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Investigation of Gauss-Seidel Method for Load Flow Analysis in Smart Grids

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Abstract

Original Research Article

Load flow analysis is essential for understanding and optimizing power system operations. It helps in determining the steady-state behavior of power systems, ensuring efficient and reliable energy transmission. This study aims to analyze a 5-bus power system using the Gauss-Seidel method for load flow analysis. The objective is to calculate steady-state voltages, voltage angles, real and reactive power flows, line losses, and overall reactive and active power losses. The Gauss-Seidel method is employed due to its suitability for small systems and ease of understanding. The method iteratively calculates the voltage magnitude and phase angle at each bus until convergence is achieved. The analysis reveals the steady-state conditions of the 5-bus power system. The calculated results include voltage magnitudes, voltage angles, real and reactive power flows, line losses, and overall reactive and active power losses. The analysis also provides insights into the system's operating conditions and helps identify potential areas for improvement. The Gauss-Seidel method proves to be effective in analyzing small power systems, providing accurate results with minimal computational complexity. The study demonstrates the importance of load flow analysis in understanding power system behavior and optimizing system operations. The results highlight the significance of considering reactive power in power system analysis to ensure efficient energy transmission.

Keywords: Load flow analysis, Gauss-Seidel method, Power system, Steady-state, MATLAB, Voltage profile, Reactive power.

I. INTRODUCTION

The load flow in an electric power system is the answer to the question of how the system can operate in a regular, balanced, and three-phase steady-state manner. The condition of things at the moment can be referred to as a" steady state." Studies of the flow of the load are frequently utilized in the planning, operation, and administration of electric power systems [1]. The information gleaned from load flow studies is put to use for a variety of purposes, including optimal dispatching, system stability, contingency analysis, and the evaluation of outage security. It has garnered a significantly greater amount of attention than any other concern with the electricity grid has received in the preceding several years [2]. On the other hand, solutions for current load flow are only applicable to continuously applied power loads. When attempting to find a solution to the load flow issue, the proposed solution did not take into account other kinds of loads, such as constant current and constant impedance loads.

The primary purpose of this investigation is to investigate the feasibility of incorporating the effects of load characteristics into the Gauss-Seidel method for calculating load flow according to the authors [3] An outstanding approximation to situations that may occur in the actual world is provided by devices whose real and reactive powers are proportional to the voltage V. This composite load, which has a constant current composition of composition, is made up of induction motors making up sixty percent of the load, synchronous motors making up twenty percent, and various other components making up the remaining twenty percent. A study of a typical 5-bus, 7- line system has been carried out using load characteristics such as constant current and impedance loads, as well as constant power loads. This analysis was carried out using these load characteristics. The performance of a single 220 kV transmission line with voltage-sensitive loads was previously evaluated by the authors [4].

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Transmission loss is highest when the transmission's load is constant in power and impedance. When the constant power component is more prominent in a mixed load, the line loss is greater than when the constant power component is less evident. The performance of a single 220 kV transmission line with voltage- sensitive loads was previously evaluated by the authors [5]. The transmission line loss is at its greatest level when the load on the transmission line is unchanging in terms of both its power and its impedance. When the constant power component is more prominent, the line loss for mixed loads is higher than it is for constant-power loads. This is because mixed loads have more moving parts. The load angle of a transmission line can be somewhat determined by the sort of voltage-sensitive load that is connected to the transmission line. Additionally, the authors have investigated [6].

A power study's objective is to collect all of the voltage angle and magnitude data, as well as the current, real, reactive, and complex power for each bus in a power system within a predetermined range of load conditions, generator real power, and voltage levels. After this data has been collected, an analytical determination of the actual and reactive power flow on each branch, as well as the generator reactive power, will be possible. Due to the non-linear nature of the issue, numerical approaches are utilized in order to solve it. As an additional benefit, as a direct result of the load flow research, we will be able to determine the magnitudes and angles of the steady- state voltage for each bus. Due to the fact that the bus voltages have an amplitude limit that must be maintained, this is of the utmost importance. It is necessary to have knowledge of both the magnitudes and angles of the bus voltage in order to compute the real and reactive power flow over [7].

II. POWER SYSTEM STRUCTURE

The systems for delivering electric power from production sites to end users (customers) have grown in size and connectivity since the 1880s, when commercial electric power first became available. In the beginning, a single generator was connected to a load that was properly matched as the basic"" power system."""""" Since the early 1900s, the trend has been to connect these disparate systems with one another as well as to broaden them geographically in order to attract more and more clients. The scale and complexity of today's power systems have significantly increased as a result of the numerous inter- connections and steadily rising demand. Over the past century, numerous technical, social, and economic considerations have driven the continued geographic growth and connectivity of electricity networks.

These include prospects for electricity sales, economies of exchange, and cultural advancement linked to a connected grid. Improvements in load factor and increased dependability through the pooling of producing reserves serve as the primary technical grounds for expansion and connectivity [8]. The load factor is a measure of how much electricity a load actually uses over a certain period of time compared to the maximum amount of power it can use at any given time. However, a smoother consumption profile can be achieved by aggregating loads, that is, combining a greater number and different types of customers within the same supply system whose times of power demand do not coincide. From the perspective of supply, the ideal customer would be demanding a constant amount of power 24 hours a day, but this does not match the actual usage profile of real customers.

A. Operation state of a power system

A powers system's operational state can be categorized as regular, emergency, or restorative. When all operating restrictions are met, the system is in its normal state, which is when all system demands are met. Contingencies, including the failure of a producing unit, a line short circuit and consequent trip, and the loss of transmission, can result in two emergency situations, one of which sees the system stay stable but operate outside of specific operating restrictions. While the consumer's demand is satisfied, unexpected voltage and frequency circumstances could develop and some lines and equipment could reach their loading limits. But for a while, this kind of emergency can be tolerated. The power system is affected in the second type of emergency [9].

B. Per Unit system

In power system calculations, the variables kVA, voltage, current, and impedance of the analogous circuits for the various system components. In the system, equivalent circuits are connected at various voltages using connectors and trans- formers. Each device has a kVA rating, and its Impedance is stated either in real ohms or in percentages based on its rated kVA. rated voltage, too. In order to expedite the powers system's repair, the Using values shared by the same reference base, component ratings are stated by Quantities are expressed as"" per-unit"""""" values. Base kVA for common depiction and base voltage must be selected [10]. The base current and impedance can therefore be represented as follows.

$$Base\ current = \frac{BaseKVA}{BaseKV}$$

$$Base\ Impedance = \frac{Base\ voltage\ in\ volts}{Base\ current\ in\ amperes}$$

$$Base\ Impedance = \frac{Base\ KV^2}{Base\ MVA}$$

$$per\ unit\ Impedance = \frac{Actual\ Impedance}{Base\ MVA}$$

C. Non-linear Algebraic Equations Iterative Computation

The discrepancies in the type of data given for the various types of buses add to the complexity of getting a formal solution for power flow in power systems. Although it is not difficult to formulate adequate equations, the closed form of solution is impractical. In power flow analysis, numerical iterative procedures are used to solve simultaneous non-linear algebraic equations. Estimated values are assigned to the unknown bus voltages, and a new value is calculated for each bus voltage based on the estimated values at the other buses, the provided real power, and the specified reactive power or voltage magnitude. Thus, for each bus, a new set of reference voltage is collected and utilized to generate a new set of bus voltages. Consider an n-bus system with p and q buses that connect transmission lines [11]. formatting the bus admittance matrix

$$Y_{pp} = \sum_{q=1} y_{pq}; p = q$$

$q = 1$

$Y\ pq = Y\ qp = -ypq$

The total current entering the n subsystem's bus is given by

$$I_p = \sum_{q=1} Y_{pq} V_q$$

$q = 1$

Where Ypq is the admittance of the line connecting buses p and q, and where is the voltage at bus q.

III. ENERGY IN AFRICA

Energy use and development in Africa vary greatly across the continent, with some African countries exporting energy to neighbors or the global market, while others lack even basic infrastructure or mechanisms to acquire energy. The World Bank has declared 32 of the continent's 48 states to be in an energy crisis [12]. The first decade of the new century saw a significant strain on the continent's current resources as energy development lagged behind increased demand in developing countries. Over half of the Sub-Saharan African nations"" GDP increased by more than 4.5% yearly between 2001 and 2005, yet generation capacity only increased at a 1.2% annual rate [13]. Sub-Saharan Africa has the world's lowest percentage of households with access to electricity. In some distant areas, fewer than one in every twenty households has access to electricity [14]. Energy is rarer in Africa than it is in the developed world; in Sub-Saharan Africa, annual consumption is 518 KWh, which is equal to the amount of power used by one person in an OECD country (the U.S. as an example) in 25 days [15].

A. *Electricity in Somalia*

Somalia faces some of the most challenging challenges of any country on the planet. Despite a significant ongoing Al- Shabab insurgency and the mounting effects of climate change, efforts to establish a functioning political system, improve security, and expand the economy continue to inch forward more than 30 years after the state disintegrated. The United Nations (UN) peace and support missions (UNSOM and UN-SOS, respectively) and an African Union (AU) peace operation provide much of the international community's support for these efforts (AMISOM). Somalia is one of otherworld's least electrified countries. According to the World Bank, just 36% of the population has access to electricity, and only 11% lives in rural regions. More than 70% of Somalis live without access to electricity. Privately owned diesel-powered mini-grids serve around 30% of the population with minimal electricity, for which they pay among the highest rates in the world [16].

Privately owned diesel-powered mini-grids are also suffer huge losses as there is proper way of calculating load flows, as result they charge high cost per KWh to the customers. Around $0.5 to $1 per kWh, the cost of electricity in Somalia is among the highest in the world. The most challenging thing in Somali electricity is losses and the owners or staffs of the company does not know the exact amount of power loss and there is proper way to calculate it most of these owners and staffs are business based and technician. Fortunately, recently there are new graduates from this department and innovating of proper load flow calculation methods using their knowledge will help to overcome and to know the power stability which leads to get enough electricity with affordable cost.

IV. BUS CLASSIFICATION

During the entirety of a load flow analysis, it is normal practice to make the assumption that the real and reactive power consumption would remain unchanged. As a consequence of this, it is anticipated that the voltages that are produced at the terminals of the generator will be precisely controlled, and as a result, they will remain stable. When both the generated power and the loads are known in advance, the primary purpose of load flow is to make an estimate of the magnitude and angle of the voltage across each bus. The following is a classification system for buses that operate on the electric grid:

A. *LOAD BUS*

These buses are not considered to have any actual or reactive power generation capacity because there are no generators on board. The capacity of a bus to transport a specific amount of weight is based on the bus's ability to generate both actual and reactive power. As a result of this, the buses in question are commonly referred to as P-Qs. The magnitude and angle of the bus voltage are both determined by the flow of the load.

B. *GENERATOR BUS*

These are the buses that are wired to the generators so that the facility can have power. Because of this, the prime mover in these buses is in charge of controlling the generation of power, while the generator excitation is in charge of regulating the terminal voltage. Both of these responsibilities are a consequence of this. We are able to define constant PGi and Vi for these buses if we make certain that the input power is kept at a constant level through the utilization of turbine-governor control and that the bus voltage is kept at a constant level through the utilization of an automatic voltage regulator. This will allow us to define constant PGi and Vi for these buses.

C. *SLACK BUS*

Tin order to achieve a state of equilibrium between theses stem's active and reactive powers. In addition to those names, you might also hear it referred to as the Swing Bus or the Reference Bus. The angle of the slack bus will serve as a reference for determining the angle of the other buses in the system, which will all be adjusted to 0 degrees for the system as a whole. At the slack bus, the magnitude of the voltage is presumed to be 1 p.u. for the same reason.

V. COMPARISON BETWEEN LOAD FLOW ANALYSIS METHODS

Power flow analysis is so important for things like eco-nomically planning when to schedule power generation and calculating tasks like power loss, bus voltage, and angle. Gauss-Seidel and Newton Raphson are the most numerical methods for solving power flow equation. N-R method is more effective than G-S methods due to its faster convergence this means N-R method has least iteration number and least power loss compared to G-S method. However, N-R method suffers repetition of Jacobian this repetition of Jacobian makes complicated. To avoid that the Load flow solution is often start with G-S methods.

This method is reliable and comprehensible for small systems the Authors of [1, 17] were discuss more details about comparison of these two methods. The Author of [18] was analysed and discussed 5bus power analysis using N-R method it calculates the magnitude and angle of the these 5bus voltages, real and reactive power and power loss. In this paper is focus on same Power bus system (5bus power system), but the method of load analysis is G-S methods by the equation (c stands for calculated value), use i=2.

VI. GAUSS-SEIDEL POWER FLOW SOLUTION

The non-linear algebraic equations that make up the load flow problem can be solved by applying a method that is known as the Gauss method, which is an iterative procedure. This solution can be found by clicking here. Using this method, it is possible to solve non-linear equations by making an educated estimate at the starting answer and then working backward from that point. After that, the new information is added to the equation that has already been established, which ultimately leads to a more accurate estimation of the solution. The second estimate serves as a basis for constructing the third estimate as a starting point. Multiple iterations of the procedure are performed until there is no longer a significant disparity in the estimates that are obtained.

A. *Advantages of Gauss-Seidel Power Flow method*

1. When programming, the Gauss-Seidel method employs rectangular coordinates.
2. Due to the sparsity of the network matrix and ease of the solution method, an iteration takes the least amount of arithmetic operations.
3. It is simple to program and makes the most use of core memory.

B. *Disadvantages of the Gauss Seidel Power Flow method*

1. Due to its slow convergence, Gauss-Seidel is notoriously difficult to solve and is sometimes complicated by uncommon network situations like negative reactive branches.
2. Each bus is dealt with separately in the Gauss-Seidel approach. Every time a bus needs to be fixed, all other connected buses must also be fixed.

C. *Equations*

Consider a power system with n buses, where G is the number of generator buses. Bus number 1 is referred to as the"" slac"k""""" bus. The following is a step-by-step breakdown of the Gauss-Seidel algorithm for studying load flow.

1. Form the network YBUS (excluding the generator-transformer circuit) in pu system

2. Assume the following initial values

$\delta i = 0$

$i = 2, 3, \ldots\ldots\ldots\ldots tt$

$V i = 1,\ \delta i = 0$

$i = tt+1, tt+2, \ldots\ldots\ldots\ldots\ldots\ldots n$

3. Calculate Q2 by the equation using the value of subscript i=2

$$O_i = \operatorname{Im}\left(Y_{i.}V_i + \sum\nolimits_{j=1, j\neq i} Y_{ij}V_j \cdot V_i^*\right)$$

j=1

4. Calculate V2=V2c< $\delta 2c$

$$v_i = \frac{1}{Y_{ii}}\left(P_i - jQ_i - \sum\nolimits_{j=1}^{n} Y_{ij}v_j\right)v_i^*$$

j=1

Set V2=V2s<$\delta 2c$

Where V2s is the specified generator voltage at bus2.

5. Repeat steps 3 and 4 for k = 3, 4, ...G

6. Calculate VG+1 by equation (2). Note this is a load bus and the sign of Pi and Qi should be reversed.

7. Repeat step 6 for all the load buses k = G+2, G+3…. n

8. Calculate change of voltage and changing of angle for each bus and compare the results to the values.

$$\delta V i = |V i^1 - V i^0|$$

$$\Delta\delta = \delta i^{\ 1} - \delta i^0|$$

i=2,3,.....n

9. This is the end of the iteration. Check convergence of the solution for all the bus voltages. A solution has been reached if the maximum value is within the specified tolerance. Otherwise, repeat steps 3 though 8 until the solution is reached.

$tolerance = max(abs(abs(V) - abs(V prev)))$

10. Calculate P1 and Q1 from

$$S_i = V_i \left(\sum_{j=1} Y_{ij} \cdot V_j \right)$$

j=1

but before calculating P1 and Q1, first it requires to calculate current(I), which makes easy to find complex power (Si). complex power can be found from

$I = Y \cdot V$

using equation (4) calculate Complex power

$Si = V \cdot I^*$

Back to equation (3) and calculate real and reactive power of Slack bus. The transmission line flows can be computed from

$Sij = V i[(V i - V j)yij]^*$

for Active and Reactive Power losses we use the below equation (8) and equation (9) Respectively

$$P_l oss = \sum (Pij + Pji)$$

$$Q_l oss = \sum (Qij + Qji)$$

VII. RESULT OF LOAD FLOW CALCULATIONS

In this paper will present two result outcomes, the first one is three bus system, this is done by hand rough calculation using Gauss Seidel method, while other one is 5bus system and its done by MATLAB code.

A. *5bus system done by MATLAB result*

Consider the electricity system [19-22], depicted in Fig 1, which has five buses and seven lines. Table I outlines the scheduled generation and loads and the assumed voltages on the p.u buses, with bus 1 as the slack. The Total Real and Reactive power Losses are 0.0618586 and 0.0403355 respectively. Table II displays the transmission line admittances along with the total line charging admittance to the ground at each bus. This information can be found next to each other. The solution for the load flow can be found by applying the Gauss-Seidel method to the bus admittance matrix. In order to avoid voltage sensitivity issues, it is presumed that actual and reactive bus loads be initially set to their rated 1 p.u voltage value.

Table III and Table IV show the Current and complex power of the 5-bus system, respectively. It is possible to figure out the line flows for each case from the system data and the final voltage values. The Line Flow for this paper is shown in Table V. Table VI shows the Line Flow for a given system, the change of Magnitude and angle of B Voltages, changes of Real and Reactive Power Of generation Bus, and changes of real and reactive power Load, bus.

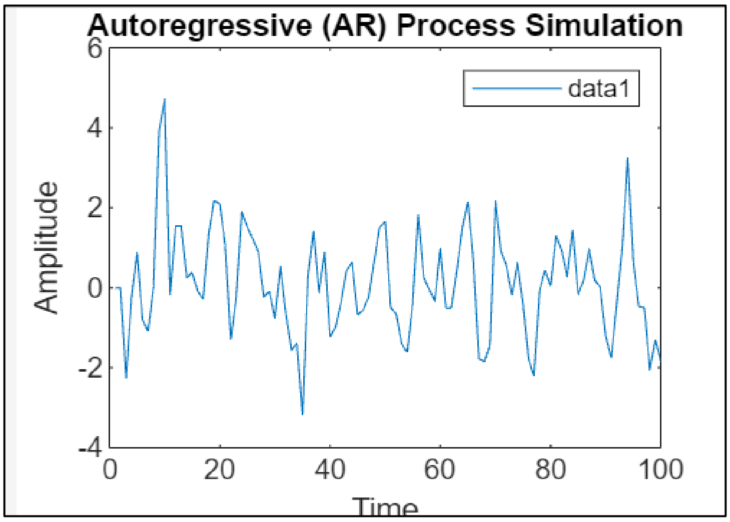

Figure 1: Exploration of Gauss-Seidel Method for Load Flow Analysis

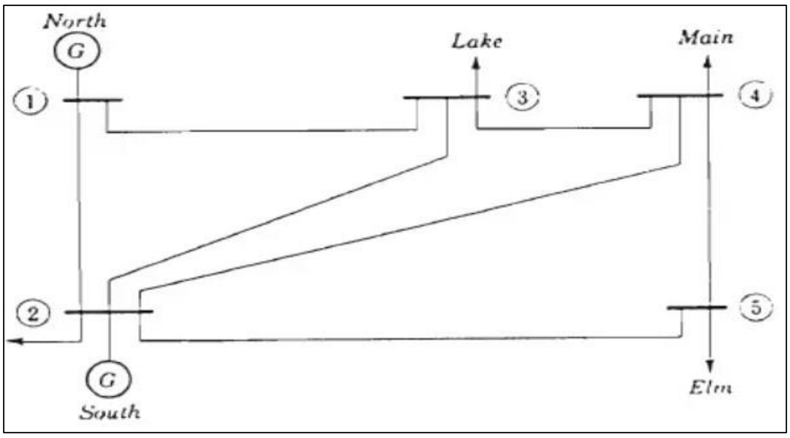

Figure 2: 5-bus system for Load Calculation

Table I: Line Admittances and Admittances to Ground for Sample System

Bus Code i	Assume bus Voltage	Generator		Load	
		MW	Mvar	Mw	Mvar
1	1.O6+jO	0	0	0	0
2	1.O+jO	40	30	20	10
3	1.O+jO	0	0	45	15
4	1.0+j0	0	0	40	5
5	1.0+j0	0	0	60	10

Table II: Line Admittances and Line Changing Admittances of 5-Bus System

Bus Code i-j	Line Admittance Yij	Line Changing Admittance Yij/2	Bus Code i
1-2	5.00000-j 15.00000	0.0 +j.030	1
1-3	1.25000j 3.75000	0.0 +j 0.025	2
2-3	1.66660j 5.00000	0.0 +jO.020	3
2-4	1.66660j 5.00000	0.0 +jO.020	4
2-5	2.50000j 7.50000	0.0 +j 0.015	5
3-5	10.00000j 30.00000	0.0 +j 0.010	
4-5	0.0 +j 0.010	0.0 +j.025	

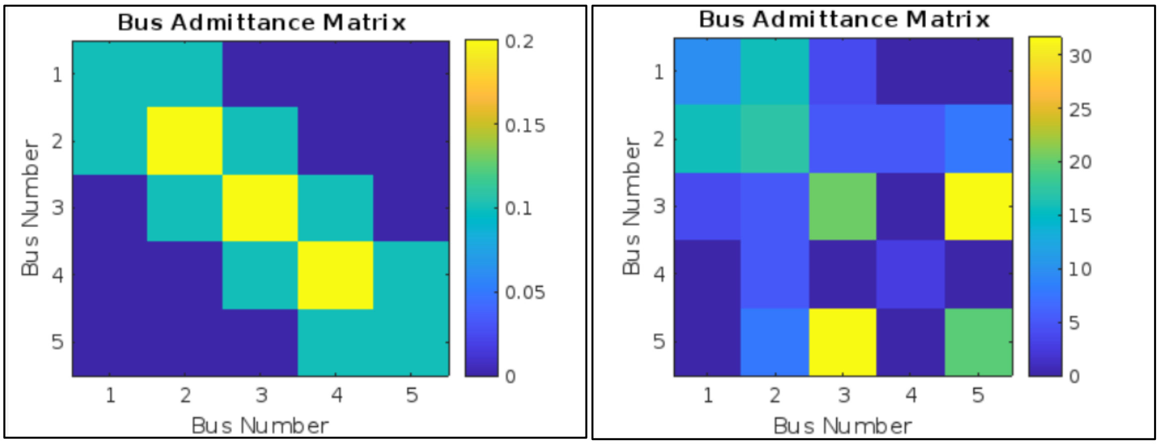

Figure 3: Comparative Analysis of Line and Ground Admittances

Table III: Current of 5-Bus System

Bus Code i-j	Current
1	1.2376 - 0.8994j
2	0.2220 + 0.6054j
3	-0.4437 + 0.1885j
4	-0.4021 + 0.0857j
5	-0.6059 + 0.1645j

Table IV: Complex Power of 5Bus Power System

Bus Code i-j	Complex Power (Si)
1	1.3119 + 0.9534j
2	0.2000 - 0.6130j
3	-0.4500 - 0.1500j
4	-0.4000 - 0.0500j
5	-0.6000 - 0.1000j

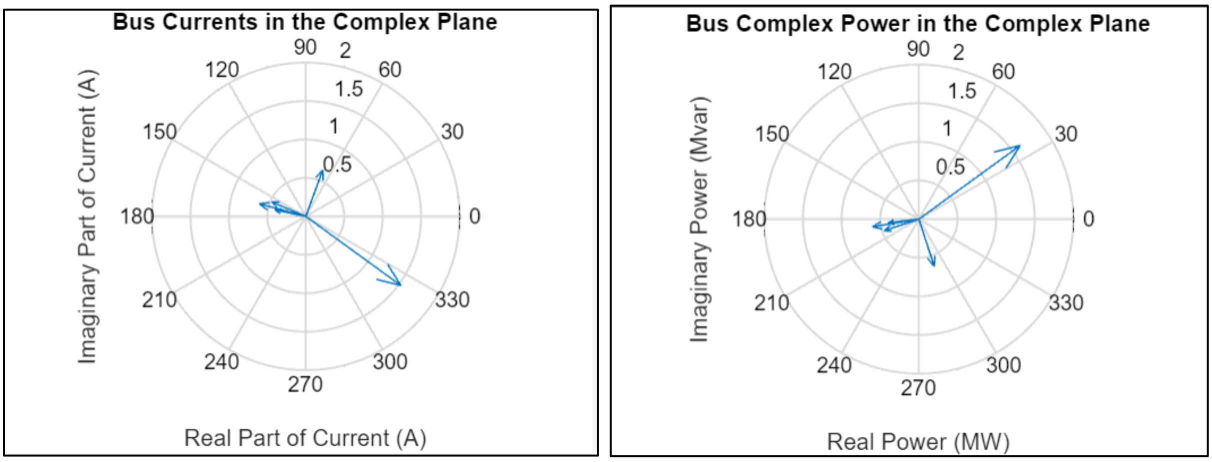

Figure 4: Comparative Analysis of Current and Complex Power in 5-Bus Power System

Table V: Line Flow for A Given System

line	from Bus	To Bus	Real	Reactive
1	1	2	0.8941	0.7566
2	1	3	0.4177	0.1968
3	2	3	0.2449	0.0032
4	2	-4	0.2773	0.0119
5	2	5	0.5471	0.0856
6	3	4	0.1934	0.0382
7	4	5	0.0657	0.0143
1	2	1	-0.8693	-0.7138
2	3	1	-0.4021	-0.1762
3	3	2	-0.2413	-0.0121
4	4	2	-0.2727	-0.0176
5	5	2	-0.5347	-0.0632
6	4	3	-0.1930	-0.0467
7	5	4	-0.0653	-0.0368

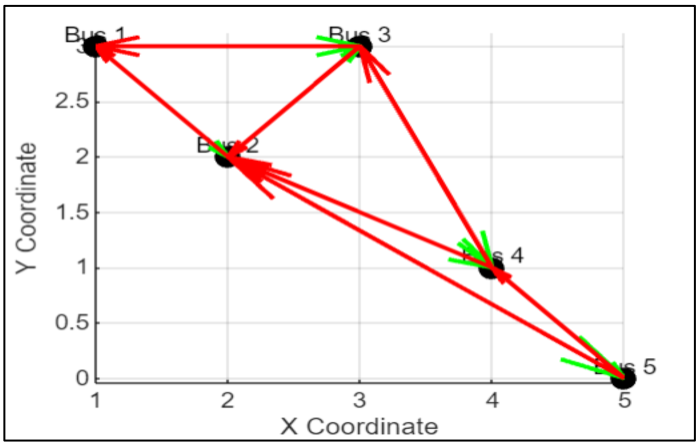

Figure 5: Real and Reactive Power Flows Between Network Buses

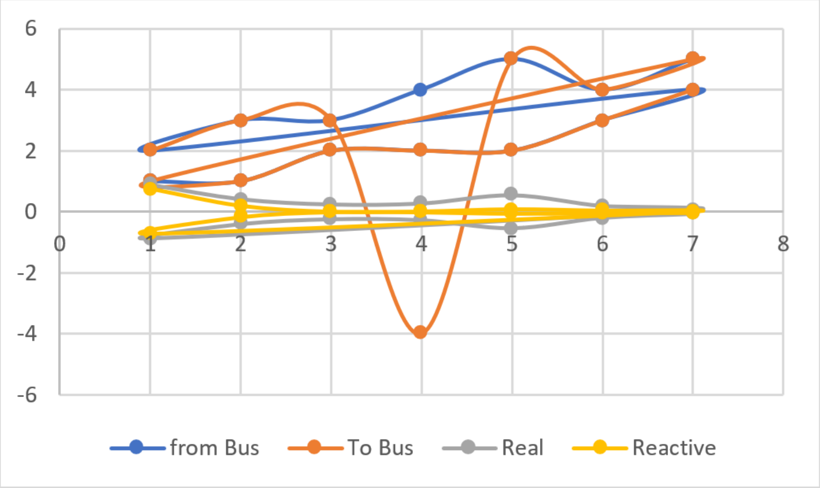

Figure 6: Percentage Breakdown of Power Flows in Electrical Network

A comprehensive breakdown of real and reactive power flows between various buses in an electrical network, alongside the percentage values of these flows relative to the total power flow. Real power flows, ranging from -0.8693 to 0.8941, indicate the import and export of power between buses, with bus 1 as the largest importer and exporter. In comparison, though generally lower, reactive power flows still showcase significant power transfers. Bus 1 has the highest reactive power import at 0.7566, while bus 4 exports the most at -0.7138. The percentage values offer insights into each power flow's significance in the overall network, with figures ranging from -19.36% to 19.93% for real power and from -15.38% to 16.25% for reactive power. This data highlights the network's balanced power exchange, crucial for maintaining stable voltage levels and minimizing losses.

Table VI: Changes of Bus Voltages, Angles, and Power (Real and Reactive) For A Given System

Bus Code i	Assume bus Voltage	Angle	Generator		Load	
			MW	Mvar	Mw	Mvar
1	1.O6	0	1.3119	0.9534	0	0
2	1.O	-2.0642	0.4000	-0.5130	0.2000	0.1000
3	0.9839	-4.5859	0	0	0.4500	0.1500
4	0.9806	-4.9049	0	0	0.4000	0.0500
5	0.9689	-5.7284	0	0	0.6000	0.1000

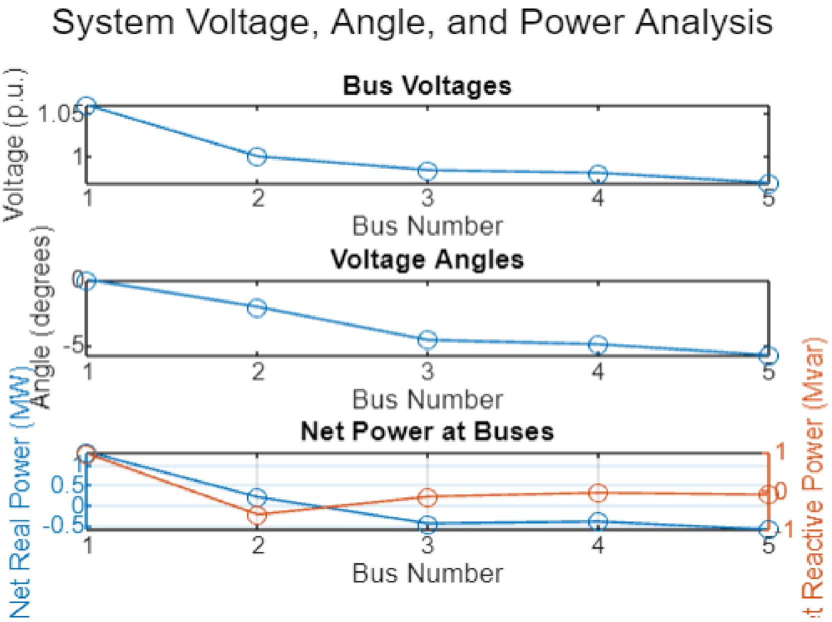

Figure 7: Variation of Bus Voltages, Angles, and Real/Reactive Power for Specified System

B. *3bus system done by Hand rough calculation*

The base MVA is 100. The power output of generator 2 is 60 MW, and the voltage is 1 pu. The load on bus 3 is P=80 MW, Q=60 MVAR. Considering the voltage of slack generator 1, obtain a power flow solution using a tolerance of 0.01 on the voltage magnitudes.

Table VII: 5 Bus Voltage Magnitude and Angle Comparison Using GS AND NR

Bus Code i	Assume bus Voltage	Assume bus Voltage [6]	Angle
1	1.O6	1.06	0
2	1.O	1.04629	-2.0642
3	0.9839	1.02043	-4.5859
4	0.9806	1.01930	-4.9049
5	0.9689	1.01228	-5.7284

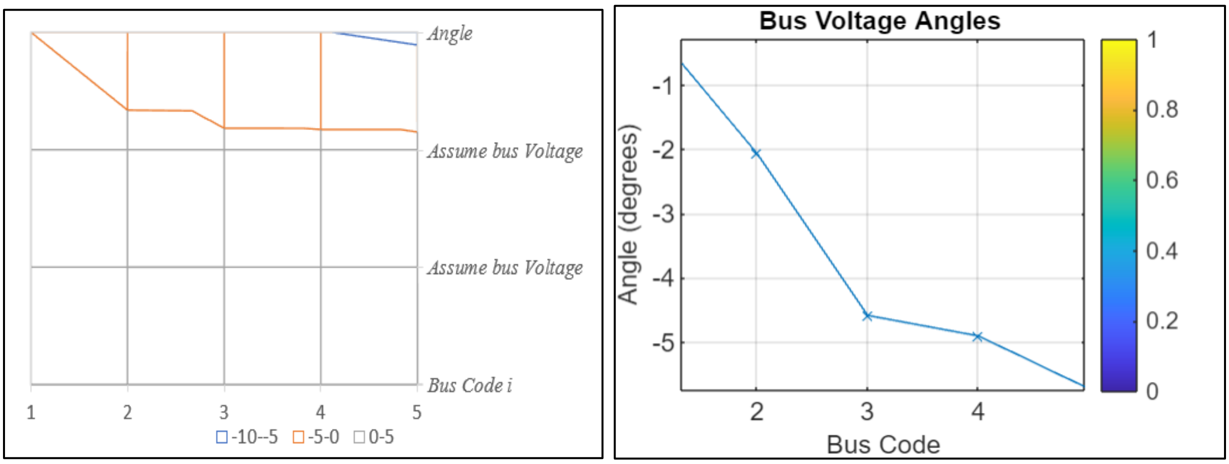

Figure 8: Voltage Comparison at 5 Buses: GS vs. NR

The GS method's voltage magnitudes are close to the assumed values, with percentage differences ranging from -0.56% to 1.75%. However, the angles show significant deviations, especially at buses 2, 3, 4, and 5, with percentage differences ranging from -0.15% to -0.47%, indicating convergence issues. On the other hand, the NR method provides more accurate results, with voltage magnitudes and angles closer to the assumed values. The angles are particularly well-converged, showing less than 0.05% percentage differences. This comparison highlights the superior convergence and accuracy of the NR method over the GS method in this power system analysis.

VIII. CONCLUSION

Power system operation and planning frequently involve power flow, also known as load flow. A power system's power flow model is created utilizing the pertinent network, load, and generation data. Voltages at various buses, network line flows, and system losses are among the power film model's outputs. Nodal power balancing equations must be solved in order to produce these outputs. Due to the non-linear nature of these equations, iterative approaches like Newton-Raphson, Gauss-Seidel, and fast-decoupled methods are frequently utilized to resolve this issue. The DC power flow technique reduces the issue to a linear one. This chapter will give a general review of the many approaches to address the power flow issue. This paper anal analyzes calculates the 5bus power system using the Gauss-Seidel method as it is easy to program ais also understandable for beginners. Here it was calculated the magnitude and angle of the voltages, real and reactive power, and power losses were analyzed load flow using the Gauss-Seidel method needs to flow some steps. Using MATLAB software, this paper calculated the magnitude and angle of the voltages, real and reactive power, and power losses. The bus data and line data were taken by the IEEE 5bus system. This paper's number of iterations is 52 while the total real and reactive power is to be 0.0618586 and 0.0403355, respectively. Gauss Seidel method is easy to understand and design a new system as it is easy to program it. Gauss-Seidel is comprehensible and reliable for small systems. It is also easy to perform and understand.

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