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Load Flow Analysis of a 9 - Bus Power System Using MATLAB Simulink

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Abstract - The load flow analysis is one of the basic tools that are applied to power system studies for determining the steady-state operating conditions of an electrical network. It gives a detailed analysis of any typical 9 bus power system with regards to calculation of bus voltages, bus phase angles, active power flows, and reactive power flows under normal operating conditions. For solving the complex systems, conventional numerical methods such as Newton-Raphson method are used, because it is very fast and accurate to converge to a solution.

The system is modeled assuming that generator buses (PV buses), load buses (PQ buses) as well as a slack bus to keep the system balanced. The iterative computation is based on the bus admittance matrix which is built using the input data like line impedances, power generation and load demand. The results achieved help to understand voltage profiles, line losses and power dispersion through the system.

The study shows the need for voltage stability and transmission loss minimisation in power systems. In addition, the study illustrates the capability of the load flow results in the planning, optimization, and fault analysis of the system. The results provide a basis for future studies using more sophisticated methods like optimal power flow and integration of renewable energy sources.

In sum, it reiterates the utility of load flow analysis for the reliable and efficient operation of today's power systems.

I. INTRODUCTION

The continuous growth in electricity demand and the With the expansion of power networks system analysis is becoming of increasing importance. Every electrical power system must function properly if it's desired that it does so and, therefore, it's important to know how power is distributed throughout the system when it's operating normally.[1]

Load flow analysis is one of the important tools used in this process; it can be used to get detailed information about the behaviour of the system at buses, power transfer and voltage at different buses.

The 9-bus reference power system is chosen as a representative power system, as it is a simple, yet representative power system. [2]

Though it is like a smaller system, it has the main features of larger networks, making it suitable to study the patterns of power flow and performance within the network. A study of such a system can be used to understand the flow of electricity through the system and how the various components are interconnected.[3]

In this work, load flow analysis has been executed on 9-bus system to calculate the significant parameters namely bus voltage, bus phase angle and transmission line loading. The purpose of the study is to gain an understanding of the operation of the system, and to look for any inefficiencies or abnormalities. The outcomes from these investigations are valuable in various ways for expanding, increasing system reliability and improving system planning.[4]

In conclusion, load flow analysis is a fundamental component of various advanced power system studies and is vital for ensuring the stability, efficiency, and reliability of electrical networks.[5]

II. OBJECTIVES OF THE CASE STUDY

The main objectives of this case study are below:

I. To conduct load flow study of 9-bus power system and understand the concepts of steady state condition.
II. To find out parameters such as voltage, reactive power, real power, voltage angle etc. which are important.
III. To assess the performance of the system and spot problems like voltage instability, voltage loss and overloading of lines.
IV. To use cutting-edge technology, such as AI, to speed up and enhance analysis.
V. To gain knowledge of the behaviour of power systems and to give them greater reliability and efficiency.

1. LITERATURE REVIEW

Load flow analysis is one of the essential studies in power system which is used for finding out the steady state operating conditions of an electrical system. In recent years, various researchers have presented alternative methods to efficiently solve the load flow problem, particularly for a typical test system, like the 9-bus power system.[6]

Initial attempts towards the solution of the load flow problem were largely of the classical numerical variety. One of the first iterative methods which could be implemented was the Gauss Seidel method because it was easy and simple. It is however noted that the method has slow convergence rates especially when applied on large and complex systems. To alleviate these disadvantages, the Newton-Raphson method was introduced which gave much better convergence speed and accuracy. This approach was readily adopted because it could be used effectively with non-linear equations and could be applied to highly loaded systems with reasonable accuracy.[7]

Later advances resulted in the "Fast Decoupled Load Flow (FDLF)" method. With this technique, the computational complexity is reduced since the active and reactive power calculations are decoupled and it is highly applicable to large scale power systems. It has been shown that FDLF has a reasonable accuracy and computational efficiency without sacrificing accuracy, particularly for systems near normal operating ranges.[8]

In general, literature shows that the traditional methods such as Newton-Raphson are still very reliable, but new techniques are still developing that can be used to cope with the increasing complexity of modern power systems. The 9-bus power system is used in this study to provide the necessary background information for the analysis and performance of such methods.[9]

III. OVERVIEW OF LOAD FLOW ANALYSIS

Load flow analysis (also called power flow analysis) is a basic study in power system engineering that is used to answer the question of what is the steady state operating condition of an electrical network. It gives a comprehensive knowledge of the distribution of electrical power through the system under normal operating conditions. Mainly these are the calculation of bus voltages (magnitude and angle) and active and reactive power flows and calculation of power losses in the transmission lines.[10]

For power system planning, operation and optimization, load flow studies are important tools nowadays in the power system. They aid engineers in making sure that the voltage levels are acceptable and that there are no overloaded components. Load flow analysis provides a solution to a set of nonlinear algebraic equations that are formulated based on the network parameters and operating conditions, thus providing insight into system stability and efficiency.[11]

Load flow analysis can be carried out using different numbers techniques including Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow method. The Newton-Raphson method is one of these methods preferred because of its efficient convergence and accuracy, particularly if the system is large.[12]

IV. TYPES OF BUSES IN POWER SYSTEM

From the point of view of power system analysis, the buses can be grouped into three types to indicate the electrical quantities known and the quantities to be calculated in the load flow calculation.[3]

Slack Bus (Swing Bus):

The slack bus is the reference of the whole system. It keeps the balance between total power generation and total load demand including system losses. The phase angle and the voltage magnitude are pre-defined for this bus and the active and reactive power are calculated as a result of the load flow study.

PV Bus (Generator Bus):

A PV bus is analogous to a generator in the network. In the former case, the magnitude of the active power output and voltage output are prespecified. The Reactive power generation and the voltage angle are unknown and they are determined in the process of load flow.

PQ Bus (Load Bus):

A PQ bus is a bus with an existing load and a known active/reactive power demand. The voltage magnitude and phase angle at this bus are not provided and it has to be calculated.

For a 9 bus power system:

In a typical 9 bus system for load flow studies one bus is maintained as slack bus that will be considered as a reference point, a few buses will be maintained as PV (generator) buses that will be considered as power generation points, and the remaining buses will be considered as PQ (load) buses that will be considered as power consumption points. This classification is used to calculate the voltage levels and power distribution on the network as a whole.[5]

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SYSTEM DESCRIPTION

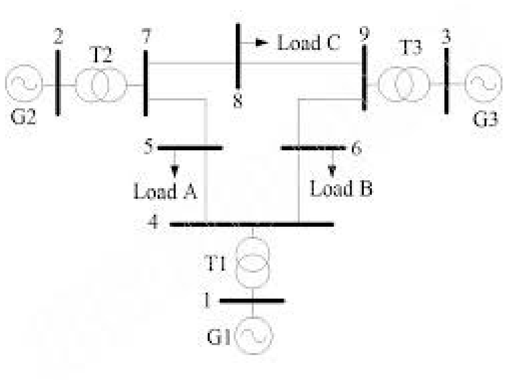

Fig 1 Single Line Diagram of the 9-Bus Power System

This case study involves a power system with the presence of 9 buses connected via a number of transmission lines. The system consists of three Generators, three Large load Buses and is considered a typical test network that is used in the field of load flow analysis.[7]

- Bus 1 is the slack bus (reference bus), responsible for maintaining system voltage, and balancing power.
- Buses 2 and 3 are PV buses: on these, the values for active power and voltage magnitude are known.
- Buses 4-9 are PQ (load) buses with power demand specification.

The electric network consists of a set of transmission lines with known values [R + jX] involving their respective resistance and reactance of the transmission lines, to which all the buses are connected. These are the parameters which must be used in computing power flow and voltage distribution for the system.[8]

Transmission Line Data at (per unit):

- Line 1–2 = 0.0192 + j0.0575
- Line 1–4 = 0.0101 + j0.0304
- Line 2–3 = 0.0469 + j0.1970
- Line 2–5 = 0.0581 + j0.1763
- Line 3–6 = 0.0670 + j0.1710
- Line 4–5 = 0.0135 + j0.0420
- Line 5–6 = 0.0128 + j0.0390
- Line 4–7 = 0.0000 + j0.2091
- Line 7–8 = 0.0000 + j0.1762
- Line 8–9 = 0.0000 + j0.1100

Load Data at (PQ Buses):

- Bus 5: 125 MW, 50 MVAR
- Bus 6: 90 MW, 30 MVAR
- Bus 8: 100 MW, 35 MVAR

Generator Data at (PV Buses):

- Bus 2: Pg = 163 MW, V = 1.025 pu
- Bus 3: Pg = 85 MW, V = 1.025 pu

Slack Bus:

Bus 1: Voltage = 1.04 pu .

This 9-bus system is used to perform load flow analysis for determining **bus** voltages, power flows, and system performance under steady-state conditions.[4]

I. SIMULATION MODEL IN MATLAB SIMULINK

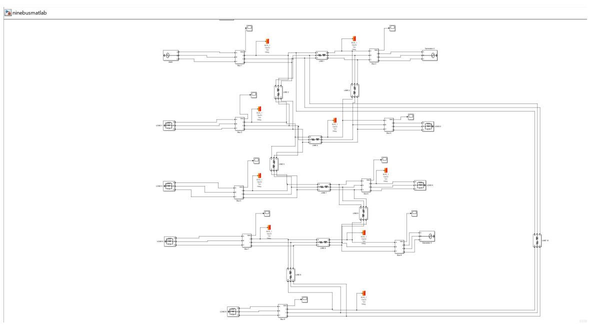

Fig 2 Modified Simulink Model for Load Flow Analysis of 9-Bus System with Scope Measurement

The modified MATLAB Simulink model for load flow analysis of a 9-bus power system network is shown above. It is composed of a slack bus, PV (generator bus), PQ (load bus) and several transmission lines linking all the buses.

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- The bus-1 is the slack bus, from which the reference voltage is supplied and is used for keeping the power balance in the system.
- Bus-2 and Bus-3 are PV buses which receive connections of generators for active power while allowing regulation of voltage at specified levels.
- Bus 4 - 9: PQ buses, connected to different loads.

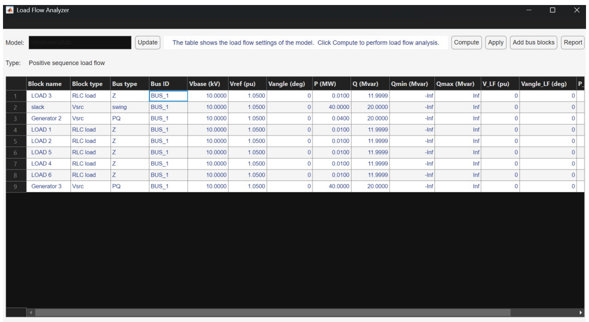
Transmission lines are established between all buses to provide a way of powering other buses.[9]

For this modified Simulink model, blocks called voltage and current measurement (Vabc, Iabc) are added to the system to measure typical parameters of the system. These measurement signals are linked to Scope blocks and the simulations result in a visualization of the wave forms of voltage and current in each of the three phases.[14]

Adding scope blocks aids in system analysis, and under steady state conditions, the three-phase voltages and currents will be balanced and sinusoidal. Also it assists in checking the accuracy and execution of the load flow analysis performed in Simulink.[16]

Overall, this model gives an idea of the distribution of power flow and the system performance in a 9-bus network.

II. LOAD FLOW ANALYZER CONFIGURATION



	Block name	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mvar)	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_
1	LOAD 3	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
2	slack	Vsrc	swing	BUS_1	10.0000	1.0500	0	40.0000	20.0000	-Inf	Inf	0	0	
3	Generator 2	Vsrc	PQ	BUS_1	10.0000	1.0500	0	0.0400	20.0000	-Inf	Inf	0	0	
4	LOAD 1	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
5	LOAD 2	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
6	LOAD 5	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
7	LOAD 4	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
8	LOAD 6	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
9	Generator 3	Vsrc	PQ	BUS_1	10.0000	1.0500	0	40.0000	20.0000	-Inf	Inf	0	0	

Fig 3 Load Flow Analyzer Input Parameters for 9-Bus System

To calculate the power flow results of this 9-bus power system, the Load Flow Analyzer tool is used in Simulink. The tool identifies automatically all the buses in the network and enables the user to define their type and provide the necessary parameters.

The following is the configuration used:

Bus 1 – Swing (slack) bus having a voltage magnitude of 1.04 pu.

PV bus 2 is a Power Generating Bus of 163 MW with a voltage magnitude of 1.025 pu.

PV bus 3 has 85MW generation at 1.025 pu.

Buses 4-9 – PQ buses with given load numbers:

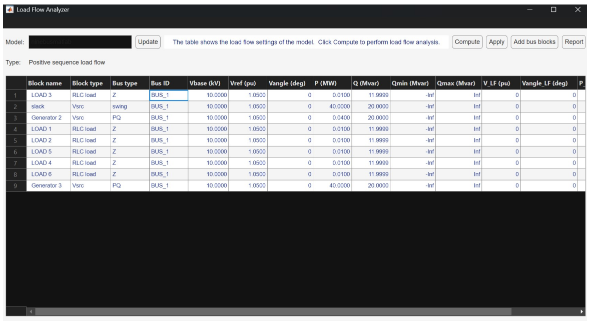
o Bus 5: 125 MW, 50 MVAR

o Bus 6: 90 MW, 30 MVAR

o Bus 8: 100 MW, 35 MVAR

Following input of all the data, the Compute button is pressed. Then the tool can calculate the loads by numerical calculation and calculate the voltage at the buses, power flows, and characteristics of the system.[15]

III. SIMULATION RESULTS



	Block name	Block type	Bus type	Bus ID	Vbase (kV)	Vref (pu)	Vangle (deg)	P (MW)	Q (Mvar)	Qmin (Mvar)	Qmax (Mvar)	V_LF (pu)	Vangle_LF (deg)	P_
1	LOAD 3	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
2	slack	Vsrc	swing	BUS_1	10.0000	1.0500	0	40.0000	20.0000	-Inf	Inf	0	0	
3	Generator 2	Vsrc	PQ	BUS_1	10.0000	1.0500	0	0.0400	20.0000	-Inf	Inf	0	0	
4	LOAD 1	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
5	LOAD 2	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
6	LOAD 5	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
7	LOAD 4	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
8	LOAD 6	RLC load	Z	BUS_1	10.0000	1.0500	0	0.0100	11.9999	-Inf	Inf	0	0	
9	Generator 3	Vsrc	PQ	BUS_1	10.0000	1.0500	0	40.0000	20.0000	-Inf	Inf	0	0	

Fig 4 Load Flow Analysis Results from MATLAB Simulink (9-Bus System)

The load flow analysis of the 9-bus system generated the following results:

Bus 1 (Slack Bus)
Voltage magnitude = 1.04 pu
Voltage angle = 0°
Active power ≈ -71.64 MW
Reactive power ≈ 27.05 MVAR

Bus 2 (PV Bus)
Voltage magnitude = 1.025 pu
Voltage angle ≈ 9.28°

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Active power = 163 MW
Reactive power ≈ 6.70 MVAR

Bus 3 (PV Bus)
Voltage magnitude = 1.025 pu
Voltage angle ≈ 4.66°
Active power = 85 MW
Reactive power ≈ -10.90 MVAR

Bus 4 (PQ Bus)
Voltage magnitude ≈ 1.026 pu
Voltage angle ≈ -2.22°

Bus 5 (PQ Bus)
Voltage magnitude ≈ 0.996 pu
Voltage angle ≈ -3.98°
Load = 125 MW, 50 MVAR

Bus 6 (PQ Bus)
Voltage magnitude ≈ 1.013 pu
Voltage angle ≈ -3.69°
Load = 90 MW, 30 MVAR

Bus 7 (PQ Bus)
Voltage magnitude ≈ 1.026 pu
Voltage angle ≈ 3.70°

Bus 8 (PQ Bus)
Voltage magnitude ≈ 1.016 pu
Voltage angle ≈ 0.73°
Load = 100 MW, 35 MVAR

Bus 9 (PQ Bus)
Voltage magnitude ≈ 1.032 pu
Voltage angle ≈ 1.97°

These results indicate that the load buses experience slight voltage variations due to power demand, while the slack bus balances the system by supplying the required active and reactive power. The PV buses maintain constant voltage while adjusting reactive power, ensuring overall system stability.[18]

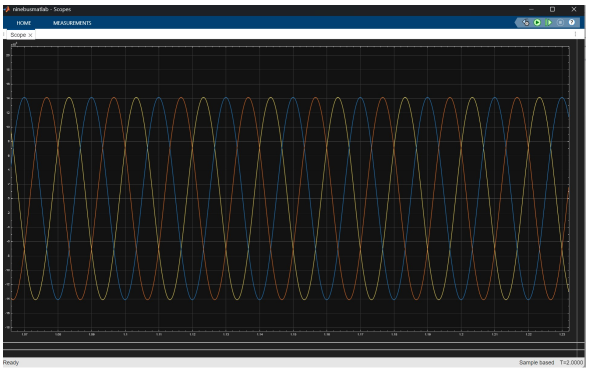

Fig 5 Three-Phase Voltage Waveforms from Simulink Scope (9-Bus System)

The above shows the three-phase voltage signals generated using MATLAB Simulink simulation of the 30 bus power system. Phase-A, Phase-B and Phase-C voltages of a network bus shown as 3 curves. The waveforms are sinusoidal and are offset by about 120 degrees, thus indicating a balanced operating condition with 3 phases.[19]

During this simulation, the amplitude of each phase voltage stays very close together, suggesting not only stable steady state operating conditions for the 9-bus network but also that no significant performance deterioration is occurring.[20] This is a balanced vibration, too, which can be used to ensure the correct working of generators, transmission lines and loads in the simulation model.

In general, the results are found to be correct and proved that under normal operation, the overall system structure provides voltage balance.[21]

Fig 6 Three-Phase Current Waveforms from Simulink Scope (9-Bus System)

The three phase current waveforms shown above correspond to the Simulink model of the 9-bus power system. Like voltage waveforms, the three-phase currents are sinusoidal in nature and are shifted in phase with each other by 120° degrees, as shown, which proves that their system is balanced.

It is to be noted that the magnitude of the currents can change as per power required or as per the power supplied by generator (PV) buses located in the system at various buses in the system called as PQ (load) bushes. Multiple buses are present in the 9-bus system and the data displayed is the overall distribution of the total load flow.

There is no noticeable distortion or harmonics in the system during simulation, as evidenced by the smooth and continuous sinusoidal plot. This validates the proper loads flow convergence and efficient operation of the power system model.

V. DISCUSSION OF RESULTS

The load flow study of 9-bus system reveals the stable operation of system as most of the bus voltages are within limits. The slack bus provides a balancing of the power mismatch, and generator buses provide voltage control with a range of reactive power output.

Based on the higher loading of some transmission lines, there may be transmission congestion during peak demand. Line resistance is causing some power losses but these are within reasonable limits. Long-distance buses with voltage drops indicate the need for reactive power support.

The overall results validate proper system operation and identify system aspects for improvement.

VI. APPLICATION OF LOAD FLOW ANALYSIS

Study of the flow of power in a 9 bus power system under normal conditions is performed using load flow analysis. It assists in the determination of bus voltages, power flow in transmission lines and system losses.[23]

Main applications are:

•Maintaining the proper voltage levels at all buses Running power flow checks and preventing line overload.

•Designing new and additional facilities and improving existing ones.

•Reducing transmission losses

Supporting economical and efficient power operation.

•Representing the system with ease of use .

•To put it simply, load flow can assist engineers in safely and efficiently operating and planning the power system.

IX. ADVANTAGES OF MATLAB SIMULINK FOR POWER SYSTEM STUDIES

The simple and effective model driven approach makes MATLAB Simulink to be widely adopted to carry out load flow study in power systems including 9-bus system. It offers a graphical interface and makes it possible to create models of a power system using blocks rather than complicated equations.[21]

It also exploits the powerful computation capability of MATLAB to solve load flow problems in a fast and precise manner. Simulink allows for simple setting of parameters of the system for analysis of various operating conditions.

One of the other benefits is ability to see the results clearly, e.g. voltage and power flow, hence more understanding. Moreover, the libraries are built-in, which makes it easy to model and suitable for learning and research.[23]

In general, Simulink is a versatile, efficient and convenient power system analysis tool.

X. FUTURE WORK

The current load flow study of a 9-bus power system here is a solid basis for understanding the performance of a power system under steady state circumstances. There are, however, a number of avenues associated with this work that may be developed in the future.

Over the next few studies, the model can be extended to incorporate larger and more complex power systems, like 14-bus, 30-bus or a real-time utility network. This will facilitate the analysis of the applicability of the load flow methods used under realistic operating conditions and assess their scalability and robustness.

Additional development can also include the integration of renewable energy sources, like solar and wind. As these sources are intermittent in nature, the inclusion of the resources in load flow studies will give detailed understanding of the power fluctuations voltage stability and the reliability of the system.

Another big direction is the application of sophisticated optimization methods. Artificial Intelligence (AI), machine learning, and metaheuristic algorithms are some of the methods that can be employed to improve the convergence speed and accuracy of their solution for load flow problem, particularly in a large-scale system.

Finally, user-friendly and more accurate modelling with software based simulation tools like MATLAB/Simulink, ETAP or Power World can be further used to simulate more accurately and visualize the parameters of the power system. In general, it is desired that future work will contribute to the understanding of how the theoretical analysis could be applied to actual power systems, turning the load flow studies into more practical, adaptable, and applicable in modern power systems.

XI. CONCLUSION

Load flow analysis of a 9-bus is useful to determine the distribution of electrical power in the power system during steady-state operating modes. In this study, voltage magnitude, phase angle, active power and reactive power of each bus was successfully achieved giving a full view of the performance of the system.

The results, show how the power from generation buses to the load buses are generated and delivered with maintaining the system balance and operational status.

limits. It can also be seen that some buses have a voltage dip and need voltage stabilisation. This analysis can be beneficial in assessing weak buses, transmission losses, and where system changes could be made to improve things.

Further, the study shows the significant role of load flow analysis for the power system in planning activities and in operational and optimization aspects.

systems. As a stand-alone, the device provides engineers with an indispensable tool for making decisions on the expansion of systems, voltage control and efficient power delivery.

Finally, the 9-bus load flow analysis doesn't just show the theoretical aspects of power system operation, it underscores the actual importance of using one in a power system to maintain reliability, stability and efficiency.

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IEEE Power & Energy Society. Technical papers on load flow studies and IEEE 9-bus system models.

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Standard lecture notes and academic materials related to load flow analysis and bus system modeling