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Renewable Energy Integration In Unbalanced Three Phase Power Flow using Gauss-Seidel and Newton-Raphson Methods

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***Abstract*—This paper presents the solution of three phases power flow in unbalanced electrical network. The main objective of the three flow analysis of power is to calculate the active and reactive powers flowing in each phase with the magnitude and the angle of the voltage at each bus of the system for the specific loading conditions. In this work, the negative- and zero-sequence components are presented using nodal voltage equations. The three phase power flow is formulated and solved by using Gauss-Seidel and Newton-Raphson methods and has been tested using IEEE 5 bus system. The wind power in this work represented by wind electric system which made up of a wind turbine mounted on a tower to provide better access to stronger winds, after that, we inject wind power generator to show the effect of the wind energy in the power flow for unbalanced electrical power system. The solar unit is considered in this work by adding two energy types in one bus.**

Keywords-component; Three phase, power flow, Unbalanced system, Gauss-Seidel, Newton-Raphson, Wind power, Solar power.

I. Introduction

The power distribution analysis is one of the basic tools for studying the behavior of a power system steady. To date, different algorithms have been designed to perform power distribution analysis [1],[2]. The power flow analysis is on a mains in electrical network whose the electrical components and their models are known. When the network modeling is accurate, the results of the analysis reflect, fairly reliably, In addition to the measurements on the ground [3].

The calculation of power flow is the steady state analysis of any complex power which consists in determining, in the first place, to each busbar, the amplitude and the phase of the voltage and the active and reactive power injected. For that, we can calculate the voltages of busbars and the injected powers, secondly, powers and currents in the lines and those provided by the source [4].

There are many several strategies for finding the solution of the three power flow, as Alternative Newton-Raphson [5], Network topology based method [6], Distributed Generation(DG) [7], Phase-decoupled method [8],

Parallel Sequence Decoupled Full Newton-Raphson [9], Generic Three-Phase Power Flow Method [10], Current Injection Power Flow [11], and A modified Gauss-Seidel algorithm [12].

The present work investigates the three phase power flow solution in unbalanced system using two traditional methods: Gauss-Seidel and Newton-Raphson.

However voltage unbalance may makes worse effect on power quality of electrical power at distribution level. In this work, we study the extent of the influence of the Newton-Raphson, Gauss-Seidel and methods in solving the three-phase power flow. The process of injecting wind and solar energy was also tested to study its effect on the balance in electrical network.

II. Modeling Lines

In this work, the electricity distribution network basis is presented by three-phase circuits' form. It uses three-phase circuits between generators industrial and residential networks. The system which has three phases, the current will pass through the three wires, and there will be one neutral wire for passing the fault current to the earth is known as the three phase system. In other words, the system which uses three wires for generation, transmission and distribution is known as the three phase system.

The three phase system is also used as a single phase system if one of their phase and the neutral wire is taken out from it. The sum of the line currents in the 3-phase system is equal to zero, and their phases are differentiated at an angle of 120º. The three-Phase circuits have some advantages over single-phase circuits which make their use very attractive [13],[14]. This system as a whole has many advantages such as it requires fewer conductors compared to the single-phase system. It also gives a constant supply of pregnancy. The three-stage system is characterized by higher efficiency and less losses.

The figure 1 presents the three-phase by a π circuit [14]; the matrix form presents the parameters:

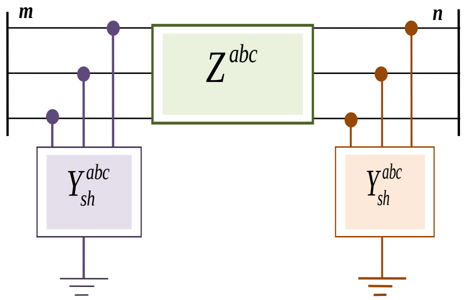


Figure 1.Three-phase line with π circuit equivalent.

The matrices of Z^{abc} and Y_{sh}^{abc} represented by Figure.1 are:

$$Z^{abc} = \begin{bmatrix} Z^{aa} & Z^{ab} & Z^{ac} \\ Z^{ba} & Z^{bb} & Z^{bc} \\ Z^{ca} & Z^{cb} & Z^{cc} \end{bmatrix} \quad (1)$$

$$Y_{sh}^{abc} = \begin{bmatrix} Y^{aa} & 0 & 0 \\ 0 & Y^{bb} & 0 \\ 0 & 0 & Y^{cc} \end{bmatrix} \quad (2)$$

Where Z^{aa}, Z^{bb}, Z^{cc} are the series impedance of phase a, b and c, respectively; $Z^{ab} = Z^{ba}$; $Z^{bc} = Z^{cb}$ and $Z^{ac} = Z^{ca}$, are the mutual impedance between phases a and b, b and c with a and c, respectively; Y^{aa}, Y^{bb} and Y^{cc} are the shunt capacitive susceptance of the line of phase a, b and c, respectively.

III. THREE-PHASE POWER FLOW USING GAUSS-SEIDEL EQUATIONS

This method involves sequentially remove each node and update its voltage based on available values of all voltages [15],[16]. In the specific case of the power flow, the resolution of the following nodal equation:

$$V_i^k = \frac{1}{Y_{ii}}\left[\frac{P_i^{spec} - jQ_i^{spec}}{V_i^{(k-1)*}} - \sum_{j=1}^{i-1} Y_{ij}V_j^k - \sum_{j=i+1}^{n} Y_{ij}V_j^{k-1}\right] \quad (3)$$

Where P_i^{spec} and Q_i^{spec} are the specified power of bus i. The voltage due to injections of current is calculated by the Y-bus factorization as:

$$\begin{bmatrix} Y_{11} & \cdots & Y_{1i} & \cdots & Y_{1n} \\ \cdots & \ddots & \cdots & \cdots & \cdots \\ Y_{i1} & \cdots & Y_{ii} & \cdots & Y_{in} \\ \cdots & \cdots & \cdots & \ddots & \cdots \\ Y_{n1} & \cdots & Y_{ni} & \cdots & Y_{nn} \end{bmatrix} \begin{bmatrix} V_1^k \\ \cdots \\ V_i^{k-1} \\ \cdots \\ V_n^{k-1} \end{bmatrix} = \begin{bmatrix} I_1 \\ \cdots \\ I_i \\ \cdots \\ I_n \end{bmatrix} \quad (4)$$

Where each element of Y-bus is 3×3 matrix as follow:

$$Y_{11}^{abc} = \begin{bmatrix} Y_{11}^{aa} & Y_{11}^{ab} & Y_{11}^{ac} \\ Y_{11}^{ba} & Y_{11}^{bb} & Y_{11}^{bc} \\ Y_{11}^{ca} & Y_{11}^{cb} & Y_{11}^{cc} \end{bmatrix} \quad (5)$$

IV. THREE-PHASE POWER FLOW USING NEWTON-RAPHSON EQUATIONS

As an example of numerical analysis, we mention Newton's method, also known as the Newton–Raphson method, named after Isaac Newton and Joseph Raphson, is a root-finding algorithm(mathematical equations) which produces successively better approximations to the roots (or zeroes) of a real-valued function. In this words, Newton's algorithm is an iterative algorithm used in numerical analysis to solve equations and systems of nonlinear equations [17],[18].

This method solves "n" non-linear algebraic equations with "n" unknowns, where y represents the active and reactive power as a function of the variables x representing the electrical values such as voltage and current [18].

$$P_k^p = V_k^p \left\{\sum_{i=k,m} \sum_{j=a,b,c} V_i^j \left[G_{ki}^{pj} \cos\left(\theta_k^p - \theta_i^j\right) + B_{ki}^{pj} \sin\left(\theta_k^p - \theta_i^j\right)\right]\right\} \quad (6)$$

$$Q_k^p = V_k^p \left\{\sum_{i=k,m} \sum_{j=a,b,c} V_i^j \left[G_{ki}^{pj} \sin\left(\theta_k^p - \theta_i^j\right) - B_{ki}^{pj} \sin\left(\theta_k^p - \theta_i^j\right)\right]\right\} \quad (7)$$

where the k, m represent the number of bus while P represent, the non-linear equations is combined and expressed in compact form, with :

$$f(x) = 0 \quad (8)$$

The Newton equation is given by:

$$J(x)\Delta x = -f(x) \quad (9)$$

$$J(x) = \frac{\partial f(x)}{\partial x} \quad (10)$$

J(x): is the system Jacobian matrix.

The J matrix is considered a Jacobian by its constitution. Indeed, as shown in [18], the elements that constitute the matrix J are expressed as rectangular coordinates. Thus, it is possible to show that each element of the matrix J is a partial derivative with respect to a variable[19].

$$\begin{bmatrix}\Delta P_l^p \\ \Delta Q_l^p\end{bmatrix}^i = \begin{bmatrix} \frac{\partial P_l^p}{\partial \theta_j^p} & \frac{\partial P_l^p}{\partial V_j^p} V_j^p \\ \frac{\partial Q_l^p}{\partial \theta_j^p} & \frac{\partial Q_l^p}{\partial V_j^p} V_j^p \end{bmatrix}^i \begin{bmatrix}\Delta \theta_j^p \\ \frac{\Delta V_j^p}{\Delta^p}\end{bmatrix}^i \qquad (11)$$

where $l = k, m$, $j = k, m$, and i is the number of iteration [20].

The solution steps of three phase load flow using Newton-Raphson algorithm are summarized in the flowchart of figure. 2.

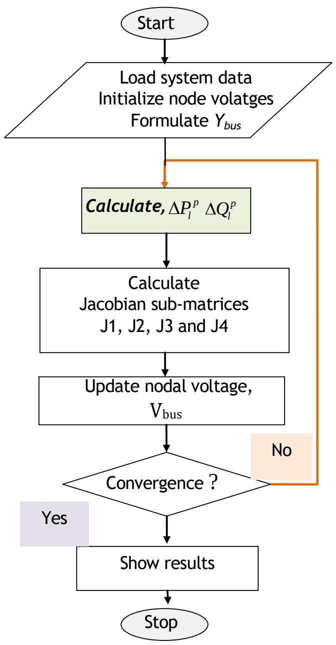


Figure 2. Flowchart of Newton-Raphson algorithm.

V. WIND AND SOLAR POWER INJECTION

The wind and solar power is growing fast in terms of installed capacity in the world [21],[22]. The wind power is the renewable energy source most reliable: a wind turbine has a hardware availability rate of over 98%. The recovered energy is the wind speed function and the area traversed by the wind [23],[24].

Wind electric system is made up of a wind turbine mounted on a tower to provide better access to stronger winds. In addition to the turbine and tower, small wind electric systems also require balance-of-system components. The use of this energy is direct (grinding, pumping) or indirect (electricity via a generator). Two applications are possible: electricity production, and wind pumping [25]. The power contained in the form of kinetic energy, P(W), the wind is expressed by:

$$\min P = \frac{1}{2} . \rho . A . V^3 \qquad (12)$$

A is the area traversed by the wind (m^2); ρ is the density of air (= 1.225kg/m3) and V is the wind speed (m / s).

In the case of solar power, the active power can be presented by this equation:

$$P_s = P_1 . E_c . [\ 1 + P_2\ (T_j + T_{jref})] \qquad (13)$$

Where: E_c is solar radiation, T_{jref} is the reference temperature of the panel of 25°C, T_j is cells junction , P_1 represent the characteristic dispersion of the panel, and P_2 is parameter which equal 0.47%C°.

VI. RESULTS AND DISCUSSIONS

In this work, we study an electrical system which presented by 5-bus system, taken from [26], with 2 generator buses and 3 load buses and the initial parameters are shown in tables 1, 2 and 3. The Gauss-Seidel and Newton-Raphson algorithms were applied to find the solution of three-phase power flow [27]. The algorithms are implemented on i3 processor 2.53 GHz, 4 GB RAM personal computer and in MATLAB R2011a platform.

TABLE 1. INITIAL PARAMETERS OF VOLTAGES AND ANGLES

Bus	Voltage Magnitude (p.u)			Angle (Degree)		
1*	1.06	1.06	1.06	0	240	120
2	1	1	1	0	240	120
3	1	1	1	0	240	120
4	1	1	1	0	240	120
5	1	1	1	0	240	120

1*: is the slack bus.

TABLE 2. INITIAL PARAMETERS OF ACTIVE AND REACTIVE POWERS (P.U)

Bus	Active power (Load) p.u			Reactive power (Load) p.u			Active power (Generation) p.u			Reactive power (Generation) p.u		
	Phase A	*Phase B*	*Phase C*	*Phase A*	*Phase B*	*Phase C*	*Phase A*	*Phase B*	*Phase C*	*Phase A*	*Phase B*	*Phase C*
1*	0	0	0	0	0	0	0	0	0	0	0	0
2	0.20	0.1739	0.23	0.10	0.0869	0.115	0.40	0.40	0.40	0	0	0
3	0.5175	0.45	0.3913	0.1725	0.15	0.1304	0	0	0	0	0	0
4	0.3478	0.46	0.40	0.0435	0.0575	0.050	0	0	0	0	0	0
5	0.60	0.5217	0.69	0.10	0.087	0.115	0	0	0	0	0	0

TABLE 3. LINE DATA PARAMETERS (P.U)

Bus		Series impedance				Shunt impedance			
Fr.	***To***	***R***	***X***	***G***	***B***	***R***	***X***	***G***	***B***
1	2	0.02	0.06	0	0.06	0.06	0.18	0	0.18
1	3	0.08	0.24	0	0.05	0.24	0.72	0	0.15
2	3	0.06	0.18	0	0.04	0.18	0.54	0	0.12
2	4	0.06	0.18	0	0.04	0.18	0.54	0	0.12
2	5	0.04	0.12	0	0.03	0.12	0.36	0	0.09
3	4	0.01	0.03	0	0.02	0.03	0.09	0	0.06
4	5	0.08	0.24	0	0.05	0.24	0.72	0	0.15

Cas 1: *Three-phase power flow with wind power injection :*

To show the impact of wind power integration in our system studied, we integrate a wind power generator as a productive bus between bus 4 and bus 5 with 0.5 p.u active power.

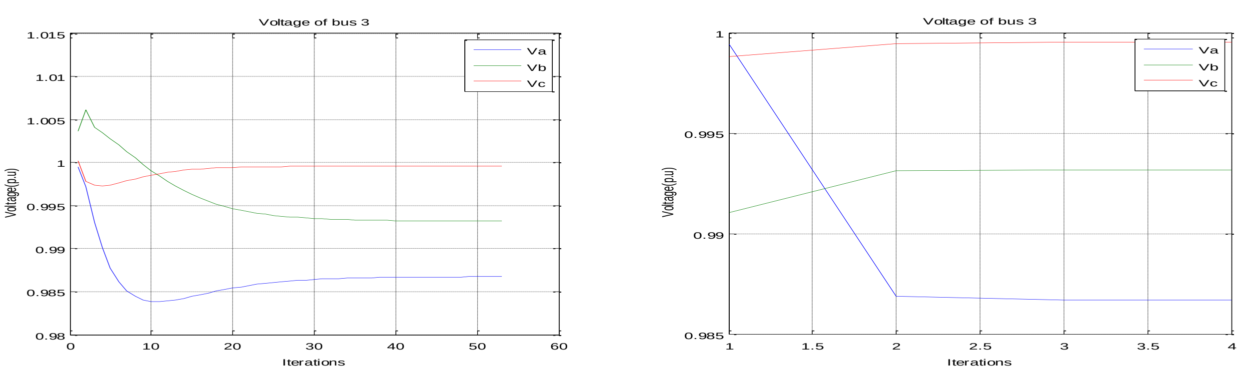
Table 4 shows the three-phase voltage results for unbalanced load. It can be seen the difference of the voltage for each phase in buses (3, 4 and 5). The wind bus is presented as productive bus, so that, there is no change in voltage for the three phases.

The figures 3, 4 and 5 present a comparison between Gauss-Seidel and Newton-Raphson results, and we can note that Newton-Raphson method gives the solution with minimal iterations.

The table 4 shows the convergence in the results between Gauss-Seidel and Newton-Raphson methods. We note that the low voltage is at bus 5 especially in the phase C (0.9644 *p.u*).

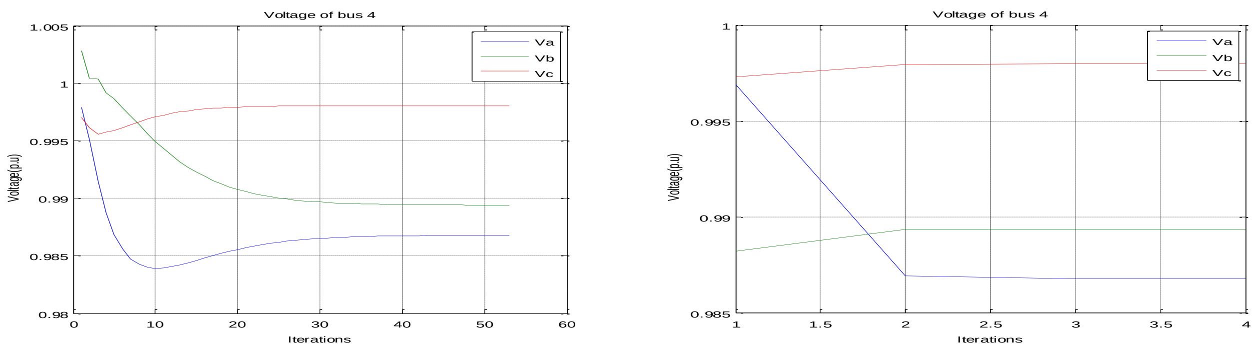
TABLE 4. COMPARISON OF THREE-PHASE VOLTAGES RESULTS (PU)

Bus	Phase A		Phase B		Phase C	
	Gauss-S	***Newton-R***	***Gauss-S***	***Newton-R***	***Gauss-S***	***Newton-R***
1*	1.06	1.06	1.06	1.06	1.06	1.06
2	1.00	1.00	1.00	1.00	1.00	1.00
3	0.9867	0.9867	0.9932	0.9932	0.9996	0.9996
4	0.9868	0.9868	0.9894	0.9894	0.9980	0.9980
5	0.9855	0.9855	0.9817	0.9817	0.9644	0.9644
(Wind) bus	1.00	1.00	1.00	1.00	1.00	1.00



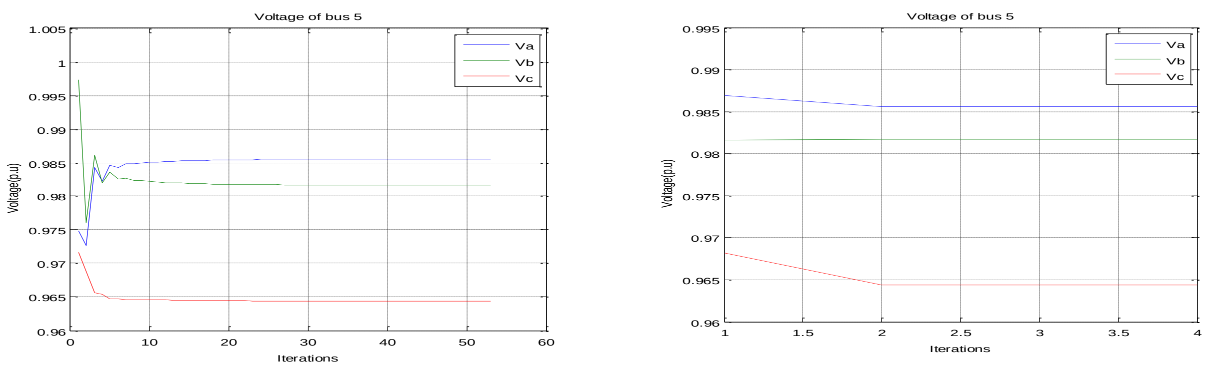
(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 3. Three-phase voltages results in bus 3.



(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 4. Three-phase voltages results in bus 4.



(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 5. Three-phase voltages results in bus 5 .

TABLE 5. COMPARISON OF THREE-PHASE ANGLES RESULTS

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	0	0	240.0	240.0	120.0	120.0
2	-0.6987	-0.6977	-120.4976	239.5019	118.9046	118.9045
3	-2.6581	-2.6563	-122.9014	237.0980	117.3883	117.3880
4	-2.4421	-2.4403	-122.8772	237.1222	117.2744	117.2741
5	-3.1566	-3.1552	-121.7712	238.2282	115.8689	115.8688
(Wind) bus	0.8612	0.8628	-118.8725	241.1267	120.0942	120.0942

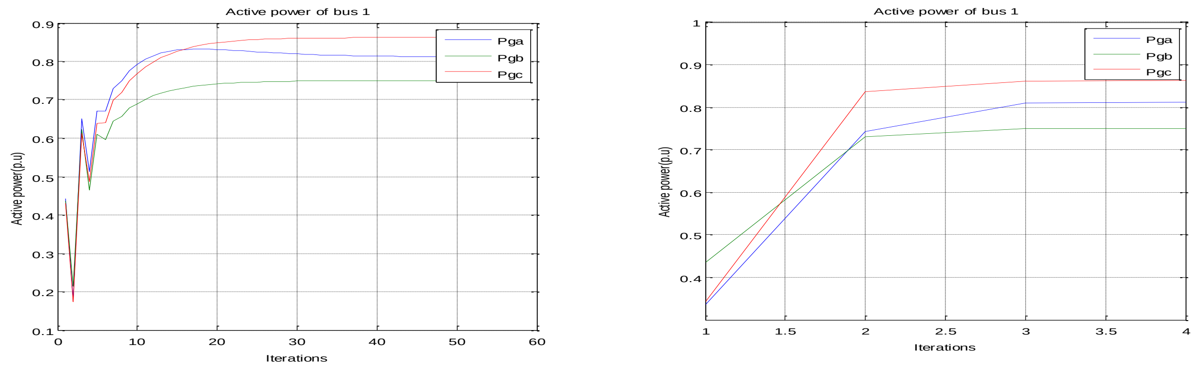
The table 5 presents the three-phase angles for each bus, and we can note that the wind bus has also three-phase angles because it is presented as a productive bus in this system which the angle of phase A is 0.8612°, of phase B is -118.8725°, and of phase C is 120.0942° using Gauss-Seidel method.

TABLE 6. COMPARISON OF THREE-PHASE ACTIVE POWER RESULTS IN SLACK BUS (P.U)

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	0.8119	0.8116	0.7504	0.7505	0.8622	0.8622

Table 6 presents the three-phase active power results in Slack bus for unbalanced load. We can see that the two algorithms give the same results with small error ($\approx$ 0.0001).

The low active power is at the phase B (Gauss-S: 0.7504 *p.u*, Newton-R: 0.7505 *p.u*). The active power of slack bus for each phase is shown in figure 6.



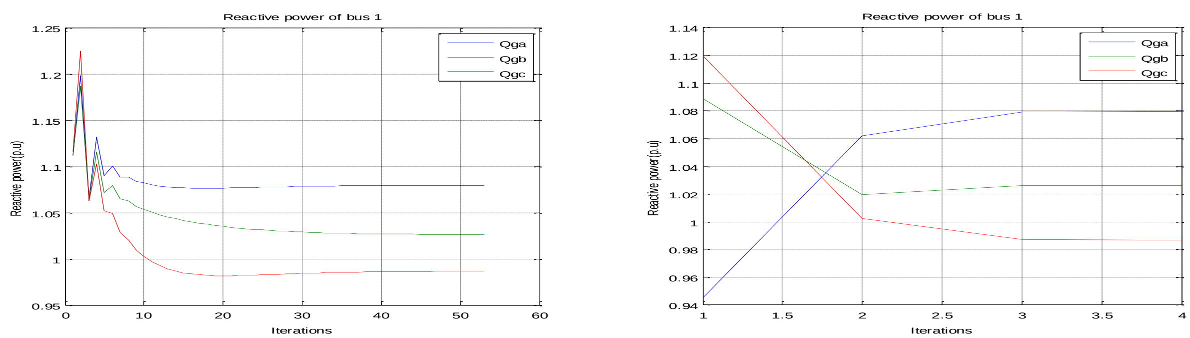
(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 6. Three-phase active power results in Slack bus.

TABLE 7. COMPARISON OF THREE-PHASE REACTIVE POWER RESULTS IN SLACK BUS AND BUS 2 (P.U)

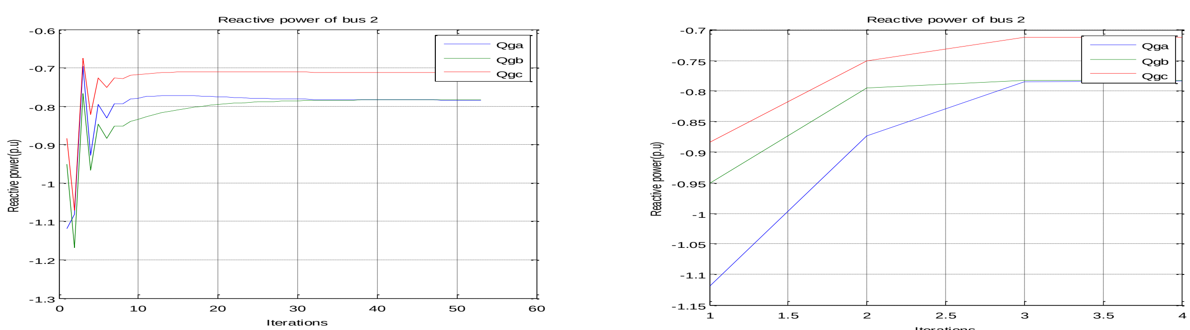
Bus	Phase A		Phase B		Phase C	
	Gauss-S	***Newton-R***	***Gauss-S***	***Newton-R***	***Gauss-S***	***Newton-R***
1*	1.0794	1.0795	1.0262	1.0261	0.9865	0.9867
2	-0.7839	-0.7840	-0.7830	-0.7829	-0.7121	-0.7121
(Wind) bus	-0.0791	-0.0791	-0.0705	-0.0705	-0.0597	-0.0597

Table 7 presents three-phase voltage results in Slack bus and bus 2 for unbalanced load. The voltage in Slack bus for each phase is shown in figure 7, and the voltage in bus 2 for each phase is shown in figure 8.



(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 7. Three-phase reactive power results in Slack bus.



(a) Gauss-Seidel **(b)** Newton-Raphson

Figure 8. Three-phase reactive power results in bus 2.

In this case test system and after the results, it can be seen that the Slack bus absorbs the reactive power (positive reactive power in the table) because its inductive effect unlike the bus 2 which injects the reactive power (negative reactive power in the table) because its capacitive effect.

After the implementation of the Gauss-Seidel and Newton-Raphson algorithms, we find that the number of iterations using Gauss-Seidel is 53 and the Losses are 0.1423 *p.u*; the number of iterations using Newton-Raphson is 4 and the losses are 0.1420 *p.u*.

Cas2: *three-phase load flow with wind and solar power injection:*

In this case, we add another renewable generator to the wind power generator; this generator is presented by solar unit which can produce 0.3 *p.u* active power [28],[29].

TABLE 8. COMPARISON OF THREE-PHASE VOLTAGES RESULTS (P.U).

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	1.06	1.06	1.06	1.06	1.06	1.06
2	1.00	1.00	1.00	1.00	1.00	1.00
3	0.9863	0.9863	0.9928	0.9928	0.9993	0.9993
4	0.9861	0.9861	0.9887	0.9887	0.9975	0.9975
5	0.9849	0.9849	0.9810	0.9810	0.9638	0.9638
(Wind+Solar) bus	1.00	1.00	1.00	1.00	1.00	1.00

TABLE 9. COMPARISON OF THREE-PHASE ANGLES RESULTS

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	0	0	240.0	240.0	120.0	120.0
2	0.0617	0.0627	-119.7347	240.2649	119.6728	119.6727
3	-1.5271	-1.5253	-121.7746	238.2251	118.5271	118.5265
4	-1.0962	-1.0944	-121.5377	238.4620	118.6261	118.6257
5	-1.3767	-1.3753	-119.9946	240.0049	117.6574	117.6572
(Wind+Solar) bus	4.6913	4.6929	-115.0588	244.9406	123.9359	123.9358

TABLE 10. COMPARISON OF THREE-PHASE ACTIVE POWER RESULTS IN SLACK BUS (P.U).

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	0.5224	0.5221	0.4600	0.4600	0.5694	0.5694

TABLE 11. COMPARISON OF THREE-PHASE REACTIVE POWER RESULTS IN SLACK BUS, BUS 2, AND (WIND+SOLAR) BUS (P.U).

Bus	Phase A		Phase B		Phase C	
	Gauss-S	*Newton-R*	*Gauss-S*	*Newton-R*	*Gauss-S*	*Newton-R*
1*	1.1726	1.1726	1.1213	1.1212	1.0797	1.0798
2	-0.7812	-0.7813	-0.7793	-0.7792	-0.7122	-0.7122
(Wind+Solar) bus	-0.1464	-0.1464	-0.1379	-0.1379	-0.1303	-0.1303

The table 8 shows the convergence in the results between Gauss-Seidel and Newton-Raphson methods. We note that the low voltage is at bus 5 especially in the phase C (0.9638 *p.u*).

The table 9 presents the three-phase angles for each bus, and we can note that the wind bus has also three-phase angles because it is presented as a productive bus in this system which the angle of phase A is 4.6929°, of phase B is 244.9406°, and of phase C is 123.9358° using Newton-Raphson method.

In table 10, it can be seen that the two algorithms give the same results with small error ($\approx$0.0001). The low active power is at the phase B (Gauss-S: 0.4600 *p.u*, Newton-R: 0.4600 *p.u*).

The table 11 presents the three-phase reactive power in Slack bus, Bus 2, and (wind+solar) bus. We cane note that the renewable power unit (wind+solar) can give more reactive power to the system, and this augmentation can help the system for electrical power management.

VII. CONCLUSION

In this paper, we try to present the three-phase power flow solution in unbalanced system using Gauss-Seidel and Newton-Raphson methods. In this work we describe the effects of unbalanced voltage and load on the electrical system and the power flow. The injection of the wind and solar power can give more equilibrium in the electrical systems which need more power. We cane note that the renewable power unit (wind+solar) can give more reactive power to the system, and this augmentation can help the system for electrical power management. The study of unbalanced electrical networks must be linked to the study of the causes of unbalanced loads, and the optimal flow of electrical energy, on the other hand. We also say that the integration of renewable energies would increase the effectiveness of meeting the needs of demand, and support solving the problem of unbalanced networks.

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