Comparative Analysis of Particle Swarm Optimization with Classical Methods for Load Flow Analysis

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***Abstract*—**Power flow analysis are one of the main aspects for planning and operation of power system and its analysis. Main aim is to apply Power Flow Analysis provide information about system variables and these variables are complex voltage V, complex power P, and consequently currents, voltages in constant state. Load always remains stationary and it is the power that flows through transmission lines, due to which load flow analysis is preferred to be called as Power Flow Analysis. Through the load flow studies obtained parameters are the voltage magnitudes and angles at each bus in the stationary state. It is a necessity that the bus voltages should remain within a specified limit. Additionally, Particle Swarm Optimization Technique (PSO) is also utilized. Particle Swarm Optimization (PSO) is a computational method that optimizes a given problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. Classical iterative methods such as Newton Raphson method, and Gauss- Siedel Method are also applied with artificial intelligence based algorithm Particle Swarm Optimization (PSO). Main aim of this research is to build algorithm to obtain optimized results. For reference comparison of PSO is made between Gauss- Siedel and Newton-Raphson and the results are also verified through Matlab Codes.

***Keywords*—**Particle Swarm Optimization, Load Flow Analysis, Newton Raphson, Gauss Siedel

I. INTRODUCTION

Power flow analysis also known as load flow analysis. The study identifies the operational state of a system for given loading. Power flow study solves the system for a set non-linear algebraic equations for the two unknown variables. To solve these parameters it is required to have fast, accurate and efficient numerical techniques[1-2]. The important information which we acquire from this analysis is

- Magnitude of voltage
- Phase angle of Voltage

The output of power flow analysis is the real and reactive power, slack bus power and line losses.

Moreover particle swarm optimization technique will be adopted to search for appropriate bus voltages and phase angles. PSO is an optimization technique in which particles change their position with time. In this system, particles fly around in multidimensional search space. Every particle in the swarm tries to look for best possible position which is linked as the best possible solution that has been so far attained by that particle. Particles have the capability to change their position by forming communication with neighboring particles by utilizing the best position encountered by itself and its neighbors. There is another best value which is known as global best and is tracked by the PSO. This is the best possible value that has been obtained by any particle in the neighborhood. Implementation of PSO is quite convenient as only few parameters requires adjustment. PSO has been fortuitously applied to solve optimization problems in the area of electric power systems such as: economic dispatch, Reactive Power Control and Power Losses Reduction function, Optimal Power Flow (OPF), Power System Controller Design, artificial neural network training, generation expansion planning, load forecasting, feeder-switch relocation problem and fuzzy system control. This technique was first introduced by Kennedy and Eberhart motivated by social behavior of swarms such as fish schools and bird flocking.

II. PROBLEM STATEMENT

Determination of voltage magnitude and phase angle obtained at each bus Determine the active and reactive power flow in each power line. Each bus has four state variables

- Voltage magnitude
- Voltage phase angle
- Real power injection
- Reactive power injection

III. EXPLANATION

Each bus has either two of the four above variables described or given. It is a usual practice to consider first bus as slack bus. The angle of voltage of this bus basically serves as a reference for all other buses and their angular voltages. Angle designated to slack bus is generally 0 which is not considered important because the difference between voltage and angles determines the calculated values of P_i and Q_i.[3] No defined mismatches are defined for the slack bus, voltage magnitude V is specified as the other known quantity along with $\delta_1 = 0°$. Therefore, there is no requirement to include the slack bus in the power-flow problem[4]. Rest of the two buses are described below

A. Regulated bus (generator bus, PV bus)

- Generation model station buses.
- Real power and magnitude of voltage are given.
- Solution: Reactive power flow and angular voltage.

B. Load Bus (P-Q bus)
- Models load center buses
- Active and reactive power injections are given (Negative values for loads).
- Solution: Magnitude of voltage and angle

IV. TECHNIQUES ADOPTED FOR SOLVING POWER FLOW PROBLEMS:

The functions Pi and Qi are non-linear functions of the state variable V_i and δ_i. Therefore iterative techniques can be utilized to solve a power flow problem. The techniques which are most commonly adopted for solving a power-flow problem are

- Newton-Raphson Technique
- Gauss-Siedel Power Technique

V.NEWTON RAPHSON TECHNIQUE

Newton Raphson is mathematically a better technique as compared to Gauss-Siedel Method due to its quadratic-convergence. Its divergence is least with ill-conditioned problems. For prominent power-systems, the Newton Raphson method is found to be

- More Efficient
- More Practical

The number of iterations required to obtain a solution is independent of the system size, but more practical evaluations are required at each iteration. [5]
The power flow equation is given in polar form.

$$I_i=\sum |Y_{ij}||V_j| < \theta_{ij} + \delta_j \qquad (1)$$

where Y_{ij} is the admittance of the matrix in between the buses i and j and V_j is the voltage at bus θ_{ij} shows the angular voltage in between buses i and j and δ_j is the phase angle at bus j. For the typical bus of the power-system the current entering at bus i is specified by

$$I_i= \sum_{j=1}^{n} |Y_{ij}|V_j| \qquad (2)$$

The above equation includes j at bus i. Expressing the equation in polar form.

$$I_i=\sum |Y_{ij}||V_j| < \theta_{ij} + \delta_j \qquad (3)$$

The complex power will be expressed as

$$P_i-jQ_i=|V_i|<-\delta_i\sum_{j=1}^{n} |Y_{ij}|\ |V_j| < \theta_{ij} + \delta_j \qquad (4)$$

In the above equation P_i is the active power of the system at bus i and Q_i is the reactive power at bus i and j is the vector operator which shifts the vector by an θ of 90 °.

A. Newton Raphson Steps

The process for power flow solution by Newton Raphson method involves the following steps
- Set Flat Start:
- Calculate power mismatch:
- Form the Jacobian Matrix:
- Find the Matrix Solution (choose a or b):
- Find new estimates for the bus voltage magnitudes and angles
- Repeat the process until the mismatch (residuals) are less than the specified accuracy.[6-7]

$$| P_i\ k)| \leq \epsilon \qquad (5)$$
$$| Q_i\ (k)| \leq \epsilon \qquad (6)$$

ϵ this symbol stands for epsilon not which defines specified accuracy of the system

B. Merits of Newton Raphson Technique:

This method is superior to Gauss Siedel and fast decoupled power flow solution due to following advantages and reasons
- The solution is reached within minimum iterations which are usually not more than 3.
- 3 iterations are required to obtain the solution. In case of Gauss-Siedel Method minimum iterations should be 7 and with fast decoupled method minimum iterations should be 14.
- The accuracy of this method is greater with a power mismatch of 2.5×10^{-4}.[8]

C. Demerits of Newton Raphson Method

The disadvantages of this method are summarized below.
- It is a very lengthy method and requires large computer memory
- Computer Programming is difficult

V. GAUSS SIEDEL TECHNIQUE:

In the power flow study it is important to solve the set of non-linearized equations for two unspecified variables at each node. In the Gauss-Siedel method following equation is used to solve for V_i, and the iterative process becomes

$$V_i^{(k+1)} = \frac{\frac{P_i^{sch} - jQ_i^{sch}}{V_i^{*(k)}} + \sum y_{ij} V_j^{(k)}}{\sum y_{ij}} \quad j\neq i \qquad (7)$$

Where y_{ij} shown in lowercase letters is the actual admittance in per unit. P_i^{sch} and Q_i^{sch} are the net real and reactive power expressed in per unit.

A. Gauss Siedel Method:

In case of Gauss-Siedel method, an initial estimate of 1+j0 for unspecified voltage is satisfactory and the converged solution co relates with the actual operating states.
Real And Imaginary Components of Voltages;

$$(e_i^{(k+1)})^2 + (f_i^{(k+1)})^2 = |V_i|^2 \qquad (8)$$
$$(e_i^{(k+1)})^2 = |V_i|^2 - (f_i^{(k+1)})^2 \qquad (9)$$

where $e_i^{(k+1)}$ and $(f_i^{(k+1)})$ are real and imaginary parts of the voltage $V_i^{(k+1)}$ of the iterative sequence.
Rate of Convergence:

The rate of convergence is increased by applying an **acceleration factor** to the approximate solution obtained from each iteration.

$$V_i^{(k+1)} = V_i^{(k)} + \alpha(V_{ical}^{(k)} - V_i^{(k)}) \qquad (10)$$

α is the acceleration factor. Its value depend upon the system. The range of 1.3 or 1.7 is satisfactory. It has the advantage that it can improve the rate of convergence if $\alpha > 1$

B. Application of Gauss- Siedel Power Flow:

The consumer wants to know the voltage profile
The nodal voltages for a given load and generation schedule
Types of Network Buses:
• Load Bus:
Known real (P) and reactive (Q) power injections
•Generator Bus:
Known real (P) power injection and the voltage magnitude (V)
•Slack Bus:
Known voltage magnitude (V) and voltage angle (δ)
Must have one generator as the slack bus.
Takes up the power slack due to losses in the network. [9]

C. Solution by Gauss-Siedel

System Characteristics:
• Since both components (V &δ) are specified for the slack bus,
• There are 2(n-1) variables which must be solved iteratively.
• For load buses, the real and reactive powers are known: scheduled
• The voltage magnitude and angle must be estimated
• In per unit, the nominal voltage magnitude is 1pu.
• The angles are generally contiguous, so an initial value of 0 degrees is appropriate.

VI. PARTICLE SWARM OPTIMIZATION (PSO):

In this technique the particles positions can assume continuous values within the limits specified in the input data. The rule function parameters will be minimized in the PSO algorithm which is defined as fitness. The fitness is defined as the sum of the buses apparent power. Each particle has a local fitness, value obtained by its local best. The global fitness is the fitness related to the best global of all the particles. The global fitness is fitness related to the best global of all particles. The current fitness is the fitness obtained by a particle at a given iteration. [10] The first step of algorithm is to generate the initial values to particle position. Velocities, local best parameter and global best parameter. The angle receives random initial value with in specified boundary. Before initialization of the module value of each particle, the bus type needs to be verified and related in the equation. In the case of a P-Q bus, the voltage module receives a random value within the specified boundary, for a PV bus, the voltage module receives the related value specified in the input data. The initial velocities are null. The local best parameters receive the particles positions values and the global best parameters receive the first particle value, arbitrarily. The grades are initialized with high values in order to be minimized later. Having that done, the iterations are initialized. The following process is accomplished to each particle of the swarm.

A. Description of PSO:

The particle swarm optimization algorithm is multi-agent parallel search technique which maintains a swarm of particles and each particle represents a potential solution in the swarm. Each particle will keep a track of its coordinates in the given space which are linked with the best solution (fitness) that it has reached so far. This optimum value of particle is called pbest (local best).Another best value which is obtained by PSO will actually be the best position that is obtained by any particle in the whole swarm and that value is called gbest (global best).[11]

$$v_i^{k+1} = W * v_i^{k} + c_1 * r_1(Gbest_i^{k} - X_i^{k}) + c_2 * r_2(Pbest_i^{k} - X_i^{k}) \qquad (11)$$

All the symbols are defined in detail in the next page

Fig1. Diagram of PSO:

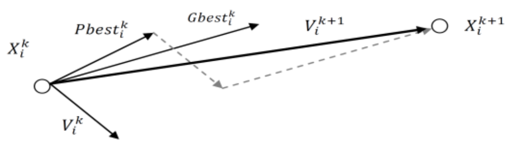

Fig.1 Particle Swarm Optimization Flow Diagram

B. Parameters of PSO:

There are some parameters which are of paramount importance in determining efficiency of PSO while others have belittle effect. The important parameters of PSO are number of iterations, acceleration coefficients, swarm size, velocity components, acceleration coefficients and inertia weight.[12]

i) Swarm size

Swarm size is the number of particles n in swarm. A big swarm provides larger space to cover per iteration. A large number of particles will minimize the number of iteration needed to obtain good optimization result. In comparison, large amount of particles per iteration enhances the computation complexity per iteration. Therefore most of the PSO implementations use an interval of 20 to 60 for swarm size

ii) Iteration number

The number of iterations is also necessary to obtain a good result in optimization. Too low number of iterations may stop the search process prematurely, while too large iterations have the consequences of adding unnecessary computational complexity and more time requirement
[13-15]

iii) Velocity components

The velocity components are very important for updating particle velocity. There are three terms of particle's velocity

1. The term v_i^k is called inertia component that provides the previous flight direction. This component represents as moment which prevents to drastically change the direction of the particles and to direct towards the current direction.

2. The term $c_1 * r_1 (Gbest_i^k - X_i^k)$ is called social component which measures the performance of particles i with respect to their neighbors. The social component's effect is that each particle flies toward the best position found by the particles in neighborhood.

3. The term $c_2 * r_2 (Pbest_i^k - X_i^k)$ is called cognitive component which measures the performance of particles i relative to past performance [16-17].

iv). Acceleration Coefficient:

The acceleration coefficient c_1 and c_2 with random values r_1 and r_2 maintain the influence of social and cognitive components of particles velocity. The c_1 shows how much confidence a particle has in its neighbors, while c_2 shows how much confident a particle has in itself. There are some properties of c_1 and c_2.

1. When $c_1 = c_2 = 0$ then all particles continue to fly at their current speed until they hit the search space's boundary and velocity updated equation is calculated as $v_i^{k+1} = v_i^k$

2. When $c_1 > 0$ and $c_2 = 0$ then all particles will be attracted to single point G best in the entire swarm and updated velocity becomes $v_i^{k+1} = W * v_i^k + c_1 * r_1 (Gbest_i^k - X_i^k)$

3. When $c_2 > 0$ and $c_1 = 0$ then all particles are independent and updated velocity becomes $v_i^{k+1} = W * v_i^k + c_2 * r_2 (Pbest_i^k - X_i^k)$

4. When $c_1 = c_2$ all particles are attracted towards the average of $Pbest_i^k$ and $Gbest_i^k$.[18]

When $c_1 \gg c_2$ then all particles are largely influenced by global best position, which cause particles to run prematurely to optima. In contrast, in scenario when $c_2 \gg c_1$, each particle is strongly influenced by personal best position, which results in
excessive wandering.

v) Inertia weight**:**

Inertia weight in PSO plays an important role because of its control on particle speed. Hence, a suitable selection of it is important. Its value is from 0.1 to 0.9

$$w = rand(1) \qquad (12)$$

where w stands for inertia weight

C. Steps of the PSO Algorithm

- Assign the PSO algorithm's parameters.
- Initialize the particle's position as bus voltage.
  - Real part of bus voltage is between 0.9 to 1pu population size and bus voltage.
  - Imaginary part of the bus voltage are generated between -0.1 to 0 pu.
- Set iterations.
- Initialize local best particle as bus voltage.
- Calculate objective function.
- Calculate Fitness Function.
- Check whether the particle is fit or not.
- Go to global particles and check whether it is suitable as compared to the local particle.
- Update velocities and particle positions.
- Go to next particle.
- After all particles go to next iteration. End finish this process till last iteration

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Fig. 2 Flow Chart of Particle Swarm Optimization Technique:

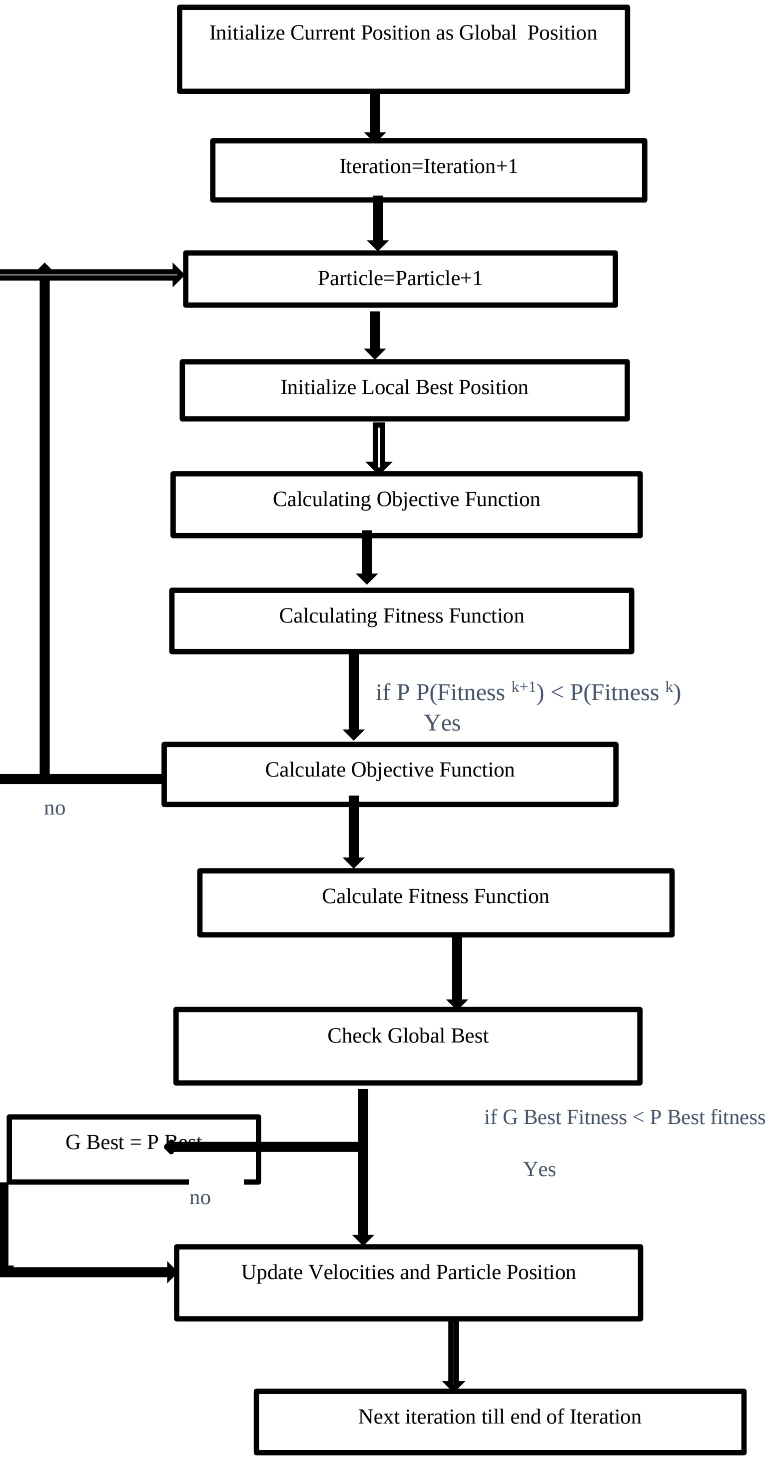

Fig.2 Flow Chart of Particle Swarm Optimization Technique

Fig 3. Single Line Diagram For Load Flow Analysis:

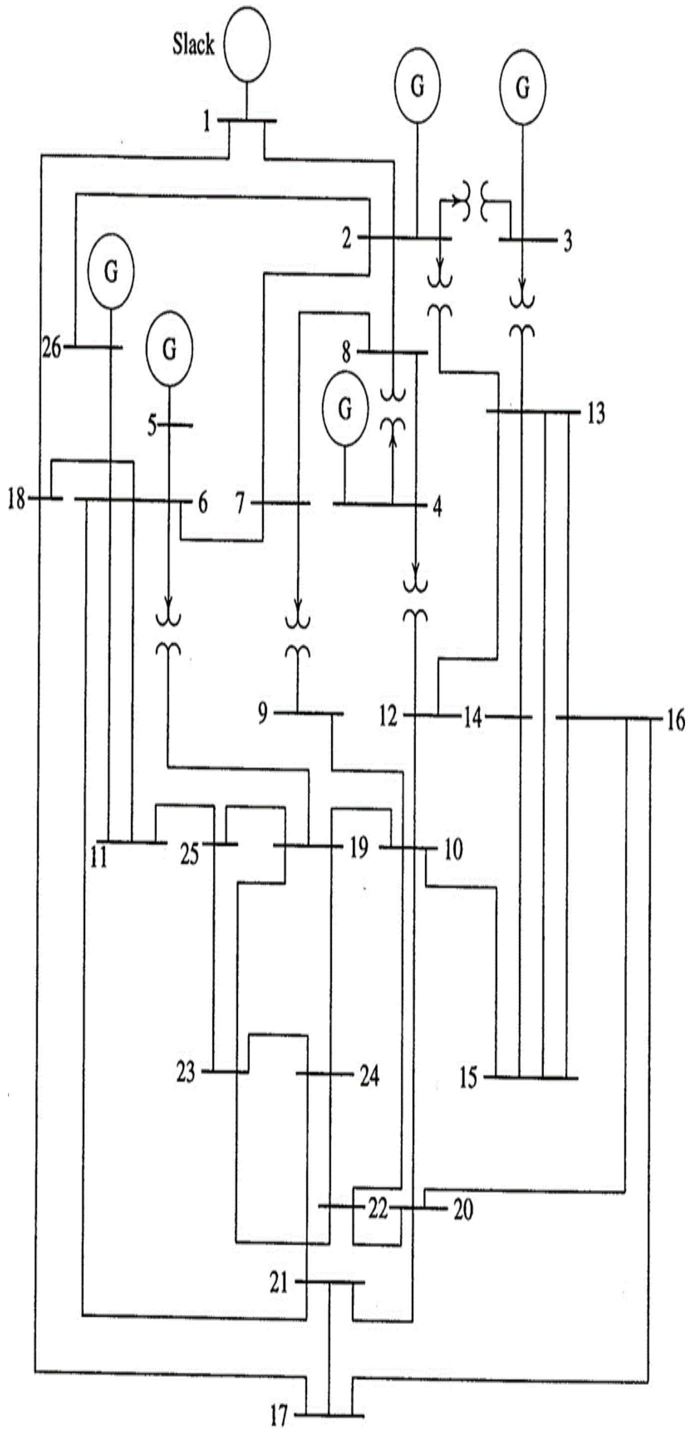

Fig.3 Single Line Diagram for Load Flow Analysis

A. Single Line Diagram and Computation of Load Flow Analysis

It is 26 bus system Single Line diagram. Voltages and phase angles on each bus are calculated using two techniques of power flow which are Gauss Siedel and Newton Raphson. SLD was simulated on Software which is Power World Simulator (PWS) and also the bus voltages were verified and phase angles by using Matlab Code. 45 iterations were done for Gauss- Siedel and 5 iterations for Newton-Raphson to achieve accuracy[19]. The results of simulations and Matlab code matched and accuracy level was also attained.

Fig 4. Simulation of Single Line Diagram In PWS (Power World Simulator):

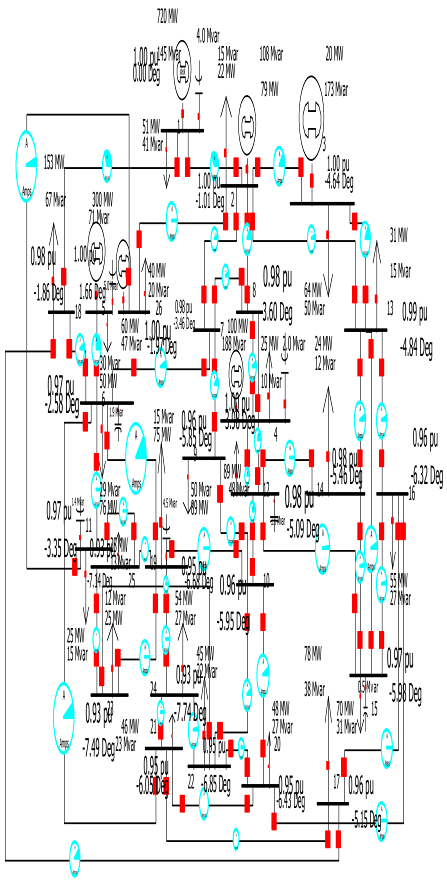

Fig.4 Simulation of Single Line Diagram in Power World Simulator

VII. Matlab Results:

Matlab results obtained after implementation of Particle Swarm optimization and comparative analysis between Gauss-Siedel and Newton Raphson technique are shown below:

A. Particle Swarm Optimization Results

Table below depicts results obtained from Particle Swarm Optimization technique

Tab.1 PSO Code Results

Bus No	Bus Voltages
1)	1<0
2)	0.9999<-0.7735
3)	1<-5.8137
4)	0.9999<-9.2767
5)	1<-4.318
6)	0.96362<-4.613
7)	0.97707<-4.69
8)	0.98366<-1.057
9)	0.936<-9.8668
10)	0.9613<-10.882
11)	0.9035<-2.416
12)	0.95086<-6.582
13)	0.98448<-7.57
14)	0.97204<-5.0343
15)	0.9830<-16.183
16	0.96611<-14.102
17	0.9695<-10.729
18	0.984<-1.8577
19	0.9921<-7.6163
20	0.9896<-9.15110
21	0.9444<-4.1227
22	0.94445<-8.813
23	0.92476<-3.335
24	0.9502<-9.675
25	0.9898<-5.35
26	0.9999<-6.1712

XI. Comparative Analysis of Results Between Gauss Siedel and Newton Raphson Power Flow Techniques

A. Gauss-Siedel 45 Iteration Result:

Table below shows the results obtained from Gauss Siedel Analysis

Tab 2 Gauss Siedel Iteration Results

Bus No	Voltages
1	1<0
2	1<-0.55575
3	0.9999<-1.90266
4	1<-2.5848
5	0.9999<-1.0428
6	0.9769<-2.317
7	0.986<-1.16226
8	0.9886<-1.6693
9	0.9712<-3.47
10	0.96966<-3.9146
11	0.96527<-4.8612
12	0.98463<-2.8699
13	0.99448<-2.27
14	0.98963<-2.623
15	0.98454<-2.9926
16	0.97743<-3.5134
17	0.958826<-3.905
18	0.98887<-1.0777
19	0.9276<-6.804
20	0.9620<-4.3818
21	0.9395<-5.8829
22	0.94876<-5.243
23	0.88612<-9.7588
24	0.91277<7.5797
25	0.79314<-13.384
26	0.9999<-6.206

B. Newton Raphson 5th Iteration Result:

Table below shows the results obtained from Newton Raphson Analysis

Tab. 3 Newton Raphson Iteration Results

Bus No	Voltages
1	1<0
2	0.99998<-1.35
3	0.9999<-3.853
4	1<-5.6353
5	1<-3.537
6	0.9791<-4.6397
7	0.98004<-3.609
8	0.9858<-4.7419
9	0.96855<-6.7713
10	0.96986<-6.8216
11	0.97763<-7.4405
12	0.9835<-5.78305
13	0.99434<-4.262
14	0.98928<-4.8766
15	0.98283<-5.3184
16	0.97831<-5.8020
17	0.96424<-5.248
18	0.99056<-1.938
19	0.93267<-9.3421
20	0.963<-7.158
21	0.9428<-8.318
22	0.9509<-8.107
23	0.89129<-12.4005
24	0.91677<-10.228
25	0.8024<-15.918
26	0.9999<-8.493

X. Conclusion

Matlab code did 45 iterations for Gauss Siedel to obtain the results. Most desired optimum results should be close to 1. In Gauss- Siedel Results magnitudes of voltages were 0.8 on some buses. While in Newton- Raphson code did 5 iterations and these results were more precise than Gauss- Siedel. In PSO number of particles are hundred and we obtained the desired results in just 20 iterations and the results were approximately near to one and also comparable with Newton-Raphson. PSO is preferable as compared to Newton-Raphson because in very less- time it give results and it does not require large memory as for Newton Raphson. It takes less run-time [20]. It just involves 2 loops. One for iterations and one for particle while for Newton- Raphson each iteration has 4 loops and each loop runs for 25 times to make jacobian matrix. And one extra loop for mismatch calculation. One extra loop is used to calculate fitness function. And we can get suitable answers by running the program twice or thrice so that a best particle would be picked up but in PSO results are somewhat different every time because of the random samples but every time the values are acceptable because they are close to expected results obtained from Newton-Raphson. As our objective was to get results in less time. So by setting 20 iterations in PSO case optimum results were obtained. This scheme has been duly and successfully implemented. So it has been shown that mathematical conversion of heuristic technique can be easily translated to the Load Flow Problem. When this technique was compared to Newton- Raphson the results were although similar to each other and the results obtained by this technique were more appropriate.

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