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Electrical Load Flow Studies for Efficient Power Supply in Bayelsa Stateusing Newton Raphson Technique

D.C. Idoniboyeobu[1], B. E. Nemine[2]

[1,2](Department of Electrical Engineering, Rivers State University, Nkpolu-Oroworukwo, Port Harcourt, Rivers State, Nigeria.)

Abstract:

Electrical load flow studies, was conducted in Bayelsa State power network. It is necessary for planning, operation, future expansion of the network and exchange of power between utilities. The objective of this work is to determine the voltage magnitude, phase angle at the buses, real and reactive power of the transmission line. A detailed survey was carried out on the network and the Ybus admittance matrix formed. The load flow equation was formulated. The equation is non-linear and complex. The complexity of the equation resulted applying Newton Raphson algorithm. A MATLAB program was developed to solve the Newton Raphson algorithm and the bus voltages obtained are 0.1347pu, 0.1742pu, 0.101pu, 0.335pu and 0.254pu, while the phase angles are 0.00284pu, -0.0166pu, -0.0519pu, 0.0013pu and -0.0039pu on the buses. The real and reactive power obtained at the slack bus is 0.6530pu and 255.1123pu. The power dispatched and received on each line was also calculated. The losses on each feeder or line were obtained. This will help the system engineer during operation and future expansion of the network.

Keywords— **Bus admittance, Ybus Matrix, Power Network, Load flow analysis, Newton Raphson Method and MATLAB Programming, Real and Reactive Power, Power Dispatched and Received and Power loss**

I. INTRODUCTION

The load flow analysis is the backbone of power system analysis and design. It is necessary for planning, operation, economic scheduling and exchange of power between utilities.Many modeling techniques and algorithms are proposed to fully exploit the peculiarities of distribution systems, and to enhance computational efficiency of the load flow algorithms [1-2].

Mathematical methods are used to find approximate solution to a problem which cannot be solved directly, by starting from the exact solution of a related problem. This gives expressions for the desired solution in terms of power series in some “small” parameter that qualifies the derivation from the exact solvable problem [3-7]. Most problems regarding steady-state and transient analysis of power systems require interactive solutions of large sets of equations representing system components. Barboza [8] presented a method for solving uncertain Power Flow problems. A mathematical representation for Load Flow analysis by Krawczyk’s methodto solve non-linear equations was also presented [9].

Load flow calculation is one of the most basic problems in power engineering [10-11] and different existing methods are compared [14]. An iterative method is used in solving the sparse- matrix and generate the appropriate algorithm [12-13].

Load flow analysis gives us the sinusoidal steady state condition of the full system voltage, real power and reactive power generated /consumed as well as line losses. Since the load is a static quantity of the power system, it is the complex power that flows across the transmission lines. This study helps us to analyze the voltage magnitudes and angles at each bus.[16]. It also assists in deducingthe difference between real and reactive power flows in the sending and receiving ends [15]. The losses in a particular line can also be computed using MATLAB programming in the load flow, the real and reactive power flow constantly of each line. Furthermore, from the line flow we can also determine the over and under load conditions. The steady state power and reactive power supplied by a bus in a power network are expressed in terms of nonlinear algebraic equations

It is considered that the loads are constant and they are defined by their real and reactive power consumption in power system [17]. Load flow studies enable us to obtain the voltage magnitudes and angles at each bus in the steady state [18-19]. This is rather important as the magnitudes of the bus voltages are required to be within a specified limit. Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed.Power Flow Analysis under uncertainty using Fuzzy Arithmetic has been widely examined [20-22]. Milano built test scenario by fuzzifying the well-known IEEE 14-bus system [20]. He proposed to address uncertainty with an original solution based on fuzzy algebra.

The planning, design operation and future expansion of the Bayelsa State power network require load flow analysis.

II. MATERIALS AND METHOD

A. Materials

The data collected was carried out as follows:

Collection of data was from the Ministry of Power [23-25], "Inventory, condition survey, property identification and GIS mapping of electrical infrastructure in Bayelsa State [24]. The data collected are the capacity and the percentage impedance of the transformer.

Identification of the transformers in each feeder as it is in the network.

In the analysis of the data, the impedance of each substation was calculated and the admittance was formed. All the facts gathered from the method of the investigation were analysed exhaustively and discussed appropriately before conclusion and recommendation was done. The research methodology involves data collection and analysis.

B. Method

The transformers considered on the network were used to calculate the actual impedance and the admittance of each feeder on the network. The power flow equation was solved using the Newton Raphson method. A Matlab programme was developed to solve the complexity of the power equation. The voltage magnitude and phase angle on each feeder was also analysed.

C. The Case Study of the 2x 40MVA Injection Station

The Port Harcourt Electricity Distribution company (PHEDC) are the operators of the Bayelsa State electricity network, the power is supplied to Bayelsa state through the 2x 40MVA, 132/33KV injection substation at Gbaratoru. This injection substation has five (5) feeders which feed different parts of the State.

The feeders are namely: Feeder 1, Feeder 2, Opolo Feeder, Amassoma Feeder and Tungbo Feeder. These feeders supply power to Yenagoa LGA, Kolokuma /Opokuma LGA, Sagbama LGA and Southern Ijaw LGA of the State.

Fig 1 shows the single line diagram of the network as operated by The Port Harcourt Electricity Distribution Company (PHEDC)[25]

SCHEMATIC DRAWING OF YENAGOA TRANSMISSION STATION, 33KV NETWORK AND INJECTION SUBSTATIONS IN YENAGOA BUSINESS UNIT

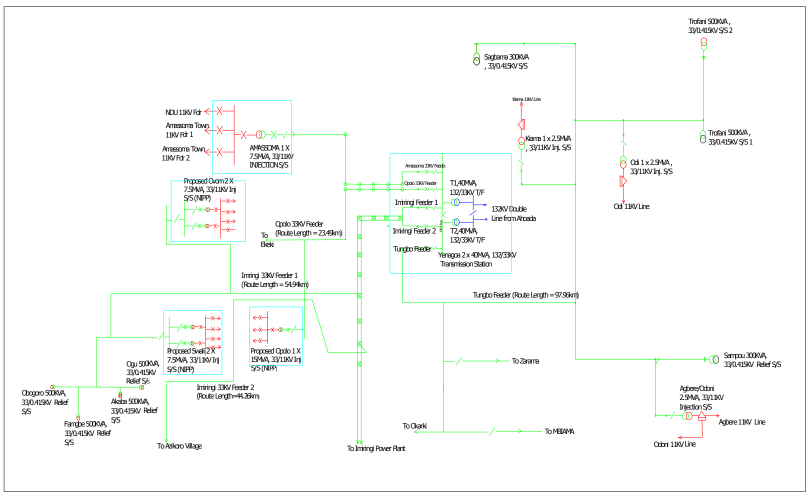

Figure 1 SINGLE LINE DIAGRAM OF 33KV NETWORK, TRANSMISSION AND INJECTION SUBSTATION IN THE PORT HARCOURT ELECTRICITY DISTRIBUTION COMPANY (PHEDC) OF YENAGOA BUSINESS UNIT

Figure 1: Diagram of 33KV Network, Transmission and Injection Substation in Yenagoa Business Unit [25]

D. The Impedance of each Feeder

Based on the data collected from Ministry of Power, [24].

The base impedance $(Zbase)$ was calculated as stated in equation (1)

$$Z_{base} = \frac{(PrimaryVoltage)^2}{MVA} \qquad (1)$$

And the actual impedance was calculated as stated in equation (2)

where the $Actualimpedance(Z_{base}) = \; Percentage(\%)Impedance \times Baseimpedance$

$Z_{actual} = \%\ impedance\ x\ Z_{base}(2)$

Figure 3 shows the schematic representation pf the Bayelsa Power Network.

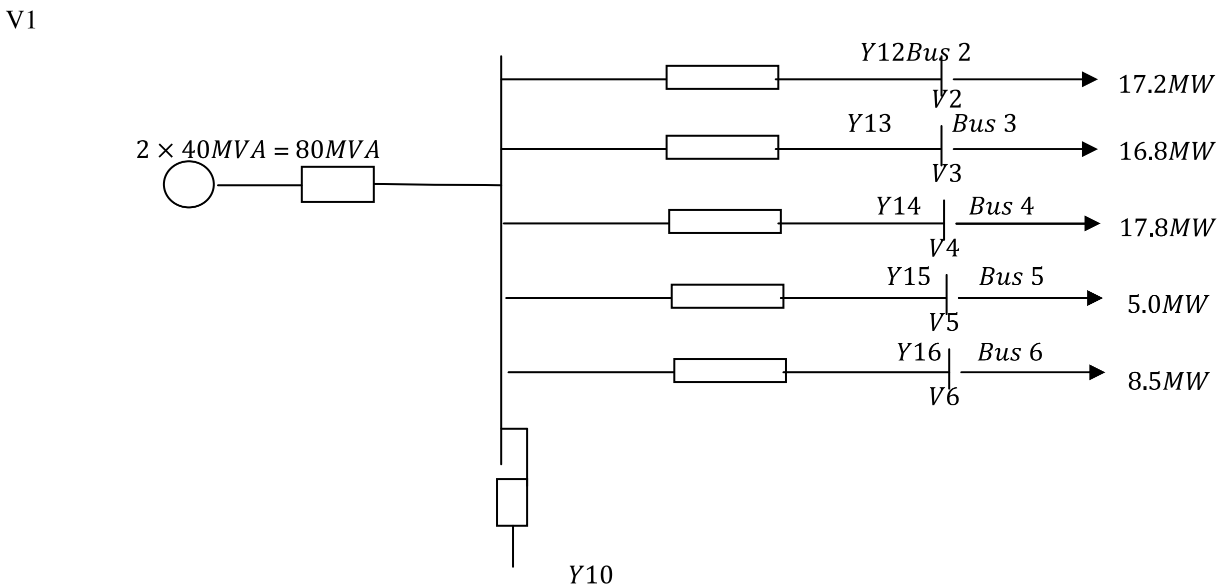

Figure 3 Schematic representation of the Bayelsa Power network

E. Bus Admittance Matrix

Load flow calculations are either used as bus admittance matrix or bus impedance matrix. But it is simpler to use the bus admittance matrix.

Applying Kirchhoff's Current law to figure 3.

The impedances of the load, are converted to admittance. Where the admittance is the inverse of the impedance.

The admittance Y=1/z

$$Y = \frac{1}{Z} = \frac{1}{0+jx} = \frac{1}{(0+jx)}\frac{(0-jx)}{(0-jx)}$$

$$= \frac{-jx}{-(-1^2)(x^2)} = \frac{-j}{x} = J(-1/X) \qquad (3)$$

$$Y_{ij} = \frac{1}{Z} = \frac{1}{r_{ij}+jX_{ij}} \qquad (4)$$

Converting the admittance into polar form

$$Y = -JX < -90^0$$

The bus admittance is calculated using equation (4)

$Y = 1/Z = 1/0 + jX = -jx/x^2$

The admittance results calculated for each feeder are given below in table 1

Table 1 ADMITTANCE OF FEEDER IN YENAGOA BUISNESS UNIT

S/No	FEEDERS		Actual Impedance	(Z)= jX	ADMITTANCE (Y)
					Y=1/Z= 1/0 +jX = -jx/x^2
1	FEEDER 1	y12	0.02223	0.02223	44.98425551
2	FEEDER 2	y13	0.01719	0.01719	58.1733566
3	OPOLO FEEDER	y14	0.02954	0.02954	33.85240352
4	AMASSOMA FEEDER	y15	0.008943	0.008943	111.8193
5	TUNGBO FEEDER	y16	0.01176723	0.01176723	84.98176716
		Y11			333.8110828

F. Load flow problem formulation.

Applying Kirchhoff's Current Law to the network, the Power flow equation becomes

$I_1 = Y_{10}V_1 + Y_{12}(V_1-V_2)+Y_{13}(V_1-V_3) +Y_{14}(V_1-V_4) + Y_{15}(V_1-V_5)+Y_{16}(V_1-V_6)$

$I_I = (Y_{10}+Y_{12}+Y_{13}+Y_{14}+Y_{15}+Y_{16})V_1-Y_{12}V_2-Y_{13}V_3-Y_{14}V_{14}-Y_{15}V_{15}-Y_{16}V_6$ (5)

From equation (5)

$Y_{11}= (Y_{10}+Y_{12}+Y_{13}+Y_{14}+Y_{15}+Y_{16})$

And $Y_{11}=Y_{22}=Y_{33}=Y_{44}=Y_{55}=Y_{66}$

Where as

$Y_{12} = Y_{21} = -y_{12}$; $Y_{13} = Y_{31} = -y_{13}$; $Y_{14} = Y_{41} = -y_{14}$

$Y_{15} = Y_{51} = -y_{15}$; $Y_{16} = Y_{61} = -y_{16}$; $Y_{10} = 0$

$Y_{11} =Y_{22} =Y_{33}=Y_{44} =Y_{55}=Y_{66}$

$Y_{11}=Y_{10}+Y_{12}+Y_{13}+Y_{14}+Y_{15}+Y_{16}$

Substituting values Y_{11}= 0-44.98- 58.17-33.85+-111.81 - 84.98 =-333.81

Converting the admittance into polar form

$Y= -JX<-90^0$

$Y11 = -j333.81 = 333.81 < -90^0$

$Y12 = Y21 = -(-y12) = j44.98 = 44.98 < 90^0$

$Y13 = Y31 = -(-y13) = j58.17 = 58.17 < 90^0$

$Y14 = Y41 = -(-y14) = j33.85 = 33.85 < 90^0$

$Y15 = Y51 = -(-y15) = j111.81 = 111.81 < 90^0$

$Y16 = Y61 = -(-y16) = j84.98 = 84.98 < 90^0$

From the power flow equation,

$$Y_{bus} = \begin{matrix} Y11 & Y12 & Y13 & Y14 & Y15 & Y16 \\ Y21 & Y22 & 0 & 0 & 0 & 0 \\ Y31 & 0 & Y33 & 0 & 0 & 0 \\ Y41 & 0 & 0 & Y44 & 0 & 0 \\ Y51 & 0 & 0 & 0 & Y55 & 0 \\ Y61 & 0 & 0 & 0 & 0 & Y66 \end{matrix}$$

Substituting the values into the Y_{bus}

$$Y_{bus} = \begin{bmatrix} -j333.81 & j44.98 & j58.17 & j33.85 & j111.81 & j84.98 \\ j44.98 & -j333.81 & 0 & 0 & 0 & 0 \\ j58.17 & 0 & -j333.81 & 0 & 0 & 0 \\ j33.85 & 0 & 0 & -j333.81 & 0 & 0 \\ j111.81 & 0 & 0 & 0 & -j333.81 & 0 \\ j84.98 & 0 & 0 & 0 & 0 & -j333.81 \end{bmatrix}$$

. $I_1 = V_1\sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij}V_j$ where $j \neq 1$ (6)

The real and reactive power at bus 1 is calculated using

$$P1 + jQ1 = V1I_1^*$$ (7)

$$I_1 = \frac{P_1 - jQ_1}{V_1^*}$$ (8)

Substituting for I_1 in equation (8)

$$\frac{P_1 - JQ_1}{V_1^*} = V_1\sum_{j=0}^{n} Y_{ij} - \sum_{j=1}^{n} Y_{ij}V_j \qquad j \neq i$$ (9)

G. Load Flow Solution using Newton Raphson Method

Newton Raphson method is applied to the load flow solution in a number of ways and the most commonly used are

(i) The rectangular coordinate and
(ii) The polar coordinate

However, this project is done using the polar coordinates. The reason is that the polar coordinate form results that have lesser number of equations and smaller size of jacobian. Infact, this is the main advantage of polar form over the rectangular form

E1. The polar form of Newton Raphson Method:

We know that the power at bus P

$$P_i - JQ_i = \sum_{q=1}^{n} V_i Y_{ij} V_j$$ (10)

Let $Y_{ij} = G_{ij} - JB_{ij} = |Y_{ij}| < -\theta_{ij} = |Y_{ij}|e^{-j\theta ij}$

While

$V_p = |V_P|e^{-j\delta i}$ and $V_j = |V_i|e^{j\delta i}$

Substituting the above quantities in equation (10)

$$P_i - JQ_i = \sum_{q=1}^{n}|V_i|e^{-j\delta i}|Y_{ij}|e^{-j\theta}ij\,|V_i|e^{j\delta i}$$

$$P_i - JQ_i = \sum_{q=1}^{n}|V_i Y_{ij} V_j|e^{-j(\theta_{ij}+\delta i-\delta_j}$$ (11)

Substituting the real and imaginary parts of equation (11)

The real part now becomes

$$P_i = \sum_{q=1}^{n}|V_i Y_{ij} V_j|\cos(\theta_{ij} + \delta_j - \delta_i)$$ (12)

And the imaginary part is

$$Q_i = -\sum_{q=1}^{n}|V_i Y_{ij} V_j|\sin(\theta_{ij} + \delta_j - \delta_i)$$ (13)

The real and reactive powers at each bus are the function of magnitude and phase angle of bus voltage

Thus $P_i = g_1(\delta, |V|$

$Q_i = g_2(\delta, |V|$

The Bayelsa State network consists of six numbers of buses and Bus 1 is assumed the slack Bus. All other buses are the load buses. The generator controlled bus PV is not present.

E2. Newton Raphson Method using polar coordinates

Equation (12) and (13) can be written as

$$P_i = V_i^2 G_{11}\sum_{q=1}^{n}|V_i|[V_j]|Y_{ij}|\cos(\theta_{ij} + \delta_j - \delta_i)$$

Similarly, the reactive power Q is

$$Q_i = -(V_i^2 B_{11}\sum_{q=1}^{n}|V_i|[V_j]|Y_{ij}|\sin(\theta_{ij} + \delta_j - \delta_i))$$

III. RESULTS

Tables 2 and 3 show the phase angles/voltage magnitudes in the buses, Real and Reactive Power flows respectively. Tables 4 and 5 show the Power in the slack bus and Power losses on each feeder respectively.

Table 2: Phase angle (δ) and voltage magnitude in the Buses

δ2	δ3	δ4	δ5	δ6	V2	V3	V4	V5	V6
0	0	0	0	0	1.0000	1.0000	1.0000	1.0000	1.0000
-0.0038	-0.0029	-0.0053	-0.0004	-0.0100	0.5361	0.5477	0.5267	0.6006	0.5729
-0.0088	-0.0064	-0.0123	-0.0009	-0.0210	0.3066	0.3257	0.2914	0.4164	0.3683
-0.0156	-0.0109	-0.0229	-0.0012	-0.0321	0.1965	0.2223	0.1764	0.3483	0.2813
-0.0232	-0.0149	-0.0367	-0.0013	-0.0384	0.1495	0.1828	0.1237	0.3354	0.2567
-0.0277	-0.0165	-0.0481	-0.0013	-0.0393	0.1360	0.1746	0.1047	0.3350	0.2544
-0.0284	-0.0166	-0.0518	-0.0013	-0.0393	0.1347	0.1742	0.1014	0.3350	0.2544
-0.0284	-0.0166	-0.0519	-0.0013	-0.0393	0.1347	0.1742	0.1013	0.3350	0.2544
-0.0284	-0.0166	-0.0519	-0.0013	-0.0393	0.1347	0.1742	0.1013	0.3350	0.2544

Table 3 Summary of the phase angle (δ) and voltage magnitude in the buses, the real power and reactive power flow in the buses

Bus	Phase angle (rad) (pu)	Voltage (V) (pu)	Real Power (P) (pu)	Reactive Power (Q) (pu)
1	0	1	0.6530	255.1123
2	-0.00284	0.1347	0.172	8.88e-6
3	-0.0166	0.1742	-0.168	0
4	-0.0519	0.1013	-0.178	5.3069e-12
5	-0.0013	0.3350	-0.05	7.1054e-15
6	-0.0039	0.2546	-0.085	0

The slack bus real and reactive power

The real power in the slack bus is

$$P_i = V_i^2 G_{11} \sum_{q=1}^{n} |V_i| \left[V_j\right] |Y_{ij}| \cos\left(\theta_{ij} + \delta_j - \delta_i\right)$$

Similarly, the reactive power Q is

$$Q_i = -(V_i^2 B_{11} \sum_{q=1}^{n} |V_i| \left[V_j\right] |Y_{ij}| \sin\left(\theta_{ij} + \delta_j - \delta_i\right))$$

Table 4 Real and reactive power of slack bus

SLACK BUS	P1	Q1
1	**0.6630**	**255.1123**

Power loss

The current that flows on each line is

$I_{ij}= -Y_{ij}(V_i-V_j)$

The complex power dispatched is

$S_{ij}=VI$

$S_{ik}=V_i \text{ x } (-Y_{ij}(V_i-V_k))$

Similarly

$S_{ji}=V_j \text{ x } (Y_{ij}(V_j-V_i))$

Total Power loss $S_L= S_{ij} - S_j$

Table 5 Power loss on each feeder

FROM BUS	POWER DESPATCHED	TO BUS	POWER RECEIVED	LOSS (MW)
1	-0.1720+38.9236i	2	-0.1720+38.9236i	0
1	-0.1682+48.0382i	3	0.1096+8.3676i	0.35
1	-0.1779+30.4256i	4	0.1419+3.0789i	5.19
1	-0.0487+74.3537i	5	0.0160+24.9085i	0.14
1	-0.08440+63.3443i	6	0.0414+16.1274i	0.39
Total Losses				6.07

Total Power loss on the lines is 6.07MW

Discussion:

The results of the voltage magnitude are within the acceptable range. The steady state power and reactive power supplied by a bus in a power network is also equal to the load demand. The dispatched power and the power received on the line were analyzed. The line losses on each feeder is considerably small except the Opolo feeder which has 5.19MW. Capacitor bank should be introduced in Opolo feeder in order to reduce losses on the feeder. The total loss of power on the system is 6.07MW.

IV. CONCLUSION:

This project gives detailed analysis of Load Flow in Bayelsa State power network. The line data from the respective feeders were taken and used in the load Flow analysis. A Load Flow problem was formulated and it enables us to get the voltage magnitude, phase angle, real and reactive power. The line flow and losses on each feeder was also gotten. The load flow equation was non-linear and complex. Due to this complexity, Newton Raphson algorithm was used to analyze the equation. A Matlab program was formulated on the Newton Raphson algorithm. Newton Raphson method in solving Load flow problem is reliable and converges faster than any other approach even when the number of buses increases. The results obtained in this study will be useful to the system engineer for the expansion efficient operation of the Bayelsa State power network.

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