus Voltages

Bus No.	Generation		Load		Bus Voltage	
	MW	MVAr	MW	MVAr	Voltage(per unit)	Angle
1	**121.6**	**-9.95**	0	0	1.06	0
2	40	30	22	11	1.05	-2.6
3	0	0	42.2	14.1	1.027	-4.89
4	0	0	37.5	4.68	1.027	-5.15
5	0	0	55.8	9.3	1.022	-5.77

Observation of Line flow & Line losses

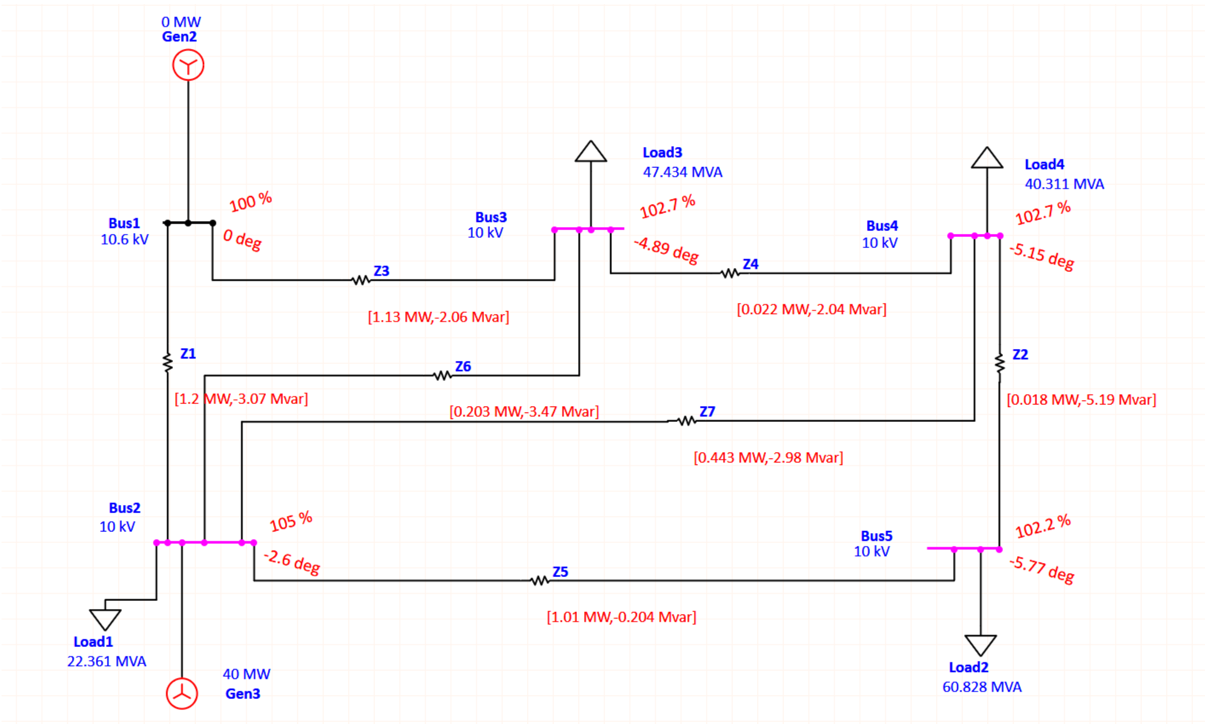

Figure 3: Computation of Line flow & Line losses

2. Verify the results obtained in Task no. 1 by writing a MATLAB code adopting any load flow analysis method.

Team Introduction

```
%{
Military Institute of Science and Technology (MIST)
Dept. of Electrical, Electronic and Communication Engineering
EECE 306: Power System Laboratory
Open Ended Lab Project

Group: 03

%}
```

Memory Initialization

```
clc; clear; close all;
```

1.Data Initialization

```
%% Segment 1: Data Initialization
bus_data = [1 1.06 0.0 0 0;  % Bus data: [Bus, Voltage (p.u.), Angle, P (MW), Q (MVAR)]
            2 1.00 0.0 20 20;
            3 1.00 0.0 -45 -15;
            4 1.00 0.0 -40 -5;
            5 1.00 0.0 -60 -10];

line_data = [1 2 0.02 0.06 0.03;  % Line data: [From Bus, To Bus, R, X, B]
             1 3 0.08 0.24 0.025;
             2 3 0.06 0.25 0.02;
             2 4 0.06 0.18 0.02;
             2 5 0.04 0.12 0.015;
             3 4 0.01 0.03 0.01;
             4 5 0.08 0.24 0.025];

V_base = [10.6; 10; 10; 10; 10];  % Base voltages in kV
```

2.Y-bus Matrix Calculation

```
%% Segment 2: Y-bus Matrix Calculation
n_lines = size(line_data, 1);  % Number of lines
n_buses = size(bus_data, 1);   % Number of buses
Y_bus = zeros(n_buses);        % Initialize Y-bus matrix

for i = 1:n_lines
    from = line_data(i, 1);  % From bus
    to = line_data(i, 2);    % To bus
    Z = line_data(i, 3) + 1i * line_data(i, 4);  % Impedance
    Y = 1 / Z;  % Admittance
    B = 1i * line_data(i, 5);  % Shunt admittance

    Y_bus(from, to) = Y_bus(from, to) - Y;  % Off-diagonal elements
    Y_bus(to, from) = Y_bus(from, to);  % Symmetric update
    Y_bus(from, from) = Y_bus(from, from) + Y + B;  % Diagonal elements
    Y_bus(to, to) = Y_bus(to, to) + Y + B;  % Diagonal elements
end
```

```
disp('Y-bus Matrix:');
disp(Y_bus);  % Display Y-bus matrix
```

Output:

```
Command Window
Y-bus Matrix:
  Columns 1 through 4

   6.2500 -18.6950i  -5.0000 +15.0000i  -1.2500 + 3.7500i   0.0000 + 0.0000i
  -5.0000 +15.0000i  10.0744 -31.1971i  -0.9077 + 3.7821i  -1.6667 + 5.0000i
  -1.2500 + 3.7500i  -0.9077 + 3.7821i  12.1577 -37.4771i -10.0000 +30.0000i
   0.0000 + 0.0000i  -1.6667 + 5.0000i -10.0000 +30.0000i  12.9167 -38.6950i
   0.0000 + 0.0000i  -2.5000 + 7.5000i   0.0000 + 0.0000i  -1.2500 + 3.7500i

  Column 5

   0.0000 + 0.0000i
  -2.5000 + 7.5000i
   0.0000 + 0.0000i
  -1.2500 + 3.7500i
   3.7500 -11.2100i

>> |
```

3.Power Flow Calculation (Gauss-Seidel)

```
%% Segment 3: Power Flow Calculation (Gauss-Seidel)
base_power = 100;  % Base power in MVA
V = bus_data(:, 2);  % Initial voltage guess
P = bus_data(:, 4);  % Real power demand
Q = bus_data(:, 5);  % Reactive power demand
tolerance = 1e-5;  % Convergence tolerance
max_iterations = 100;  % Maximum iterations
error = 1;  % Initialize error
iteration = 0;  % Initialize iteration count

while error > tolerance && iteration < max_iterations
    iteration = iteration + 1;  % Increment iteration
    V_prev = V;  % Store previous voltages

    for i = 2:n_buses  % Skip slack bus
        sum_term = 0;  % Initialize sum term
        for j = 1:n_buses
            if i ~= j
                sum_term = sum_term + Y_bus(i, j) * V(j);  % Summation
            end
        end
        V(i) = ((P(i) - 1i * Q(i)) / base_power) / conj(V(i)) - sum_term;  %
Voltage update
        V(i) = V(i) / Y_bus(i, i);  % Normalize
    end

    error = max(abs(V - V_prev));  % Update error
end

disp('Converged Voltages (p.u.):');
```

```
disp(V);  % Display converged voltages
```

Output:

```
Command Window
Converged Voltages (p.u.):
   1.0600 + 0.0000i
   1.0464 - 0.0503i
   1.0187 - 0.0928i
   1.0179 - 0.0978i
   1.0118 - 0.1093i

>> |
```

4.Voltage Magnitudes and Angles

```
%% Segment 4: Voltage Magnitudes and Angles
voltage_magnitude = abs(V);  % Magnitude of voltages
voltage_angle = angle(V) * 180 / pi;  % Angle of voltages

fprintf('Bus Voltages (p.u.) and Angles (degrees):\n');
for i = 1:n_buses
    fprintf('Bus %d: |V| = %.4f p.u., Angle = %.2f°\n', i, voltage_magnitude(i),
voltage_angle(i));  % Print results
end
```

Output:

```
Command Window
Bus Voltages (p.u.) and Angles (degrees):
Bus 1: |V| = 1.0600 p.u., Angle = 0.00°
Bus 2: |V| = 1.0476 p.u., Angle = -2.75°
Bus 3: |V| = 1.0229 p.u., Angle = -5.21°
Bus 4: |V| = 1.0226 p.u., Angle = -5.49°
Bus 5: |V| = 1.0177 p.u., Angle = -6.17°
>> |
```

5.Real Voltages in kV

```
%% Segment 5: Real Voltages in kV
V_real = voltage_magnitude .* V_base;  % Calculate real voltages in kV

fprintf('\nReal Voltages in kV:\n');
for i = 1:n_buses
    fprintf('Bus %d: Voltage = %.4f kV, Angle = %.2f°\n', i, V_real(i),
voltage_angle(i));  % Print results
end
```

Output:

```
Command Window

Real Voltages in kV:
Bus 1: Voltage = 11.2360 kV, Angle = 0.00°
Bus 2: Voltage = 10.4759 kV, Angle = -2.75°
Bus 3: Voltage = 10.2291 kV, Angle = -5.21°
Bus 4: Voltage = 10.2256 kV, Angle = -5.49°
Bus 5: Voltage = 10.1766 kV, Angle = -6.17°
>>
```

6.Generation and Load Power at Each Bus

```
%% Segment 6: Generation and Load Power at Each Bus
fprintf('\nGeneration and Load Power at Each Bus:\n');
for i = 1:n_buses
    S_bus = V(i) * conj(Y_bus(i, :) * V);  % Calculate complex power
    P_bus = real(S_bus) * base_power;  % Real power
    Q_bus = imag(S_bus) * base_power;  % Reactive power

    if P_bus >= 0
        fprintf('Bus %d: Generation Power = %.2f MW, Reactive Power = %.2f
MVAR\n', i, P_bus, Q_bus);
    else
        fprintf('Bus %d: Load Power = %.2f MW, Reactive Power = %.2f MVAR\n', i, -
P_bus, -Q_bus);
    end
end
```

Output:

```
Command Window

Generation and Load Power at Each Bus:
Bus 1: Generation Power = 129.57 MW, Reactive Power = -7.06 MVAR
Bus 2: Generation Power = 20.01 MW, Reactive Power = 20.00 MVAR
Bus 3: Load Power = 44.97 MW, Reactive Power = 15.00 MVAR
Bus 4: Load Power = 40.00 MW, Reactive Power = 5.00 MVAR
Bus 5: Load Power = 60.00 MW, Reactive Power = 10.00 MVAR
>>
```

3.Make an under-voltage event in Bus-4 and apply any technique to overcome the under-voltage problem of the system. (Consider, below 85% to be undervoltage for any bus)

Answer:

An under-voltage event occurs when the voltage at a bus falls below 85% of its nominal value. This can be caused by system overloading, faults, weak grid connections, high line impedance, or unbalanced loads. Under-voltage can lead to equipment malfunction, reduced system stability, and power quality issues.

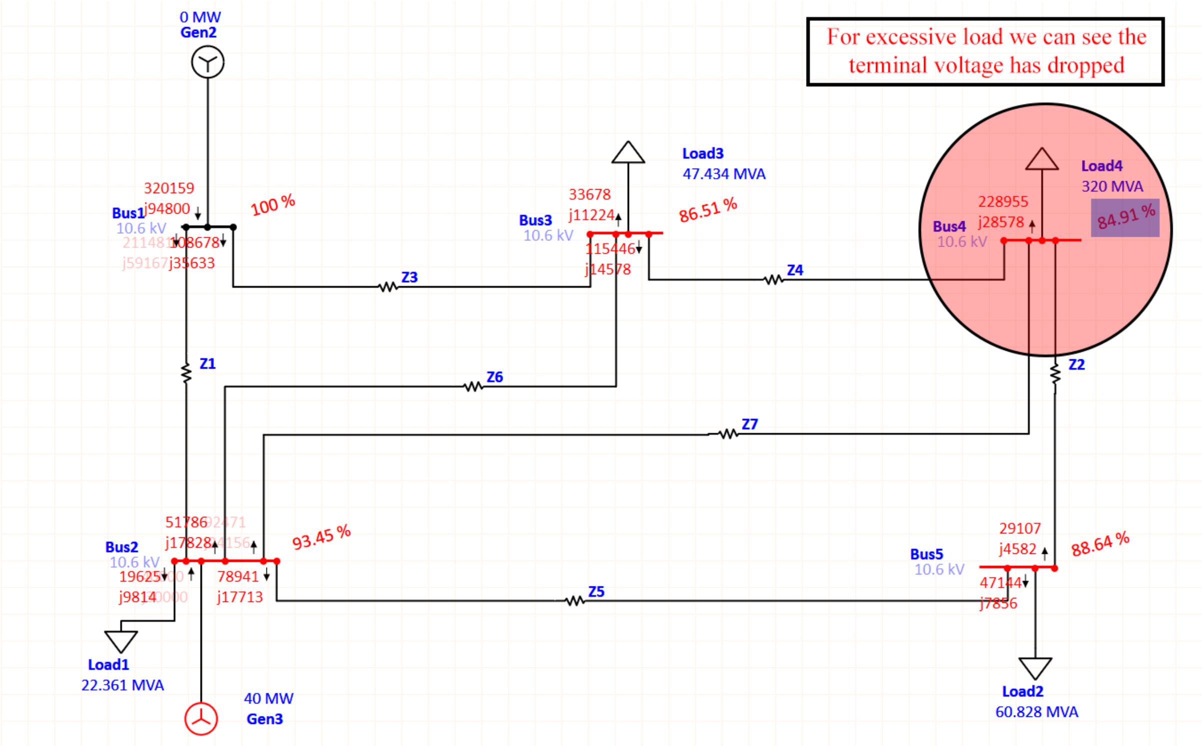

Figure 4: Increasing the load

Techniques to Overcome Under-Voltage

Reactive Power Compensation:

- Shunt Capacitors
- Synchronous Condensers
- Static VAR Compensators (SVC)

Adding Static Shunt Capacitor Bank

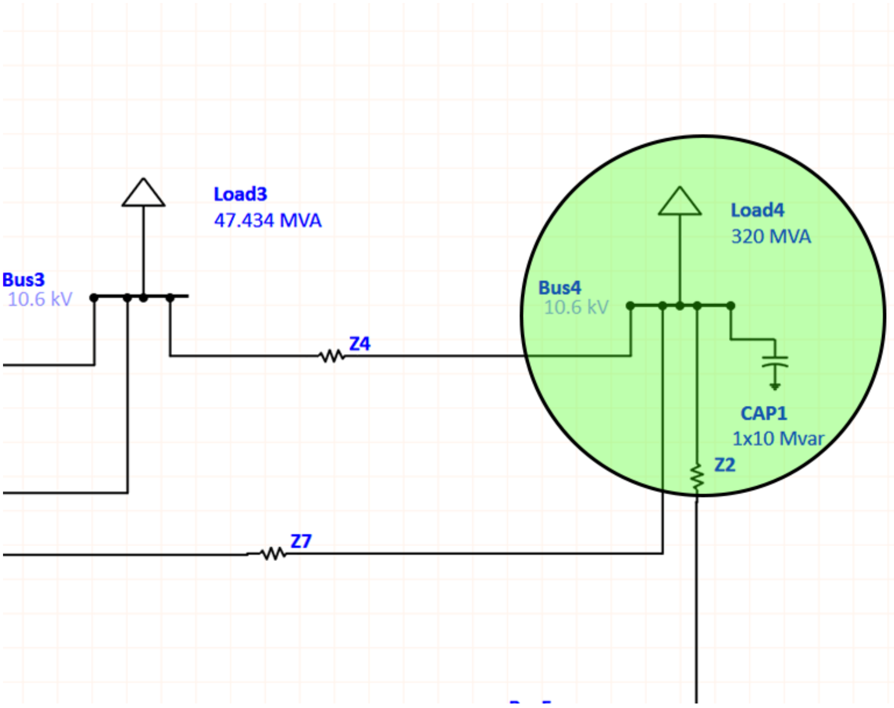

Figure 5: Adding Capacitor

Adjusting Values:

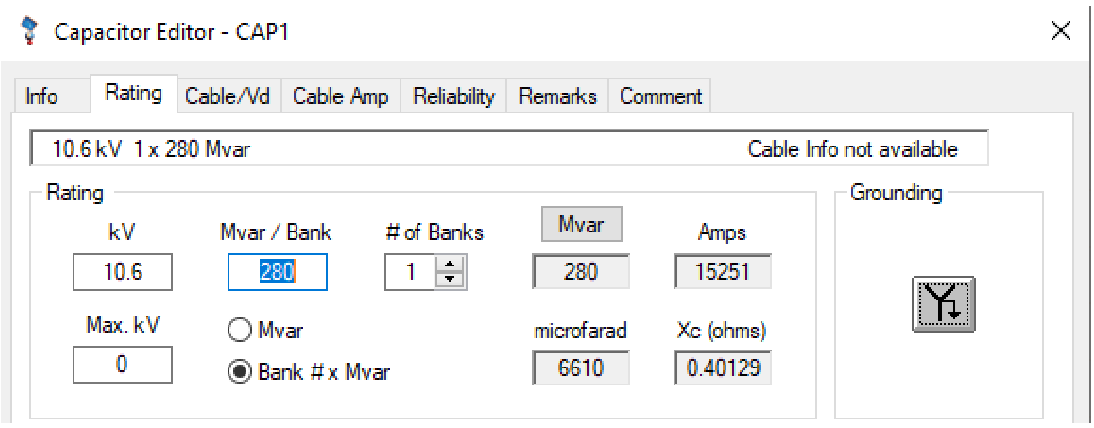

Figure 6 Adjusting The values of Capacitor

After adjusting proper values

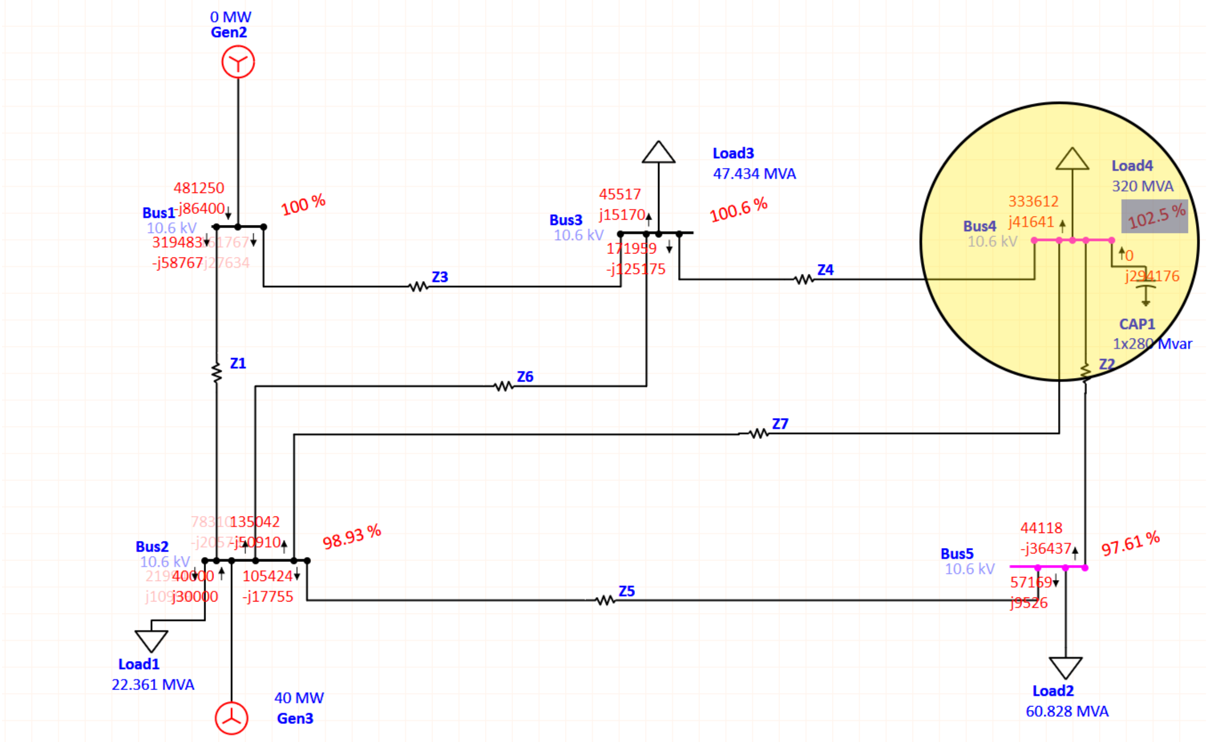

Figure 7: The Adjusted terminal voltage

Adding a capacitor is an effective solution to mitigate under-voltage events. Capacitors inject reactive power (VAR) into the system, which helps to support voltage levels by reducing the overall reactive power demand on the network. This improves voltage stability, compensates for reactive power losses, and helps maintain the voltage within acceptable limits, preventing under-voltage conditions.

4. Initiate an unsymmetrical fault (L-G, L-L-G, L-L) in the transmission lines. Group-1 initiate fault in line 1-3, Group-2 initiate fault in line 2-3, Group-3 initiate fault in line 2-4 and Group-4 initiate fault in line 2-5. Observe the change in the results of the load flow studies after the fault initiation.

<u>Group-3 initiate fault in line 2-4</u>

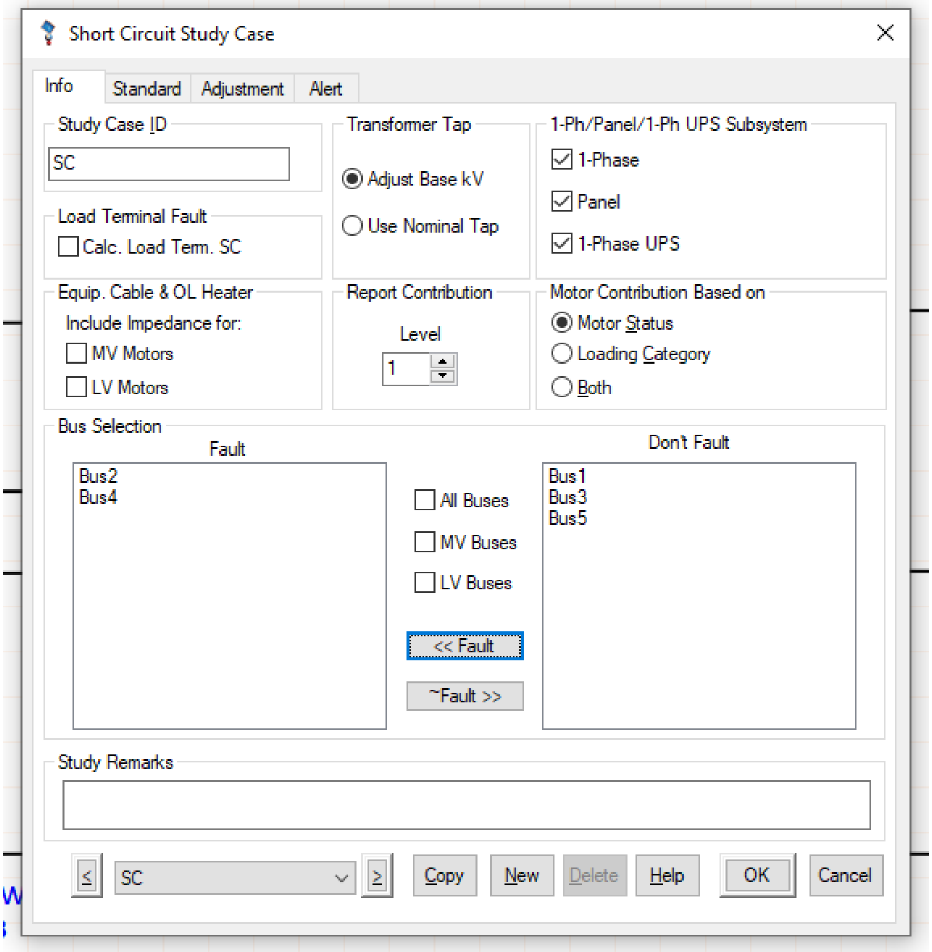

Figure 8: Fault in Bus 2 & Bus 4

Observation 2: L-L

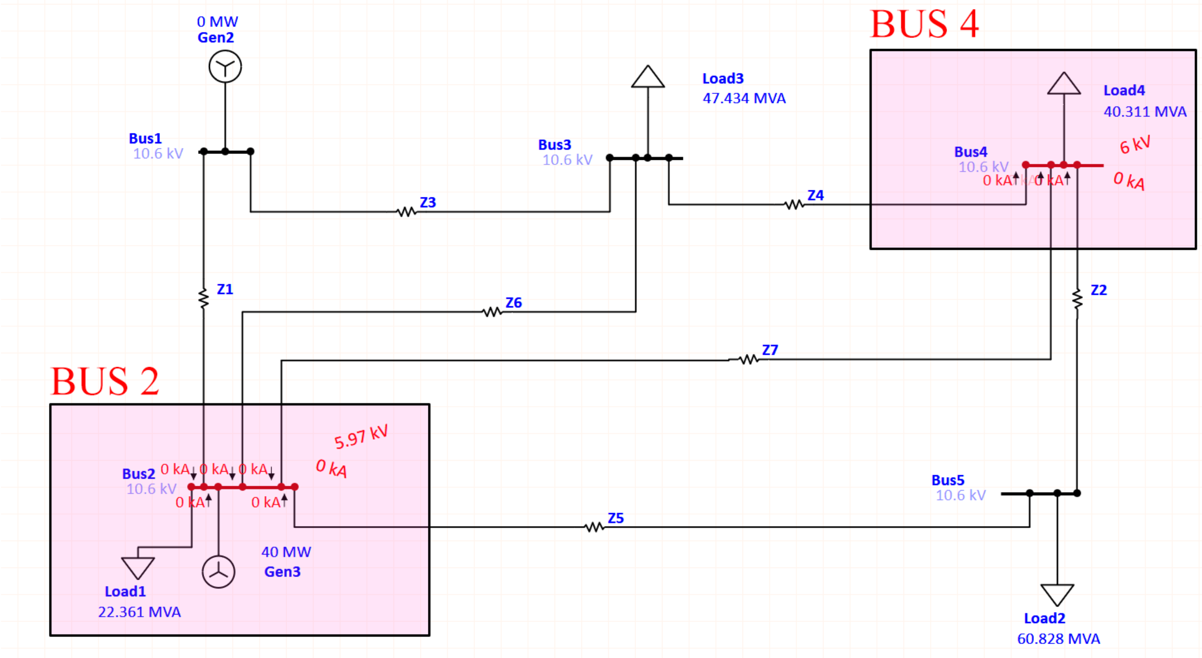

Figure 9: Line to Line fault

Observation 2: L-G

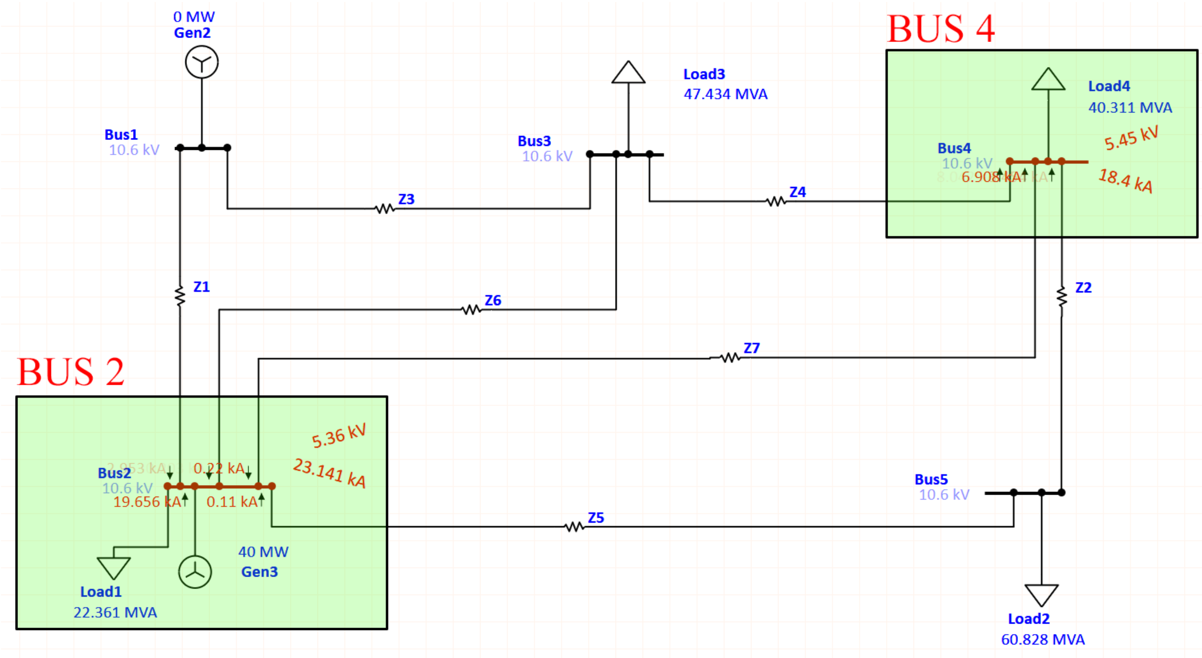

Figure 10: Line to Ground fault

Observation 3 : L-L-G

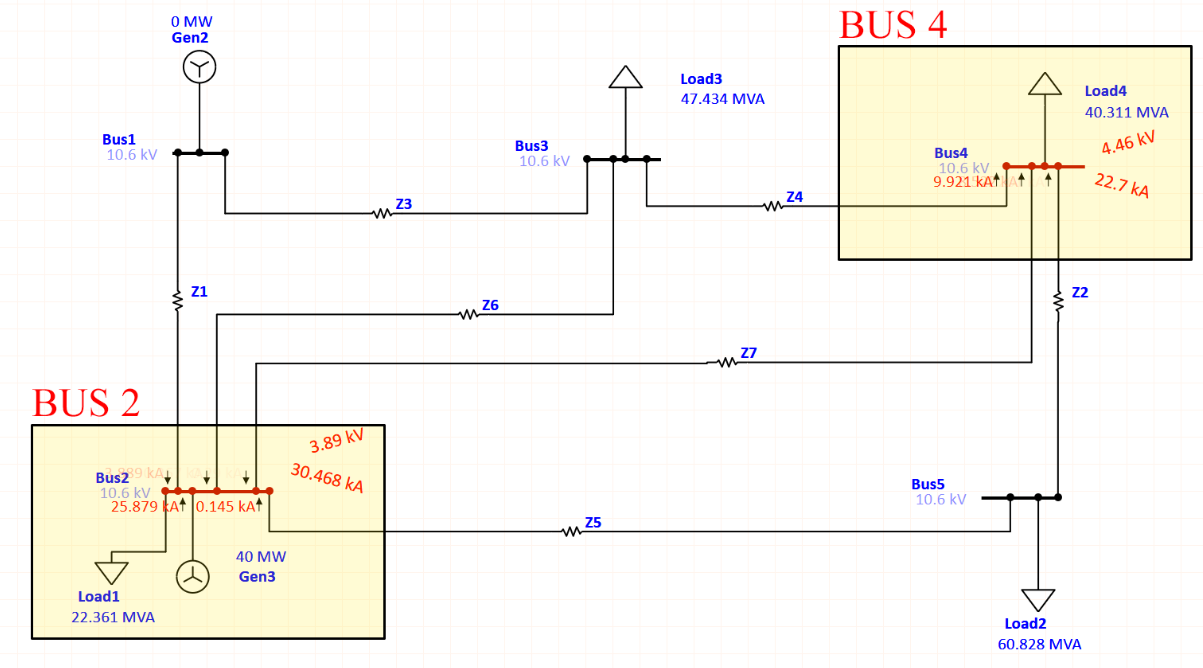

Figure 11: Double Line-to-Ground Fault

Undervoltage happens when the voltage in an electrical system drops below the normal range, which can disrupt the proper functioning of electrical devices and appliances. Power systems aim to keep voltage within a specific range to ensure everything operates smoothly. Several factors can lead to undervoltage, including:

- **System Faults**: Issues like short circuits, equipment failures, or transformer problems can cause voltage levels to drop suddenly.
- **Overloading**: When the demand for electricity exceeds the system's capacity, particularly during peak usage times or when many high-power devices are used at once, voltage can fall.
- **Voltage Regulation Issues**: If voltage regulating devices are malfunctioning or incorrectly adjusted, they may not maintain the required voltage levels.
- **Long Transmission Lines**: As electricity travels long distances, it can lose voltage due to resistance and other factors, resulting in undervoltage at the destination.
- **Grid Instability**: Sudden changes in demand, network faults, or insufficient generation can create instability in the power grid, leading to voltage fluctuations.

To tackle undervoltage issues and improve the power factor, several effective methods can be employed:

- **Static Capacitor Bank**: These devices, also known as power factor correction capacitors, help to offset reactive power, which reduces voltage drops and boosts system efficiency. By regulating voltage and minimizing the demand for reactive power, they can improve overall system performance. They can be installed in parallel or series, depending on the needs of the system.

- **Synchronous Condenser**: A synchronous motor that runs without a load can act as a synchronous condenser. By maintaining an overexcited field, it injects reactive power into the system, which enhances the power factor, stabilizes voltage, and supports overall system stability.
- **Transformer Tapping**: Although transformer tapping doesn't directly improve the power factor, it helps regulate voltage levels. By keeping the voltage stable, transformer taps can indirectly influence the power factor, reducing fluctuations caused by varying loads.

By using these techniques, we can effectively address undervoltage situations and ensure a more reliable and efficient electrical system.

Reference:

Book- Hadi Sadat (chap-6), VK Metha
Basic of ETAP from Youtube