

Load Flow Analysis of a Three-Bus Power System using MATLAB Simulink

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ABSTRACT: There is load flow study an important case study in electrical power systems. It helps engineering student to understand passing of electrical power in transmission lines and buses. This case study, a three-bus power system is developed and simulated with the help of MATLAB Simulink and the Simscape Electrical toolbox. This system is comprised of a slack bus, PV bus and a PQ bus. The buses are interconnected by transmission lines and it allows the flow of power.

The Simulink's Load Flow Analyzer block calculates system variables we can say like the voltage magnitude, voltage angle, active power flow and reactive power flow. The result obtained from the simulation, is used to determine the power and voltage conditions in the system.

This case study is representing the modeling and analysis of a simple electric power system through simulation. The results indicate that the system is operating with acceptable voltage levels and that the slack bus provides the power balance for the system. The case study also highlights the viability of using MATLAB Simulink for power system education, research and analysis.

I. INTRODUCTION

Load flow analysis is one of the major studies that performed in the power system [1], [5]. Power systems are extremely large and complex systems. It produces, transmit and supply power to consumers. It involves of generators, transformers, transmission lines, substations and loads. It can be ensuring operation will be ensure safe and better performance, engineering student conducted various power system case study.

As we know load flow analysis is very essential. This steady-state is operating point of the electrical system is determined by load flow analysis. It computes voltage's magnitude, voltage angle and also power transmission on various buses. Load flow analysis is required for a number of engineering tasks such as system planning, transmission system expansion, voltage regulation and to calculate losses. It assists engineering student to determine if the system is running safely and efficiently.

Now a days computer technology is very advanced so it is easy to do load flow analysis using simulation tools. MATLAB Simulink offers a user-friendly interface for engineering student to develop power system models and perform simulations in a relaxed way [7], [8].

This case study involves modelling to three-bus electric power system with the help of MATLAB Simulink. Load Flow Analyzer is used to get power flow solution. This research demonstrates that simulation techniques may be used to conduct efficient power system analysis.

OBJECTIVES OF THE CASE STUDY

Purpose is given below:

- A. To gain knowledge load flow's analysis in power systems.
- B. To design a three-bus electric power system on MATLAB Simulink.
- C. In power system, identify various categories of buses.
- D. Load flows manipulate using the Load Flow Analyzer tool.
- E. To study the system voltages and power flows.
- F. To identify the effects of generators and load on the system.
- G. To demonstrate simulation's result in power system case studies.

II. LITERATURE REVIEW

Load flow analysis has been studied by many researchers and engineers as it is very important regarding operation and design of power systems.

Traditionally load flow analysis was done manually using mathematical equations. However, with the development of very large and complex power systems manual calculations were impossible.

Numerical techniques such as Gauss-Seidel method, Newton-Raphson method and Fast Decoupled Load Flow method [9], [10], [11] were developed.

The Newton-Raphson method is very popular cause of its rapid convergence. This method is used by few of the updated power system analysis tools.

Applications tool as MATLAB Simulink have made it easier to model a power system. Students can build replica using blocks and simulate them quickly. The Simscape Electrical toolbox provides pre-built components such as generators, transmission lines and loads [7], [8].

A number of papers have used MATLAB Simulink to study small and large power systems. These studies show that simulation results are accurate and convenient for research and education system [14].

This study is also inspired by such approach, and uses MATLAB Simulink to model a three-bus system.

III. OVERVIEW OF LOAD FLOW ANALYSIS

Load flow analysis is commonly used in power system planning and operation [2], [4], [12].

Load flow analysis is a case study of power flow in an electrical system in steady state. It determines the flow of electric power from generators to loads through transmission lines.

Load flow analysis considers the following factors:

- A. Magnitude of voltage at buses
- B. Active power (P)
- C. Reactive power (Q)
- D. Power flow via transmission lines

These calculations are important because they allow engineering student to ensure that:

- A. Voltage levels remain in acceptable bounds
- B. Electrical lines do not become overloaded
- C. Generators operate proficiently

Load flow analysis is based on mathematical equations which represent the electrical connections between buses. These equations are nonlinear and are solved numerically.

Computer software automatically performs this calculation and displays the results in an intuitive format.

Load flow analysis is a powerful tool used to study the power flow, voltage levels and stability in a power system [15].

IV. TYPES OF BUSES IN POWER SYSTEM

In power system analysis, there are three types of buses based on the known and unknown quantities [1], [5].

Slack Bus (Swing Bus): Slack bus is the reference bus. It ensures power balance between generation and consumption. In load flow studies, the slack bus has a specified voltage magnitude and phase angle, but the active and reactive power are gotten.

PV Bus or Generator Bus: A PV bus is a generator bus. There can be active power and the voltage magnitude are known in this bus. The reactive power and the voltage phase angle are unknowns which are computed in the load flow.

PQ Bus or Load Bus: PQ bus is a load bus. The active and reactive power expects are specified in this bus. The voltage magnitude and phase angle are calculated in the load flow analysis.

In this case study, there are three-bus system as follows:

Bus 1 is the Slack Bus.

Bus 2 is the PQ Bus.

Bus 3 is the PV Bus.

V. SYSTEM DESCRIPTION

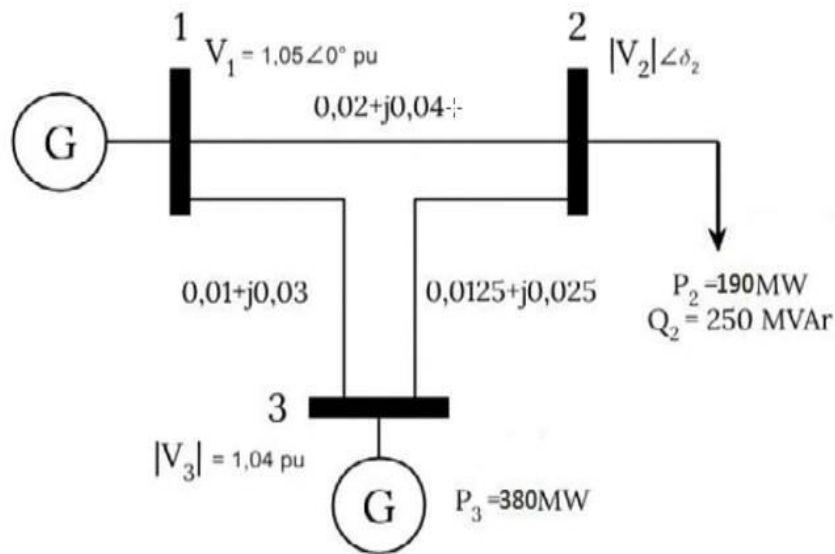


Fig.1. Above diagram in 3-bus power system is Single Line Diagram.

In this research paper, a simple power system having three buses connected by transmission lines. There are two generators and one load is connected with the system.

Bus 1 is main generator and acts as slack bus. Bus 2 has the load and it is PQ bus. Bus 3 has another generator and is the PV bus.

The buses are interconnected by transmission lines of certain impedances. The impedances correspond to the resistance and reactance of the transmission lines [13].

Transmission line data:

Line 1-2 impedance = $0.02 + j0.04$ pu

Line 1-3 impedance = $0.01 + j0.03$ pu

Line 2-3 impedance = $0.0125 + j0.025$ pu

Load data at Bus 2:

Active power = 190 MW

Reactive power = 250 MVAR

Generator data at Bus 3:

Active power generation = 380 MW

Voltage magnitude = 1.04 pu

The slack bus voltage is maintained at 1.05 pu.

VI. SIMULATION MODEL IN MATLAB SIMULINK

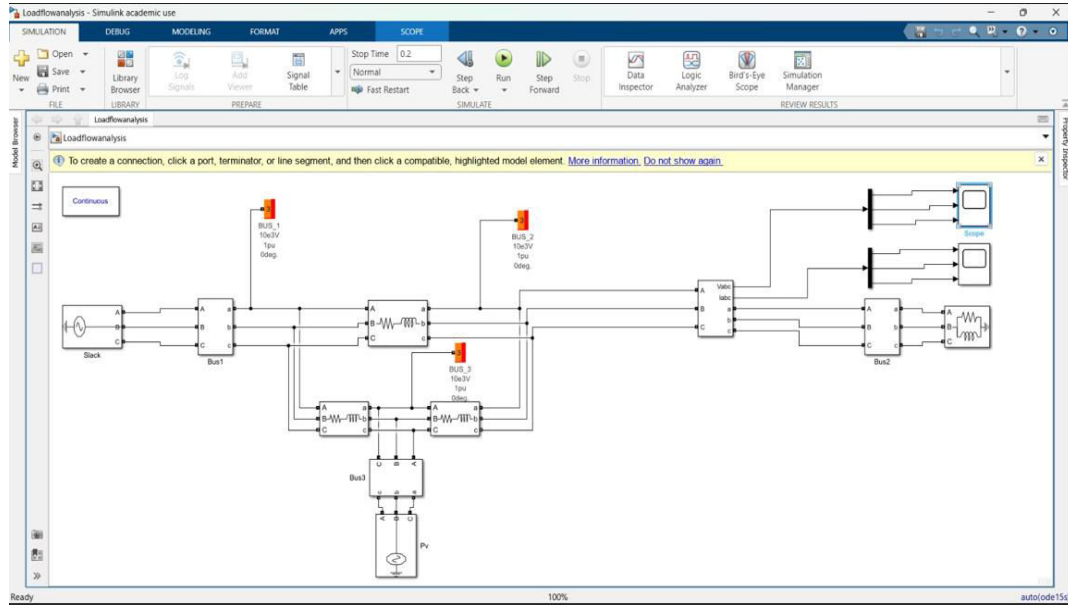


Fig.2. Above figure is for Load Flow Analysis with Scope Measurement, Modified Simulink Model

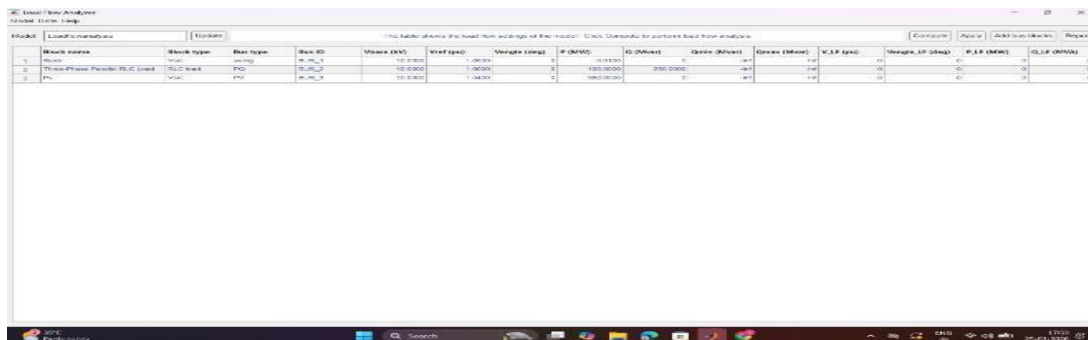
As a above diagram is the updated version' s MATLAB Simulink model and it is indicating for load flow research of this electric power system network. The network comprises of a slack bus, transmission lines, load buses and PV bus (generator) [7], [8].

Bus-1 is nothing but it is slack bus which sets voltage reference and balances the power system. Bus-2 and Bus-3 are connected with transmission lines to model the power flow between buses. Bus-3 also includes a PV generator which provides active power to the system.

In this updated model, three-phase voltage and current blocks (Vabc and Iabc) are included to monitor the system's electrical quantities. These are connected to the Scope blocks to observe the three-phase voltage and current during simulation.

The scope blocks enable the analysis of the system dynamics and ensures that the three-phase signals are balanced and sinusoidal. This also helps in proving the operation of the load flow model in Simulink.

VII. LOAD FLOW ANALYZER CONFIGURATION



Bus ID	Voltage (kV)	MVA	MVar
Slack	10.0000	1.0000	0.0000
Three-Phase Parallel RLC Load	10.0000	1.0000	0.0000
PV	10.0000	1.0000	0.0000

Fig.3. Load Flow Analyzer Input Parameters

Simulink Load Flow Analyzer tool is used to obtain the power flow results. The tool automatically searches for the buses in the replica and allows the user to select their type and characteristics.

The following configuration is used:

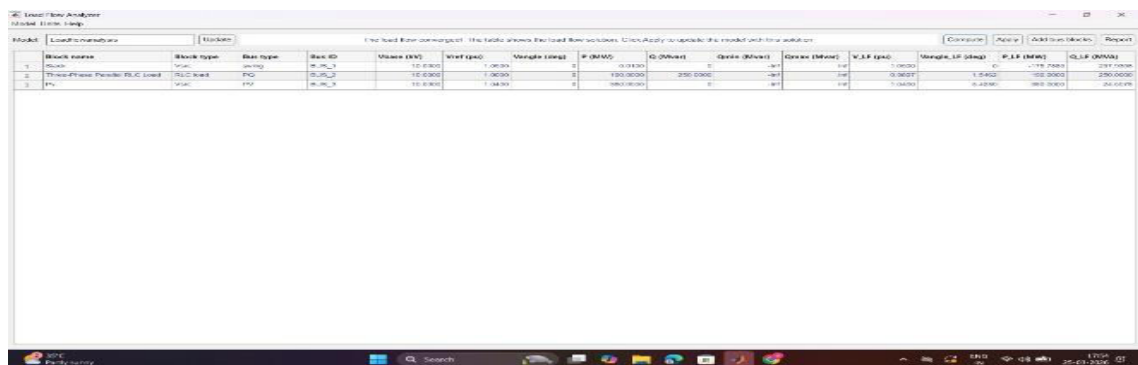
Bus 1 - Swing bus with voltage magnitude 1.05 pu.

Bus 2 – PQ bus with load of 190 MW and 250 MVAR.

Bus 3 - PV bus with generation of 380 MW and voltage magnitude 1.04 pu.

Once the data is entered, the Compute button is clicked. The load flow results are then computed. The results are presented in a table, which shows the voltage magnitude, voltage angle, and power for all buses.

VIII. SIMULATION RESULTS



Bus #	Bus Name	Bus Type	Bus ID	Voltage (pu)	Voltage Angle (deg)	P (MW)	Q (MVAR)	Generation (MW)	Generation (MVAR)	Losses (MW)	Losses (MVAR)	W.P.F. (pu)	Margin (pu)	P.L.F. (sec)	OLPF (MW)
1	Swing	Swing	B_1_1	1.0500	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	1.0000	0.0000	0.0000	0.0000
2	Three-Phase Positive-Seq Load	PQ	B_2_2	0.9897	1.5460	190.0000	250.0000	0.0000	0.0000	0.0000	0.0000	0.9897	1.5460	0.0000	250.0000
3	PV	PV	B_3_3	1.0400	3.4280	380.0000	24.5000	380.0000	0.0000	0.0000	0.0000	1.0400	3.4280	0.0000	0.0000

Fig.4. Load Flow Analysis Results from MATLAB Simulink

The results of load flow scanning are shown below.

Bus 1 (Slack Bus)

Voltage magnitude = 1.05 pu

Voltage angle = 0 degrees

Active power = -175.78 MW

Reactive power = 257.93 MVAR

Bus 2 (PQ Bus)

Voltage magnitude = 0.9897 pu

Voltage angle = 1.546 degrees

Active power = 190 MW

Reactive power = 250 MVAR

Bus 3 (PV Bus)

Voltage magnitude = 1.04 pu

Voltage angle = 3.428 degrees

Active power = 380 MW

Reactive power = 24.50 MVAR

These results demonstrate that the load bus voltage is slightly reduced by the load. The slack bus supplies the extra power to maintain the balance.



Fig.5. Three-Phase Voltage Waveforms from Simulink Scope

The waveform above represents the three-phase voltages from the MATLAB Simulink model. Each waveform corresponds to phase A, phase B and phase C voltages value of the n/w. The plots are sine waves and have a phase difference of around 120 degrees, thus indicating the system is operating under balanced three-phase conditions.

The voltages of each phase are of constant amplitude, which confirms stable power system functioning. This is a confirmation that it is correct operation of the transmission lines and generators in the model too.

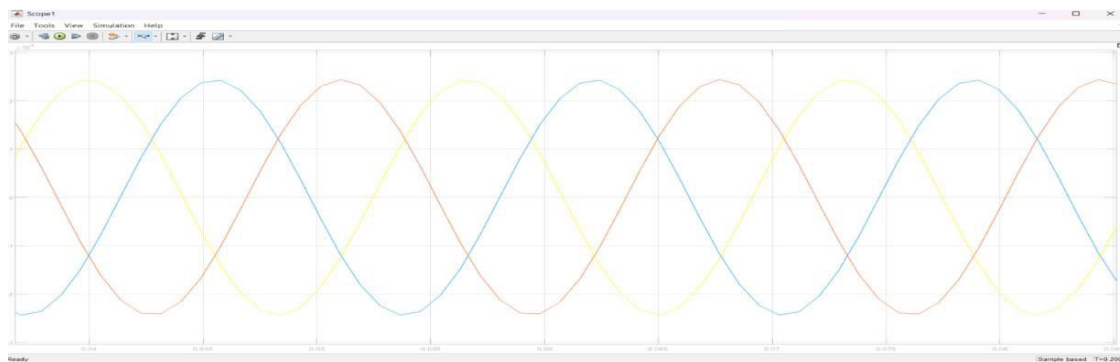


Fig.6. Three-Phase Current Waveforms from Simulink Scope

The figure above shows the three-phase current measurements. Like the voltage, the three currents are sinusoidal and 120 degrees out of phase with each other. Such a phase shift is common of three-phase power systems.

The current amplitude current varies according to load at the load bus and power electric system supplied by the generators. The sinusoidal nature of the waveform shows that the system is stable during the simulation.

IX. APPLICATION OF LOAD FLOW ANALYSIS

Power flow scanning is an important tool in power engineering to plan, run and optimize power systems [6]. Some important applications contain:

Power system planning - identifying the optimal transmission network structure.

Voltage control - maintaining the voltage within the limits.

Loss calculation - approximately calculate power losses in transmission lines.

Renewable energy combination - to study the effect of solar and wind power.

Expansion planning - scanning, how the system will react in case of new generators' or loads' aggregation.

These uses make load flow analysis an important part of today's power systems.

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X. BENEFITS OF MATLAB SIMULINK

There are several benefits of MATLAB Simulink for power system prospective of these studies. The block diagram allows easy creation of power system models. Engineering Student can easily drag and drop components and connect them.

The Simscape Electrical toolbox is supplied with a range of pre-defined blocks. This reduces the modeling time and results accuracy.

Another advantage is that the simulation outcomes can be easily reviewed using MATLAB tools including graph, data analysis and visualization.

For these reasons, MATLAB Simulink is popular in academic, research and power industries.

XI. DISCUSSION OF RESULTS

The results from the load flow simulation give insights into the status of the three-bus power system.

At bus 1, voltage is fixed at 1.05 pu and serves indicate voltage reference for the system. Here, lack bus gives the additional active and power of reactive too. It needed to achieve the system demand and its losses are also included. This verifies that the bus of slack is balancing the active as well as reactive power.

PQ load bus is on bus 2, the voltage magnitude equal to 0.9897 pu and lower than the slack bus voltage. This is because of the load connected to this bus that absorbs active power (190 MW) and reactive power (250 MVAR). But the value is still within the normal operating limits of power systems (0.95 pu - 1.05 pu), which means that the voltage is stable. Voltage magnitude is equal to 1.04 pu on PV bus. Generates active power = 380 MW to the system. The bus generates 24.50 MVAR of reactive power, which contributes to the stability of the system.

The simulation also indicates that it increases in the voltage angles starting from Bus 1 to continue till Bus 3, with the power flowing from creation buses to the load bus. This validates the load flow model's operation.

In addition, the sinusoidal and balanced three-phase voltage and current waveforms shown on the simulation scopes confirm that the system is functioning inside steady state and also it is stable minimal distortion.

In conclusion, resultants of load flow validate that it is 3 bus system that has been designed operates within acceptable voltage tolerances, and power efficiently flows from the generators to the load via the transmission lines. This investigation also shows that MATLAB Simulink can be used to gain insight into power system operation.

XII. FUTURE WORK

This study can be extended in a number of directions in future work.

More complex power systems with multiple buses can be considered. It can also consist renewable energy sources just like solar and wind.

Short circuit analysis and stability analysis can also be performed to evaluate the system's stability.

Smart grids and energy storage can also be incorporated in future replica.

This will provide a better insight into modern electrical power systems.

XIII. CONCLUSION

This case study has considered three bus system's load flow scanning with MATLAB Simulink. This system has three bus like slack, PV bus and PQ bus with transmission lines in between.

The Load Flow Analyzer tool was employed to calculate 1st is voltage magnitude, 2nd is voltage angle, 3rd is active power and 4th is reactive power at all buses.

It was found that the system operates within the voltage limit and power is balanced by the slack bus.

The case study has shown that MATLAB Simulink can be used to model and analyses power systems and to gain a better understanding of power system operation using simulations [15]. It provides a very easy-to-use and efficient method to perform load flow analysis and to simulate power system operations.

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