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# Power Flow Analysis of Hybrid Renewable Energy Sources in Power System Applied For IEEE Six Buses

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A R T I C L E I N F O

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A B S T R A C T

*Power flow analysis is a critical tool for power system planning for determination of the best operation and revealing the capability of the hybrid power system to be suitable and efficient for load area. The power flow equation is nonlinear and more measuring time is needed as it becomes more complicated as the number of bus system increases that prevents obtaining accurate results because of continuous changes in power demand and generation. This paper presents an analysis of power flow in hybrid power system using MATLAB software to simulate iterative algorithms such as Gauss Seidel method, Newton Raphson method and Fast Decoupled method for solving the nonlinear power flow equation are used in order to obtain the power flow solution and system losses. The analysis case is applied in steady-state condition for a test case IEEE 6 buses standard system. The paper also illustrates a comparison among power flow study methods according to line loss active power, line loss reactive power, number of iterations, maximum power mismatch and elapsed time. Based on the obtained results, Newton Raphson is found to be more reliable method and accurate because it has the lowest maximum power mismatch and the fastest convergence.*

## 1. Introduction

This paper focuses on technical evaluation of a hybrid system of power flow or load flow analysis used to obtain magnitude and phase angle of load bus voltage and also to obtain active and reactive power flow on the transmission line at the reference bus. The different branches of the microgrid network carry power from the generation area to the load area. The flow of active and reactive power assess the power system steady-state operation in order to ensure delivery of electrical power to load areas across the grid in stable, relaiable, and finance saving method. [1, 2]

The main aim of load flow calculations is to determine the steady-state operating characteristics for a given load, power, and voltage conditions, in order to use that knowledge to calculate active and reactive power flow in all branches together with power losses. [3]

All features of the digital computer such as efficiency, large memory, flexibility, and speed assist the numerical methods in determining the best approach for the load flow analysis. [3]

Power flow analysis is a comprehensive statistical approach to estimate bus voltages, phase angles, active and reactive power in different branches of the network through the power system. The load flow study was made to determine the performance of hybrid power system for power generating buses at reference bus [3] [4].

The losses in one particular case line can be calculated using MATLAB Load-flow programming also each line

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active power and reactive power flow. In addition, assess the over and under load conditions from the line flow. The steady-state power and reactive power is given by a bus in the power network is expressed in terms of algebraic nonlinear equations. [5]

To increase the size of the power system, the dimension of the power flow equation shall be increased to make it impossible for the power flow numerical mathematical approach to converge to the perfect solution. This is useful for power system engineers who seek reliable techniques to achieve precision load flow solution in a short time. [3, 5]

This research is carried out for the case of nonlinear nodal power flow equation; at different types of buses line flow and losses, in the hybrid power system that required iterative techniques to solve power flow equation. This is accomplished using numerical methods such as the Gauss Seidel method, the Newton Raphson method, and the fast Decoupled method. [6, 7]

The Gauss Seidal method deals with nodal power flow equation as matrices with non- zero diagonal elements. Features of the Gauss Seidal method are the variables expressed in rectangular coordinates. The linear convergence characteristics lead to poor convergences properties also the choice of slack bus is critical. [7, 8].

Newton Raphson method is comparatively good, and the solution leads to divergence The Features of The Newton Raphson method are that variables are expressed in polar coordinates. The quadratic convergence characteristics lead to fast convergences properties while the choice of slack bus is arbitrary. [3, 7, 8]

The Fast decoupled method is a derivative of Newton Raphson method which is designed in polar coordinates with a few assumptions to make the Jocobian matrix simple to solve that results in a fast algorithm for load flow solution. [3, 9, 10]

In this paper the power flow study made by the PSAT Matlab toolbox for hybrid power system located in IEEE six buses system then applying the three load flow methods by using MATLAB code.

## 2. Power Flow Analysis Methods

The numerical analysis is used to solve the power flow equations [3, 11]. At the beginning formation of Y bus admittance is needed by using the nodal equation in equation (1) for power system network.

$$I = Y_{Bus}V \qquad (1)$$

Where $Y_{Bus}$ is the bus admittance. Equation (2) show nodal equation for n buses.

$$I_i = \sum_{j=1}^{n} Y_{ij}V_j \quad \text{for i=1,2,3,n} \qquad (2)$$

Where $Y_{ij}$ is the bus admittance, n is the bus number.

Equations (3), (4) present the nodal equation for the case of complex power.

$$P_i + jQ_i = V_i I_i^* \qquad (3)$$

Where $P_i$ is the real power, $Q_i$ is the reactive power, $V_i$ is voltage magnitude.

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (4)$$

Where $V_i^*$ is conjugate of voltage magnitude.

Substituting for Ii of equation (4) in equation (2), the equation (5) gives nonlinear equation.

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=1}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij}V_j \quad j \neq i \quad (5)$$

Iterative methods techniques are used to solve power flow problems in equation (5)

There are various methods of power flow technique such as the Gauss Seidel method, Newton Raphson method, and Fast Decoupled method.

In the following analysis of each method is applied to solve power flow nonlinear equation

### 2.1 *Gauss-Seidel Method:*

It is an iterative method for solving nonlinear equations that starts with an initial guess at the voltage value. Replace the measured voltage value with the initial guess of voltage, and repeat until the solution converges. Equation (6) is used in this method. [7]

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^*} + \sum y_{ij}V_j^{(k)}}{\sum y_{ij}} \quad j \neq i \qquad (6)$$

Kirchhoff's current law is applied so the power is moving away from the buses, in both active and reactive power as shown in the equations (7), (8).

$$P_i^{(k+1)} = Real\left[V_i^{*(k)}\left\{\sum_{i=0}^{n} y_{ij} - \sum_{ji}^{n} V_i^{(k)}\right\}\right] \quad j \neq i \qquad (7)$$

$$Q_i^{(k+1)} = Imaginary\left[V_i^{*(k)}\left\{\sum_{i=0}^{n} y_{ij} - \sum_{ji}^{n} V_i^{(k)}\right\}\right] \quad j \neq i \qquad (8)$$

The measured voltage, active and reactive power in terms of Y bus admittance and non-diagonal elements are shown in equations (9),(10),(11).

$$V_I^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} + \sum Y_{ij} V_j^{(k)}}{Y_{ii}} \quad (9)$$

$$P_i^{(k+1)} = Real\left[V_i^{*(k)}\left\{V_i^{*(k)} Y_{ii} - \sum_{i=1, j=1}^{n} y_{ij} V_j^{(k)}\right\}\right] \quad j \neq i \quad (10)$$

$$Q_i^{(k+1)} = Imaginary\left[V_i^{*(k)}\left\{V_i^{*(k)} Y_{ii} - \sum_{i=1, j=1}^{n} y_{ij} V_j^{(k)}\right\}\right] \quad j \neq i \quad (11)$$

Where $P_i^{sch}$, $Q_i^{sch}$ is scheduled active and reactive power.

### 2.2 Newton Raphson Method:

It is an iterative method using Taylor's series expansion for solving nonlinear equations. The Newton Raphson method is the most commonly used iterative method because of its powerful convergence to other methods and the fast produced results. This approach has formula or mathematical steps that are used in order to solve the power flow problem [3][11].

The current enter power system in equation (12).

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j = \sum_{j=1}^{n} Y_{ij} V_j \angle(\theta_{ij} + \delta_j) \quad (12)$$

Where $Y_{ij}$ is the bus admittance, n is the bus number and $V_j$ is voltage magnitude.

Active and reactive powers are shown in equation (13).

$$P_i - jQ_i = V_i^* I_i \quad (13)$$

Where $V_i^*$ is conjugate of voltage magnitude at bus i,

Equation (14) is derived by comes substituting for Ii of equation (12) in equation (13).

$$P_i - jQ_i = (V_i \angle -\delta_i) * \left(\sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j\right) \quad (14)$$

Equations (15) & (16) show active power and reactive power as stated in equation (14).

$$P_i = Re\{V_i^* . I_i\} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \quad (15)$$

$$Q_i = -Im\{V_i^* . I_i\} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad (16)$$

Where $V_i$ is voltage magnitude at bus i , $V_j$ is voltage magnitude at bus j, $\delta_i$ is the phase angle , $\delta_j$ is the phase angle at bus j.

Two equations (15), (16) are solved using Taylor's series to achieve linear equation in equation (17).

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(K)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{ccc|ccc} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} & \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} & \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \\ \hline \frac{\partial Q_2^{(K)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(K)}}{\partial \delta_n} & \frac{\partial Q_2^{(K)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(K)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(K)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(K)}}{\partial \delta_n} & \frac{\partial Q_n^{(K)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(K)}}{\partial |V_n|} \end{array}\right] \begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(K)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix}$$

(17)

Equation (18) represents the Jacobian matrix obtained by the partial derivatives the linear equation of voltage magnitude and phase angle using Taylor's series to simplify the matrix.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (18)$$

$J_1$ ,$J_2$ ,$J_3$ , $J_4$ are the elements of Jacobian matrix

Equations (19), (20) shows the term ΔP and ΔQ which are the difference (the mismatch) between the specified and calculate values.

$$\Delta P_i^{(k)} = P_i^{Spec} - P_i^{(k)} \quad (19)$$

$$\Delta Q_i^{(k)} = Q_i^{Spec} - Q_i^{(k)} \quad (20)$$

Equations (21), (22) are the new estimates for bus voltage

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

$$|V_i|^{(K+1)} = |V_i|^{(K)} + \Delta |V_i|^{(K)} \quad (22)$$

### 2.3 Fast Decoupled Method:

It is an iterative method based on improving the simplification of the Newton Raphson method [7].

Fast decoupled Method depends on the simple jocabain matrix as shown in equation (23).

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & 0\\ 0 & J_4\end{bmatrix}\begin{bmatrix}\Delta\delta\\ \Delta|V|\end{bmatrix} \quad (23)$$

Separate equation (23) gives two separate matrices in equations (24), (25).

$$\Delta P = J_1\Delta\delta = \left[\frac{\partial P}{\partial\delta}\right]\Delta\delta \quad (24)$$

$$\Delta Q = J_4\Delta|V| = \left[\frac{\partial P}{\partial|V|}\right]\Delta|V| \quad (25)$$

Where $J_1, J_4$ are the elements of Jacobian matrix.

## 3. Simulation Methodology

All the developed models were tested using MATLAB software in IEEE six buses. For the power flow analysis obtained from different methods that are Gauss Sedial method, Newton Raphson method and Fast Decoupled as Respectively. Buses have three type categories, slack bus, PV generator bus, and PQ load bus .in the following introduces the differences between the bus types.

Slack bus is a reference bus to achieve the power balance case. Slack bus adjust generating unit to ensure power balance, the angle of this bus is usually set to zero [3, 7].

PV bus is a voltage control bus where the generation unit is connected. The voltage controlled by adjusting the excitation of the generator reactive power. PV bus depends on the characteristic of each generation unit [3,7].

PQ bus is a non-generator bus that the Load is connected on this bus [3, 7].

Figure 1 shows the flow chart of simulation methodology of power flow study applied to tested hybrid system.

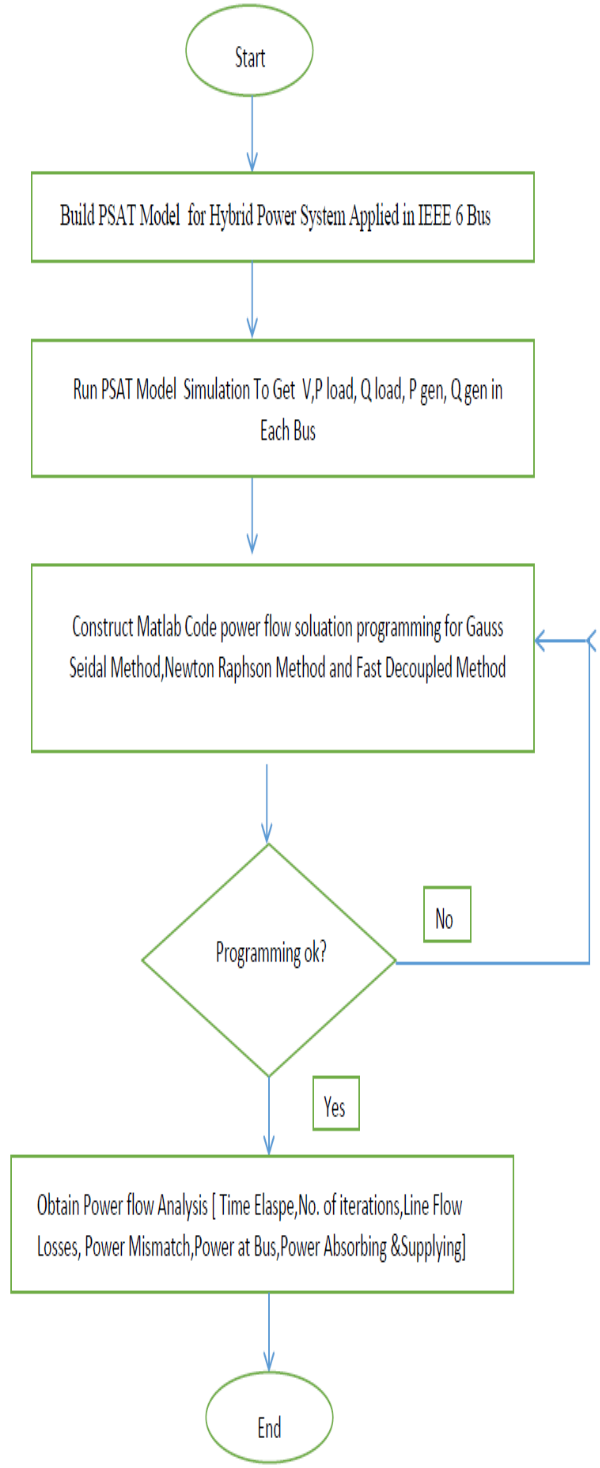


**Figure 1: flow chart of Simulation methodology**

## 4. Simulation Results

The Power flow analysis is performed using PSAT (power system analysis toolbox) software that runs under MATLAB. Power system analysis toolbox (PSAT) is used to build a hybrid system model which consists of wind turbine, photovoltaic array, Diesel generator and battery as shown in figure (2). PSAT model is used to deliver power to the load area. In PSAT simulation, the power rate is 100[MVA].

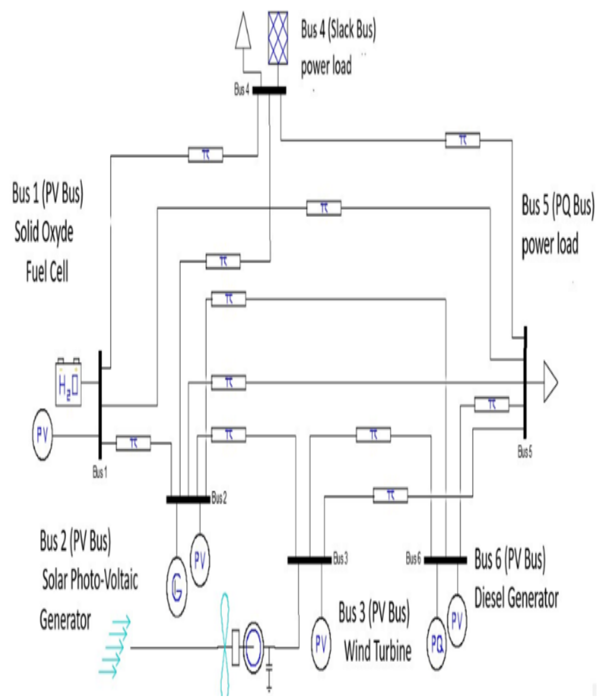


**Figure 2: Matlab Model using PSAT toolbox**

In table (1) Slack bus which is symbolized by the number (0), PV Bus is symbolized by the number (2) and PQ Bus is symbolized by the number (1).

Figure (2) shows the MATLAB model of hybrid system .the data of PSAT model simulation at each bus are as follows:
Bus 1 (PV Bus) has a Solid Oxide Fuel Cell (0.1204 MWATT, 11 KV)

Bus 2 (PV Bus) has Solar Photo-Voltaic generator (4.263 MWATT, 11 KV)

Bus 3 (PV Bus) has a Constant speed wind turbine with third order asynchronous generator and dynamic shaft (4 MVA, 11 KV)

Bus 4 (Slack Bus) has power load (3 MVA, 11 KV)

Bus 5 (PQ Bus) has power load (3 MVA, 11 KV)

Bus 6 (PV Bus) PQ generator (5.333 MVA,11 KV).The PSAT gave the initial data that help to load flow analysis.

**Table 1: Data of study hybrid power IEEE 6 buses system**

| Bus No. | Bus Type | votage | Phase angle | Qmin | Qmax |
|---|---|---|---|---|---|
| 1 | 2 | 1 | 0.07793 | -0.005 | 0.032 |
| 2 | 2 | 1 | 0.09804 | -0.015 | 0.032 |
| 3 | 2 | 1 | 0.16303 | -0.011 | 0.032 |
| 4 | 1 | 1 | 0 | 16.55 | 21.92 |
| 5 | 0 | 1.001 | 0.0004 | 0 | 0 |
| 6 | 2 | 1 | 0.18916 | -0.018 | 0.074 |

**Table 2: load and generation data of study hybrid power IEEE 6 buses system**

| Bus No. | Load Pd | Load Qd | Gen Pg | Gen Qg | Qsh |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 0.032 | -0.00558 | 0 |
| 2 | 0 | 0 | 0.032 | -0.0156 | 1.0 |
| 3 | 0 | 0 | 0.032 | 0.01111 | 1.5 |
| 4 | 22.0386 | 16.5289 | 21.9011 | 16.5419 | 0 |
| 5 | 0.024 | 0.018 | 0.036 | 0 | 0 |
| 6 | 0 | 0 | 0.07466 | -0.01839 | 0 |

In Table (2) the abbreviations are (Pd) is active power for the load, (Qd) is reactive power for the load, (Pg) is active power for the power generation unit, (Qg) is reactive power for the power generation unit, and (Qsh) is injection reactive power in each bus.

**Table 3: Resistance and Reactance of study hybrid power IEEE 6 buses system in each line.**

| Bus From | Bus To | R | X | B/2 | X tap |
|---|---|---|---|---|---|
| 1 | 2 | 0.10 | 0.20 | 0.02 | 1 |
| 1 | 4 | 0.05 | 0.20 | 0.02 | 1 |
| 1 | 5 | 0.08 | 0.30 | 0.03 | 1 |
| 2 | 3 | 0.05 | 0.25 | 0.03 | 1 |
| 2 | 4 | 0.05 | 0.10 | 0.01 | 1 |
| 2 | 5 | 0.10 | 0.30 | 0.02 | 1 |
| 2 | 6 | 0.07 | 0.20 | 0.025 | 1 |
| 3 | 5 | 0.12 | 0.26 | 0.025 | 1 |
| 3 | 6 | 0.02 | 0.10 | 0.01 | 1 |
| 4 | 5 | 0.20 | 0.40 | 0.04 | 1 |
| 5 | 6 | 0.10 | 0.30 | 0.03 | 1 |

In table (3) shows line data of IEEE six buses where R is resistance of line and X is the reactance of the line and B/2 the line loss and X tap is the transformer tap ratio.

Table (1), (2), (3) data put in MATLAB code to study power flow by three methods Gauss Seidal , Newton Raphson , Fast decoupled method in details. Simulation results shown in Tables (4), (5), (6), (7), (8), (9) which have abbreviations are (Volt. Mag.) is voltage magnitude, (MW) is active power in megawatts, (MVAR) is reactive power mega-volt-amperes, (MVA) is active power mega-volt-amperes and (Gene.) is generation unit.

*1- Simulation of Power Flow Solution*

Ybus is the bus admittance matrix of the hybrid power system as shown in equation (17).

Ybus =[

4.0063 -11.7479i -2.0000 + 4.0000i 0.0000 + 0.0000i -1.1765 + 4.7059i -0.8299 + 3.1120i 0.0000 + 0.0000i

-2.0000 + 4.0000i 9.3283 -23.1955i -0.7692 + 3.8462i -4.0000 + 8.0000i -1.0000 + 3.0000i -1.5590 + 4.4543i

0.0000 + 0.0000i -0.7692 + 3.8462i 4.1557 -16.5673i 0.0000 + 0.0000i -1.4634 + 3.1707i -1.9231 + 9.6154i

-1.1765 + 4.7059i -4.0000 + 8.0000i 0.0000 + 0.0000i 6.1765 - 14.6359i -1.0000 + 2.0000i 0.0000 + 0.0000i

-0.8299 + 3.1120i -1.0000 + 3.0000i -1.4634 + 3.1707i -1.0000 + 2.0000i 5.2933 -14.1378i -1.0000 + 3.0000i

0.0000 + 0.0000i -1.5590 + 4.4543i -1.9231 + 9.6154i 0.0000 + 0.0000i -1.0000 + 3.0000i 4.4821 -17.0047i ]

*Power Flow Solution by Gauss-Seidel Method*

**Table 4: Gauss-Seidel Method power flow solution in each Bus**

| No | Volt. Mag. | Angle Degree | Load MW | Load MVAR | Gene. MW | Gene. MVAR | Injec. MVAR |
|---|---|---|---|---|---|---|---|
| 1 | 1.000 | -0.008 | 0.000 | 0.000 | 0.032 | -9.992 | 0.000 |
| 2 | 1.000 | 0.005 | 0.000 | 0.000 | 0.032 | -14.58 | 1.000 |
| 3 | 1.000 | 0.022 | 0.000 | 0.000 | 0.032 | -11.43 | 1.500 |
| 4 | 1.000 | 0.000 | 22.03 | 16.52 | 21.76 | 7.436 | 0.000 |
| 5 | 1.009 | -0.183 | 0.024 | 0.018 | 0.036 | 0.000 | 0.000 |
| 6 | 1.000 | 0.014 | 0.000 | 0.000 | 0.075 | -9.558 | 0.000 |
| Tot | ------- | -------- | 22.06 | 16.54 | 21.97 | -38.13 | 2.500 |

*Power Flow Solution by Newton Raphson Method*

**Table *5:* Newton Raphson Method power flow soluation in each Bus**

| No | Volt. Mag. | Angle Degree | Load MW | Load MVAR | Gene. MW | Gene. MVAR | Injec. MVAR |
|---|---|---|---|---|---|---|---|
| 1 | 1.030 | -0.65 | 0.000 | 0.000 | 0.032 | 3.137 | 0.000 |
| 2 | 1.030 | -0.79 | 0.000 | 0.000 | 0.032 | -4.22 | 1.000 |
| 3 | 1.050 | -1.10 | 0.000 | 0.000 | 0.032 | 2.257 | 1.500 |
| 4 | 1.000 | 0.000 | 22.03 | 16.52 | 22.74 | -46.0 | 0.000 |
| 5 | 1.044 | -1.00 | 0.024 | 0.018 | 0.036 | 0.000 | 0.000 |
| 6 | 1.050 | -1.12 | 0.000 | 0.000 | 0.075 | 5.528 | 0.000 |
| Tot | ------- | ------- | 22.06 | 16.54 | 22.94 | -39.3 | 2.500 |

*Power Flow Solution by Fast Decoupled Method*

**Table 6: Fast Decoupled Method power flow soluation in each Bus**

| No | Volt. Mag. | Angle Degree | Load MW | Load MVAR | Gene. MW | Gene. MVAR | Injec. MVAR |
|---|---|---|---|---|---|---|---|
| 1 | 1.000 | -0.01 | 0.000 | 0.000 | 0.032 | -9.99 | 0.000 |
| 2 | 1.000 | 0.000 | 0.000 | 0.000 | 0.032 | -14.5 | 1.000 |
| 3 | 1.000 | 0.014 | 0.000 | 0.000 | 0.032 | -11.4 | 1.500 |
| 4 | 1.000 | 0.000 | 22.03 | 16.52 | 21.9 | 7.37 | 0.000 |
| 5 | 1.009 | -0.18 | 0.024 | 0.018 | 0.036 | 0.00 | 0.000 |
| 6 | 1.000 | 0.007 | 0.000 | 0.000 | 0.075 | -9.54 | 0.000 |
| Tot | ------ | ------- | 22.06 | 16.54 | 22.11 | -38.1 | 2.500 |

From the results of all power flow methods show that the total load is active power is 22.063 MW and the total load reactive power is 16.547 MVAR and Injected reactive power is 2.5 MVAR are the same in every method.
The fastest calculation method is Gauss Seidal method for 0.018134 second.
For power flow solution results, Gauss Seidal method has the total generation active power is 21.972 MW and the total generation reactive power is -38.137 MVAR. For Newton Raphson method has the total generation active power is 22.063 MW and the total generation reactive power is -39.34 MVA, For Fast decoupled method has the total generation active power is 22.111 MW and the total generation reactive power is -38.123 MVAR.

*2- Simulation of Line flows and losses*

*Line flows and losses by Gauss-Seidel Method*

**Table 7:** ***Line power flow and line power loss by Gauss Seidal Method***

| From line | To line | MW Bus | Mvar Bus | MVA Bus | Mw Line loss | MVAR Line loss |
|---|---|---|---|---|---|---|
| 1 | - | 0.032 | 3.137 | 3.137 | - | - |
| 1 | 2 | 1.038 | -2.639 | 2.836 | 0.001 | -4.241 |
| 1 | 4 | -1.880 | 13.832 | 13.959 | 0.122 | -3.635 |
| 1 | 5 | 0.874 | -8.048 | 8.096 | 0.018 | -6.380 |
| 2 | - | 0.032 | -3.226 | 3.226 | - | - |
| 2 | 1 | -1.037 | -1.602 | 1.908 | 0.001 | -4.241 |
| 2 | 3 | 0.700 | -11.556 | 11.577 | 0.033 | -6.324 |
| 2 | 4 | 0.997 | 29.439 | 29.456 | 0.439 | -1.183 |
| 2 | 5 | -0.225 | -6.684 | 6.687 | 0.020 | -4.241 |
| 2 | 6 | -0.403 | -12.802 | 12.808 | 0.068 | -5.214 |
| 3 | - | 0.032 | 3.757 | 3.757 | - | - |
| 3 | 2 | -0.667 | 5.232 | 5.275 | 0.033 | -6.324 |
| 3 | 5 | 0.346 | -0.295 | 0.455 | 0.007 | -5.464 |
| 3 | 6 | 0.353 | -1.173 | 1.225 | 0.000 | -2.205 |
| 4 | - | 0.704 | -62.566 | 62.570 | - | - |
| 4 | 1 | 2.001 | -17.467 | 17.581 | 0.122 | -3.635 |
| 4 | 2 | -0.558 | -30.623 | 30.628 | 0.439 | -1.183 |
| 4 | 5 | -0.693 | -14.492 | 14.509 | 0.221 | -7.913 |
| 5 | - | 0.012 | -0.018 | 0.022 | - | - |
| 5 | 1 | -0.855 | 1.668 | 1.875 | 0.018 | -6.380 |
| 5 | 2 | 0.245 | 2.443 | 2.455 | 0.020 | -4.241 |
| 5 | 3 | -0.339 | -5.169 | 5.180 | 0.007 | -5.464 |
| 5 | 4 | 0.914 | 6.579 | 6.642 | 0.221 | -7.913 |
| 5 | 6 | 0.049 | -5.539 | 5.539 | 0.005 | -6.560 |
| 6 | - | 0.075 | 5.528 | 5.529 | - | - |
| 6 | 2 | 0.472 | 7.588 | 7.603 | 0.068 | -5.214 |
| 6 | 3 | -0.353 | -1.032 | 1.091 | 0.000 | -2.205 |
| 6 | 5 | -0.044 | -1.021 | 1.022 | 0.005 | -6.560 |
| Total loss | | | | | 0.934 | -53.361 |

For Line flows and losses results in both methods Gauss Seidal method and Fast decoupled method had the same total line loss active power is 0.049 MW and the same total line loss reactive power is -52.130 MVAR

*Line flows and losses by Newton Raphson Method*

**Table** ***8*****: Line power flow and line power loss by Newton Raphson Method**

| From line | To line | MW Bus | MVAR Bus | MVA Bus | MW Line loss | MVAR Line loss |
|---|---|---|---|---|---|---|
| 1 | - | 0.032 | -9.991 | 9.992 | - | - |
| 1 | 2 | -0.08 | -1.957 | 1.959 | 0.000 | -4.000 |
| 1 | 4 | -0.10 | -1.975 | 1.977 | 0.000 | -4.000 |
| 1 | 5 | 0.223 | -6.052 | 6.056 | 0.007 | -6.026 |
| 2 | - | 0.032 | -13.538 | 13.538 | - | - |
| 2 | 1 | 0.087 | -2.043 | 2.045 | 0.000 | -4.000 |
| 2 | 3 | -0.09 | -2.981 | 2.982 | 0.000 | -6.000 |
| 2 | 4 | 0.000 | -1.000 | 1.000 | 0.000 | -2.000 |
| 2 | 5 | 0.101 | -5.026 | 5.027 | 0.009 | -4.009 |
| 2 | 6 | -0.05 | -2.480 | 2.481 | 0.000 | -5.000 |
| 3 | - | 0.032 | -9.921 | 9.921 | - | - |
| 3 | 2 | 0.096 | -3.019 | 3.021 | 0.000 | -6.000 |
| 3 | 5 | -0.17 | -5.870 | 5.873 | 0.014 | -5.016 |
| 3 | 6 | 0.118 | -1.024 | 1.030 | 0.000 | -2.000 |
| 4 | - | -0.13 | -9.158 | 9.159 | - | - |
| 4 | 1 | 0.102 | -2.025 | 2.028 | 0.000 | -4.000 |
| 4 | 2 | -0.00 | -1.000 | 1.000 | 0.000 | -2.000 |
| 4 | 5 | -0.23 | -6.128 | 6.132 | 0.009 | -8.000 |
| 5 | - | 0.012 | -0.018 | 0.022 | - | - |
| 5 | 1 | -0.21 | 0.026 | 0.217 | 0.007 | -6.026 |
| 5 | 2 | -0.09 | 1.017 | 1.021 | 0.009 | -4.009 |
| 5 | 3 | 0.192 | 0.854 | 0.876 | 0.014 | -5.016 |
| 5 | 4 | 0.241 | -1.926 | 1.941 | 0.009 | -8.054 |
| 5 | 6 | -0.13 | 0.012 | 0.130 | 0.009 | -6.026 |
| 6 | - | 0.075 | -9.543 | 9.543 | - | - |
| 6 | 2 | 0.057 | -2.520 | 2.520 | 0.000 | -5.000 |
| 6 | 3 | -0.11 | -0.976 | 0.983 | 0.000 | -2.000 |
| 6 | 5 | 0.139 | -6.039 | 6.040 | 0.009 | -6.026 |
| Total loss | | | | | 0.049 | -52.130 |

For Line flows and losses Results of Newton Raphson method show that the total line loss active power is 0.934 MW and the total line loss reactive power is

-53.361 MVAR.

*Line flows and losses by Fast Decoupled Method*

**Table** ***9: Line power flow and line power loss by Fast Decoupled Method***

| From line | To line | MW Bus | MVAR Bus | MVA Bus | Mw Line loss | MVAR Line loss |
|---|---|---|---|---|---|---|
| 1 | - | 0.032 | -9.991 | 9.992 | - | - |
| 1 | 2 | -0.087 | -1.957 | 1.959 | 0.000 | -4.000 |
| 1 | 4 | -0.102 | -1.975 | 1.977 | 0.000 | -4.000 |
| 1 | 5 | 0.223 | -6.052 | 6.056 | 0.007 | -6.026 |
| 2 | - | 0.032 | -13.538 | 13.538 | - | - |
| 2 | 1 | 0.087 | -2.043 | 2.045 | 0.000 | -4.000 |
| 2 | 3 | -0.096 | -2.981 | 2.982 | 0.000 | -6.000 |
| 2 | 4 | 0.000 | -1.000 | 1.000 | 0.000 | -2.000 |
| 2 | 5 | 0.101 | -5.026 | 5.027 | 0.009 | -4.009 |
| 2 | 6 | -0.057 | -2.480 | 2.481 | 0.000 | -5.000 |
| 3 | - | 0.032 | -9.921 | 9.921 | - | - |
| 3 | 2 | 0.096 | -3.019 | 3.021 | 0.000 | -6.000 |
| 3 | 5 | -0.178 | -5.870 | 5.873 | 0.014 | -5.016 |
| 3 | 6 | 0.118 | -1.024 | 1.030 | 0.000 | -2.000 |
| 4 | - | -0.135 | -9.158 | 9.159 | - | - |
| 4 | 1 | 0.102 | -2.025 | 2.028 | 0.000 | -4.000 |
| 4 | 2 | -0.000 | -1.000 | 1.000 | 0.000 | -2.000 |
| 4 | 5 | -0.232 | -6.128 | 6.132 | 0.009 | -8.000 |
| 5 | - | 0.012 | -0.018 | 0.022 | - | - |
| 5 | 1 | -0.215 | 0.026 | 0.217 | 0.007 | -6.026 |
| 5 | 2 | -0.091 | 1.017 | 1.021 | 0.009 | -4.009 |
| 5 | 3 | 0.192 | 0.854 | 0.876 | 0.014 | -5.016 |
| 5 | 4 | 0.241 | -1.926 | 1.941 | 0.009 | -8.054 |
| 5 | 6 | -0.130 | 0.012 | 0.130 | 0.009 | -6.026 |
| 6 | - | 0.075 | -9.543 | 9.543 | - | - |
| 6 | 2 | 0.057 | -2.520 | 2.520 | 0.000 | -5.000 |
| 6 | 3 | -0.118 | -0.976 | 0.983 | 0.000 | -2.000 |
| 6 | 5 | 0.139 | -6.039 | 6.040 | 0.009 | -6.026 |
| Total loss | | | | | 0.049 | -52.130 |

The difference between the Results of Newton Raphson method and the Results of Gauss Seidal method and Fast decoupled method because the Newton Raphson method is more accurate as Maximum Power Mismatch is the lowest by 0.00029234 as shown in Figure 6.

3- *Charts show a comparison between the three methods for power flow study for hybrid system*

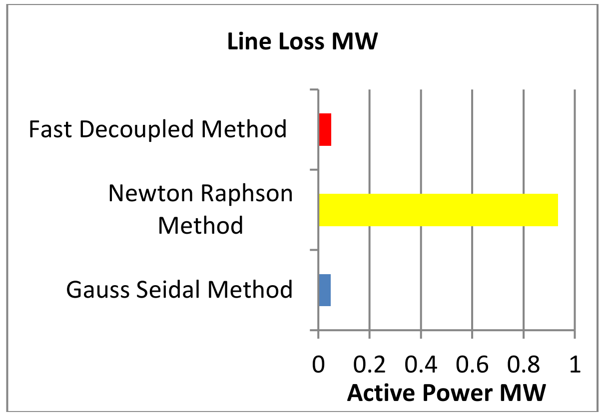


**Figure 3: Line loss of the Power Flow Study Methods**

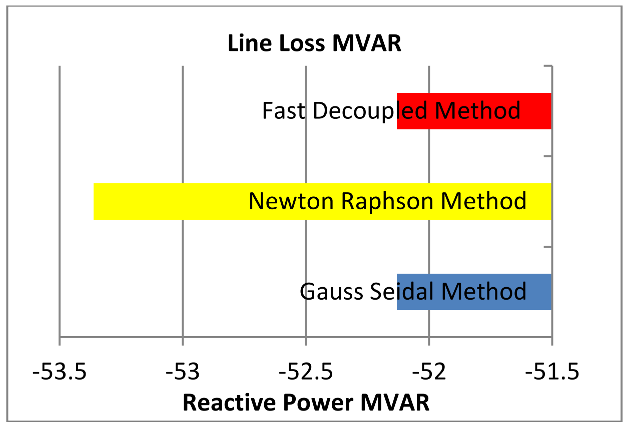


**Figure 4: Line loss of the Power Flow Study Methods**

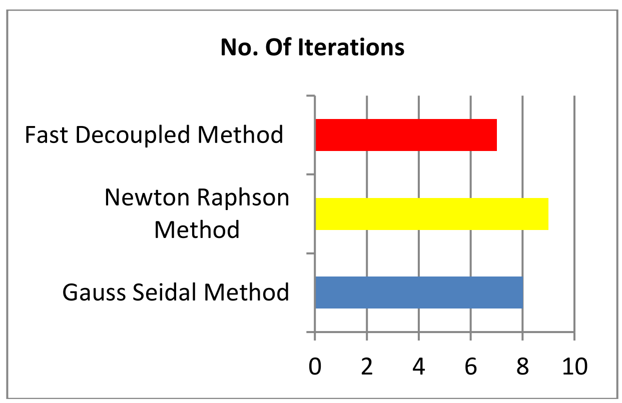


**Figure 5: Number of Iterations of the Power Flow Study Methods**

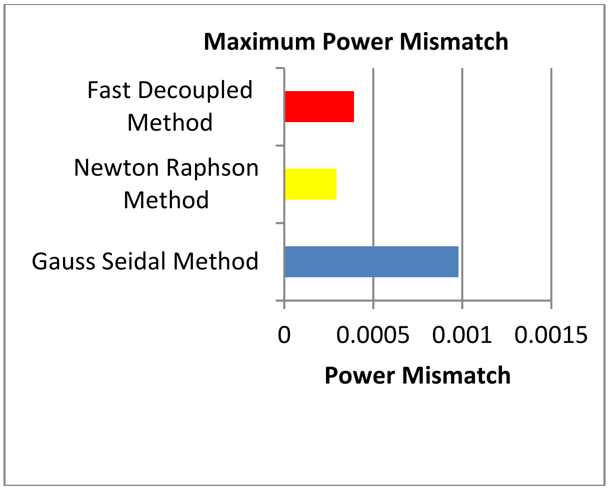


**Figure 6: Maximum Power Mismatch of the Power Flow Study Methods**

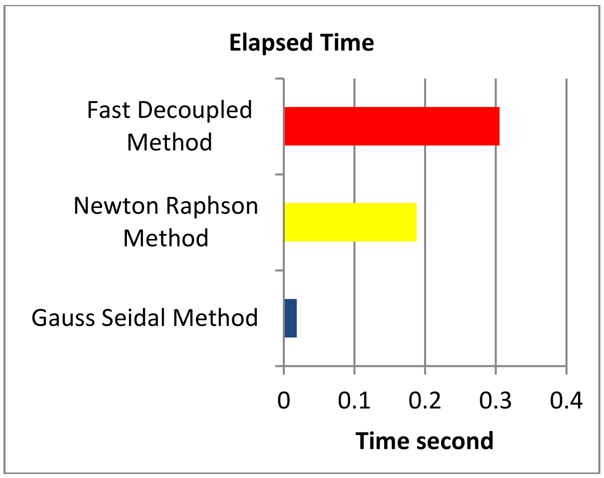


**Figure 7: Elapsed Time of the Power Flow Study Methods**

Figures 3, 4, 5, 6, 7 illustrates a comparison between different among power flow study methods.

Convergence used to determine speed at which power flow reaches its solution. The convergence is determined by plotting a chart between the maximum power mismatch and the number of iterations. Figure 8 shows the comparison of each Load Flow Study Methods.

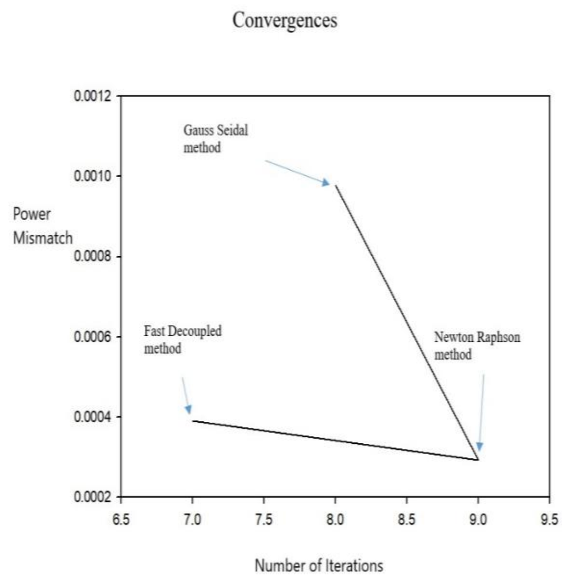


**Figure 8: Convergences of the Load Flow Study Methods**

## 5. CONCULATION

Power flow or load-flow studies are essential for both planning future power system expansion and deciding procedures to make better operating systems. The magnitude and phase angle of the voltage at each bus, as well as line loss active and reactive power the line loss in each bus are the features showing the microgrid is achieving more security and stability.

All the simulation are carried out by using Matlab and applied to IEEE 6-bus at steady state condition with the tolerance values used for simulation are 0.001 and 0.1. The time for iterations in Gauss Seidel increases as the number of buses increases. The effective and most reliable amongst the three load flow methods is the Newton Raphson method because it converges fast, and its calculations are more accurate. Gauss Seidel method has the slowest convergence.

As for line losses the following remarks are concluded:

- According to the Results of Gauss Seidal method and Fast decoupled method the highest line loss is between two buses; bus 3 which is connected to the wind turbine and bus 5 which is connected to the load power, so the hybrid system designer should increase the wind turbine capacity to compensate line losses.
- According to the Results of Newton Raphson method the highest line losses is between two buses; bus 2 which is connected to the power load and bus 4 which is connected to the Photo-voltaic generator, so the hybrid system designer should increase the

Photovoltaic generator capacity to compensate line losses.

For small hybrid power systems with less computational complexity Gauss Seidel method can be the ideal method used for power system planning. The comparison between different power flow study methods reveals that Newton Raphson method has the fastest rate of convergence among the others numerical methods. Newton Rahpson has easy calculations and is simple to execute, but as the number of buses increase, the number of iterations increases.

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