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A Study of Load Flow Analysis Using Particle Swarm Optimization

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ABSTRACT
Load flow study is done to determine the power system static states (voltage magnitudes and voltage angles) at each bus to find the steady state working condition of a power system. It is important and most frequently carried out study performed by power utilities for power system planning, optimization, operation and control. In this project a Particle Swarm Optimization (PSO) is proposed to solve load flow problem under different loading/ contingency conditions for computing bus voltage magnitudes and angles of the power system. With the increasing size of power system, this is very necessary to finding the solution to maximize the utilization of existing system and to provide adequate voltage support. For this the good voltage profile is must. STATCOM, if placed optimally can be effective in providing good voltage profile and in turn resulting into stable power system. The study presents a hybrid particle swarm based methodology for solving load flow in electrical power systems. Load flow is an electrical engineering well-known problem which provides the system status in the steady-state and is required by several functions performed in power system control centers.

Keywords : FACTs Devices, Load Flow Study, Particle Swarm Optimization, Power System, Statcom

I. INTRODUCTION

Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Conventional techniques for solving the load flow problem are iterative using the Gauss-Seidel methods Load flow analysis forms an essential prerequisite for power system studies. In this analysis, iterative techniques are used due to there no known analytical method to solve the problem. This resulted nonlinear set of equations or called power flow equations are generated. To finish this analysis there are methods of mathematical calculations which consist plenty of step depend on the size of system. This process is difficult and takes much time to perform by hand. Power flow analysis is required for many other analyses such as transient stability, optimal power flow and contingency studies. The principal information of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. Power flow analysis is an importance tool involving numerical analysis applied to a power system.

Power flow analysis software develops by the author use MATLAB software. MATLAB as a high-performance language for technical computation integrates calculation, visualization and programming in an easy-to-use environment, thus becomes a standard instructional tool for introductory and advanced courses in mathematics, engineering and science in the university environment. Most of the students are familiar with it.

Particle Swarm Optimization is population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking. The algorithm has been found to be robust for solving problems featuring non-linearity and non-differentiability, multiple optima and high dimensionality through adaptation and provides high quality solutions with stable convergence.

PSO is an extremely simple algorithm that seems to be effective for optimizing a wide range of functions. PSO is applied for solving various optimization problems in electrical engineering.

II. LOAD FLOW ANALYSIS

Load flow problem are iterative, using the Newton-Raphson or the Gauss-Seidel methods. The Newton-Raphson method, or Newton Method, is a powerful technique for solving equations numerically. Like so much of the deferential calculus, it is based on the simple idea of linear approximation. The Newton Method, Recently, however, there has been much interest in the application of stochastic search methods, such as Genetic Algorithms or particle swarm optimization technique to solving power system problems.

The objective of this kind of problem is to obtain the system buses voltages – module and angle – in order

to determine later the power adjustments in the generation buses and the power flow in the system lines. The power flow study provides the system status in the steady-state, i.e., its parameters do not vary with the time variation. The importance of the power flow calculation is also the obtaining of an optimal point of operation, regarding to quality and economy. Once the steady-state of the system is known, it is possible to estimate the amount of power generation necessary to supply the power demand plus the power losses. In the system lines, moreover the voltage levels must be kept within the boundaries and overloaded operations, besides the operations in the stability limit must be avoided.
Load flow studies are based on a nodal voltage analysis of a power system.

The conventional load flow methods used for power systems are as follows:-
1. Gauss-Seidel method with admittance matrix (YGS)
2. Gauss-Seidel method with impedance matrix (ZGS)
3. Newton-Raphson (NR) method
4. Decoupled Newton-Raphson (DNR)
5. Fast Decoupled Newton-Raphson (FDNR)

The most important load flow methods, which can be applied to new distribution networks, are categorized to six groups: NR based methods, Gauss- Seidel based methods, super position based methods, compensated backward/forward sweep methods, optimization based methods and artificial intelligence based methods.

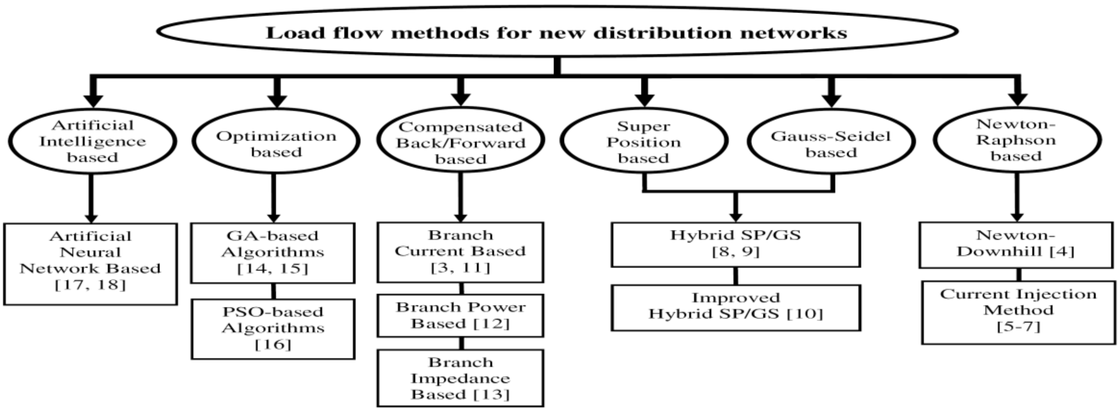

Fig.(a)

II.I Modeling of STATCOM

The static compensator (STATCOM) is one of the most prominent members in the family of FACTS devices, which is connected in shunt to the transmission grid. It is usually used to control transmission voltage by reactive power compensation. In ideal steady state analysis, it can be assumed that active power exchange between the AC system and the STATCOM can be neglected, and only the reactive power can exchanged between them.

The presence of FACTS controllers is accommodated and accounted for by adding new equations to the set of the power flow equations and modifying some of the existing power flow equations as needed. The Jacobian equation is modified accordingly. The STATCOM is modeled as a controllable voltage source (Ep) in series with impedance.

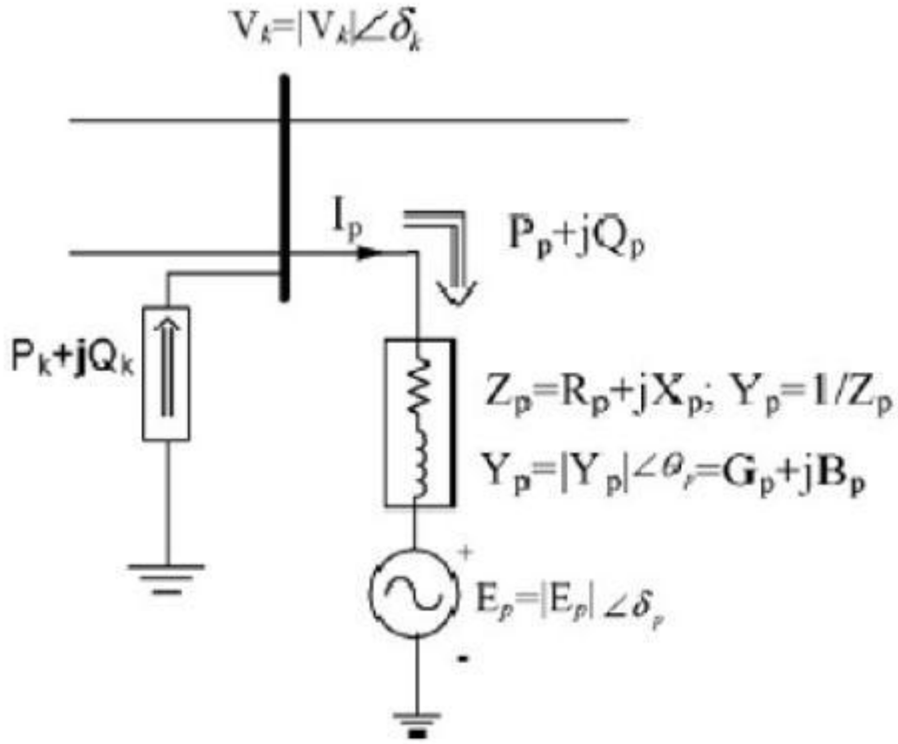

Fig. (b) Steady State model of STATCOM

.With the addition of STATCOM connected at bus k the power flow equations of the system remain same as the power flow equation of the system without STATCOM for all buses.

$$P_p = G|V_k^2| - |V_k||E_p||Y_p|\cos(\delta_k - \delta_p - \theta p) \quad \text{(i)}$$

$$Q_p = B|V_k^2| - |V_k||E_p||Y_p|\sin(\delta_k - \delta_p - \theta p) \quad \text{(ii)}$$

Where $|E_p|$, δ_p, $|Y_p|$ and θ_p are define in the earlier figure.

Addition of STATCOM introduces two new variables ($|E_p|$ and δ_p). Thus one more equation needed to solve the power flow problem. This equation is found using the fact that power consumed by the source E_p (called P_{Ep}) must be zero in steady state and is given by eq.(2.35)

$$P_{Ep} = \mathrm{Re}\,al[E_p I_p^*] = -(G_p)|E_p^2| + |E_p||V_k||Y_p|\cos(\delta_k - \delta_p - \theta p) = 0 \quad \text{(iii)}$$

A row and a column related to P_{Ep} and δ_p are added to Jacobian matrix.. The modified Jacobian elements are as given below:

$$\frac{\partial P_{Ep}}{\partial \delta_k} = +|E_p||V_k||Y_p|\sin(\delta_k - \delta_p - \theta p) \quad \text{(iv)}$$

$$\frac{\partial P_{Ep}}{\partial \delta_k} = -2G_{p|}|E_p| + |V_k||Y_p|\cos(\delta_k - \delta_p - \theta p) \quad \text{(v)}$$

$$\frac{\partial P_{Ep}}{\partial \delta_p} = -|E_p||V_k||Y_p|\sin(\delta_k - \delta_p - \theta p) \quad \text{(vi)}$$

And the following terms are found from equations. (3.33) and (3.34):

$$\frac{\partial P_p}{\partial \delta_p} = -|V_k||E_p||Y_p|\sin(\delta_k - \delta_p - \theta p) \quad \text{(vii)}$$

$$\frac{\partial P_p}{\partial \delta_k} = -\frac{\partial P_p}{\partial \delta_p} \quad \text{(viii)}$$

$$\frac{\partial P_p}{\partial E_p} = |V_k||Y_p|\cos(\delta_k - \delta_p - \theta p) \quad \text{(ix)}$$

$$\frac{\partial Q_p}{\partial E_k} = -|V_k||Y_p|\sin(\delta_k - \delta_p - \theta p) \quad \text{(x)}$$

The steps to incorporate STATCOM are as follows:
Step 1: Read the system database.
Step 2: The system buses, at which STATCOM are assumed to be placed are made PV buses.
Step 3: The specified real power and reactive power at which STATCOM is placed is calculated using eq. (iii) and eq. (iv).
Step 4: On the buses with STATCOM, the specified voltage is set according to the desired voltage and upper and lower limits of reactive power are set according to the STATCOM ratings.
Step 5: Modify Jacobian elements by using eq.(vii) to eq.(x).
Step 6: Carry Newton-Raphson load flow with modified Jacobian elements.
Step 7: Voltages and angles of system and STATCOM are updated.

III. PARTICLE SWARM OPTIMIZATION (PSO)

This chapter presents the basic theory of the PSO method and introduces the concept of a new enhanced particle swarm optimizer that is proposed in this research to improve the performance of the canonical PSO formulation.

The theoretical background includes a detailed description of the PSO in the real number space with its corresponding mathematical equations, different configurations of the swarm (including the gbest and lbest topologies), and an explanation of the PSO parameters.

Additionally, the integer PSO variant that is used when some (or all) the decision variables are integer numbers is fully described together with the theory of the proposed enhanced particle swarm optimizer.

Topology of the swarm

Particles have been studied in two general types of neighborhoods: (i) global best (gbest) and (ii) local best (pbest). In the gbest neighborhood the particles are attracted to the best solution found by any member of the swarm. This represents a fully connected network where each particle has access to the information of all other members in the community. However, in the case of using the local best approach, each particle has access to the information corresponding to its immediate neighbors, according to a certain swarm topology. The two most common topologies are the ring topology, where each particle is connected with two neighborhood and the wheel topology (typical for highly centralized business organizations), where the individuals are isolated from one another and all the information is communicated to a focal individual.

Kennedy suggested that the gbest version converges fast but may be trapped in a local minimum, while the lbest networks have more chances to find an optimal solution, although with slower convergence. Kennedy and Mendes have evaluated all the topologies in Fig. (c) as well as the case of random neighbors. In their investigations with a total number of 20 particles, they found that the best performance occurred in a randomly generated neighborhood with an average size of 5 particles.

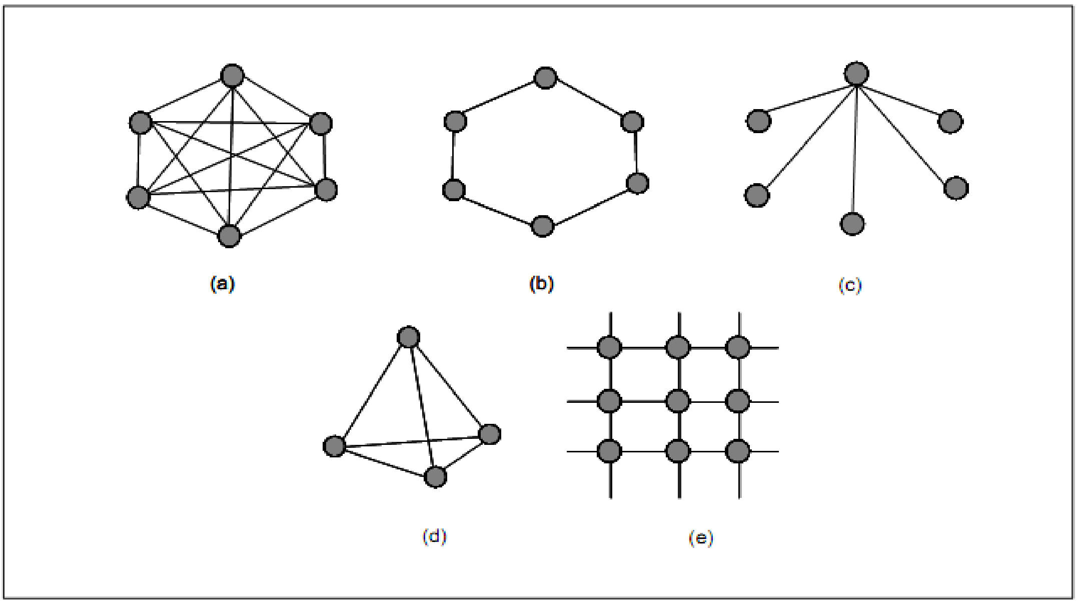

Fig.(c) Swarm topologies: (a) global best, (b) ring topology, (c) wheel topology,(d) pyramid topology, (e) Von Neumann topology

IV. FIGURES & TABLES

In the PSO algorithm, there are five different parameters to be tuned for optimal performance: (a) type and value of inertia constant (w_i), (b) acceleration constants ($c_1$and c_2), (c) maximum velocity (v_{max}) for each dimension of the problem hyperspace, (d) number of particles in the swarm, and (e) maximum number of iterations.

Tested values for PSO parameters

Parameter name	**Tested value**
Inertia weight	Fixed inertia weight: {0.5, 0.7, 0.9} Linearly decreasing inertia weight Randomly decreasing inertia weight
No. of particle	5,10
Individual acceleration constant	1.5 to 3
Social acceleration constant	$4-c_1$
No. of iteration	5,10,20
Maximum velocity	1,3,5
Minimum velocity	0,1

Optimal PSO parameters

Parameter name	**Optimal value**
Inertia weight	Linearly decreasing inertia weight
No. of particle	10
Individual acceleration constant	2.6
Social acceleration constant	1.4
No. of iteration	10
Maximum velocity	3
Minimum velocity	1

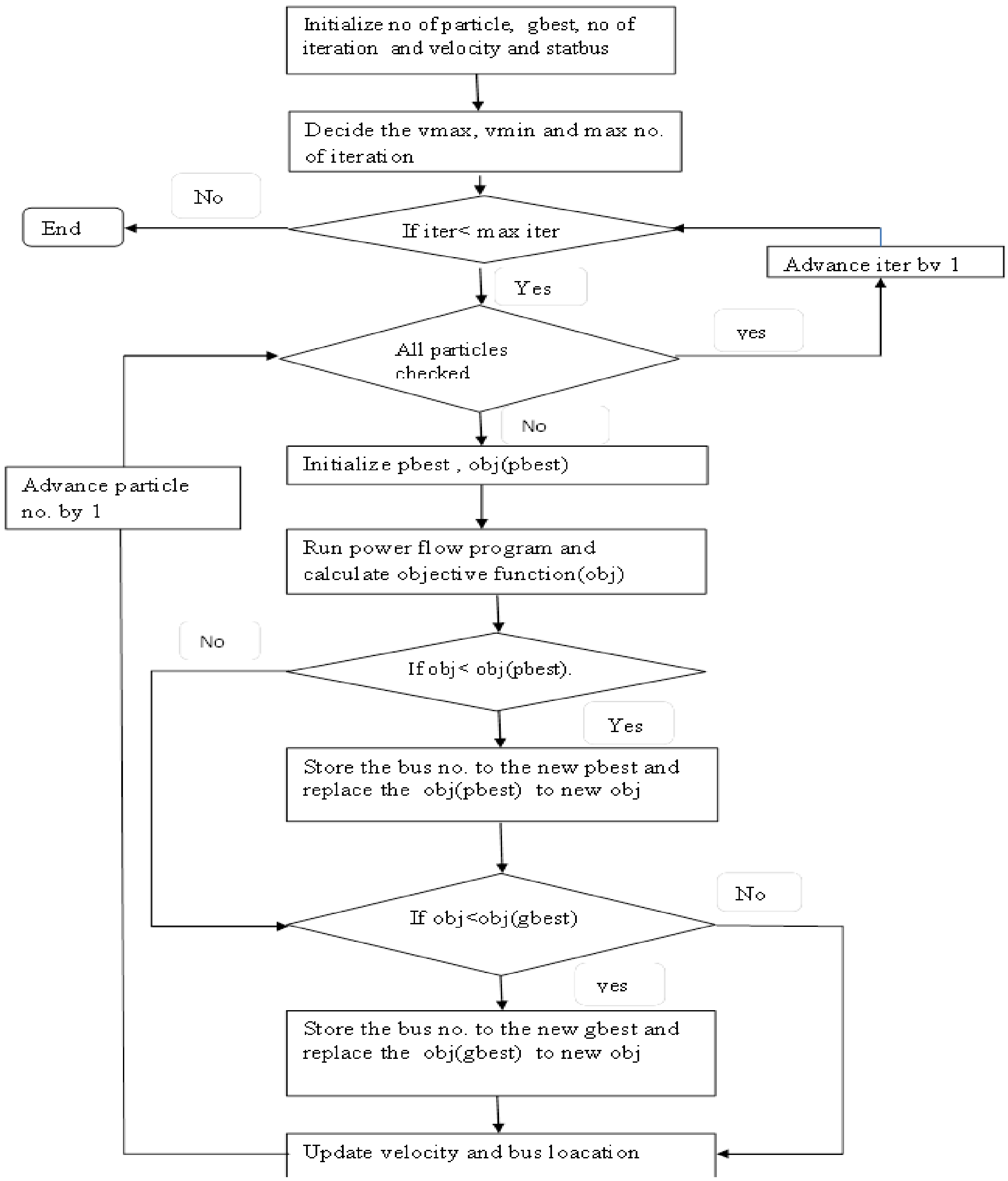

Fig. (d) Algorithm for implementing PSO

Result with PSO

As per implementation of PSO technique we find the following result given is:-

No. of STATCOM connected	Optimal location of STATCOM	Objective function
One	**Bus no. 38**	**0.4493**

Graphical Representation

The graphical representation between Bus no. and voltage deviation are shown in fig. (e) in which the bus no.38 has the minimum point value.

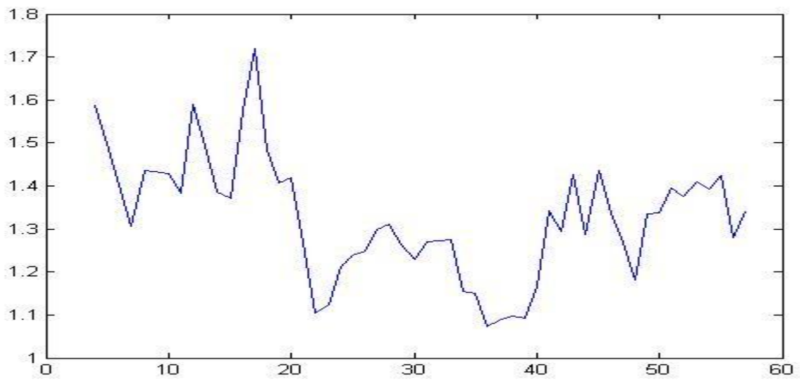

Fig. (e) Plot between bus no and voltage deviation.

V. Conclusion

The work on particle swarm optimization (PSO) assisted Optimal Placement of STATCOM Controllers in Power System has been carried out to find optimal location of STATCOM to improve the voltage profile of the system. The developed algorithm is effective in deciding the placement of STATCOM. This helps in improving voltage profile of the system and also results in reduced active power losses. Guass-Seidel Method & Newton-Raphson Methods techniques for solving the load flow problem are iterative, time consuming & more complex. Moreover, the algorithm of PSO maintains its advantages when the power system size is increased.

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