MULTIDISCIPLINARY APPLIED RESEARCH AND INNOVATION
e-ISSN: 2773-4773

MARI

Vol. 6 No. 2 (2025) 89-95
https://publisher.uthm.edu.my/periodicals/index.php/mari

A Comparative Study of Gauss-Seidel and Newton-Raphson Methods in Power Flow Analysis

Nurfaraliyana Samburi[1], Ahmad Fateh Mohamad Nor[2]*

[1] *Department of Electrical Engineering, Faculty of Electrical and Electronic Engineering, University Tun Hussein Onn Malaysia, Parit Raja,86400, MALAYSIA*
[2] *Green and Sustainable Energy (GSEnergy), Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia,86400 Parit Raja, Johor, MALAYSIA*

*Corresponding Author: afateh@uthm.edu.my
DOI: https://doi.org/10.30880/mari.2025.06.02.010

Article Info

Received: 31 August 2024
Accepted: 31 December 2024
Available online: 20 February 2025

Keywords

power flow analysis, Gauss-Seidel method, Newton-Raphson method, bus voltage magnitude, MATLAB

Abstract

The comprehensive study highlights the growing demand for electricity driven by global population growth, making the stability and efficiency of electric power systems increasingly critical. With global electricity demand predicted to rise significantly by 2050, the stability and efficiency of electric power systems have become a key challenge. Power flow analysis is fundamental in addressing these challenges, particularly with voltage levels and overall system performance. In this research, a comparative analysis of the Gauss-Seidel (GS) and Newton-Raphson (NR) methods was conducted to assess their effectiveness in solving power flow problems. MATLAB simulations were utilized to perform the analysis on the IEEE 57-bus test system. According to the result obtained, the GS method is more suitable for smaller, and simpler power systems due to its computational efficiency, while the NR method provides superior accuracy and is more appropriate for large-scale systems. The findings indicate that the NR method is the most appropriate for performing the 57-bus test system. The novelty of this research is based on the evaluation of both methods under varying load conditions for a larger-scale system, offering significant insights into their applicability in voltage profile analysis. Overall, the findings emphasize the importance of selecting the appropriate method to ensure the accuracy and reliability of power system operations.

1. Introduction

In the new global economy, electricity has become a central issue as the increasing world population has caused energy demand to increase constantly. Electricity has become fundamental to almost every aspect of our daily routines. It is used for lighting homes, powering appliances, operating communication networks, and supporting industrial processes. Global electricity demand continues to rise due to population growth, industrialization, and the widespread adoption of modern technologies. It has been found that total energy consumption is predicted to be 20% today and is expected to increase by 50% in 2050 [1]. Therefore, electricity systems are becoming more complex and require comprehensive studies to ensure efficient and reliable operation under current conditions.

It has previously been observed that power flow has been identified as a key method for solving issues in electric power systems under balanced and steady-state operating conditions [2]. The primary goal of power flow analysis is to assess how increased load affects the most critical aspects such as voltage levels and overall system stability. For instance, the higher load levels can lead to lower voltage values for certain buses. Thus, after numerous considerations, conventional methods based on numerical iterative techniques such as Gauss-Seidel (GS) and Newton-Raphson (NR), are widely used.

The literature highlights the study performing the power flow analysis using these two methods for the IEEE 5-bus system [2]. According to the research findings, NR is characterized by quadratic convergence, which refers to faster convergence as the solution approaches the correct value. However, it requires more computational time due to the more complex calculations involved in each iteration. In contrast, GS is known as linear convergence because this method only uses the current values of variables, rather than iteratively adjusting and refining values like NR. Overall, these studies highlight that NR is better suited for large systems due to its higher accuracy and faster convergence, while GS is more appropriate for smaller systems with lower computational complexity.

This research aims to focus on more complex systems such as the IEEE 57-bus system. A comparative analysis will be conducted by applying both the GS and NR methods to evaluate their effectiveness in different operational contexts.

2. Methodology

The present study utilizes the IEEE 57-bus test system as a model for conducting power flow analysis through MATLAB simulations. Two frequently used numerical iterative techniques in power flow analysis are the Newton-Raphson and Gauss-Seidel methods. It is essential to conduct power flow analysis on large systems, such as the 57-bus system because the benefit of this approach will assist future researchers and academicians in the field of power system stability.

2.1 Flow of the Research Study

Figure 1 presents a comprehensive project plan, which serves as a workflow for the successful execution of the study. This workflow outlines the progress from inception to completion, achieving the predefined goals and objectives. This ensures the study can be executed as targeted.

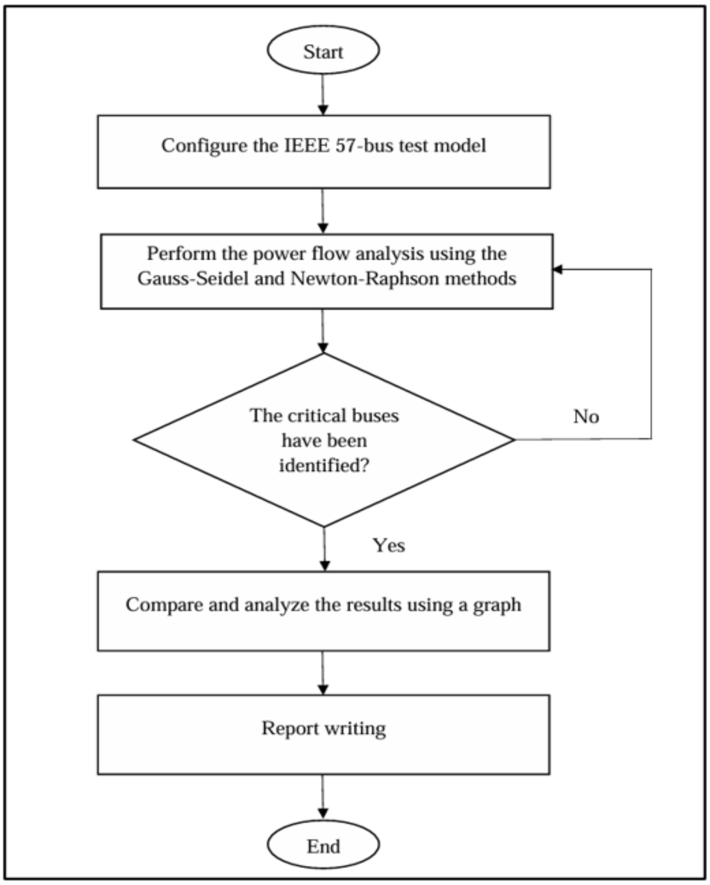

Fig. 1 *Flowchart of the research study*

2.2 IEEE 57-Bus Test System

The single-line diagram of the standard IEEE 57-bus test system is presented in Figure 2. The data used to construct the test system model was derived by referencing this diagram, which provides the necessary specifications for the buses, generators, transformers, and transmission lines [3]. In the data, Bus 1 is designated as the slack bus, and there are seven generator buses: Bus 2, Bus 3, Bus 6, Bus 8, Bus 9, and Bus 12. The remaining buses are categorized as load buses, comprising a total of 42 buses designated for load distribution. Additionally, there are 17 transformers connected to the buses, along with 63 transmission lines.

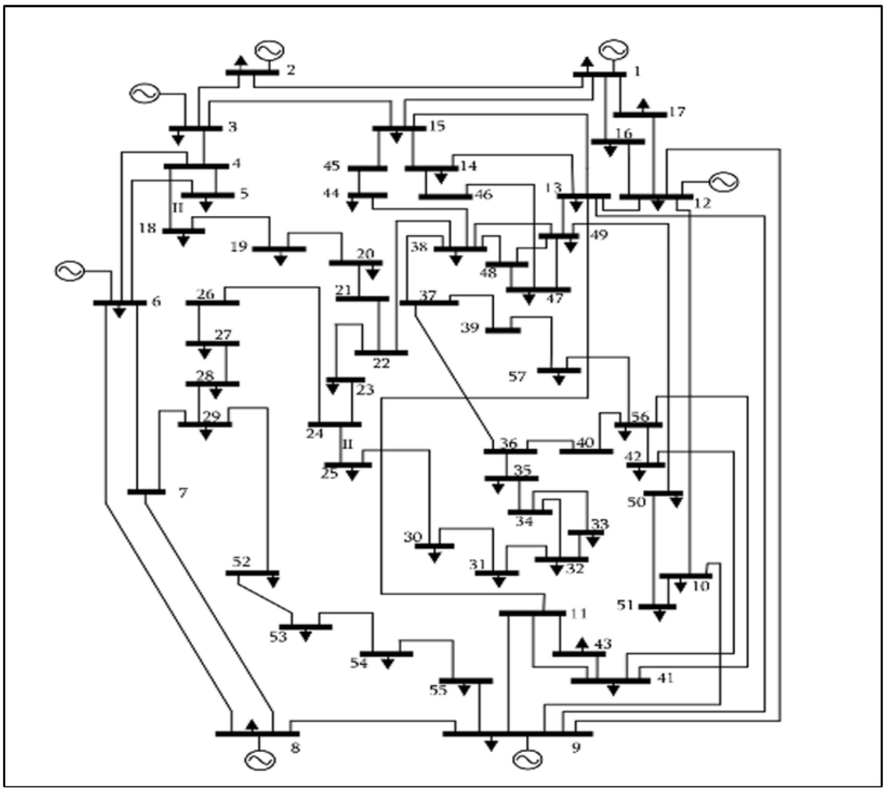

Fig. 2 *Standard IEEE 57-Bus Test System [3]*

2.3 Power Flow using Gauss-Seidel Technique

The Gauss-Seidel (GS) method is an iterative technique for solving non-linear equations. The iterative process is repeated until convergence is achieved, and the solution meets the prescribed accuracy. This indicates that, in power flow analysis, the GS method calculates the voltages at each bus in a system based on power flow equations, continuing the process until the results meet the desired accuracy. To perform this method, the process begins by specifying the types of buses, such as the slack bus, generator buses, and load buses. Then assume the initial values such as voltage magnitudes by referring to the IEEE data. The simulation subsequently updates the voltage values at each bus iteratively until the difference between the calculated voltages in one iteration and those from the previous iteration falls below a predefined tolerance level. This tolerance is often set as a small value. In addition to its simplicity and ease of implementation, the GS method is more popular for smaller systems due to its lower computational time [4].

2.4 Power Flow using Newton-Raphson Technique

This iterative technique is superior to the previously discussed Gauss-Seidel method. The Newton-Raphson (NR) method has become one of the most effective techniques for solving power flow problems [5]. The main advantage of this method over the GS method is its faster convergence and higher accuracy, especially in larger or more complex power systems such as the 57-bus system. The process begins with the initialization of system variables, including voltage magnitudes and angles for all buses. Power flow equations are then formulated, detailing the power balance at each bus by considering both real and reactive power. The special NR method involves the Jacobian matrix, which contains the partial derivatives of the power flow equations. The formula for the Jacobian matrix is given in Equation 1 [2]. The partial derivatives describe how small changes in voltage will influence the power at each bus. After the power mismatches are represented at any bus, the Jacobian matrix adjusts the voltages until the power mismatches are sufficiently small, and finally, the voltage values and power angles are updated using Equations 2 and 3 [2].

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \tag{1}$$

$$V_i^r = V_i^{r+1} \tag{2}$$

$$\delta_i^r = \delta_i^{r+1} \tag{3}$$

Where,
ΔP is defined as the changes in real power at each bus during the iterative process
ΔQ is defined as the changes in reactive power at each bus during the iterative process
$\Delta \delta$ is defined as a power mismatch in the voltage changes
ΔV is defined as a power mismatch in the power angle changes
J_1 - J_4 is defined as elements of the Jacobian matrix
V_i^r is defined as the updated voltage values
δ_i^r is defined as the updated power angles

2.5 MATLAB Code

MATLAB is a mathematics software, that is the industry leader in numerical calculations and is widely used in many fields due to its support for matrix operations, algorithm implementation, and connection with other programming languages [6]. To conduct this study, the scripts for the GS method [7] and the NR method [8] have been implemented to perform the power flow analysis. Key parameters including bus data, line data, impedance values, active and reactive loads, and reactive power limits, are adjusted in accordance with the standard IEEE 57-bust test system to ensure the accuracy of the results. Finally, the voltage values at each bus are recorded, and the results obtained from both methods are compared and discussed.

3. Results and Discussion

This section presents a comparison of the voltage values obtained from the GS and NR methods, focusing on the analysis of the differences between the two approaches.

3.1 Power Flow Solution

Table 1 presents the results of the power flow analysis using the Gauss-Seidel (GS) and Newton-Raphson (NR) methods, focusing on the voltage values at each bus. For the GS and NR methods, the highest voltage magnitude is observed at Bus 1, with a value of 1.040 p.u., while the lowest voltage magnitude is found at Bus 31, with a value of 0.823 p.u. for the GS method and 0.834 p.u. for the NR method.

Table 1 *Simulation result of two iterative techniques*

Bus Number	Voltage Magnitudes (p.u.) for GS method	Voltage Magnitudes (p.u.) for NR method
1	1.040	1.040
2	1.010	1.000
3	0.985	0.975
4	0.975	0.963
5	0.973	0.950
6	0.980	0.950
7	0.977	0.940
8	1.005	0.955
9	0.980	0.950
10	0.979	0.945
11	0.969	0.942
12	1.015	0.965
13	0.972	0.945

14	0.961	0.941
15	0.981	0.968
16	1.011	0.977
17	1.015	0.999
18	0.954	0.965
19	0.965	0.961
20	0.984	0.971
21	0.972	0.960
22	0.980	0.966
23	0.978	0.963
24	0.962	0.940
25	0.867	0.883
26	0.926	0.902
27	0.958	0.929
28	0.977	0.946
29	0.992	0.961
30	0.848	0.862
31	0.823	0.834
32	0.848	0.852
33	0.845	0.850
34	0.934	0.915
35	0.942	0.923
36	0.951	0.933
37	0.959	0.943
38	0.985	0.972
39	0.957	0.941
40	0.947	0.931
41	0.982	0.960
42	0.956	0.929
43	1.003	0.975
44	0.992	0.980
45	1.016	1.009
46	1.039	1.025
47	1.007	0.995
48	1.001	0.988
49	1.011	0.996
50	1.003	0.981
51	1.040	1.008
52	0.949	0.925
53	0.933	0.912
54	0.973	0.949
55	1.022	0.994
56	0.959	0.929
57	0.955	0.924

As observed in the results in Table 1, the voltage magnitude values for the NR method are generally lower compared to the GS method. One reason for this is that, in larger systems, NR requires fewer iterations and more computation time rather than GS. The lower voltage magnitudes observed in the NR method indicate that it provides a more accurate representation of the voltage profile under the system's actual load conditions. This is because the NR method captures more details on the system's behavior such as non-linear effects and interactions between real and reactive power. In contrast, the GS method may show higher voltage magnitudes, as it relies on simplifying assumptions and linear approximations that do not fully capture the complexities of the system's response. Therefore, this discussion shows the effectiveness of the NR method rather than the GS.

Furthermore, the critical buses were identified after conducting the power flow analysis, as shown in Figure 3. These critical buses are located at Bus 25, Bus 30, Bus 31, Bus 32, and Bus 33. The lowest voltage magnitude occurs at Bus 31, with a value of 0.834 p.u. for the NR method and 0.823 p.u. for the GS method. In this context, the critical buses refer to those bus voltage magnitudes that are outside the permissible voltage limit of 0.95 p.u.–1.05 p.u. [9]. These critical buses must be emphasized, as they exhibit the lowest voltage magnitudes even before increasing the load demand. However, the results of this study indicate that the NR method is more effective than the GS method, as the GS method results in lower voltage magnitudes at the critical buses compared to the NR method.

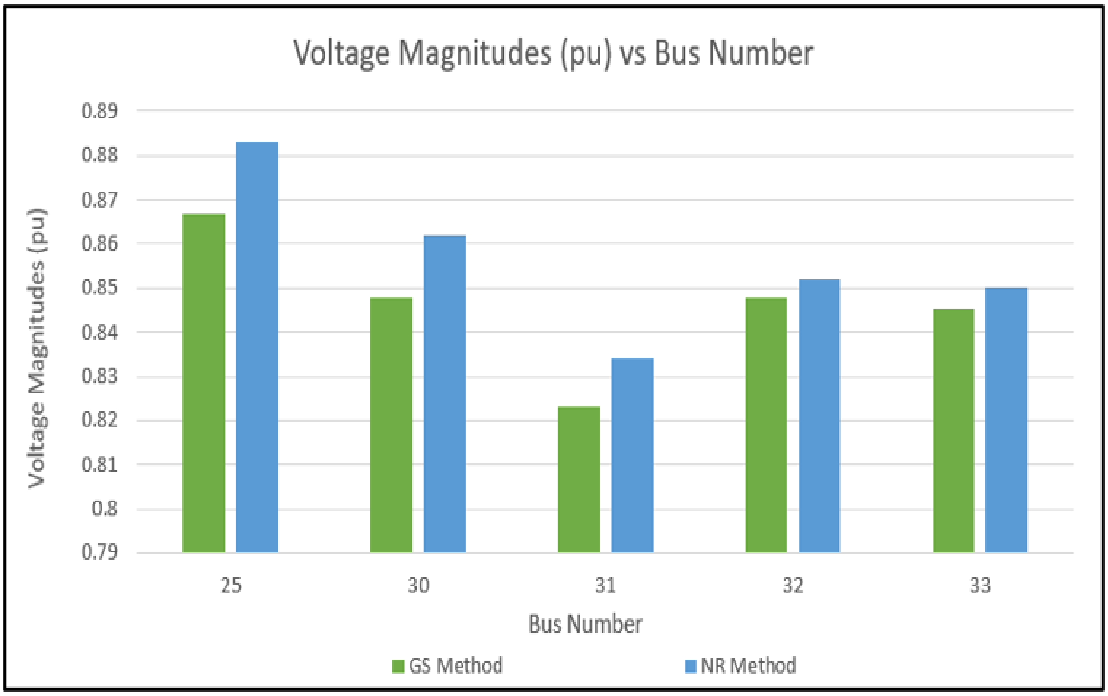

Fig. 3 *Comparison of GS and NR method results at critical buses*

4. Conclusion

This research presents a comparative analysis of the Gauss-Seidel (GS) and Newton-Raphson (NR) methods in solving power flow problems for large-scale electrical systems, specifically applied to the IEEE 57-bus test system. The study aims to highlight the importance of selecting the appropriate method to ensure accurate and stable power system operations under varying load conditions. MATLAB code was used to conduct power flow analysis on the 57-bus system using the GS and NR methods. The results showed that the NR method required fewer iterations and more computation time while providing a more precise voltage profile compared to the GS method. This study demonstrates that the GS method offers computational efficiency when applied to smaller and less complex systems. In contrast, the NR method proves to be more effective for large-scale systems due to its accuracy and reliability in handling the complexities of power systems. Based on these comparisons, the NR method produced the most precise and optimal results. By demonstrating these advantages, the research underscores the necessity of employing the most suitable method to ensure reliable and efficient electric power systems.

As a suggestion in the continuation of this study, it is recommended to introduce a voltage stability index, such as the Voltage Collapse Proximity Index (VCPI), to enhance the analysis of power system stability. Unlike simply observing voltage levels, the VCPI provides a more detailed assessment of a power system's proximity to voltage collapse. By incorporating this index into the study, researchers can evaluate not only the effectiveness of the GS and NR methods but also the overall robustness of the system in maintaining voltage stability under varying operational scenarios. Thus, this approach would make the study more comprehensive and applicable to real-world challenges in large-scale power systems.

Acknowledgement

The authors would like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for providing support for this research.

Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

References

[1] E. Kocak, E. E. Ulug, and B. Oralhan, “The impact of electricity from renewable and non-renewable sources on energy poverty and greenhouse gas emissions (GHGs): Empirical evidence and policy implications,” Energy, vol. 272, 2023, doi: 10.1016/j.energy.2023.127125.

[2] R. S. Tiwari, A. Priyadarshi, and O. H. Gupta, “A Comparative Analysis of Numerical Iterative Methods for Power Flow Using IEEE 5-Bus Test System,” in IEEE 2nd International Conference on Applied Electromagnetics, Signal Processing, and Communication, AESPC 2021 - Proceedings, 2021. doi: 10.1109/AESPC52704.2021.9708525.

[3] R. Anand and V. Balaji, “Power flow analysis of simulink IEEE 57 bus test system model using PSAT,” Indian J Sci Technol, vol. 8, no. 23, 2015, doi: 10.17485/ijst/2015/v8i23/79266.

[4] Dr. C. S. Hiwarkar, A. M. Halmare, A. A. Belsare, N. B. Mohriya, and R. Milmile, “Load Flow Analysis on IEEE 14 Bus System,” Int J Res Appl Sci Eng Technol, vol. 10, no. 4, 2022, doi: 10.22214/ijraset.2022.41590.

[5] V. V Mehtre and U. Raj Verma, “Load Flow Analysis by Newton Raphson Method,” IREJournal, vol. 5, no. 12, 2022.

[6] L. Yu, “Matlab programming environment based on web,” in Proceedings of 2018 IEEE 4th Information Technology and Mechatronics Engineering Conference, ITOEC 2018, 2018. doi: 10.1109/ITOEC.2018.8740716.

[7] Ashish Kumar (2024). IEEE 57 Bus system Load Flow Analysis (https://www.mathworks.com/matlabcentral/fileexchange/63719-ieee-57-bus-system-load-flow-analysis), MATLAB Central File Exchange. Retrieved November 18, 2024.

[8] A Chandan (2023). IEEE 30 BUS Newton Raphson Load Flow Analysis (https://www.mathworks.com/matlabcentral/fileexchange/58884-ieee-30-bus-newton-raphson-load-flow-analysis), MATLAB Central File Exchange. Retrieved December 16, 2023.

[9] T. Fasina, B. Adebanji, A. Abe, and I. Ismail, “Impact of distributed generation on the Nigerian power network,” Indonesian Journal of Electrical Engineering and Computer Science, vol. 21, no. 3, 2021, doi: 10.11591/ijeecs.v21.i3.pp1263-1270.