An Optimal Power Flow to Improve Power System Security by Using Particle Swarm Optimization

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ABSTRACT

This paper proposes an approach to solve the Optimal Power Flow (OPF) problem with an aim to enhancing the power system security. The approach uses proposed Particle Swarm Optimization (PSO) based algorithm to acquire the optimal power dispatch meeting steady state security constraints under different loading conditions. The PSO algorithm can be used to solve many complex OPF problems are non differentiable, non linear and multi modal. This PSO based OPF algorithm computes the efficiently relieves line flow violations and optimal generation schedule under different single line severe contingencies. The proposed approach efficiency is demonstrated by carrying simulation studies on standard IEEE 30 bus system .This analysis reveals that the proposed PSO algorithm is relatively efficient and simple for solving many complex OPF problems.

KEYWORDS

Optimal Power Flow, Contingencies, Particle Swarm Optimization, Power System Security and Severity Index.

1. INTRODUCTION

It is impossible to forecast, when a part of the Power System will fail. Normally, each component of a Power System will be arranged with an automatic protection system, which takes it out of service but it will be operated beyond at some certain limit or when a fault occurs. If any event an outage of one part of the system can push some other parts of the Power System to exceed their respective limits, which would result during further outages [1]. Due to such cascading outages, a major segment of the system or the entire system may collapse. In the Power Systems, a contingency could be the failure of on-line generators or the failure of one or more transmission lines. By means of redundancy in the design and having accurate flow of power, it is sufficient to avoid failures of cascading. A Power System with such characteristics is considered secure.

In the operation of Power System, the security problem in the system is an essential optimization problem [2]. Furthermore, it has non-linear and complex characteristics among significant equality and inequality constraints. The solution of power system problem must be optimum globally; however the solution searched by means of mathematical optimization methods used is optimum locally. The Optimal Power Flow (OPF) is one of the non-linear constraint and occasionally combinatorial Power System optimization problem.

The OPF problem has been developed repeatedly from the time when it's beginning by H.W.Dommel in the year 1968 [3]. For the reason that OPF is a very large, non-convex, non-linear, large scale, static optimization problem and mathematical programming problem, it has

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taken few decades to develop efficient algorithms designed for its solution. The main aim of the solution of the OPF is to optimize the chosen objective function such as Severity Index (SI) and optimal adjustment of the Power System control variables. It also satisfies the various equality and inequality constraints. The classical methods used for solving the OPF problem are Lambda iteration method, Newton's method, and Gradient method, Linear programming method, quadratic programming method, Non-Linear programming method, and Interior point method [4]-[6]. Until now excellent advancements have been made in classical methods, they suffer with the following disadvantages: In some cases, mathematical formulations have to be simplified to obtain the solutions because of the particularly limited capability to solve real-world with large-scale Power System problems. They are very weak in handling some of the qualitative constraints. They contain poor convergence, may get stuck at local optimum, they can find just a single optimized solution in a only simulation run, they are computationally expensive for solution of a large system and it will become too slow if number of variables are large[7]-[8].

To overcome the deficiencies and limitations in analytical methods, intelligent methods are based on Artificial Intelligence (AI) techniques have been developed in the recent ancient times. These methods can be divided into Artificial Neural Networks (ANN), Ant Colony Algorithm (ACO), Genetic Algorithms (GA), and Particle Swarm Optimization (PSO). The main important advantages of the intelligent methods are relatively adaptable designed for handling various qualitative constraints. These methods can also find many several optimal solutions in single simulation run. Accordingly they are quite suitable for solving multi objective optimization problems. In most of the cases, they can find the global optimum solution. The intelligent methods advantages are fast, Possesses learning ability, appropriate for non-linear modeling, etc.

Now a day's PSO has been used gradually more as an effective technique for solving difficult and complex optimization problems. PSO is a population based stochastic optimization technique. It was developed by Kennedy and Eberhart in 1995 [9]. It was inspired by swarming behavior as is displayed by a flock of birds, a school of fish, or even human social behavior being influenced by other individuals. PSO can be applied to almost any real-valued optimization problem. Unlike gradient based optimization method, PSO doesn't need gradient information about the function being optimized, and thus PSO is applicable to a wider range of problems [10]-[13].In this paper, PSO is used for solving the optimal power flow problem effectively with the objective of enhancing the system security. The proposed PSO algorithm is tested on IEEE 14 bus test system by using MATLAB software.

2. Mathematical Formulation of Optimal Power Flow (OPF) Problem

The Optimal Power Flow (OPF) problem is to optimize the steady state performance of a Power System in terms of an Objective Function (OF) though satisfying some of the equality and inequality constraints. Generally, the OPF problem is formulated as following.

$$\text{Min } F(y, v) \qquad (1)$$

$$\text{Subject to } g(y, v) = 0 \qquad (2)$$

$$h(y, v) \leq 0 \qquad (3)$$

Where y is a vector of dependent variables consisting of the slack bus power P_{G_1}, generator reactive power outputs Q_G, load bus voltages V_L, and the transmission line loadings S_l. Hence y can be expressed as given

$$Y^T = [P_{G_1}, V_{L_1} ... V_{L_{NL}}, Q_{G_1} ... Q_{G_{NG}}, S_l .... S_{l_{nl}}] \quad (4)$$

Where *NL, NG* and *nl* are number of load buses, number of generators and number of transmission line respectively. v is the vector of independent variables consisting of generator voltages V_G, generator real power outputs P_G except at the slack bus P_{G_1}, transformer tap settings *T*, and shunt VAR compensations Q_C .Hence v can be expressed as given

$$V^T = [V_{G_1} .... V_{G_{NG}}, P_{G_2} .... P_{G_{NG}}, T_1 ... T_{NT}, Q_{C_1} ... Q_{C_{NC}}] \quad (5)$$

Where *NC* and *NT* are the number of the shunt compensators and regulating transformers respectively. *F* is the objective function to be minimized; *h* is the system operating constraints and g is the equality constraints that represent typical load flow equations.

The contingency severity on overload line is expressed in terms of Severity Index (SI). SI is proposed to evaluate the power system network security. The objective function in the proposed OPF was selected as the minimization of the proposed SI. The security of the power system increases by minimizing the value of Severity Index. The following Severity Index is proposed to determine the degree of line violations at the line L_{x-y}.

$$SI_{xy} = \frac{S_{xy} - S_{xy\max}}{S_{xy\max}} \qquad x, y \in NB \quad (6)$$

$$\text{Objective function } F = \min (SI_{xy}) \quad (7)$$

Where

SI_{xy} : The Severity Index of line overloads;

S_{xy} : The overload flow on transmission line;

NB : Set of overloaded lines.

2.1. Constraints

The OPF problem has two set of constraints are:

2.1.1. Equality Constraints

These are the sets of nonlinear power flow equations that can be manage the Power System network, i.e.,

$$P_{Gx} - P_{Dx} - \sum_{y=1}^{k} |V_x||V_y||Y_{xy}| \cos(\theta_{xy} - \delta_x + \delta_y) = 0 \quad (8)$$

$$Q_{Gx} - Q_{Dx} + \sum_{y=1}^{k} |V_x||V_y||Y_{xy}| \sin(\theta_{xy} - \delta_x + \delta_y) = 0 \quad (9)$$

Where P and Q are the real and reactive power outputs injected at the bus- *x* respectively, the load demand at the similar bus is represented by P and Q, and elements of the bus admittance matrix are represented by $|Y|$ and θ_{xy}.

2.1.2. Inequality Constraints

These are the set of constraints that represent the Power System operational as well as security limits like the limits in the following.

1) Generators real and reactive power outputs

$$P_{Gx}^{\min} \le P_{Gx} \le P_{Gx}^{\max} \quad , x=1,\ldots, NG \qquad (10)$$

$$Q_{Gx}^{\min} \le Q_{Gx} \le Q_{Gx}^{\max} \quad , x=1,\ldots, NG \qquad (11)$$

Where $P_{Gx}^{\max}, P_{Gx}^{\min}$ maximum and minimum limits of are P_{Gx}; $Q_{Gx}^{\max}, Q_{Gx}^{\min}$ are maximum and minimum limits of Q_{Gx}.

2) Voltage magnitudes at each bus in the Power System network

$$V_x^{\min} \le V_x \le V_x^{\max} \quad , x=1,\ldots, NL \qquad (12)$$

Where $V_x^{\max}, V_x^{\min}$ are maximum and minimum limits of V_x.

3) Transformer tap settings

$$T_x^{\min} \le T_x \le T_x^{\max} \quad , x=1,\ldots, NT \qquad (13)$$

Where $T_x^{\max}, T_x^{\min}$ are maximum and minimum limits of T_x. .

4) Reactive power injections due to capacitor banks

$$Q_{Cx}^{\min} \le Q_{Cx} \le Q_{Cx}^{\max} \quad , x=1,\ldots, CS \qquad (14)$$

Where $Q_{Cx}^{\max}, Q_{Cx}^{\min}$ are maximum and minimum limits of Q_{Cx}. .

5) Transmission lines loading

$$S_x \le S_x^{\max} \quad , x=1,\ldots, nl \qquad (15)$$

6) Voltage Stability Index (VSI)

$$L_{yx} \le L_{yx}^{\max} \quad , x=1,\ldots, NL \qquad (16)$$

2.1.3. Handling of Constraints

There are different ways to handle constraints in the Particle Swarm Optimization algorithms. In this paper, the constraints are also included fitness function as a result of penalty function method, which is a penalty factor multiplied with the square of the violated value of variable is added to the OB and several infeasible solution obtained is rejected.

To handle the set of inequality constraints of state variables together with load bus voltage magnitudes and also output variables with the real power generation output at slack bus, reactive power generation output, and line loading, the extended objective function can be defined as follows:

$$OF=\sum_{y=1}^{N} F_y(P_{Gy})+K_p h(P_{G1})+K_q\sum_{y=1}^{N} h(Q_{Gy})+K_v\sum_{y=1}^{NL} h(|V_y|)+K_s\sum_{y=1}^{NL} h(|S_y|) \quad (17)$$

Where K_p, K_q, K_v, K_s are penalty constants for the real power generation at slack bus, the generation of reactive power at all generator buses or slack bus and PV buses, the voltage magnitude of all PQ buses or load buses, and transformer loading or line respectively. $h(P)_{G1}$, $h(Q_{Gy})$, h ($|V_y|$) , h ($|S_y|$) are the penalty function of the real power generation at each slack bus, the reactive power generation of all PV buses and slack bus, the voltage magnitudes of all PQ buses, and transformer loading or line respectively. NL is the number of PQ buses. The penalty function can be defined as follows:

$$h(Y)=(Y-Y_{max})^2, if \quad Y > Y_{max}$$

$$= (Y_{min}-Y)^2, if \quad Y < Y_{min}$$

$$= 0 \;, if \; Y_{min} \le Y \le Y_{max} \quad (18)$$

Where h(y) is the penalty function of variable Y, Y_{max} and Y_{min} is the upper limit and lower limit of variable y respectively.

3. Particle Swarm Optimization (PSO)

The Particle Swarm Optimization (PSO) is a population-based stochastic search algorithm inspired by simulation of the social behaviour of animals such as fish schooling and bird flocking. It is used to solve linear and non-linear optimization problems. It can overcome problem of curse of dimensionality and slow convergence which the analytic methods endure. It is based on the natural procedure of group communication to allocate individual knowledge when a group of insects or birds search migrates or food and thus forth in a searching space, although all insects or birds do not know where the best position is. Yet from the nature of the social behaviour, if every member be able to find out a desirable path to go, the rest of the members will go away after rapidly.

In the PSO, each and every particular solution is a “bird” within the search space is known as “agent” (particle, individual). The entire agents have their fitness values which are evaluated by the fitness function to be optimized, and it can also contain velocities which direct the flying of the agents. The agents flying throughout the problem search space by follow the current optimum agents. PSO is developed during simulation of bird flocking in two-dimensional search space.

The position of each agent is represent in X-Z plane with position (S_x, S_z),V_x (velocity along X-axis), and V_z (velocity along Z-axis).Modification of the agent position is realized by the velocity and position information.
Each agent knows its best value as a result of this time known as 'P_{best}', which contains the information on velocity and position. This information is the comparison of personal experience of each agent. In addition to each agent knows the best value until now in the set of 'G_{best}' with all 'P_{best}'. This information is the correspondence of information, how the other neighboring agents have performed. Each agent tries to alter its position by considering the agent best (P_{best}), current positions (S_x, S_z), current velocities (V_x, V_z), and the global best (G_{best}).

These equations are making use of computing the velocity and position, in the X-Z plane:

$$V_x^{k+1} = W * V_x^k + C_1 * rand_1 * (P_{bestx} - S_x^k) + C_2 * rand_2 * (G_{best} - S_x^k) \quad (19)$$

$$S_x^{k+1} = S_x^k + V_x^{k+1} \quad (20)$$

Where

V_x^{k+1} : Velocity of X^{th} individual at $(K+1)^{th}$ iteration;
V_x^k : Velocity of X^{th} individual at K^{th} iteration;
W : Inertial weight;
C_1, C_2 : Positive constants both equal to 2;
$rand_1$: Random number selected between 0 and 1;
$rand_2$: Random number selected between 0 and 1;
P_{bestx} : Best position of the x^{th} individual (agent best);
G_{best} : Best position among the individuals (global best);
S_x^k : Position of X^{th} individual at K^{th} iteration;

The position and velocity of each agent is modified by using above equation. The inertia weight 'W' is modified by using below equation, to enable quick convergence.

$$W = W_{max} - \frac{(W_{max} - W_{min})}{iter_{max}} * iter \quad (21)$$

Where

W_{max} : Initial value of inertia weight;
W_{min} : Final value of inertia weight;
iter : Current iteration number;
$iter_{max}$: Maximum iteration number;

The following procedure can be used for implementing the PSO algorithm.

1) Initialize the swarm of agents with velocity V_x and random position as S_x within the solution space.
2) Evaluate the fitness function for each agent and find out the agent best (P_{best}).
3) For each individual agent, compare the value of agent's fitness with its P_{best} . If the present value is better than the P_{best} value, then set this value as the P_{best} and the present agent's position S_x as P_x.
4) Identify the agent that has the best fitness value. The value of its fitness function is identified as G_{best} (global best) and its position as P_g .
5) Update the positions and velocities of all the agents by using above equations.
6) If the number of iterations reaches the maximum value then the G_{best} is the optimal solution and end of the process reached.

PSO is successfully solving large scale linear and nonlinear optimization problems. It is not mainly affected with the nonlinearity and size of the problem, and be able to converge the optimal solution in a lot of problems were mostly conventional methods fail to converge. Previously, PSO has been effectively useful in many application and research areas. It is well-known that proposed PSO get better results in a faster, cheaper way compared with other conventional methods.

4. The Computational Procedure used for Solving the Problem

The implementation steps of the proposed Particle Swarm Optimization (PSO) algorithm can also be written as follows;

Step-1: Initialize the parameters are number of iterations, size of population, number of agents, velocity of agent, initial and final inertia weight etc.
Step-2: Assumed several contingencies.
Step-3: The Optimal Power Flow (OPF) calculation along with PSO used for most of the severe contingencies in order.
Step-4: If OPF is solvable then go to step-2 else go to step-5.
Step-5: If check the limit violation meant for security constraints. But iterations reached its maximum value go to step-6 else go to step 2.
Step-6: Stop

5 Simulation Results

The proposed PSO based algorithm is tested on standard IEEE 30-bus system [13]. It is also used for solving Optimal Power Flow (OPF) problem. The proposed PSO algorithm is implemented by using MATLAB software and simulation results are reported.

The parameters of PSO are used for the simulation are summarized in TABLE 1

TABLE 1: Optimal Parameter Settings for PSO

Parameters of PSO	Value
Number of iterations	150

Population size	20
Inertia weight ,w	0.3-0.95
Cognitive constant,c_1	2
Social constant ,c_2	2

Now, the base load is considered as 283.4 MW. In case Ia, load on the power system is 311.74 MW, which represents 10% increment on base load. In case Ib, load is 325.91 MW, which represents 15% increment on base load. In case Ic, load is 340.08 MW, which represents 20% increment on base load. In case Id, load is 354.25 MW, which represents 25% increment on base load. Under base case condition i.e. with a load of 283.4 MW, the line flow limit of 32 MVA is not violated for line 6-8. Whereas under Ia, Ib, Ic and Id cases, the line limit of line 6-8 is violated.

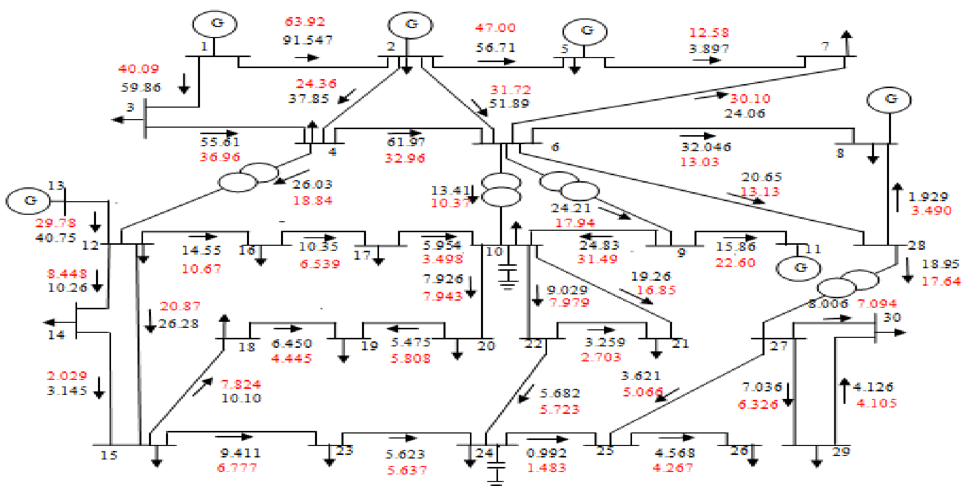

Figure.1: Line flow results under case Ia without and with PSO

To rectify the problem of over loading in line 6-8, PSO has been applied and generation rescheduling has been done for this particular problem. From last column of TABLE 2 it can observe that line flow limit violation of line 6-8 has been corrected with the application of PSO technique. Figure.1-4, shows line flow results of Case Ia, Case Ib, Case Ic and Case Id respectively. In these figures red colour values indicates the line flow results with PSO and black colour value indicates the line flow results without PSO.

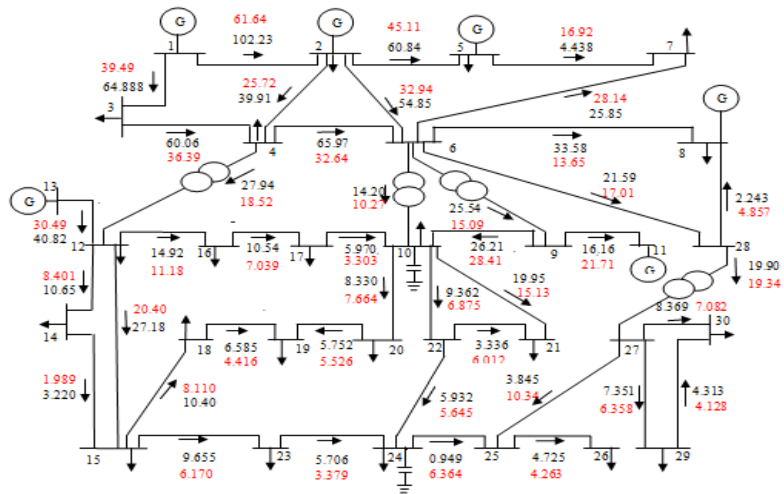

Figure.2: Line flow results under case Ib without and with PSO

From these figures, it can observe that, line flows are within the limits with the use of PSO and violation occurs without PSO. Generator Active-Power Outputs (P_G), Generator Terminal Voltages (V), Transformer Tap Settings (T) and Shunt Reactive Power Compensating elements (Q_{sh}) be use as control variables. It was noted that, proposed PSO based OPF also maintains power system security of the network as a result of maintaining line flows within their limits under various loading conditions.

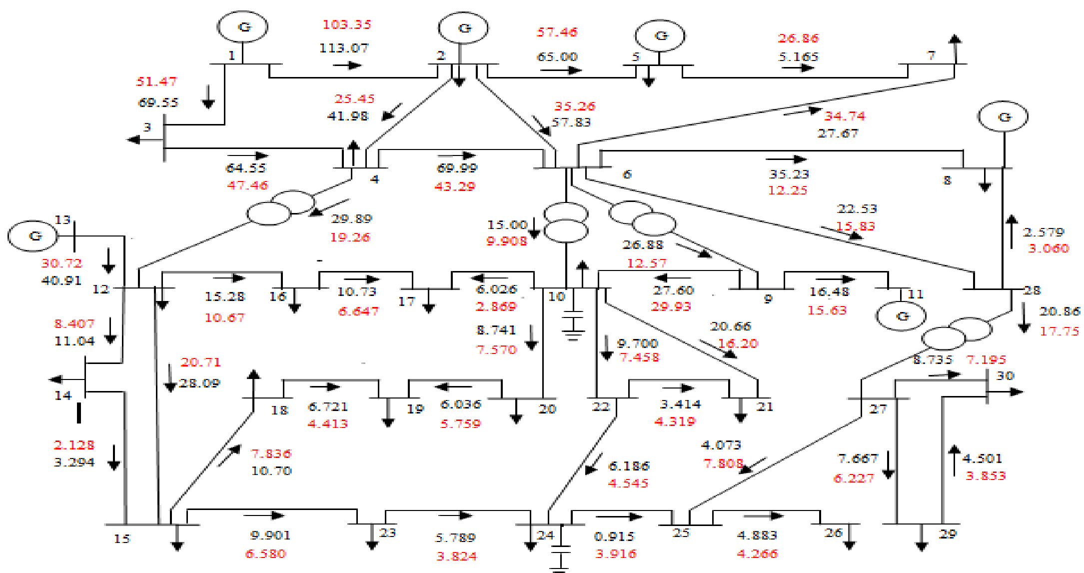

Figure.3: Line flow results under case Ic without and with PSO

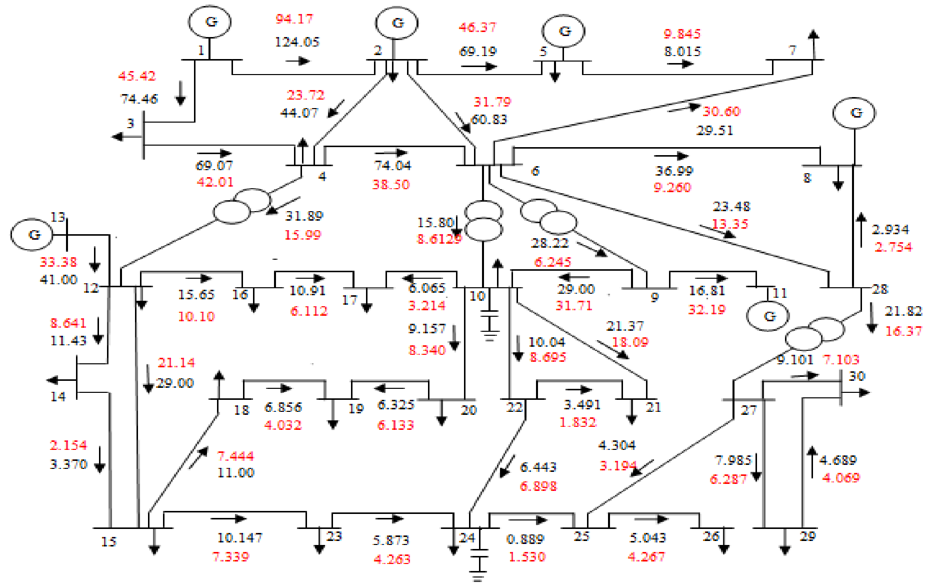

Figure.4: Line flow results under case Id without and with PSO

To prove the effectiveness of the proposed PSO based algorithm, it was applied to IEEE 30 bus system under the incidence of most of the severe contingency. Contingency analysis was carried out and outage of lines are 1-2, 2-5, 1-3 and 4-6 are created to be most of the severe contingencies, it also creates over loadings on further lines. The line flow results of Case IIa shows that outage of line is 1-2, overloaded lines are 1-3, 3-4 and 4-6. The line flow results of Case IIb shows that outage of line is 1-3, overloaded lines are 1-2 and 2-6. The line flow results of Case IIc shows that outage of line is 2-5, overloaded lines are 2-6 and 5-7. The line flow results of Case IId shows that outage of line is 4-6, overloaded lines are 1-2 and 2-6.

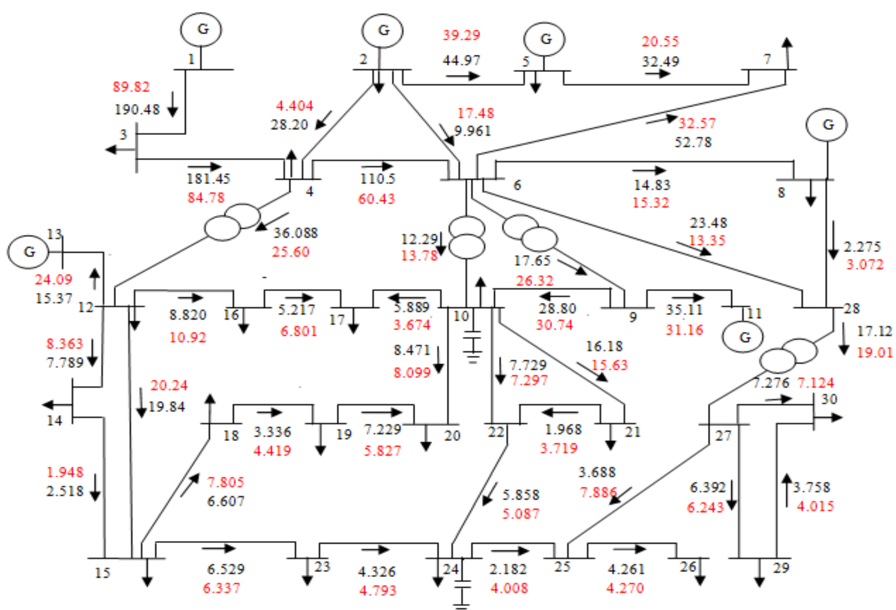

Figure.5: Line flow results under case IIa without and with PSO

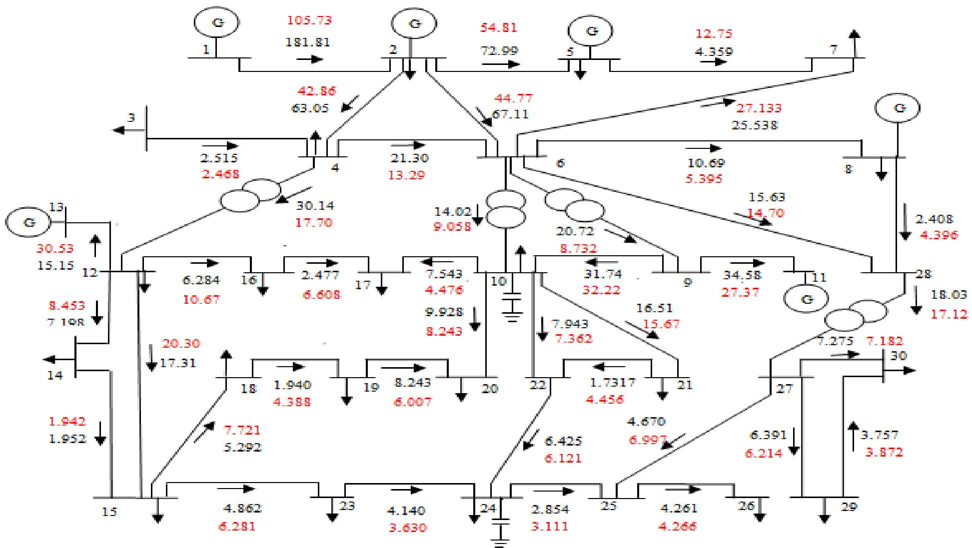

Figure.6: Line flow results under case IIb without and with PSO

The severity of the overloading was calculated by using Severity Index (SI_{mn}) and the simulation results are reported. Severity Index was calculated, Case IIa without and with PSO results are 1.089 and -0.98535, Case IIb without and with PSO results are 0.431 and -0.4978, Case IIc without and with PSO results are 0.3211 and -0.4449, Case IId without and with PSO results are 0.1052 and -0.7691. If the value of Severity Index is positive in case of without PSO then security constraints are violated, the value of Severity Index is negative in case of with PSO then security constraints are operating within the limits there is no violation takes place in PSO case. It can be reported that line flows are maintained at their respective limits by using the application of proposed PSO based algorithm and the Severity Index value is also reduced in comparison to that of without PSO.

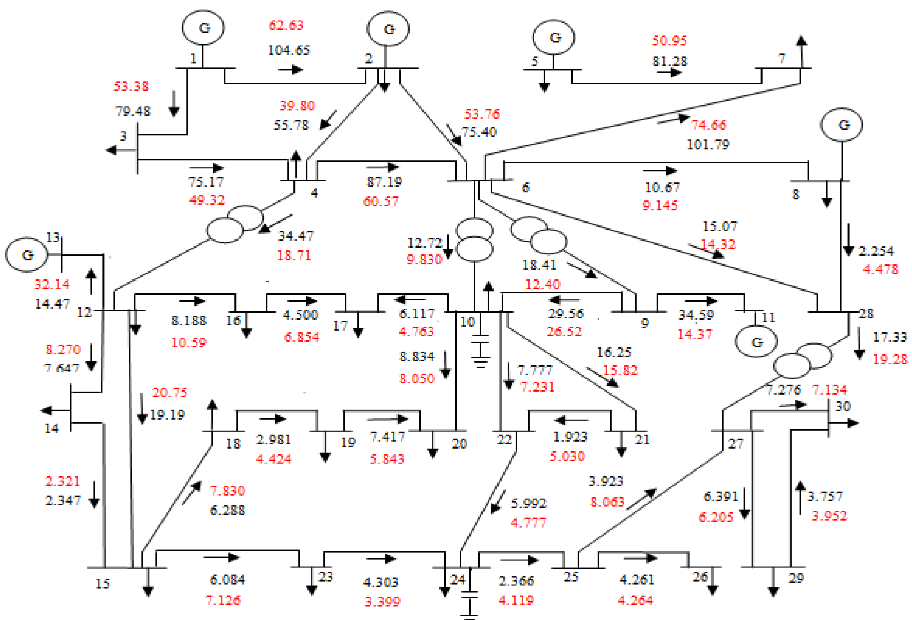

Figure.7: Line flow results under case IIc without and with PSO

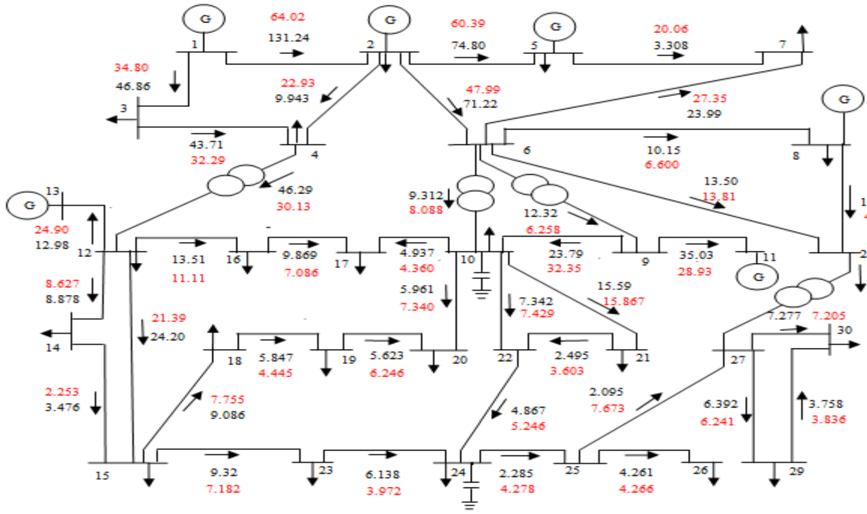

Figure.8: Line flow results under case IId without and with PSO

Figure 5-8: shows line flow results of Case IIa, Case IIb, Case IIc and Case IId respectively. In these figures red colour values indicates the line flow results with PSO and black colour value indicates the line flow results without PSO. From these figures, it can examine that, line flows are within the limits with the use of PSO and violation occurs without PSO. From the results, it was observed that all the control variables are within limits and lines are operating within the specified line limits by using application of PSO based OPF algorithm under the occurrence of various severe network contingencies.

6 CONCLUSION

This paper presents an efficient, simple, improved and reliable proposed PSO based algorithm for solving OPF problem with increase in power system network load and under occurrence of various severe contingencies. In this paper carried out generally touches upon the aspects of OPF, load flow studies and also maintaining the security of power system. These algorithms take into consideration all the equality and inequality constraints of the power system security. The improvement in system performance is achieved with power system security. The proposed method is tested on standard IEEE-30 bus system and the simulation results are reported.

The PSO based OPF algorithm not only gives consistent convergence for standard as well as conditioned systems, however also shows better performance under critical conditions. This simulation results shows the robustness and effectiveness of the proposed PSO algorithm to solve OPF problem.

7. FUTURE SCOPE

In further investigations can be carried out in the following areas:

- In PSO method selection of parameters are important so, the parameters may be optimized by combining PSO with other optimization techniques to improve their performance when applied to OPF problems.
- This paper can be extended by incorporating the FACTS (Flexible Alternating Current Transmission System) devices to improve the performance of the power system.

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