Military Institute of Science and Technology

Department of Electrical Electronic and Communication Engineering

Open Ended Lab Project

Load Flow Analysis of a 5-Bus Power System Using ETAP and MATLAB

Course Code	EECE - 306
Course Title	Power System I Laboratory

Group Number 1

Group Members	
Name	**ID**
Md. Raisul Islam	202216062
Pretom Das	202216072
Nazmul Hasan	202216069
Sabyasachi Monem	202216077
Samiha Tabassum Mehreen	202216083
Tanvir Ahammed Rahat	202216103
Uddhab Saha Roy	202216110
Tanzid Ahmed	202216104
Shifat Shahariar	202216210
Md. Reyaz Uddin	202216211
Zarin Tasnim Zim	202116162
Tashnova Elahi	202116170

Table of Contents

Objectives

- **Conduct Load Flow Analysis:** Calculate bus voltages, slack bus power, line flows, and system losses for a 5-bus power system**.**
- **Mitigate Undervoltage:** Simulate undervoltage and restore stability using shunt capacitors.
- **Control Power Flow:** Adjust power flow using transformers to optimize distribution.
- **Perform Fault Analysis:** Simulate unsymmetrical faults (L-G, L-L, L-L-G) and evaluate system impact.

Introduction

Power systems are the backbone of modern electrical grids, and their efficiency and reliability depend heavily on accurate load flow analysis. A well-executed load flow study not only ensures optimal power distribution but also helps in diagnosing potential issues such as voltage drops, power losses, and system instability. In this project, we focus on the simulation and analysis of a 5-bus power system, leveraging both ETAP software and MATLAB to explore various performance metrics of the system. The 5-bus network, a standard model used for educational and research purposes, provides an ideal platform to study key parameters including bus voltages, slack bus power, transmission line flows, and system losses.

The simulation involves critical tasks such as identifying and addressing undervoltage conditions, using shunt capacitors for voltage support, and controlling power flow through transformers. Additionally, the system's behavior under fault conditions, including unsymmetrical faults like line-to-ground (L-G) and line-to-line (L-L), is analyzed. By using ETAP for real-time simulation and MATLAB for verification through the Gauss-Seidel method, the project offers a comprehensive approach to understanding and optimizing the performance of power systems under various operational scenarios. This dual-method approach ensures that the findings are robust, reliable, and reflective of real-world power system behavior.

Literature Review

Load Flow Analysis Methods:
Load flow analysis is critical for determining power distribution, voltages, and system stability in electrical grids. Early methods like *Gauss-Seidel* are simple but slow to converge, while the *Newton-Raphson* method offers faster convergence with higher accuracy. The *Fast Decoupled Load Flow* method is preferred for large systems due to its efficiency.

Software Tools:
Modern software like ETAP and PSS/E are extensively used for load flow and fault analysis, providing powerful simulation tools for real-time system behavior. MATLAB is also popular for validating load flow results, allowing for customized algorithm implementations, such as the Gauss-Seidel method.

Fault Analysis:
Unsymmetrical faults, such as line-to-ground (L-G) and line-to-line (L-L), are major concerns in power systems. Anderson's work on faulted systems highlights the need for robust fault detection and mitigation techniques to protect system stability.

Renewable Energy Integration:
The inclusion of renewable energy sources like wind and solar complicates load flow analysis due to their intermittent nature. Studies highlight the importance of detailed load flow analysis to manage voltage stability in systems with high renewable penetration.

Given Task:
A 5-bus power system shown in Fig-1 (10 kV base). Consider Bus-1 as the swing bus.

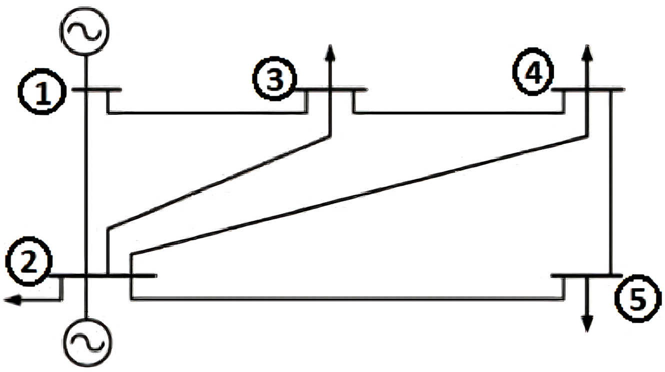

Fig 1: Single line diagram for a 5-bus power system.

Table 1: Bus data

Bus No.	Voltage	Generation		Load	
		Generation (MW)	Generation (MVAR)	Load (MW)	Load (MVAR)
1	1.06+ j0.0	0	0	0	0
2	1.00+ j0.0	40	30	20	10
3	1.00+ j0.0	0	0	45	15
4	1.00+ j0.0	0	0	40	5
5	1.00+ j0.0	0	0	60	10

Table 2: Transmission Line Data

Line	Line impedance		Line Charging (B)
	Impedance(R) per unit	Impedance (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

<u>Task 1</u>

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**]**

Solution:

A load flow analysis was performed on the 5-bus power system using simulation software "**ETAP** " Simulation diagrams of the given 5-bus system are given below:

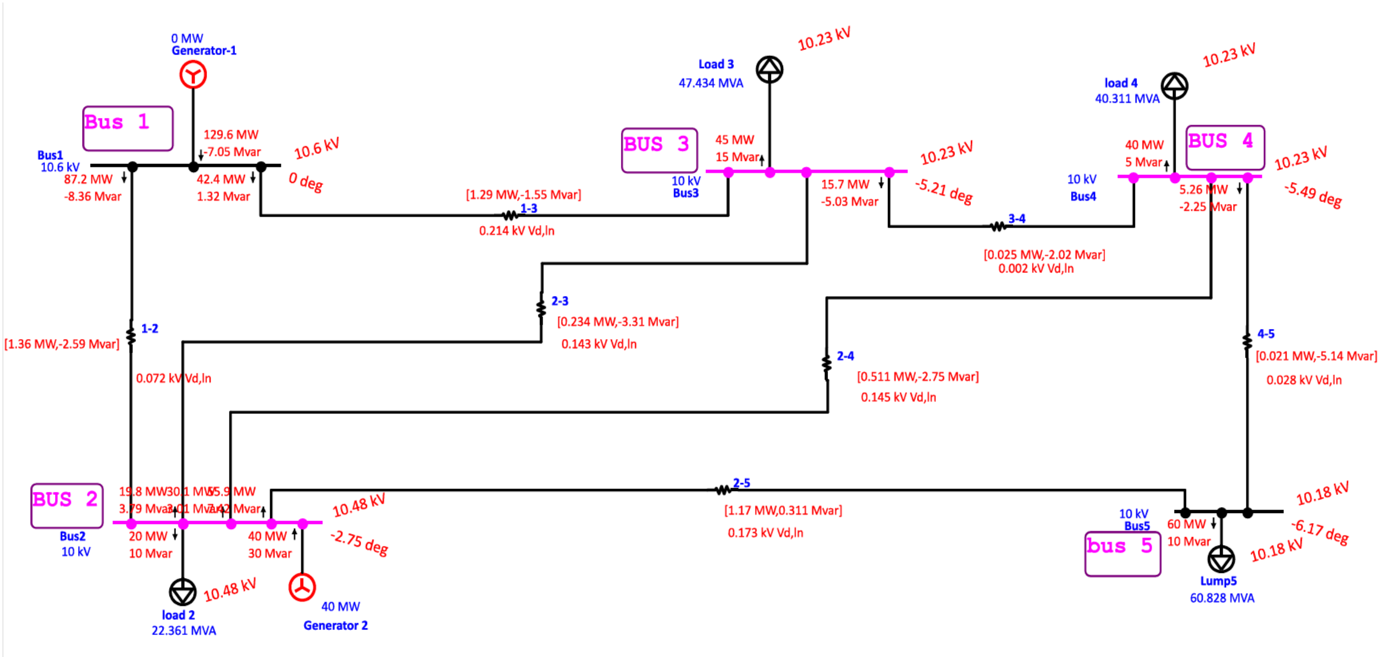

Fig 2: Simulation diagram for 5-bus power system.

We conducted a simulation of a 5-bus power system using the values provided in Table 1 and Table 2. For the line charging or susceptance (B) data, we assumed that the susceptance values in Table 2 were fully given and used them as provided. After running the simulation, we determined key parameters such as bus voltages, power generation, line flows, and system losses.

In this analysis, Bus-1 was designated as the **slack bus**, with a base voltage of 10 kV. The load flow analysis revealed that the Real power at the slack bus is **129.6 MW**, and the Reactive power is **-8.36 MVAR**. The bus voltages for Bus 2 to Bus 3 were calculated as 1.048 PU at an angle of -2.75 degrees to 1.023 PU at an angle of -5.21 degrees, respectively.

Table 3: Bus power and bus voltages

Bus No.	Bus Voltage		Generation		Load	
	PU	Angle	MW	MVAR	MW	MVAR
1	1.06	0	129.6	-7.05	0	0
2	1.048	-2.75	40	30	20	10
3	1.023	-5.21	0	0	45	15
4	1.023	-5.49	0	0	40	5
5	1.018	-6.17	0	0	60	10

Table 4: Line flows and line losses

Line	1st Bus terminal near From		2nd Bus terminal near To		Line losses	
	MW	MVAR	MW	MVAR	Losses (MW)	Losses (MVAR)
1-2	87.2	-8.36	85.84	-5.77	1.36	-2.59
1-3	42.4	1.32	41.11	2.87	1.29	-1.55
2-3	19.8	3.79	19.566	7.1	0.234	-3.31
2-4	30.1	3.01	29.59	5.76	0.51	-2.75
2-5	55.9	2.74	54.73	2.429	1.17	0.311
3-4	15.7	-5.03	15.675	-3.01	0.025	-2.02
4-5	5.26	-2.25	5.239	2.89	0.021	-5.14

<u>Task 2:</u>

Verify the results obtained in Task No. 1 by writing a **Matlab code** adopting any load flow analysis method.

Answer:

A MATLAB code was written to verify the results of Task 1, using the Gauss-Seidel method for load flow analysis. The code calculates bus voltages, line flows, and losses for the 5-bus system. The results match the previous simulation, confirming the accuracy of the load flow study.

MATLAB CODE

```
clc
clear all
close all
% bus line from  to   R        X      line charge/B
   lidata= [1    2   0.02     0.06          0.03
            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] ;


nf=(lidata(:,1));              %line form bus
nt=(lidata(:,2));              %line to bus
nbus=max(max(nf),max(nt));     %taking max no of bus
R=lidata(:,3) ;                %Resistance from line data
X=lidata(:,4);                 %reactance from line data
B=complex(0,lidata(:,5)) ;   %line charging from line data
Z=complex(R,X) ;               %calculate impedance of lines
lines=length(nf) ;             % no of total lines
Y=ones(lines,1)  ;             %initiaize admittance of the lines
Y=Y./Z ;                       %calculatee admittance of the line 1/z
Ybus=zeros(nbus,nbus) ;        %initialize n bus (5x5)

 %calculate non diagonal element
for k=1:lines
    Ybus(nf(k),nt(k))=-Y(k);
    Ybus(nt(k),nf(k))=Ybus(nf(k),nt(k));
end

% calulate for diagonal element
for n= 1:lines
    for k=1:lines
        if nf(k)==n || nt(k)==n
            Ybus(n,n)=Ybus(n,n)+Y(k)+B(k);
        end
    end
end

Ybus;

%inatialize bus data
%       Bus Bus  Voltage Angle   ---Load---- --------Generator---
%        No  code Mag.    Degree  MW    Mvar  MW   Mvar
busdata=[1   1    1.06    0.0      0.0   0.0   0.0   0.0
         2   0    1.0     0.0    20.0  10.0  40.0  30.0
         3   0    1.0     0.0    45.0  15.0   0.0   0.0
         4   0    1.0     0.0    40.0   5.0   0.0   0.0
         5   0    1.0     0.0    60.0  10.0   0.0   0.0];



% Declare Matrix
Sb=100;
S=zeros(nbus,1); %initialize complex power
pl=busdata(:,5)./Sb ;%load real power
ql=busdata(:,6)./Sb ;%load reactive power
pg=busdata(:,7)./Sb; %generation real power
qg=busdata(:,8)./Sb ;%generation reactive power
S=complex((pg-pl),(qg-ql)); % complex power of buses
V=complex(busdata(:,3),0); % bus voltages

V_old = zeros(nbus);% store the privious data

tolerance= 0.00000000000000000001;
max_err= 5000;
itt=0;
```

```
    while (max_err>tolerance)            % gauss seidal

        for i=1:nbus
            V_old(i)=V(i);
            sum=0;
            for k=1:nbus

                if(k~=i)

                    sum=sum+Ybus(i,k)*V(k);

                end

            end
            if i~=1
            V(i) = ((conj(S(i))/conj(V(i)))-sum)/Ybus(i,i);
            err(i) = abs(V(i)-V_old(i));
            end
        end
        max_err= max(err);
        itt=itt+1;
    end
    V;
    theta=angle(V);
    disp("Voltage Magnitude");
    disp(abs(V))
    disp("Angle");
    disp(rad2deg(angle(V)))
    % Calculat the real power and reactive power


    %Power to line
    for k = 1:nbus
        from_bus = nf(k);
        to_bus = nt(k);
        Yline = Y(k)+0.5*B(k);
        I_line = Yline * (V(from_bus) - V(to_bus));
        S_line = V(from_bus) * conj(I_line);  % Power flow in the line
        fprintf('From Bus %d to Bus %d: P = %.4f MW, Q = %.4f MVAR\n', from_bus,
        to_bus, real(S_line)*100, imag(S_line)*100);
    end

    % for schedule power calculation

    P=zeros(nbus,1);
    Q=zeros(nbus,1);

    for i=1:nbus
        T_P=0;
        T_Q=0;

        for j=1:nbus
            T_P=T_P+abs(V(i))*abs(V(j))*abs(Ybus(i,j))*cos(angle(Ybus(i,j))+theta(j)-
            theta(i));
            T_Q=T_Q+abs(V(i))*abs(V(j))*abs(Ybus(i,j))*sin(angle(Ybus(i,j))+theta(j)-
            theta(i));
        end
        P(i)= T_P*100;
        Q(i)=-T_Q*100;
    end

    disp("");

    disp("Real Power (Schedule)")
    P
    disp("Apparent Power (Schedule)")
    Q
    itt
```

Table: Bus voltage and schedule Power

Bus No.	Bus Voltage		Schedule Power	
	PU	Angle	MW	MVAR
1	1.0600	0	129.6117	-7.0477
2	1.0476	-2.7529	20.0000	20.0000
3	1.0229	-5.2086	-45.0000	-15.0000
4	1.0225	-5.4879	-40.0000	-5.0000
5	1.0176	-6.1672	-60.0000	-10.0000

```
Real Power (Schedule)

P =

  129.6117
   20.0000
  -45.0000
  -40.0000
  -60.0000

Apparent Power (Schedule)

Q =

   -7.0477
   20.0000
  -15.0000
   -5.0000
  -10.0000
```

```
Voltage Magnitude
    1.0600
    1.0476
    1.0229
    1.0225
    1.0176

Angle
         0
   -2.7529
   -5.2086
   -5.4879
   -6.1672
```

```
From Bus 1 to Bus 2: P = 87.1429 MW, Q = -5.0150 MVAR
From Bus 1 to Bus 3: P = 42.2658 MW, Q = 4.0707 MVAR
From Bus 2 to Bus 3: P = 19.7563 MW, Q = 5.9587 MVAR
From Bus 2 to Bus 4: P = 30.0808 MW, Q = 5.1780 MVAR
From Bus 2 to Bus 5: P = 55.8826 MW, Q = 9.0429 MVAR
```

<u>Task 3:</u>

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 Under Voltage for any bus) .

Solution:

Undervoltage Event:

An Undervoltage event was created at Bus-4 by introducing a new load of 40MW real power and 150 MVAR reactive power. Following these modifications, the simulation was rerun to analyze the impact of these loads on the system.

This setup resulted in an undervoltage condition at Bus-4, and the corresponding changes in the 5-bus power system were reflected in the updated simulation diagram.

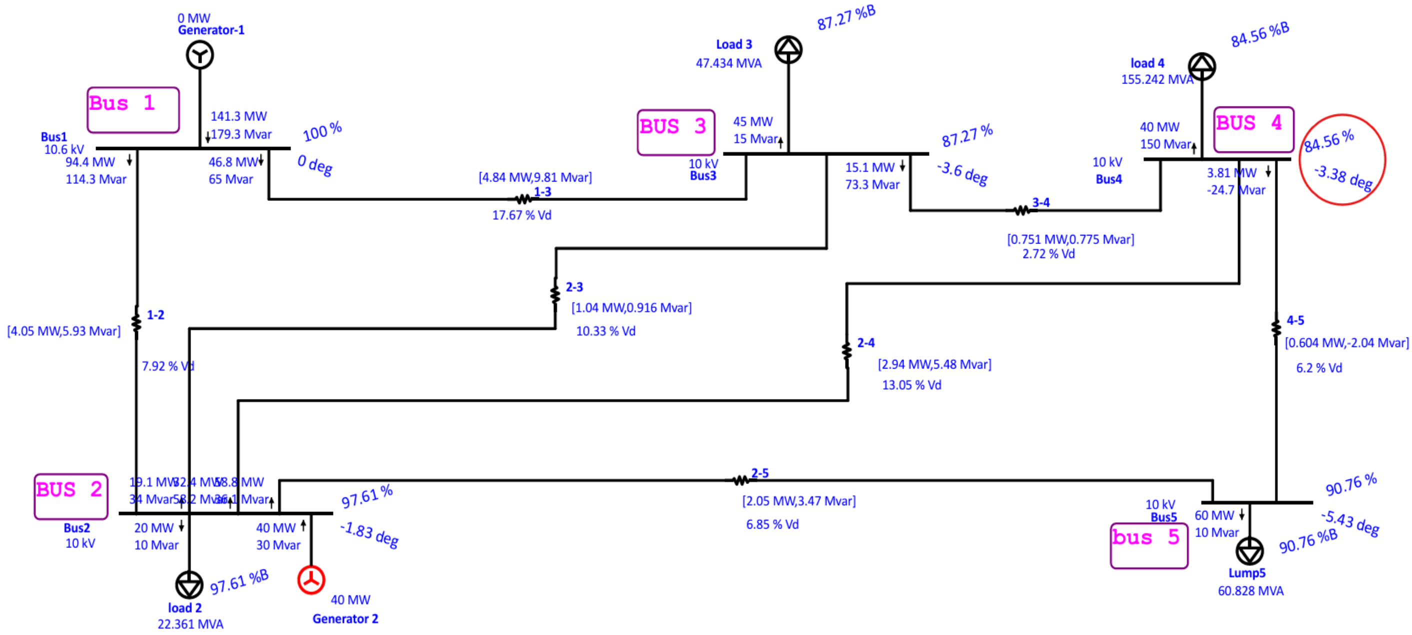

Fig 3: The 5-bus power system in an Undervoltage event

To Overcome this undervoltage simulation:

A 139 MVAR static shunt capacitor was added at Bus 4 to mitigate the undervoltage issue. After applying the shunt capacitor, the bus voltage was restored to 1.023 PU, effectively eliminating the undervoltage event.

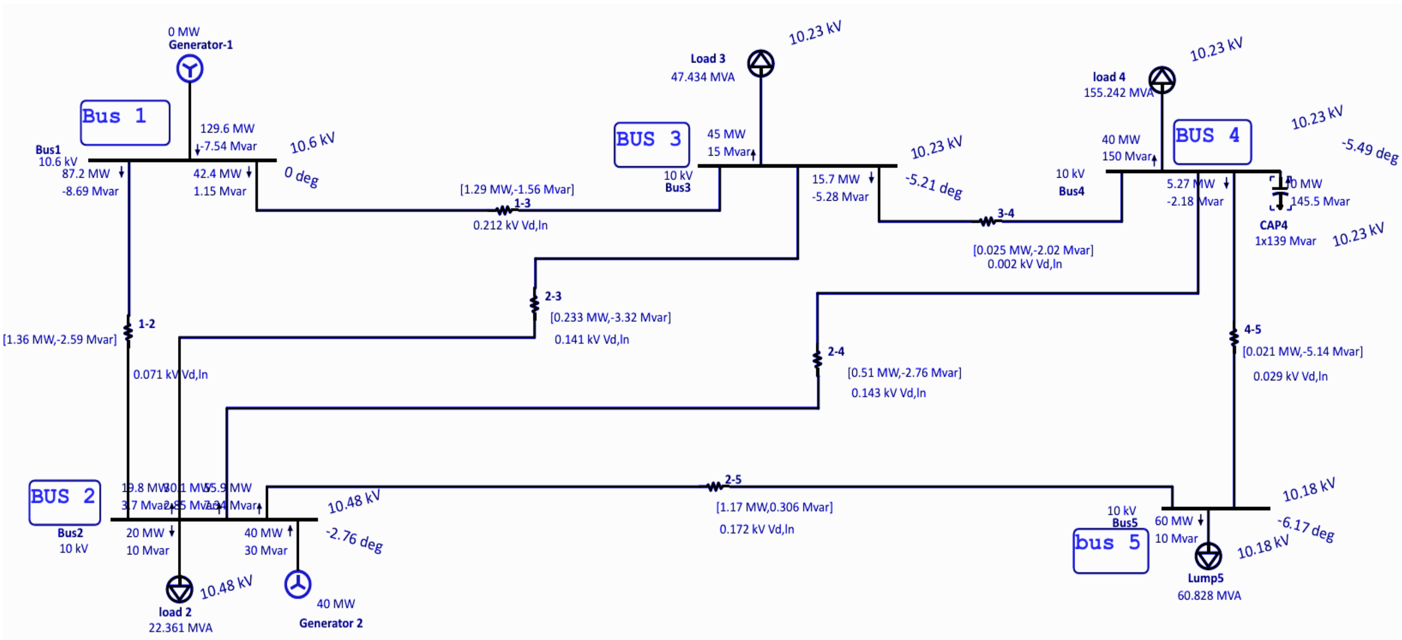

Fig 4: The 5-bus power system after switching on the static shunt capacitor[In terms of kV]

By switching on the shunt capacitor, the bus voltage at Bus-4 increased to 1.023 PU, or 10.23 kV, effectively eliminating the Undervoltage event.

A static shunt capacitor is used in power systems to improve power factor and reduce reactive power demand. It is connected in parallel with the electrical load to compensate for the reactive power consumed by the load. When a load demands reactive power, it can cause a voltage drop, potentially leading to under voltage conditions. The shunt capacitor mitigates this by providing reactive power support to the system.
The capacitor works by absorbing current during voltage peaks and releasing it during voltage troughs, thus generating reactive power. This helps balance the reactive power demand and supply, reducing voltage drops. In this case, the shunt capacitor at Bus-5 successfully eliminated the Undervoltage event by stabilizing the voltage.

Task 4:

Initiate an unsymmetrical fault (L-G, L-L-G, L-L) in the transmission lines. Group-1 initiates fault in line 1-3, Group-2 initiates fault in line 2-3, Group-3 initiates fault in line 2-4 and Group-4 initiates fault in line 2-5. Observe the change in the results of the load flow studies after the fault initiation.
Solution: As we are group 1, we had to analyze the fault in line 1-3 by initiating an unsymmetrical fault in Bus-1 and Bus-3. Hence we can see the data of L-G, L-L-G, L-L faults from e-tap simulation which are mentioned below.

L-G Fault Data:

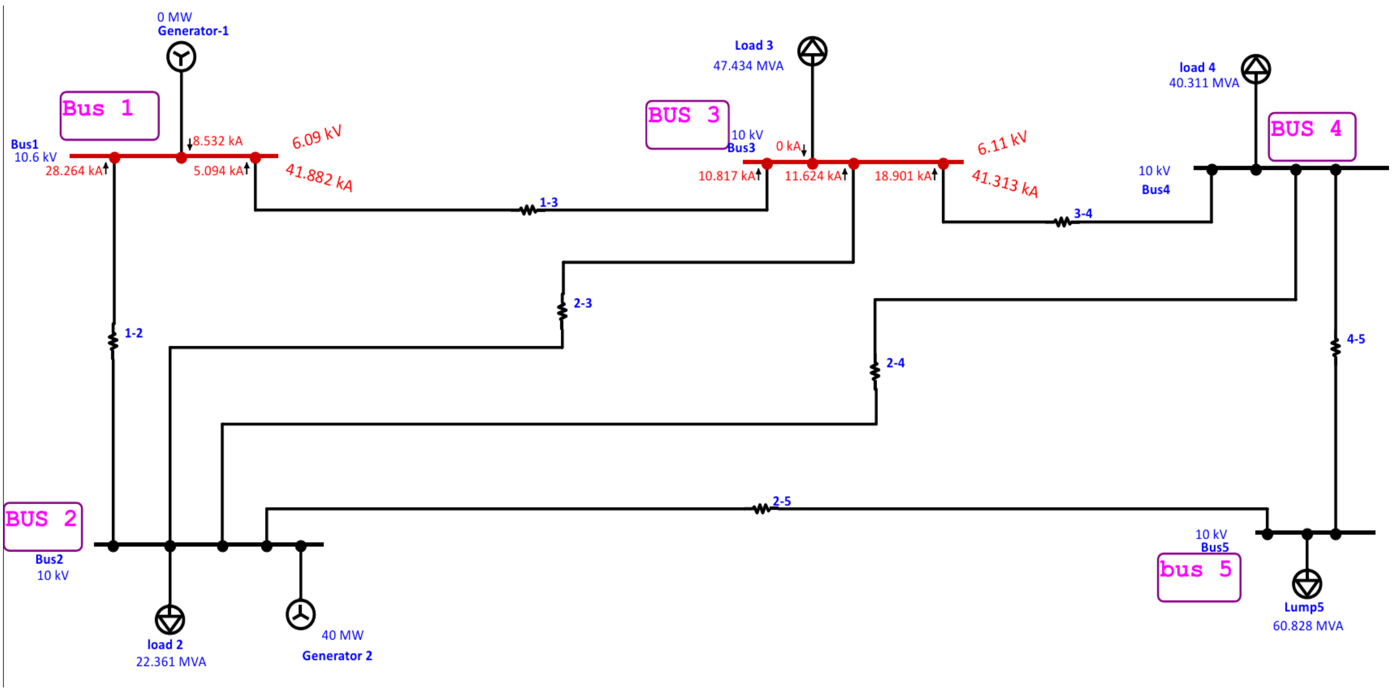

Fig 5: Line-to-ground fault data

1. **BUS 1**

Fault Voltage(kV)	Fault Current(kA)
6.09	41.882

Current data	
From	Fault Current(kA)
Bus 2	28.264
Gen 1	8.532
Bus 3	5.094

2. **BUS 3**

Fault Voltage(kV)	Fault Current(kA)
6.11	41.313

Current data	
From	Fault Current (kA)
Bus 1	10.817
Bus 2	11.624
Bus 4	18.901
Load 3	0

L-L Fault Data:

1. **BUS 1**

Fault Voltage(kV)	Fault Current(kA)
5.61	0

2. **BUS 3**

Fault Voltage(kV)	Fault Current(kA)
5.03	0

In this fault scenario, the fault voltage was lower at both Bus-1 and Bus-3 (around **5.61 kV** and **5.03 kV**, respectively), with no significant fault currents detected from the adjacent buses, as the faulted line was primarily between two buses.

L-L-G Fault Data:

1. **BUS 1**

Fault Voltage(kV)	Fault Current(kA)
5.91	36.518

Current data	
From	Fault Current (kA)
Bus 2	24.644
Bus 3	4.441
Gen 1	7.439

2. **BUS 3**

Fault Voltage(kV)	Fault Current(kA)
5.9	29.945

Current data	
From	Fault Current (kA)
Bus 1	7.841
Bus 2	8.426
Bus 4	13.7
Load 3	0

The faults caused significant changes in bus voltages and fault currents, leading to voltage drops and increased current flow in the affected lines. By analyzing the system's response to these faults, valuable insights were gained regarding the system's resilience and the importance of implementing protection mechanisms to safeguard the network. This task emphasized the need for robust fault detection and mitigation strategies to maintain system stability and ensure reliable power delivery during fault conditions.

This analysis highlighted the system's vulnerability during faults and the need for protective measures to maintain stability. The data gathered from fault voltages and currents provided insights into how the power system can be designed to handle such disturbances effectively

Discussion

The load flow analysis performed on the 5-bus power system provides valuable insights into the electrical parameters crucial for system reliability. By simulating the system using ETAP software, the study identified the slack bus as Bus-1, with a base voltage of 10 kV, and determined the real and reactive power demands. The analysis of bus voltages revealed variations across the system, particularly highlighting the importance of maintaining voltage stability. For instance, the bus voltages at Bus-2 and Bus-3 were found to be 1.048 PU and 1.023 PU, respectively, with corresponding phase angles.

Additionally, the introduction of an undervoltage event at Bus-4 underscored the vulnerability of the system to voltage drops when subjected to increased loads. The implementation of a 139 MVAR shunt capacitor successfully mitigated the undervoltage condition, restoring the bus voltage to 1.023 PU. This demonstrated the effectiveness of capacitive compensation in enhancing system voltage stability.

The study also verified the simulation results using the Gauss-Seidel method in MATLAB, which confirmed the accuracy of the load flow analysis. Through MATLAB coding, bus voltages, line flows, and losses were recalculated, showing consistency with the ETAP simulation results. This dual verification using both ETAP and MATLAB ensures high reliability of the findings.

Moreover, the report examined unsymmetrical faults, specifically line-to-ground (L-G), line-to-line (L-L), and line-to-line-to-ground (L-L-G) faults in different parts of the transmission network. These faults introduced significant changes in bus voltages and fault currents, emphasizing the need for robust protection mechanisms to ensure system stability during such events.

Conclusion

The load flow study and fault analysis of the 5-bus power system presented in this report have demonstrated the importance of proper voltage regulation and reactive power management in maintaining system stability. The successful application of a shunt capacitor to mitigate undervoltage conditions highlights a practical solution for voltage drops in power systems. Furthermore, the validation of results using both ETAP software and MATLAB confirms the reliability of the methods employed. This study provides a comprehensive understanding of the 5-bus system's performance, offering valuable insights for optimizing power distribution and ensuring the continued stability of electrical networks.