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Optimizing Power Flow: A Study of Newton Raphson (NR) Method for Load Flow Analysis (LFA) in Power Systems

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ABSTRACT This paper considers the application of an iterative method, namely the Newton Raphson (NR) method, for the study of load flow analysis (LFA) in power systems. The NR method is employed due to its computational efficiency and the ability to handle nonlinear equations. The primary objectives of LFA are to determine the specified active power (SAP), specified reactive power (SRP), active power injection (API) from and to bus, reactive power injection (RPI) from and to bus, active power loss (APL), reactive power loss (RPL), and voltage magnitude (|V|) at each node of the distribution network (DN). This technique is assessed through MATLAB simulations carried out on the IEEE-33 and IEEE-69 bus DNs.

INDEX TERMS load flow analysis, MATLAB, Newton Raphson Method, power system

I. INTRODUCTION

In a distribution network (DN), power flows from the generating station to the load through different network branches. The flow of active and reactive power is called load flow (LF) or power flow and analyzing it is known as load flow analysis (LFA). Power engineers use LFA to plan and ensure stable operating conditions of a power system. Power flow studies provide a mathematical basis for calculating bus voltages, phase angles, and the flow of active and reactive power across various branches, generators, transformer setups, and loads under steady-state conditions [1].

The main objectives of LFA are to determine the steady-state operating conditions of the system which include the calculation of specified active power (SAP), specified reactive power (SRP), active power injection (API) from and to bus, reactive power injection (RPI) from and to bus, active power loss (APL), reactive power loss (RPL), and voltage magnitude (|V|) at each node of a DN [2], [3].

The subsequent equations in terms of power, known as power flow equations, become non-linear and must be solved by iterative techniques using numerical methods. Such methods involve formulating mathematical problems in a manner conducive to reaching solutions through arithmetic operations, typically yielding only approximate solutions. According to various studies, several iterative techniques have been used to solve the problem of load flow for the last three decades including Gauss-Seidel, Fast Decouple, and Newton Raphson techniques [4]. The evolution of these techniques remains primarily driven by essential aspects of load flow calculation including convergence properties, computational efficiency, memory demand, and the convenience and flexibility of implementation [5]–[9]. Due to the availability of fast and large digital computers, it is now possible to easily

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perform all types of tests on power systems including load flow [10]. This paper assesses the Newton Raphson method for load flow analysis or LFA through MATLAB simulation carried out on the IEEE-33 and IEEE-69 bus DNs due to its computational efficiency.

II.CLASSIFICATION OF BUSES

A bus is a central node where generators, loads, and transmission lines connect in a power system. Each bus is associated with four parameters, that is, voltage magnitude (|V|), voltage phase angle (δ), active power (P), and reactive power (Q) [2], [3], [11], [12]. Typically, two parameters are known and the other two are determined by solving equations [9]. Buses are categorized based on the specified parameters.

A. SLACK BUS

A slack bus, also referred to as swing or reference bus, is employed to ensure power balance within the DN. Typically, the slack bus represents a power generator that can be controlled to maintain power equilibrium [12]. The generator associated with this bus compensates for network losses, the magnitude of which remains unknown until the ongoing calculation is completed. The slack bus is commonly identified as bus number 1 and is defined by specified parameters such as voltage magnitude (|V|) and voltage phase angle (δ), while active power (P) and reactive power (Q) are not specified.

B. GENERATOR (PV) BUS

The generator bus, also called voltage control bus, is connected to a power-generating unit, allowing the control of the output power by adjusting the mechanical speed of the rotor and voltage magnitude (|V|) through regulating the excitation field of the generator. Typically, limits are set for the reactive power values based on the characteristics of each specific machine. In this bus type, the specified parameters are P and |V|, while Q and δ remain unspecified [8], [12].

C. LOAD (PQ) BUS

This type of bus is termed as a non-generator bus and its values are derived from historical data, measurements, and forecasts. In a power system, positive values of real and reactive power signify power supply, whereas negative values signify power consumption. This bus handles the power consumed by the system. For non-generator bus types, the specified parameters are P and Q, while |V| and δ remain unspecified [8], [12]. Table I outlines the classification of buses.

TABLE I

CLASSIFICATION OF BUSES

Sr. No	Types of Bus	Parameters			
		P	Q	|V|	δ
1	Slack Bus	Unspecified	Unspecified	Specified	Specified
2	Generator (PV) Bus	Specified	Unspecified	Specified	Unspecified
3	Load (PQ) Bus	Specified	Specified	Unspecified	Unspecified

III. HISTORY OF LFA

Load flow computations using digital computers began in the mid-1950s and have progressed with the development of various techniques for LFA. These techniques have been shaped by the essential requirements for LFA calculations which can be summarized as follows:

- Convergence characteristics
- Processing efficiency and memory requirements
- Ease and general adaptability of implementation

In terms of statistics, LFA necessitates solving a set of non-linear algebraic equations. The iterative nature of the problem makes achieving consistent convergence a critical demand for any method used in LFA calculations. As the DN expands, the complexity of load flow equations substantially increases, often involving thousands to tens of thousands of variables. With such high-dimensional equations, it's not warranted that every mathematical approach may converge to an accurate solution. LFA comprises two primary stages. The initial stage involves determining the complex voltage at each node, which cannot be obtained through typical linear circuit analysis methods. This is because the power flow equations entail complex power constraints rather than impedance and source information, resulting in a set of non-linear equations. The subsequent stage entails calculating additional parameters, such as active and reactive power flows and copper losses. Once all node voltages are determined, this stage becomes relatively straightforward.

IV.NEWTON RAPHSON METHOD

The Newton Raphson (NR) method, named after Isaac Newton and Joseph Raphson, was introduced in late 1960s and is widely used today as an iterative technique for LFA [7]. It involves solving a group of nonlinear simultaneous equations by converting them into a set of linear simultaneous equations using Taylor's series expansion. This process selectively includes only terms up to the first approximation. The NR method is preferred for LFA calculations due to its strong convergence characteristics as compared to its alternative methods. It is recognized for its reliability to solve cases that may diverge with the use of other popular approaches [13]. The speed of convergence of the method depends on the proximity of the initial assumed values to the actual solution. If the assumed values are close, the method converges quickly. However, if they are far, convergence may take longer [8]. This iterative technique is widely used for solving nonlinear equations [14].

A. GENERAL FORM

Before discussing the remedy of the NR method to explain the LFA challenge, it is essential to examine the conventional form of the method.

Consider a system of e nonlinear algebraic equations

$$f_i(a_1 + a_2 + \cdots + a_e) = 0 \tag{1}$$

where i = 1, 2, 3, …, e.

Assume initial values for the unknowns as $a_1^0, a_2^0, \ldots, a_e^0$. Let $\Delta a_1^0, \Delta a_2^0, \ldots, \Delta a_e^0$ represent the corrections. When combined with the initial guesses, it returns the actual solution.

$$f_i(a_1^0 + \Delta a_1^0, a_2^0 + \Delta a_2^0, \ldots, a_e^0 + \Delta a_e^0) = 0 \tag{2}$$

By applying the Taylor series expansion around the initial guess, the equations can be expanded to yield the following expression,

$$f_i(a_1^0, a_2^0, \ldots, a_e^0) + \left[\left\{\left(\frac{\delta f_i}{\delta a_1}\right)^0 \Delta a_1^0\right\} + \left\{\left(\frac{\delta f_i}{\delta a_2}\right)^0 \Delta a_2^0\right\} + \cdots + \left\{\left(\frac{\delta f_i}{\delta a_e}\right)^0 \Delta a_e^0\right\} + \text{Higher order terms}\right] = 0, \tag{3}$$

where $\left(\frac{\delta f_i}{\delta a_1}\right)^0 \Delta a_1^0, \left(\frac{\delta f_i}{\delta a_2}\right)^0 \Delta a_2^0, \ldots, \left(\frac{\delta f_i}{\delta a_e}\right)^0 \Delta a_e^0$ are the derivatives of f_i with respect to $a_1, a_2, \ldots, a_e,$ calculated at $a_1^0, a_2^0, \ldots, a_e^0$.

We can express (3) approximately using vector matrix notation by disregarding higher order terms.

$$f^0 + J^0 \Delta a^0 \approx 0 \tag{4}$$

Equation (4) can be represented using the Jacobian matrix, denoted as J^0, which is derived by taking the derivative of the function vector f with respect to a and evaluating it at a^0.

$$f^0 \approx [-J^0] \Delta a^0 \tag{5}$$

From (5), we can derive approximate values for the corrections Δa^0.

By utilizing the techniques of triangularization and back substitution, the cluster of linear algebraic equations can be resolved efficiently. As a result, we obtain the updated values of a as follows,

$$a^1 = a^0 + \Delta a^0 \tag{6}$$

In conventional calculation, for the $(s+1)^{th}$ iteration,

$$a^{(s+1)} = a^{(s)} + \Delta a^{(s)} \tag{7}$$

The iterations are continued until the specified condition is met with the desired level of accuracy

$$\left| f_i(a^{(s)} \right| < \in (a\ specified\ value) \tag{8}$$

where $i = 1,2,3, \ldots, e$ [15].

B. PROCESS OF NR METHOD FOR SOLVING LFA

The process of NR method for solving LFA is stated below.

1. Formation of Y_{Bus} matrix as the opening step of this process.
2. Then, assume the initial values for bus voltages $|V_i|^0$ and phase angles $\delta_i{}^0$ for buses 2, 3, ..., n, while considering load buses and phase angles for PV buses. Normally, the assumed bus voltage magnitude and phase angle is set equal to the quantities of the slack bus which are $|V_1| = 1.0$ and $\delta_1 = 0^0$, respectively.
3. Calculate the values of P_i and Q_i for every load bus using (9) and (10), respectively.

$$P_i = \sum_{m=1}^{NB} Y_{im} V_m V_i \cos(\theta_{im} + \delta_m - \delta_i) \tag{9}$$

$$Q_i = -\sum_{m=1}^{NB} Y_{im} V_m V_i \sin(\theta_{im} + \delta_m - \delta_i) \tag{10}$$

Y_{im} represents the magnitude of admittance between buses i and m. The variables V_i and V_m denote the magnitudes of voltages at buses i and m, respectively. The parameter θ_{im} represents the angle of Y_{im}, while δ_m and δ_i represent the angles of voltages V_m and V_i, respectively. NB stands for the total number of buses.

4. Calculate the scheduled errors ΔP_i and ΔQ_i for every load bus using (11) and (12), respectively.

$$\Delta P_i(s) = P_i^{specified} - P_i^{calculated}(s) \tag{11}$$

$$\Delta Q_i(s) = Q_i^{specified} - Q_i^{calculated}(s) \tag{12}$$

5. For PV buses, the accurate value of Q_i is not explicitly defined, although its restrictions are specified. If the computed value of Q_i falls inside the specified restrictions, then only ΔP_i is calculated. However, if the computed value of Q_i exceeds the restrictions, a suitable limit is enforced and ΔQ_i is also calculated by subtracting the computed value of Q_i from the

enforced limit. In such cases, the bus under consideration is then treated as a load bus.

6. Calculate the Jacobian matrix.
7. Acquire the values of $\Delta\delta_i$ and ΔV_i.
8. By utilizing the previously calculated values of $\Delta\delta_i$ and ΔV_i, adjust the (|V|) and (δ) at all load buses according to (13) and (14).

$$|V_i(s+1)| = |V_i(s)| + \Delta|V_i(s)| \quad (13)$$

$$\Delta_i(s+1) = \delta_i(s) + \Delta\delta_i(s) \quad (14)$$

9. Commence the next iteration cycle by proceeding with step 2, considering the modified values of $|V_i|$ and δ_i from the previous step.
10. Continue the iteration process until the scheduled errors for all load buses fall within a specified tolerance, ensuring convergence to the desired level of accuracy,

$$\Delta P_i(s) < \in \quad (15)$$

$$\Delta Q_i(s) < \in \quad (16)$$

where ∈ indicates the tolerance level for load buses.

11. Determine the power flow at the slack bus.
12. Publish the results.
13. Stop

The flowchart of the NR method is shown below in Figure 1.

C. ADVANTAGES OF THE NR METHOD FOR LFA

The NR method has several benefits. Some of these are stated below.

- Convergence: It swiftly reaches a solution, especially with nearby initial estimates.
- Efficiency: It needs fewer iterations, making it computationally effective.
- Global Convergence: It consistently converges to the correct solution regardless of initial approximations.
- Accuracy: It ensures high accuracy in results, facilitating precise estimation of unknown variables.
- Robustness: It handles intricate systems with nonlinear equations and numerous other variables suitable for various applications.

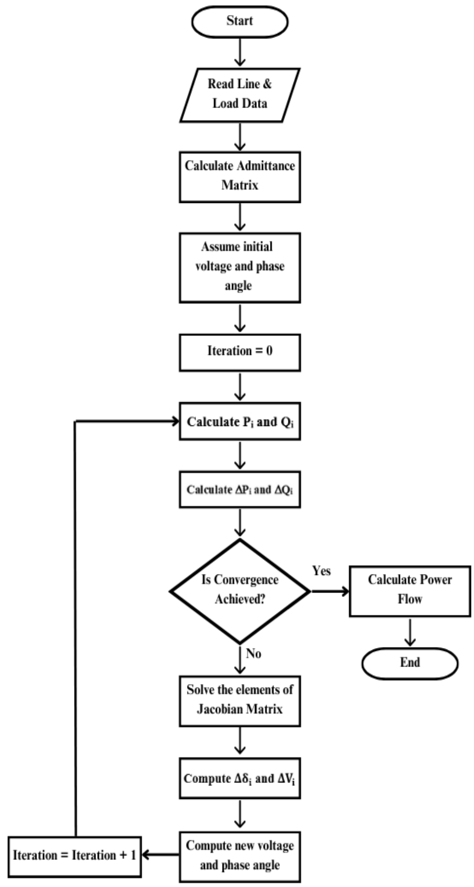

FIGURE 1. Flowchart of the NR Method for LFA

D. DISADVANTAGES OF THE NR METHOD

The NR method also has some drawbacks. These are stated below.

- Dependency on Initial Guess: Convergence heavily relies on selecting an appropriate initial estimate. If it's far from the correct solution, the method may not converge or may converge to a local minimum instead.
- Computational Complexity: Calculating Jacobian matrices and matrix inversions can be computationally demanding for large systems, especially those with more equations and variables.
- Non-Linear Systems Requirement: It's designed specifically to solve nonlinear systems. For linear systems, methods like Gaussian elimination might be quicker and simpler.
- Sensitivity to Singular Jacobians: Unique Jacobian matrices can lead to non-convergence or inaccurate results. Special techniques, such as matrix regularization, may be necessary.
- Iteration Dependence: It's an iterative process, requiring many iterations. Convergence can be slow for poorly conditioned or highly nonlinear systems.

V. RESULTS AND DISCUSSION

This paper investigated two case studies (IEEE-33 and IEEE-69 DNs) for LFA using the NR method. The simulations were conducted on a personal computer with MATLAB 2018b, operating at 2.50 GHz and equipped with an i5 processor.

A. CASE STUDY 1

Figure 2 shows the IEEE-33 bus DN operating at 12.6 kV. The network includes 33 nodes, 37 lines, 32 active switches for sectionalizing, and 5 tie switches. Initially, the system has the first 32 switches closed for sectionalizing, while the remaining 5 switches remain inactive [16].

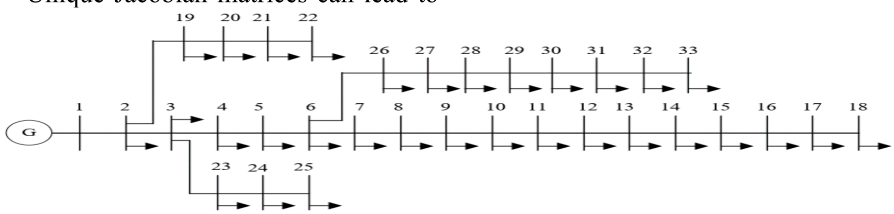

FIGURE 2. IEEE-33 Bus DN

Table II shows the SAP and SRP for IEEE-33 DN which are 3920 kW and 2410 kvar, respectively.

TABLE II

SAP AND SRP FOR CASE STUDY 1

Generator No.	Bus No.	SAP (kW)	SRP (kvar)
1	1	3920	2410
Total Specified Power		3920	2410

Table III shows the LFA results for case study 1. Figure 3 illustrates the graphical representation of APL and RPL, while Figure 4 illustrates the voltage profile of buses. It's observed from Figure 4 that the minimum voltage occurs at bus number 18, which is 0.9107 (pu).

TABLE III

LFA RESULTS FOR CASE STUDY 1

From Bus	To Bus	From Bus Injection		To Bus Injection		Power Loss	
		P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (kW)	Q (kvar)
1	2	3923.46	2411.67	-3911.26	-2405.36	12.20	6.31
2	3	3450.12	2184.28	-3398.52	-2158.00	51.60	26.28
3	4	2368.90	1660.75	-2349.12	-1650.81	19.78	9.95
4	5	2229.12	1570.81	-2210.53	-1561.34	18.58	9.46
5	6	2150.53	1531.34	-2112.53	-1528.09	38.00	3.25
6	7	1102.19	534.79	-1100.27	-528.45	1.92	6.34
7	8	900.27	428.45	-888.57	-420.01	11.70	8.44
8	9	688.57	320.01	-684.37	-316.99	4.20	3.02
9	10	624.37	296.99	-620.80	-294.46	3.57	2.54
10	11	560.80	274.46	-560.25	-274.27	0.56	0.18
11	12	515.25	244.27	-514.36	-243.98	0.89	0.29
12	13	454.36	208.98	-451.68	-206.87	2.68	2.11
13	14	391.68	171.87	-390.95	-170.91	0.73	0.96
14	15	270.95	90.91	-270.59	-90.59	0.36	0.32
15	16	210.59	80.59	-210.31	-80.38	0.28	0.21
16	17	150.31	60.38	-150.05	-60.04	0.25	0.34
17	18	90.05	40.04	-90.00	-40.00	0.05	0.04
2	19	361.14	161.08	-360.98	-160.93	0.16	0.15
19	20	270.98	120.93	-270.14	-120.18	0.83	0.75
20	21	180.14	80.18	-180.04	-80.06	0.10	0.12
21	22	90.04	40.06	-90.00	-40.00	0.04	0.06
3	23	939.61	457.24	-936.43	-455.07	3.18	2.17
23	24	846.43	405.07	-841.29	-401.01	5.14	4.06
24	25	421.29	201.01	-420.00	-200.00	1.29	1.01
6	26	950.34	973.30	-947.78	-971.99	2.56	1.31
26	27	887.78	946.99	-884.50	-945.32	3.28	1.67
27	28	824.50	920.32	-813.36	-910.50	11.14	9.82
28	29	753.36	890.50	-745.63	-883.77	7.72	6.73
29	30	625.63	813.77	-621.79	-811.82	3.84	1.96
30	31	421.79	211.82	-420.22	-210.27	1.57	1.55
31	32	270.22	140.27	-270.01	-140.02	0.21	0.24
32	33	60.01	40.02	-60.00	-40.00	0.01	0.02
21	8	0.00	0.00	0.00	0.00	0.00	0.00
9	15	0.00	0.00	0.00	0.00	0.00	0.00
12	22	0.00	0.00	0.00	0.00	0.00	0.00
18	33	0.00	0.00	0.00	0.00	0.00	0.00
25	29	0.00	0.00	0.00	0.00	0.00	0.00

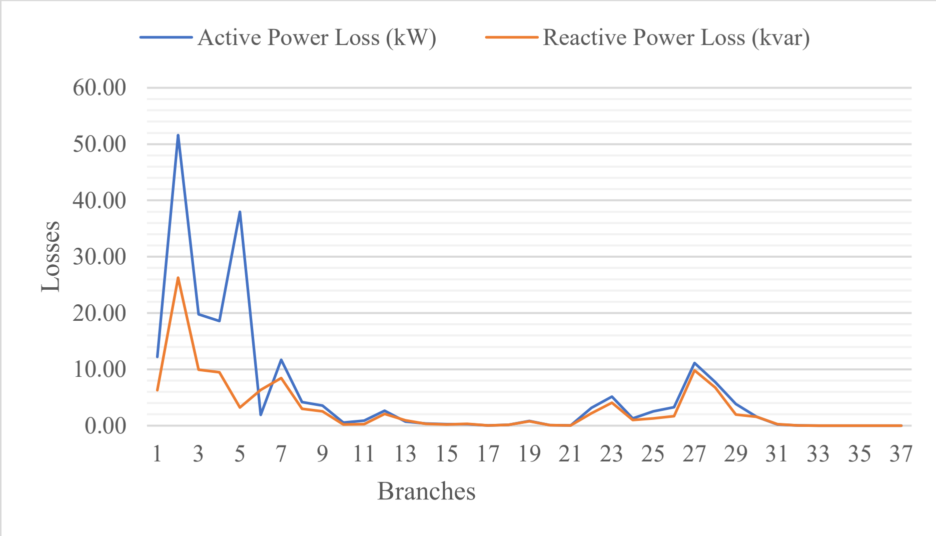

FIGURE 3. Losses for Case Study 1

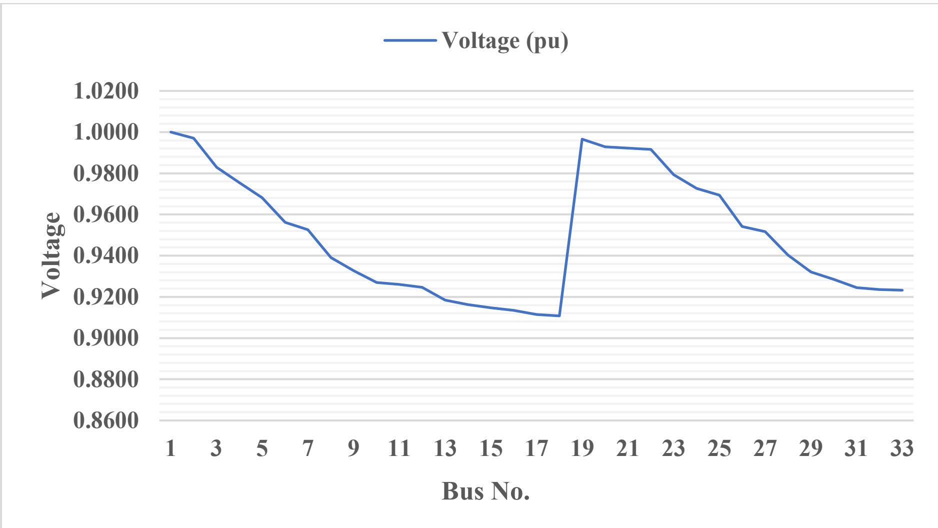

FIGURE 4. Voltage Profile of Buses for Case Study 1

B. CASE STUDY 2

Figure 5 illustrates the IEEE-69 bus DN, functioning at a voltage of 12.6 kV. The network comprises 69 nodes and consists of 73 lines, with 68 normally closed sectionalize switches and 5 normally open tie switches. Initially, the system configuration involves the closure of sectionalize switches numbered 1 to 68 and the opening of tie switches numbered 69 to 73 [16].

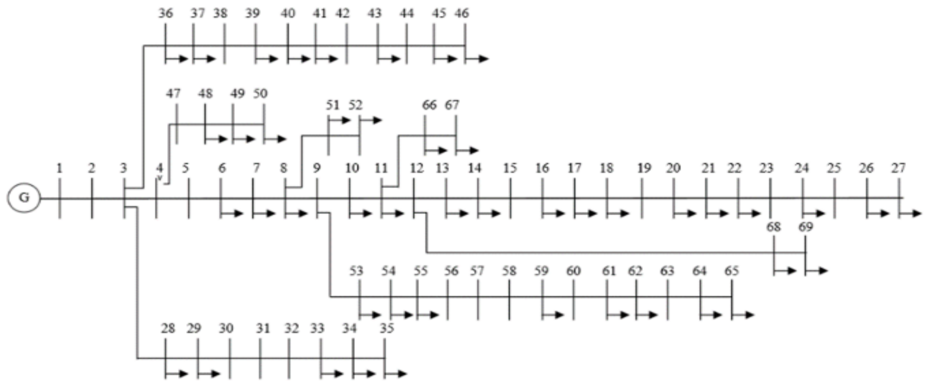

FIGURE 5. IEEE-69 Bus DN

Table IV shows the SAP and SRP powers for IEEE-69 DN which are 4030 kW and 2800 kvar, respectively.

TABLE IV

SAP AND SRP FOR CASE STUDY 2

Generator No	Bus No.	SAP (kW)	SRP (kvar)
1	1	4030	2800
Total Specified Power		4030	2800

Table V shows the LFA results for case study 2. Figure 6 illustrates the graphical representation of APL and RPL, while Figure 7 illustrates the voltage profile of buses. Figure 7 depicts that the minimum voltage occurs at bus number 65, which is 0.9091 (pu).

TABLE V
LFA RESULTS FOR CASE STUDY 2

From Bus	To Bus	From Bus Injection		To Bus Injection		Power Loss	
		P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (kW)	Q (kvar)
1	2	4027.10	2796.86	-4027.03	-2796.68	0.08	0.18
2	3	4027.03	2796.68	-4026.95	-2796.50	0.08	0.18
3	4	3749.70	2602.03	-3749.50	-2601.56	0.19	0.47
4	5	2898.75	1990.39	-2896.81	-1988.13	1.94	2.27
5	6	2896.81	1988.13	-2868.56	-1973.74	28.24	14.38
6	7	2865.96	1971.54	-2836.61	-1956.59	29.35	14.95
7	8	2796.21	1926.59	-2789.32	-1923.08	6.90	3.52
8	9	2670.21	1838.08	-2666.84	-1836.36	3.38	1.72
9	10	780.41	533.27	-775.63	-531.69	4.78	1.58
10	11	747.63	512.69	-746.61	-512.35	1.02	0.34
11	12	565.61	382.35	-563.42	-381.63	2.19	0.72
12	13	362.39	237.62	-361.11	-237.19	1.29	0.42
13	14	353.11	231.69	-351.86	-231.28	1.25	0.41
14	15	343.86	225.78	-342.65	-225.38	1.21	0.40
15	16	342.65	225.38	-342.43	-225.31	0.22	0.07
16	17	296.93	195.31	-296.61	-195.20	0.32	0.11

From Bus	To Bus	From Bus Injection		To Bus Injection		Power Loss	
		P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (kW)	Q (kvar)
17	18	236.61	160.20	-236.60	-160.20	0.00	0.00
18	19	176.60	125.20	-176.50	-125.17	0.10	0.03
19	20	176.50	125.17	-176.43	-125.14	0.07	0.02
20	21	175.43	124.54	-175.33	-124.51	0.11	0.04
21	22	61.33	43.51	-61.33	-43.51	0.00	0.00
22	23	56.03	40.01	-56.02	-40.01	0.01	0.00
23	24	56.02	40.01	-56.01	-40.00	0.01	0.00
24	25	28.01	20.00	-28.00	-20.00	0.01	0.00
25	26	28.00	20.00	-28.00	-20.00	0.00	0.00
26	27	14.00	10.00	-14.00	-10.00	0.00	0.00
3	28	91.54	65.22	-91.54	-65.22	0.00	0.00
28	29	65.54	46.62	-65.54	-46.61	0.00	0.01
29	30	39.54	28.01	-39.53	-28.01	0.01	0.00
30	31	39.53	28.01	-39.53	-28.01	0.00	0.00
31	32	39.53	28.01	-39.52	-28.01	0.01	0.00
32	33	39.52	28.01	-39.51	-28.00	0.01	0.00
33	34	25.51	18.00	-25.50	-18.00	0.01	0.00
34	35	6.00	4.00	-6.00	-4.00	0.00	0.00
3	36	185.72	129.26	-185.72	-129.25	0.00	0.00
36	37	159.72	110.65	-159.70	-110.62	0.02	0.04
37	38	133.70	92.02	-133.68	-92.00	0.02	0.02
38	39	133.68	92.00	-133.68	-91.99	0.00	0.01
39	40	109.68	74.99	-109.68	-74.99	0.00	0.00
40	41	85.68	57.99	-85.63	-57.93	0.05	0.06
41	42	84.43	56.93	-84.41	-56.91	0.02	0.02
42	43	84.41	56.91	-84.41	-56.91	0.00	0.00
43	44	78.41	52.61	-78.41	-52.61	0.00	0.00
44	45	78.41	52.61	-78.40	-52.60	0.01	0.01
45	46	39.20	26.30	-39.20	-26.30	0.00	0.00
4	47	850.76	611.16	-850.73	-611.11	0.02	0.06
47	48	850.73	611.11	-850.15	-609.68	0.58	1.43
48	49	771.15	553.28	-769.52	-549.28	1.63	4.00
49	50	384.82	274.78	-384.70	-274.50	0.12	0.28
8	51	44.10	31.00	-44.10	-31.00	0.00	0.00
51	52	3.60	2.70	-3.60	-2.70	0.00	0.00
9	53	1856.43	1281.09	-1850.65	-1278.15	5.78	2.94
53	54	1846.35	1274.65	-1839.64	-1271.23	6.71	3.42
54	55	1813.24	1252.23	-1804.12	-1247.58	9.12	4.65
55	56	1780.12	1230.38	-1771.33	-1225.91	8.79	4.48
56	57	1771.33	1225.91	-1721.64	-1209.23	49.68	16.68
57	58	1721.64	1209.23	-1697.15	-1201.01	24.49	8.22
58	59	1697.15	1201.01	-1687.65	-1197.87	9.51	3.14
59	60	1587.65	1125.87	-1576.98	-1122.63	10.67	3.24
60	61	1576.98	1122.63	-1562.95	-1115.48	14.03	7.14

From Bus	To Bus	From Bus Injection		To Bus Injection		Power Loss	
		P (kW)	Q (kvar)	P (kW)	Q (kvar)	P (kW)	Q (kvar)
61	62	318.95	227.48	-318.84	-227.43	0.11	0.06
62	63	286.84	204.43	-286.70	-204.36	0.13	0.07
63	64	286.70	204.36	-286.04	-204.02	0.66	0.34
64	65	59.04	42.02	-59.00	-42.00	0.04	0.02
11	66	36.00	26.00	-36.00	-26.00	0.00	0.00
66	67	18.00	13.00	-18.00	-13.00	0.00	0.00
12	68	56.02	40.01	-56.00	-40.00	0.02	0.01
68	69	28.00	20.00	-28.00	-20.00	0.00	0.00
11	43	0	0	0	0	0.00	0.00
13	21	0	0	0	0	0.00	0.00
15	46	0	0	0	0	0.00	0.00
50	59	0	0	0	0	0.00	0.00
27	65	0	0	0	0	0.00	0.00

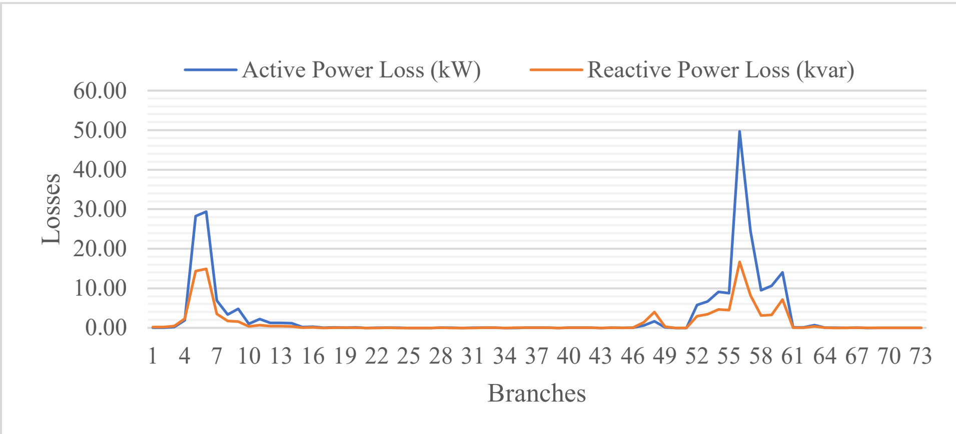

FIGURE 6. Losses for Case Study 2

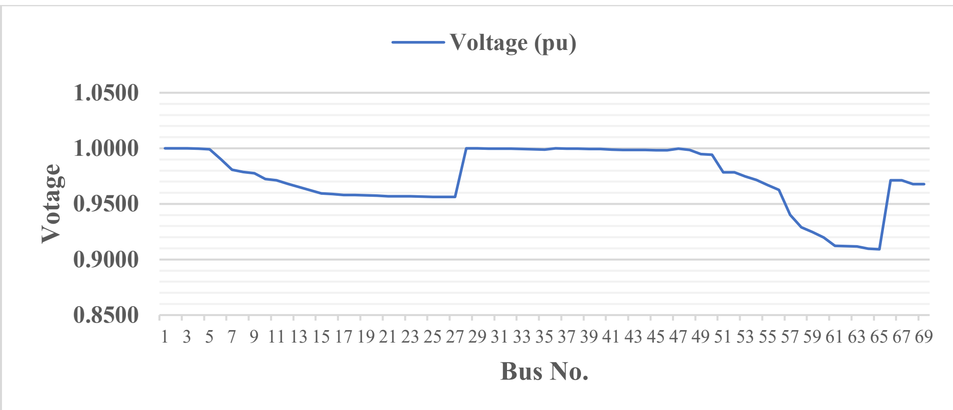

FIGURE 7. Voltage Profile of Buses for Case Study 2

VI. CONCLUSION

This paper explored the application of the Newton Raphson (NR) method for load flow analysis (LFA) in power systems, focusing on its computational efficiency and the ability to handle nonlinear equations. Through MATLAB simulations conducted on the IEEE-33 and IEEE-69 bus distribution networks (DNs), various parameters such as specified active power (SAP), specified reactive power (SRP), active power injection (API) from and to bus, reactive power injection (RPI) from and to bus, active power loss (APL), reactive power loss (RPL), and voltage were evaluated at each node of the DN. The results showed that in IEEE-33 bus DN, the APL and RPL are 208.46 kW and 111.67 kvar, respectively. While, the minimum |V| occurs at bus number 18, which is 0.9107 pu. Whereas, in IEEE-69 bus DN, the APL and RPL are 225.0 kW and 102.16 kvar, respectively. While, the minimum |V| occurs at bus number 65, which is 0.9091 pu.

A. FUTURE RESEARCH DIRECTIONS

Future research can focus on extending this analysis to larger and more complex power networks, exploring the integration of renewable energy sources, and optimizing power system operation and planning strategies based on NR-based LFA.

CONFLICT OF INTEREST

The author of the manuscript has no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

DATA AVALIABILITY STATEMENT

The data associated with this study will be provided by the corresponding author upon request.

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