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Newton-Raphson Algorithm for Power Flow Solution and Application

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Abstract

Power system insecurity often lead to frequent power system collapse. Experience has shown that power utility companies are generally poor in network argumentation and planning. For example, it is required that any new project must be simulated to ascertain its effects in the network prior to construction. The simulation could be investigating the bus voltage profile, power flow, losses, overvoltage condition etc. Consequently, this paper presents a Newton-Raphson algorithm for power flow solution and the application of the developed Q-basic computer software package to a large power system network. It involves formulation of algorithms and development of flowcharts which were used to determine the steady state operating conditions of buses, generation, branch power flows and circuit system losses of the case study network considered. The results obtained are presented and discussed. The fast convergence of the system at fifth iteration confirmed the effectiveness of the software and accuracy of the results. Having previously tested the software with a known solution network and work fine, suggest the results obtained are accurate and reliable. Transmission lines with high reactive power needs installation of equipment capable of reducing the reactive power. Buses with voltage value a little less than acceptable standard needs improvement

Keywords: *Network Argumentation, Newton-Raphson Algorithm, Power Flow, System Collapse, System Simulation.*

1. Introduction

Electric power has become virtually indispensable in modern societies in the sense that most industrial, commercial, domestic and social activities are heavily dependent on availability of electric energy. Electric power generating stations are often located far from the load (or power consumption) centers. Conventionally, several generating stations are connected and to the load centers via transmission lines to form an electric power system also known as the grid (Adesina et al, 2015; Adesina et al, 2020) A power system is required to maintain a continuous balance between electrical generation and a varying load demand so that system frequency and voltage are maintained at their statutory levels, while guaranteeing system security.

The performance of the electrical power systems is continually and extensively analyzed to assess its quality. Such analysis is used in planning expansion schemes on the system to cater for the ever-increasing power demand (Wankhade and Vaidya, 2014; Abdulkareem et al, 2014; Kusekwa 2014; Meel et al, 2014; Adejumobi et al, 2013). Some of the analysis problems in system planning, requiring attention include power (or load) flow, fault level, stability and reliability.

However, power flow studies frequently precede and, in most cases, provide the starting conditions for complicated system analysis such as optimization. Fault level, stability and outage security assessment. Generally, the problem encountered in transmission network planning has always been the multitude of situations to be examined in order to guarantee that a projected network is necessary and enough for a given year. Such situations arise from load variations, hydraulic variations, generation unit's unavailability leading to a reorganization of the

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generation program with every failure, and finally unavailability's due to transmission equipment (i.e lines and transformers) (Nayak and Wadhwani, 2014; Tingting et al, 2013).

In Nigeria, Electricity Companies comprising Genco, TCN and Disco are responsible for planning, installation, generation, transmission and distribution of electrical energy in the country and some neighboring countries. They have several generating stations including a mix of hydro and thermal power plants mostly located in the southern and middle parts of the country. Several papers had been written and research had been carried out on power flow analysis for power system grid using the Gauss, Gauss-Seidel, Fast decoupling as well as other several iterative approaches which are all slow in convergence (Shukla and Bhadoria 2013; Chakavorty and Gupta, 2012; Wankhade and Vaidya, 2012; Syai'in and Soeprijanto, 2012; Kumkratug, 2010; Kim et al, 2007; Alqadi and Khammash, 2007, Warkad, et al, 2009, Awosope and Akinbulire, 1990). Newton- Raphson Iterative method is generally believed to be faster in convergence (Adesina et al, 2015; Adesina et al, 2020; Abdulkareem et al, 2014; Kusekwa, 2014; Adejumobi et al, 2013). Thus, a suitable software package for power flow method is developed.

2 Newton-Rapson Algorithm

This section discusses the power balance equations of the Newton – Raphson algorithm as well as the review of the earlier developed Newton – Raphson Software Package (NRSP) (Adesina, et al, 2020). The NRSP detailed on supervising module, System data entry module and power flow solution module which are tagged NRPF, LAMBE 1 and LAMBE 2 respectively.

2.1 Power Balance Equations

Applying this method to power flow problem, the derivatives of the mismatch form of the power flow equation are used to force the bus power mismatch to zero. An equation is written for each bus p;

$$P_p + jQ_p = E_p I_p^* \tag{1}$$

Where,

$$I_{P=} \sum_{K=1}^{NB} Y_{pk} \ E_k \tag{2}$$

Then,

$$P_p + jQ_p = E_p \sum_{K=1}^{NB} Y_{pk} E_k^*$$

$$= |E_p|^2 Y_{pp}^* + \sum_{\substack{K=1 \\ K \neq p}}^{NB} Y_{pk}^* E_p E_k^* \tag{3}$$

For p= 1, 2, 3 …… NB, excluding the slack bus.

The parameters contained in the above equations and the subsequent ones are clearly defined in table 1.

A set of starting voltages is often used to commence the iteration process. The power $P + jQ$ calculated using equation (6) is subtracted from the scheduled power $P_s + jQ_s$ at the bus and the resulting errors stored in a vector. Polar co-ordinates are generally employed for the voltages. The voltages' magnitudes and phase angles are adjusted as separate independent variables. Each bus injection equation is differentiated with respect to all independent variables. Thus, for each bus the power mismatch is calculated as (Kusekwa, 2014; Adejumobi et al, 2013; Awosope and Esan, 1983);

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$$\Delta P_p = \sum_{k=1}^{NB} \frac{\partial P_p}{\partial \theta_k} \Delta\theta_k + \sum_{K=1}^{NB} \frac{\partial P_p}{\partial |E_{k|}} \Delta |E_k| \quad (4)$$

$$\Delta Q_p = \sum_{K=1}^{NB} \frac{\partial Q_p}{\partial \theta_k} \Delta\theta_k + \sum_{K=1}^{NB} \frac{\partial Q_p}{\partial |E_k|} \Delta |E_k| \ldots \quad (5)$$

The partial differentials are arranged in a Jacobian matrix so that the equations (4) and (5) can be written in matrix vector form as,

$$\begin{bmatrix} \Delta P_1 \\ \Delta P_{NB-1} \\ -- \\ \Delta Q_1 \\ \Delta Q_{NB-1} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_1}{\partial \theta_1} & \cdots & \frac{\partial P_1}{\partial \theta_{NB-1}} & \frac{\partial P_1}{\partial |E_1|} & \cdots & \frac{\Delta P_1}{\Delta |E_{NB-1}|} \\ \frac{\partial P_{NB-1}}{\partial \theta_1} & \cdots & \frac{\partial P_{NB-1}}{\partial \theta_{NB-1}} & \frac{\partial P_{NB-1}}{\partial |E_1|} & \cdots & \frac{\Delta P_{NB-1}}{\partial |E_{NB-1}|} \\ \hline \frac{\partial Q_1}{\partial \theta_1} & \cdots & \frac{\partial Q_1}{\partial \theta_{NB-1}} & \frac{\partial Q_1}{\partial |E_1|} & \cdots & \frac{\Delta Q_1}{\partial |E_{NB-1}|} \\ \frac{\partial Q_{NB-1}}{\partial \theta_1} & \cdots & \frac{\partial Q_{NB-1}}{\partial \theta_{NB-1}} & \frac{\partial Q_{NB-1}}{\partial |E_1|} & \cdots & \frac{\Delta Q_{NB-1}}{\partial |E_{NB-1}|} \end{array}\right] \begin{bmatrix} \Delta\theta_1 \\ \Delta\theta_{NB-1} \\ -- \\ \Delta |E_1| \\ \Delta |E_{NB-1}| \end{bmatrix} \quad (6)$$

For a fast convergence (Adejumobi et al, 2013; Wankhade and Vaidya, 2012), common method used is to multiply the voltage corrections by a constant at the end of each iteration. This constant is called acceleration factor [Adesina et al, 2020; Abdulkareem et al, 2014; Shukla and Bhadoria, 2013; Syai'in and Soeprijanto, 2012) i.e

$$Q_p^{(k)}(\text{Accelerated}) = Q_p^{(k-1)} + \propto \Delta Q_p^{(k-1)} \quad (7)$$

$$|E_p|^{(k)}(\text{Accelerated}) = |E_p|^{(k-1)} + \propto \Delta |E_p|^{(k-1)} \quad (8)$$

Where, $\propto$ = acceleration Factor, $0.7 < \propto > 1.4$

The solution to Newton-Raphson problem runs according to flowchart in Figure 1.

TABLE 1: Definition of parameters

S/N	Symbol	Description
1	kV	Kilovolt
2	NB	Number of buses
3	J	Jacobian matrix
4	NR	Newton Raphson
5	I	Current
6	E	Bus voltage in complex form
7	| |	Modulus
8	Y	Admittance
9	Q	Reactive (or imaginary power) in megavolt ampere
10	*	Conjugate
11	$\sum$	Summation
12	Δ	Incremental value
13	∂	Partial differential
14	Є	Mathematical representation of member
15	P	Active (or real power) in megawatts
16	AF	Acceleration Factor

17	K	Iteration Count
18	G	Conductance
19	B	Susceptance
20	Ypp	Admittance of diagonal matrix element
21	Ypk	Admittance of off diagonal matrix element on row p column k
22	ΔP_p	Mismatch active power on bus p
23	ΔQ_p	Mismatch reactive power on bus p
24	ΔE	Mismatch voltage
25	α	Acceleration factor
26	NRPF	Newton Raphson power flow
27	PC	Personal computer
28	N-R	Newton - Raphson
29	SB	Start Bus
30	EB	End Bus
31	Y_{sht}	Line charging admittance
32	NL	Number of transmission lines
33	P_{sp}	Schedule active power
34	Q_{sp}	Schedule reactive power
35	Ypq	Admittance of off diagonal matrix element on row p column q
36	Sub	Subroutine
37	ΔP_{max}	Maximum mismatch active power on bus p
38	ΔQ_{max}	Maximum mismatch reactive power on bus p
39	J^1_{pq}, J^2_{pp} ,J^3_{pq} , J^4_{pp}	Jacobian matrix elements
40	P_g	Active power generated
41	Q_g	Reactive power generated
42	MW	Megawatts
43	TCN	Transmission Company of Nigeria
44	MVAr	Megavolt ampere reactive
45	wrt	With respect to
46	∂Q/∂e	Derivative of reactive power wrt real voltage
47	∂Q/∂f	Deriv. of reactive power wrt Imaginary voltage
48	∂p/∂e	Derivative of active power wrt real voltage
49	∂p/∂f	Derivative of active power wrt Imaginary voltage
50	$\partial p/\partial \lvert E_k \rvert$	Deriv. of active power wrt voltage magnitude
51	$\partial Q_p/\partial \lvert E_k \rvert$	Deriv. of reactive power wrt voltage magnitude
52	∂Q/∂Θ	Deriv. of reactive power wrt phase angle
53	∂p/∂Θ	Deriv. of active power wrt phase angle

2.2 Re-Summary of developed NRPF software package

To enable the solution of power flow problem using the N- R method, a suite of computer programs has been written to create a power flow software package. This NRPF package was developed and implemented for a small power system network using a personal computer (PC) in Part 1 of this research work (Adesina et al, 2020). Iterative conversational mode was employed to interface the package with its users. The package was structured in such a way as to fit into the limited core memory of PC. This is achieved by use of the overlay technique described in section A of this part 1 paper (Adesina and Ajenikoko, 2020).

Overlaying together with interactive conversational mode are used. Overlaying permits reduction of the working memory of the computer and enables modularization of the package. For the purpose of overlaying, the package is divided into three stands – alone modules namely;

1. NRPF Supervising module
2. LAMBE 1 Power system data entry and Management

3. LAMBE 2 Newton – Raphson power flow solution.

such that only one module is resident in core memory at any given time. The CHAIN command of Quick Basic is used to interface the supervisor module NRPF to each of the modules LAMBE 1 and LAMBE 2. All programs are coded in Microsoft's Quick Basic (QB). Each module together with its subroutine procedures (if any) is complete.

2.2.1 Supervising Module (NRPF)

NRPF is the package supervisor. It controls the solution procedure by enabling the user to choose which path of the overlaying structure is to be followed. At system level the command

C: \>Quick Basic NRPF

Loads the module into memory and executes it. When the module is active the display screen is as shown in Figure 2.

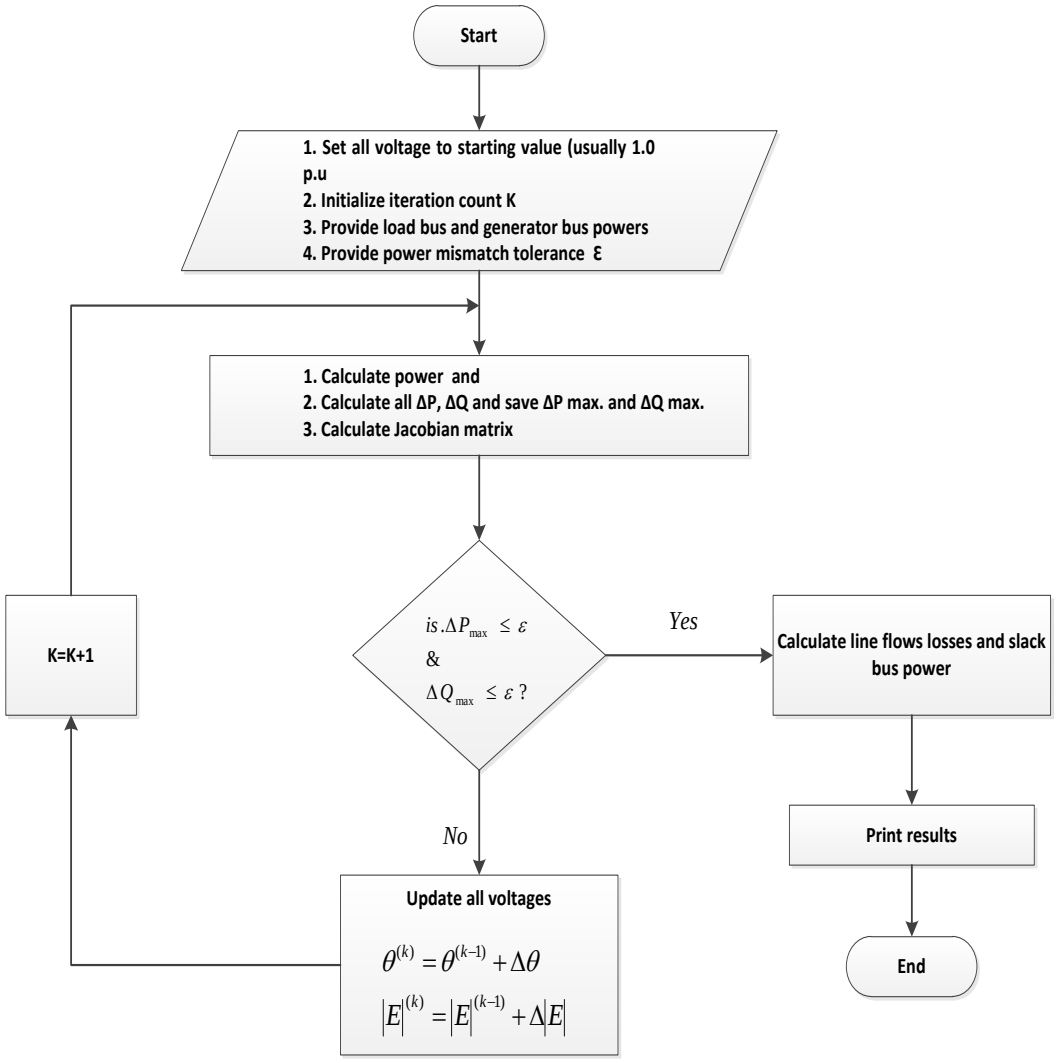


Figure 1. Flowchart of the Newton – Raphson power flow solution

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NEWTON- RAPSON POWER FLOW PROGRAM

1. System data entry
2. Power Flow solution
3. Exit form package

Enter the number (1- 3) of your choice.

Figure 2. NRPF menu display screen

2.2.2 System Data Entry Module (LAMBE 1)

The main function of this module is to permit the power system data to be entered into the computer by the user. The module is loaded and executed by selecting option 1 available on NRPF's menu. The module interactively solicits for the following data from user.

1. Number of buses (NB) in the network
2. Number of transmission lines (NL)
3. Transmission line data

- Start bus, (SB)
- End Bus, (EB)
- Series resistance, R
- Series reactance, X\
- Line charging admittance, Y_{sht}

4. Bus scheduled active and reactive powers (P_s and Q_s). The module then formulates bus admittance matrix, Y_{bus}. Due to the non – availability of in – built complex arithmetic functions in Quick Basic, the real and imaginary parts of the elements of Y_{bus} are formed separately. The Y_{bus} building algorithm is as follows;

Y_{pp} The diagonal entries of Y_{bus} are formed by summing the primitive admittance of lines and line charging admittance.

Y_{pq} The off-diagonal entries are the negatives of the admittance buses p and q. if there is no line between p and q this term is zero.

All data entered or generated in this module are stored into appropriate data files for future use, so that this module need not be called if the data files are already available. On exit from the module, the NRPF module is reloaded into memory and executed.

2.2.3 Power Flow Solution Module (LAMBE 2)

This module of the package implements the Newton- Raphson power flow solution method. It is loaded into memory and executed when data files created earlier had been inputted. If such data files are not available, the program returns an error message to the effect that the file is not available. Thus, before this module is run, the user must be sure that LAMBE 1 has already been executed.

Again, since Quick Basic does not have in – built complex arithmetic library functions, the Newton – Raphson power flow solution has to be reformulated in rectangular co-ordinates (rather than the polar co-ordinates) so that real and imaginary parts of variables and parameters are handled separately.

The module consists of a main programme and the following five subroutine procedures.

1. Sub Powers
2. Sub Currents
3. Sub Jacobian

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4. Sub Voltage
5. Sub Power flows

The flowchart for the program's logic is shown in Figure 3.

Consider now the application to an n- bus power system. The solution starts with the iteration counter K set to zero and all the buses except the slack bus being assigned voltages,

$$Ep = 1 + j\,0\ perunit \quad (9)$$

For a line connecting buses p and q of admittance

$$P_p = \sum_{q=2}^{NB} [\, e_p(\, e_q G_{pq} + f_q B_{pq}) + f_p(\, f_q G_{pq} - e_q B_{pq})\,] \quad (10)$$

$$Q_p = \sum_{q=2}^{NB} [\, f_p(e_q G_{pq} + f_q B_{pq}) - e_q(f_q G_{pq} - e_q B_{pq})] \quad (11)$$

It has been assumed that the slack bus is the bus number 1 of the network. The main program then calls SUB Powers which computes P and Q using equations (13) and (14). It also calculates the power mismatches using equation (12) and (13)

$$\Delta p_p^{(k)} = P_{sp} - P_p^{(k)} \quad (12)$$

$$\Delta \mathrm{Q}_\mathrm{p}^{(\mathrm{k})} = \mathrm{Q}_{\mathrm{sp}} - \mathrm{Q}_\mathrm{p}^{(\mathrm{k})} \quad (13)$$

For p = 2, 3, - - - - - - - NB, p ≠ Generator buses.

Furthermore, the maximum mismatches ΔPmax and ΔQ_{max} are stored in memory. If ΔPmax ≤ ϵ per unit and ΔQ_{max} ≤ ϵ per unit, then the iterative process has converged and control transfers to SUB Power flows otherwise control transferred to SUB currents to compute the bus currents using equation (14) and (15)

$$C_p^{(k)} = \frac{P_p^{(k)} e_p^{(k)} + Q_P^{(k)} f_p^{(k)}}{(e_p^k)^2 + (f_p^k)^2} \quad (14)$$

$$d_p^{(k)} = \frac{Q_p^{(k)} e_p^{(k)} - P_p^{(k)} f_p^{(k)}}{(e_p^{(k)})^2 + (f_p^{(k)})} \quad (15)$$

For p = 2, 3, ---------- NB, p ≠ Generator buses.

After the currents have been calculated, control transfers to SUB Jacobian which computes the elements of the Jacobian matrix using equations (16a) to (19b).

The entries of the Jacobian matrix are computed using equations (16a) to (19b) (Adesina, et al, 2020, Heydt, 2005)

Submatrix J^1

$$J_{pq}^1 = \frac{\partial P_p}{\partial e_q} = e_p G_{pq} - f_p B_{pq}, \quad p \neq q \quad (16a)$$

$$J_{pp}^1 = \frac{\partial P_p}{\partial e_q} = e_p G_{pp} - f_p B_{pp} + C_p \quad (16b)$$

Submatrix J^2

$$J_{pq}^2 = \frac{\partial P_p}{\partial f_p} = e_p B_{pq} + f_p G_{pq}, \quad p \neq q \quad (17a)$$

$$J_{pp}^2 = \frac{\partial P_p}{\partial f_p} = e_p B_{pp} + f_p G_{pp} + d_p \quad (17b)$$

Submatrix J^3

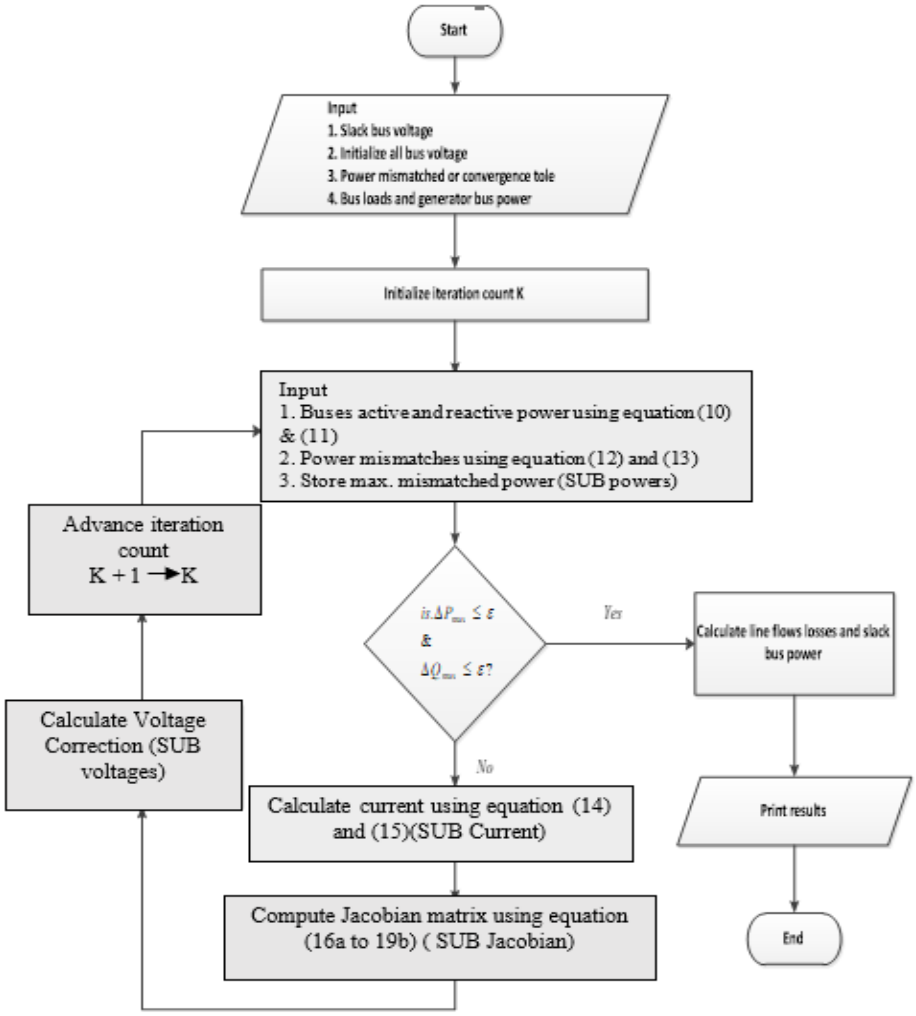


Figure 3. Flowchart for Power Flow Solution

$$J_{pq}^{3} = \frac{\partial Q_p}{\partial e_q} = e_p B_{pq} + f_p G_{pq}, \qquad p \neq q \tag{18a}$$

$$J_{pp}^{3} = \frac{\partial Q_p}{\partial e_p} = e_p B_{pp} + f_p G_{pp} - d_p \tag{18b}$$

Submatrix J^4

$$J_{pq}^{4} = \frac{\partial Q_p}{\partial f_q} = -e_p G_{pq} + f_p B_{pq}, \quad p \neq q \tag{19a}$$

$$J_{pp}^{4} = \frac{\partial Q_p}{\partial f_p} = -e_p G_{pp} + f_p B_{pp} + c_p \tag{19b}$$

SUB Voltages is then called to solve the linear system of equations (20) for the voltages Δe and Δf. This subroutine makes use of triangular factorization and forward and back substitution to solve for the voltages.

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$$\begin{bmatrix}\frac{\Delta P}{\Delta Q}\end{bmatrix} = \begin{bmatrix}\frac{\partial p}{\partial e} \cdots \frac{\partial p}{\partial f} \\ \vdots\vdots \\ \frac{\partial Q}{\partial e} \cdots \frac{\partial Q}{\partial f}\end{bmatrix}\begin{bmatrix}\frac{\Delta e}{\Delta f}\end{bmatrix} = [J][\frac{\Delta e}{\Delta f}] \quad (20)$$

Where J is the Jacobian matrix which for convenience may be partitioned as:

$$J = \begin{bmatrix}J^1 \vdots J^2 \\ J^3 \vdots J^4\end{bmatrix}$$

The entries of the Jacobian matrix are computed using equations (16a) to (19b) (Adesina et al, 2020; Heydt, 2005). This completes the solution for the voltage corrections, $\Delta e^{(p)}$ and $\Delta f^{(p)}$. The subroutine then updates the voltages for the next iteration as,

$$e_p^{(k+1)} = e_p^{(k)} + \Delta e_p^{(k)} \quad (21)$$

$$f_p^{(k+1)} = f_p^{(k)} + \Delta f_p^{(k)} \quad (22)$$

The iteration count is increased by 1, i.e, k = k+1, and control is transferred to SUB Powers. When the power mismatch becomes negligible, then control is transferred to SUB Power flows which evaluate the power flows as well as the power losses in the lines. In SUB Power flows the power flowing from Bus p to Bus q and measured at Bus p is given by equation (23),

$$P_{pq} = G_{pq}\left(e_p^2 + f_p^2\right) + \left(e_p f_q - f_p e_q\right) - G_{pq}(e_p e_q + f_p f_q) \quad (23a)$$

$$Q_{pq} = B_{pq}\left(e_p^2 + f_p^2\right) + G_{pq}\left(f_p e_q - e_p f_q\right) - B_{pq}\left(e_p e_q + f_p f_q\right) + \frac{Y_{sht}\,(e_p^2 + f_p^2)}{2} \quad (23b)$$

Similarly, the power from q to p and metered at q is given by:

$$P_{qp} = G_{pq}\left(e_q^2 + f_q^2\right) + B_{pq}\left(e_q f_p - f_q e_q\right) - G_{pq}\,(e_q e_p + f_q f_p) \quad (24a)$$

$$Q_{pq} = B_{pq}\left(e_q^2 + f_q^2\right) + G_{pq}\left(f_q e_p - e_q f_p\right) - B_{pq}\left(e_q e_p + f_q f_p\right) + \frac{Y_{sht}(e_q^2 + f_q^2)}{2} \quad (24b)$$

Power losses in each branch of the network are obtained as the algebraic sum of the power calculated using equations (23a) and (24a) and that calculated using equations (23b) and (24b) for active power P and reactive power Q respectively. While the total power losses in the system is the sum of the absolute values of the calculated power losses in each branch of the network. The slack bus power is determined by summing the power flows on the lines terminating at the slack bus.

2.3 Description of Case Study (Large Power System Network)

The network of figure 4 shows a typical example of a large power system. The grid has 32 nodes (buses) of which 9 are generator buses. There are 34 transmission lines (branches) of which 3 are mainly transformers connected in parallel. Two of these transformers are connected between generator bus 26 and bus 12, while the third transformer is connected between generator bus 1 and bus 15. These transformers are usually the power regulation type. Every generation station here, depending on its installed generation capacity has a number of generators. Some of the generators in the station are made to supply to the grid, while the remaining ones are considered as reserves. Available data shows that the total installed generation capacity is 5798MW.

3 Application of the developed software package to a large power system network

In this section, usage of the NRPF package is illustrated by applying to a large power system network. The network is shown in Figure 5. The example was used to test each step of the program. Per unit impedances of the lines are clearly written in the Network diagram of figure 5. Other given data are,

$Number\ of\ Buses = 32$

$Number\ of\ Lines = 34$

$Slack\ Bus\ Number = 1$

$Slack\ Bus\ Voltage = 1.0 + j\,0$

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$Power\ mismatch\ tolerance\ \epsilon = 0.001\ per\ unit$

The Scheduled Powers i.e. active power P_s and reactive power Q_s for all Non-Generator buses are shown in Table 2

Table 2: Bus Power and Voltage Specifications in per unit (Adesina, 1995; TCN. Mag., 2006)

BUS No	P_g(MW)	Q_g(MVAr)	P_{sp}(MW)	Q_{sp}(MVAr)	V (kV)
1	10.2	7.6	0	0	1
2	7.6	2.5	0	0	1
3	0	0	3.8	1.9	-
4	0	0	2.5	1.25	-
5	5.78	3.58	0	0	1
6	0	0	3.045	1.382	-
7	0	0	1.471	0.712	-
8	0	0	0.418	0.233	-
9	0	0	0.312	0.151	-
10	0	0	1.008	0.487	-
11	0	0	1.922	0.897	-
12	0	0	4.55	2.19	-
13	0	0	13.2	5.865	-
14	0	0	2.4	0.75	-
15	0	0	5.1	2.55	-
16	0	0	1.243	0.695	-
17	0	0	2.53	1.226	-
18	0	0	1.638	0.784	-
19	6	3.72	0	0	1
20	0	0	0.56	0.266	-
21	0	0	0.7	0.336	-
22	0	0	0.451	0.208	-
23	0	0	1.856	0.896	-
24	8.2	6.15	0	0	1
25	0	0	2.2	0.96	-
26	13.2	9.9	0	0	1
27	7	5.25	0	0	1
28	0	0	3.39	1.64	-
29	0	0	1.397	0.579	-
30	0	0	0	0	1
31	0	0	0	0	1
32	0	0	1.14	0.57	-

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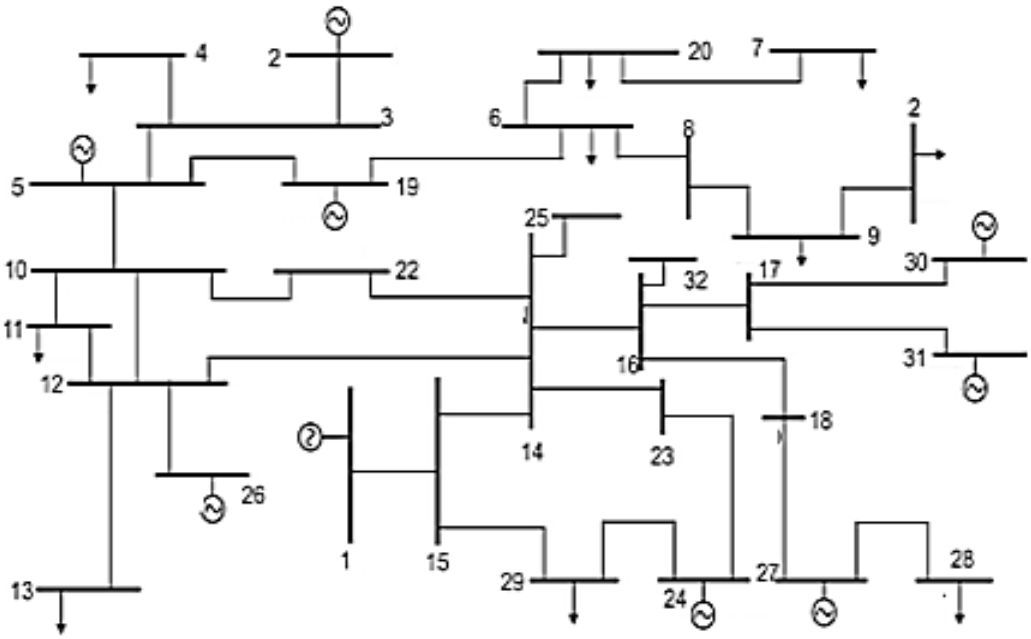


Figure 4. Large power system to illustrate usage of the power flow software package (Adesina, 1995; TCN. Mag., 2006)

LAMBE 1 is used to input and store the system data:
Number of buses, NB; Number of lines, NL; Start bus, SB; and End bus, EB for each line; Line resistance, R; Line reactance, X; Line susceptance, B; Busbar scheduled power P_{sp} and Q_{sp}
LAMBE 1 then assembles the bus admittance matrix, Y bus. A11 data are stored in data files (e.g Y2BUS. DAT and PQ2BUS.DAT).
LAMBE 2 then executes with bus voltages initialized to the slack bus voltage value E = 1.00 + j 0 per unit. The Newton- Raphson iteration process converged with power mismatch tolerance ϵ = 0.001 per unit in 5 iterations. The results are presented in table 3 to table 5:
Number of Buses = 3; Number of Lines = 3; Slack Bus Number = 1, Slack Bus Voltage = 1.00 + j 0; Program Converged in Iteration K = 5, Power Mismatch Tolerance = .001.

4. Discussion of Results

In power flow analysis, a generator bus is often used as the slack bus. Hence, bus 1 was chosen as the slack bus and its voltage is 1.0 < 0 per unit for the analysis. The voltage of each generator bus is constrained to be 1.0 < 0 per unit.

From Table 3, there is a wide variation of voltage profile, thus, for any meaningful analysis, it becomes necessary to identify buses with minimum voltage profile and buses with maximum voltage profile. The minimum and maximum voltage values acceptable for a normal power system network are 0.95 and 1.05 per unit respectively (Adesina and Fakolujo 2015; Awosope and Akinbulire, 1990). On this basis, buses whose voltage magnitude falls above maximum acceptable value are can also be seen from the same overloaded (Adesina and Ajenikoko, 2020). It would have also been seen on the same table that generator buses in the network and whose voltages values are fixed at 1.0 < 0 per unit falls within the accepted range and therefore not overloaded. Similarly, based on these results, some of the loaded buses in the network have their calculated voltages within

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the permissible range and hence, they are not overloaded. Therefore, there exist no overloaded bus in the network perhaps the distance of the buses from the source of supply are not far.

Table 3: Calculated Bus Voltages of the Network in per unit

Bus	Voltage (per unit)
1	1.0+ j 0
2	1.0+ j 0
3	1.07+ j .078
4	1.075 + j .086
5	1.0+ j 0
6	1.096 + j .115
7	1.099 + j .121
8	1.112 + j .14
9	1.126 + j .162
10	1.057 + j 0.062
11	1.051 + j .055
12	1.043 + j .045
13	1.043 + j .045
14	1.027 + j .025
15	1.021 + j .019
16	1.031 + j .029
17	1.047 + j .048
18	1.032 + j .029
19	1.0 + j 0
20	1.097 + j .118
21	1.13 + j .17
22	1.046 + j .049
23	1.024 + j .022
24	1.0 + j 0
25	1.027 + j .026
26	1.0 + j 0
27	1.0 + j 0
28	1.032 + j .029
29	1.022 + j .019
30	1.047 + j .048
31	1.047 + j .048
32	1.031 + j .03

From the flow pattern shown in Table 5 of the results, it is observed that for a steady state situation, there are no overloaded lines. The algebraic sum of Active power flow from both ends of each transmission line of figure 4 are relatively negligible. These values for all line's ranges from zero to 5 percent. This implication is that there is a negligible active power loss on these lines. While on the other hand, the algebraic sum of reactive power flow from both ends of most transmission line of the same figure is high compared to its active power flow. Here,

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about 20 number out of 34 number lines are affected.

Table 4: Calculated Bus Voltage Magnitudes, Phase Angles, Active and Reactive Powers

	Voltage (per unit)		Power (per unit)	
Bus no	Magnitude	Phase (degree)	Active (MW)	Reactive (MVAr)
1	1	0	0	0
2	1	0	0	0
3	1.073	4.17	-0.001	0.743
4	1.078	4.574	0	0.589
5	1	0	0	0
6	1.102	5.99	0	0.884
7	1.106	6.283	0	0.291
8	1.121	7.176	0	0.879
9	1.138	8.188	0.001	0.98
10	1.059	3.357	0	2.203
11	1.052	2.996	0	0.479
12	1.044	2.471	0	3.806
13	1.044	2.471	0	0.065
14	1.027	1.395	0	4.294
15	1.021	1.066	0	0.656
16	1.031	1.611	0	1.228
17	1.048	2.625	0	0.724
18	1.032	1.61	0.001	0.628
19	1	0	0	0
20	1.103	6.14	0	0.437
21	1.143	8.556	0	0.475
22	1.047	2.682	0	0.477
23	1.024	1.231	0	0.306
24	1	0	0	0
25	1.027	1.45	0	0.745
26	1	0	0	0
27	1	0	0.001	0
28	1.032	1.61	0	0.125
29	1.022	1.065	0	0.306
30	1.048	2.625	0	0.416
31	1.048	2.625	0	0.308
32	1.031	1.667	0	0.182

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Table 5: Calculated Power Flows between the Buses

Buses		Power Flow (per unit)	
From	To	Active	Reactive
1	15	1.746	-1.93
15	1	-1.746	2.004
2	3	3.362	-3.017
3	2	-3.362	3.491
3	4	0.093	0.625
4	3	-0.093	0.738
3	5	-8.184	8.367
5	3	8.13	-6.005
5	10	4.351	-2.305
10	5	-4.401	4.656
5	19	0	0.896
19	5	0	0.896
6	8	0.46	0.839
8	6	-0.462	1.466
6	19	-8.703	8.225
19	6	8.527	-4.655
6	20	0.141	1.08
20	6	-0.141	1.174
7	20	-71	0.504
20	7	0.071	0.409
8	9	0.301	0.262
9	8	-0.302	0.674
9	21	0.117	0.126
21	9	-0.117	0.254
10	11	-0.221	0.495
11	10	0.221	0.157
10	12	-0.545	0.721
12	10	0.544	-0.063
10	22	-0.516	0.704
22	10	0.514	-0.047
11	12	-0.264	0.744
12	11	0.263	0.37
12	13	0	0.518
13	12	0	0.518
12	14	-1.136	1.278
14	12	1.132	-0.226
12	26	-5.834	5.222
26	12	5.778	-3.786
14	15	-1.936	2.477
15	14	1.933	-0.568
14	16	0.219	0.768
16	14	-0.219	1.14
14	22	0.539	0.592
22	14	-0.541	1.364

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14	23	-0.075	1.029
23	14	0.075	0.866
14	25	0.036	0.953
25	14	-0.036	0.946
15	29	0.01	0.09
29	15	-0.01	0.303
16	17	0.112	0.193
17	16	-0.112	0.374
16	18	0.004	0.226
18	16	-0.004	0.329
16	32	0.035	0.28
32	16	-0.035	0.274
17	30	0	0.071
30	17	0	0.071
17	31	0	0.071
31	17	0	0.071
18	27	-9.375	10.947
27	18	9.307	-5.622
23	24	-1.571	0.958
24	23	1.553	-0.902
24	29	2.434	-1.451
29	24	-2.445	3.069
27	28	6.714	-5.047
28	27	-6.768	6.503

The remaining 14 number lines not affected with this high value includes, line 1-15, 2-3, 3-5, 5-10, 6-19, 10-12,10-22, 12- 14, 12-26, 14-15, 18-27, 23-24, 24-29 and 27-28. However, it is 'unhealthy' of any power system to have higher reactive power flow than active power flow as is the case of the listed lines above. Therefore, installation of Capacitor bank or other means of absorbing reactive power on those lines is highly required. Also, in table 5, power flow analysis shows that the slack bus power is 1.65 + j1.93 per unit and Total Power Loss is 0.263 + j9.021 per unit.

Finally, looking at the previous work done (Adesina, 1995), the system converged at the 22nd iterations and bus voltages obtained were not reliable. This is because some bus voltages are higher than 1.0 p.u while some of the bus voltage results are generally too low and unrealistic. However, in this research work, the system converged at fifth iterations and the results obtained are quite reasonable, interpretable and reliable.

5. Conclusion

The paper has presented an algorithm of Newton-Raphson power flow solution. A developed computer software package on Newton- Raphson power flow studies was applied to a large power system network. The results of this analysis converged at the fifth iteration. Again, the quick convergence of the solutions of this power flow analysis for the large network considered in this paper satisfied the theoretical reports of Newton Raphson power flow iterative technique. Newton – Raphson approach to power flow solutions was therefore observed to be the most sophisticated and very difficult to program. However, it converges faster than the other methods and the results are often more reliable. Thus, it is worth mentioning that the transmission lines with high reactive power needs installation of equipment capable of reducing the reactive power on the lines while buses with voltage values slightly less than the acceptable standard needs special attention.

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