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Particle Swarm Optimization for Total Operating Cost Minimization in Electrical Power System

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Abstract

This paper presents solution of economic dispatch problem via a particle swarm optimization algorithm (PSO). The objective is to minimize the total generation fuel cost and keep the power flows within the security limits.
The PSO is simple in concept, easy in implementation .It does not require any derivative information, sure and fast convergence, Moreover; it is needs less computational time than other heuristic methods. These features increase the applicability of the PSO, particularly in power system applications .The effectiveness of the proposed algorithm is demonstrated on the IEEE 37-bus system and their performances are compared with the results of genetic algorithm (GA). The results show that PSO can converge to optimum solution with higher accuracy in comparison with GA.
Keywords: Economic Dispatch, Genetic Algorithm, Particle Swarm Optimization

أسراب الجسيمات المتماثلة لتقليل أجمالي كلفة التشغيل في منظومة طاقة كهربائية

الخلاصة

يتضمن هذا البحث حل مشكلة التوزيع الاقتصادي بنظرية جديدة تحاكي الأسراب الطائرة . الهدف من البحث تقليل تكلفة الوقود في توليد الطاقة الكهربائية والمحافظة على سريان القدرة ضمن الحدود المسموح بها. نظرية الأسراب الطائرة بسيطة بالمفهوم سهلة بالتطبيق, ولاتتطلب اية معلومات قابلة للاشتقاق . انها تمتاز بسرعة الوصول للحل علاوة على ذلك تحتاج الى وقت حسابي أقل من الطرق الأخرى.
وبسبب هذه الميزات , فقد ازداد تطبيق هذه النظرية خصوصا في تطبيقات نظم القدرة. لقد تم تطبيق هذه النظرية على نظام يحتوي على 37 مجمعوجرى تحليل نتائجها ومن ثم تمت مقارنتها مع نتائج الخوارزمية الجينية .لقد بينت النتائج انه بأستخدام هذه النظرية , فأنه يمكن الوصول للحل الامثل بدقة اعلى مقارنة بالخوارزمية الجينية.

List of symbols

PSO practical swarm optimization algorithm.
GA genetic algorithm**.**
ED economic dispatch.
IWA: inertia weight approach.
F is the system overall cost function
a *b c* the cost coefficients of generator number *i*
P i the active power generation of generator
Number *i*

n the number of generators in the system.

NB= Number of Buses
Y_{ii} = self admittance of node i
Y_{ij} =mutual admittance between node I & j

δ_i, δ_j Bus voltage angle of bus I and bus j respectively
θ_{ij} Admittance angle of line between buses I and j

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P_{gi}, P_{di} real and reactive power generation at bus i
Q_{gi}, Q_{di} Real and reactive power demand at bus i
$P_{\min\ i}$, $P_{\max\ i}$ Minimum and maximum active power generation limits at bus i
$Q_{\min\ i}$, $Q_{\max\ i}$ Minimum and maximum reactive power generation limits at bus
$V_{\min\ i}$, $V_{\max\ i}$ Minimum and maximum active voltage limits at bus i
S_i Line flow of line i
S_i^{max} Capacity of line i
V_i^k Velocity of individual i at bus k
ω Inertia wait parameter
c_1, c_2 Acceleration coefficients
r_1, r_2 Random number between 0 and 1
X_i^k Position of individual I at iteration k
$Pbest_i^k$ Best position of individual i at iteration k
$Gbest^k$ Best position of the group until iteration k
ω_{max}, ω_{min} Initial and final inertia number
$iter_{max}$ Maximum iteration number
$iter$ Current iteration number
NL number of transmission line
NB number of buses in the system
P_{lossk} loss on transmission line k
g_{ij} conductance of line between bus I and j
V_i, V_j voltage magnitude at bus I and j respectively
δ_i, δ_j voltage angle at bus I and j respectively

1. Introduction

One of the objectives in the operation of today's complex electric power systems is to meet the demand for power at the lowest possible cost, while provides consumers with adequate and secure electricity [1]. So there should be a proper scheduling of generation for the minimization of cost of operation. Thus the economic dispatch problem is one of the most important operational functions in modern power system. The basic objective of economic dispatch (ED) of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints[1,2].

Hence, the problem is to determine the generation such that the total operating cost is minimize.Classical economic dispatch techniques included lambda iteration method, the gradient search method and dynamic programming method. Among these methods, the lambda iteration method is used frequently by power utilities due to its ease of implementation [3].However, it is realized that conventional techniques become very complicated when dealing with increasingly complex dispatch problems and are further limiting by their lack of robustness and efficiency in a number of practical applications thus developing a reliable, fast and efficient algorithm is still an active area in power systems [4].

Recently, a global optimization technique known as genetic algorithm (GA) which is a kind of the probabilistic heuristic algorithm has been studied to solve the power optimization problems [5]. The GA may find the several sub-optimum solutions within a realistic computation time. Even if there is no guaranty that the GA may find the globally optimal solutions in a finite time.

One of the most recent heuristic algorithms, the particle swarm optimization (PSO), is a population based stochastic optimization technology by Eberhart and Kennedy in 1995, inspired by social behavior of bird flocking and fish schooling. It is used for optimization of continuous nonlinear functions [6].

T. Yalcinoz, H.Altun and M. Uzam developed **a** new genetic approach based on arithmetic crossover for solving the economic dispatch problem is proposed. Elitism, arithmetic crossover and mutation are used in the genetic algorithm to generate successive sets of possible operating policies. [7]

Chao-Lung Chiang, Hong-Hsi Ko, and Shih-Nung Chenpresents an improved genetic algorithm with multiplier updating (IGA_MU) to solve the economic dispatch of cogeneration systems (EDCS). The improved genetic algorithm (IGA) equipped with an improved evolutionary direction operator and a migration operation can efficiently search and actively explore solutions. [8]

M. YOUNES, M. RAHLI AND L. ABDELHAKEM-KORIDA Kpropose a methodology (GA-Matpower-OPF) that solves OPF including both active and reactive power dispatches. It is based on combining the Genetic Algorithm (GA) to obtain a near global solution, [9]

In this paper, the PSO method has been employed to solve economic dispatch problem with system equality and inequality constraints. Where, the particle swarm adaptation has been shown to successfully optimize a wide range of continuous functions. Some of the attractive features of PSO include the ease of implementation and the fact that no gradient information is required**.**

2-Details of Economic dispatching Problem

Economic power dispatch is a common problem pertaining to the allocation of the amount of power to be generated in power system on an optimum economy basis .The traditional economic dispatch minimizes the total thermal unit operating cost of all committed plants subject to the constraints [10, 11].

$$Minimize \sum_{i=1}^{n} F_i(P_i) \ldots\ldots\ldots\ldots (1)$$

$$F_{ij}(P_i) = a_i P_i^2 + b_i P_i + c_i \ldots\ldots (2)$$

Equality constraint*s*

The equality constraints are the real and reactive power balance equations at all the bus bars in each and every bus which are itself the load flow equations. The equality constraints can be formulated mathematically as [12, 13]:

$$P_{gi} - P_{di} = \sum_{j=1}^{NB} |V_i| |V_j| |Y_{ij}| \cos(\delta_i - \delta_j - \theta_{ij}) \ldots\ldots\ldots\ldots (3)$$

$$Q_{gi} - Q_{di} = \sum_{j=1}^{NB} |V_i| |V_j| |Y_{ij}| \sin(\delta_i - \delta_j - \theta_{ij}) \ldots\ldots\ldots\ldots (4)$$

Inequality constraints:

Inequality constraints are basically operation limits and physical limits of each equipment.

$$P_{\min i} \le P_{gi} \le P_{\max i} \quad \ldots\ldots (5)$$

$$Q_{\min i} \le Q_{gi} \le Q_{\max i} \quad \ldots\ldots (6)$$

$$V_{\min i} \le V_{gi} \le V_{\max i} \quad \ldots\ldots\ldots (7)$$

$$S_i \le S_i^{max} \quad \ldots\ldots\ldots (8)$$

3-Economic Dispatch Using (PSO)

The PSO is a swarm intelligence algorithm, inspired by the social dynamics and emergent behavior that arises in socially organized colonies. The PSO algorithm exploits a population of individuals to probe promising regions of search space. In this context, the population is called swarm, and the individuals are called particles or agents. Each particle moves with an adaptable velocity within the regions of search space and retains a memory of the best position it ever encountered. The best position ever attained by each particle of the swarm is communicated to all other particles. [6, 14]

Here it is referred as classic PSO. The basic principles in "classical" PSO are very simple. A set of moving particles (the swarm) is initially "thrown" inside the search space. Each particle has the following features:

- Each particle has a position vector of X_i and a velocity vector V_i. The position vector X_i and the velocity vector V_i of the *i* th particle in the *n*-dimensional search space can be represented as $X_i= (x_{i1}, x_{i2}, xin)$ and $V_i= (v_{i1}, v_{i2}, vin)$, respectively.
- Each particle has a memory of the best position in the search space that it has found so far (*Pbesti*), and knows the best location found to date by all the particles in the swarm (*Gbest*). Let $Pbest =(x_{i1}^{Pbest}, x_{i2}^{Pbest}, ..., x_{in}^{(Pbest)}$ and $Gbest = (x_1^{Gbest}, x_2^{Gbest}, ..., x_n^{(Gbest)})$be the best position of the individual *i* and all the individuals so far, respectively. At each step, the velocity of the *i* th particle will be updated according to the following equation in the PSO algorithm [15, 16].

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 \times \left(Pbest_i^k - X_i^k\right) + c_2 r_2 \times \left(Gbest^k - X_i^k\right) \ldots\ldots (9)$$

In this velocity updating process, the acceleration coefficients $c1$, $c2$ and the inertia weight ω are predefined and $r1$, $r2$ are uniformly generated random numbers in the range of [0, 1]. In general, the inertia weight ω is set according to the following equation:

$$\omega = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{iter_{max}} \times iter \ldots (10)$$

The approach using Equ (10) is called the "inertia weight approach (IWA)" [16]. Using the above equations, diversification characteristic is gradually decreased and a certain velocity, which gradually moves the current searching point close to *Pbest* and *Gbest,* can be calculated. Each individual moves from the current position (searching point in the solution space) to the next one by the modified velocity in Equ (9) using the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \ldots\ldots\ldots\ldots (11)$$

PSO is a population based algorithm in which each particle is considered as a solution in the multimodal optimization space**.** The initial population is a set of individuals (i.e. a group) is created at random within the system constraints. Here, an individual for the ED problem is composed of a set of elements (i.e., generator outputs). Thus, individual *i* at iteration 0 can be represented as the vector $P_{gi}^0 = (P_{gi1}, P_{gin})$, where n is the number of generators, (P_{gi}) is selected randomly between P_{gi}^{min} and P_{gi}^{max}, The velocity of individual *i* at iteration 0 can be represented as the vector $V_i^0 = (V_{i0}, V_{in})$ and this corresponds to the generation update quantity covering all generators. Our objective is to minimize the objective function of the ED expressed by Equ (2), it must be noted that initialized individuals have to satisfy both the equality constraint and inequality constraints.

The search of the optimal vector is performed using into account the real power flow equation defined by Equ (3) which present the system transmission losses (P_{loss}). These losses can be approximated in terms of *B* coefficients as:

$$\min[\sum_{k=1}^{NL} P_{lossk} = \sum_{i=1}^{NB} \sum_{j=1}^{NB} g_{ij} (V_i^2 + Vj2 - 2ViVj\cos\delta i - \delta j)] \ldots\ldots\ldots\ldots (12)$$

$$P_{loss} = \sum_{i=1}^{ng} \sum_{j=1}^{ng} P_{gi} B_{ij} P_{gj} \ \ldots\ldots\ldots (13)$$

The *Bij* coefficients are obtained from a power flow solution. In this method, only the inequality constraints on active powers are handled in the cost function. The other inequality constraints are scheduled in the load flow process [6, 16]. Figure (1) show the flow chart for PSO algorithm to solving Economic Dispatch problem

4-Economic Dispatch Using Genetic Algorithm

Genetic algorithms GA are search algorithms based on the mechanics of natural selection and natural genetics. It can be used to solve a variety of optimization problems that are not well suited for standard optimization algorithms, including problems in which the objective function is discontinuous, non-differentiable, stochastic, or highly nonlinear [17].

The GA works with a set of individuals comprising the population .The initial population consists of *N* randomly generated individuals where, *N* is the size of population, at every iteration of the algorithm, the fitness of each individual in the current population is computed .The population is then transformed in stages to yield a new current population for the next iteration . The transformation is usually done in three stages by sequentially applying genetic operators, which are the selection, the crossover and the mutation [17, 18]:

The success of the genetic algorithm strongly depends on the problem mapping which involves the transformation of the problem solution to a chromosome representation and the design of the fitness function as assess the quality of a solution.

The initial population is generated after satisfying the Equ (5) $p_{min}<p<p_{max.}$ Each chromosome within the population represents a candidate solution as a vector P_{Gi}, A chromosome must represent a generation scheduling in binary coding in order to solve the economic dispatch problem by using a genetic algorithm approach. The fitness function is used to transform the cost function value into a measure of relative fitness .The fitness function is given in Equ (2).The representation takes care of the unit minimum and maximum loading limits since the real representation is made to cover only the values between the limits. So, the first step of any genetic algorithm is to generate the initial population. A binary string of length L is associated to each member) individual) of the population . The string is usually known as a chromosome and represents a solution of the problem . A sampling of this initial population creates an intermediate population .Thus, some operators (reproduction, crossover and mutation) are applied to this new intermediate population in order to obtain a new one [4, 9]. Figure (2) show the flow chart for GA algorithm to solving Economic Dispatch problem

5- Simulation Results

The proposed PSO algorithm has been implemented using Matlab. To demonstrate the effectiveness of this algorithm, the 37 bus power system has been implemented .The whole power system is illustrated in Fig (3) [19]. This system is considered large with 37-Bus, 8-Generator power system containing three different voltage levels (345 KV, 138 KV, 69 KV) with 49 transmission lines or transformers. The system data with power demand, generation are given from [19] and the output voltage from Newton-Raphson load flow analysis as in Fig (4), GA and PSO parameters as in Table (1).

The Fuel-cost functions for planets in dollars per hour, the power generation limits and the B coefficients were found to be as follows:

$C_1 = 0.0070\ P_{G1}^2 + 7.00\ P_{G1} + 240;$

$100 \le P_{G1} \le 500$

$C_2 = 0.0095\ P_{G2}^2 + 10.0\ P_{G2} + 200;$

$50 \le P_{G2} \le 200$
C_3=0.0090 P_{G3}^2 + 8.50 P_{G3}+ 220;
$80 \le P_{G3} \le 300$
C_4=0.0090 P_{G4}^2 + 11.0 P_{G4}+ 200;
$50 \le P_{G4} \le 150$
C_5=0.0080 P_{G5}^2 + 10.5 P_{G5}+ 220;
$50 \le P_{G5} \le 200$
C_6=0.0075 P_{G6}^2 + 12.0 P_{G6}+190;
$50 \le P_{G6} \le 120$
C_7 = 0.0070 P_{G7}^2 + 11.00 P_{G7} +195;
$50 \le P_{G7} \le 100$
C_8 = 0.0065 P_{G8}^2 + 11.00 P_{G8} +193;
$50 \le P_{G8} \le 120$
B= [0.0048 0.0018 0.0000 -0.0004 0.0010 0.0009 -0.0024 0.0008
0.0018 0.0148 0.0053 0.0039 -0.0012 -0.0021 0.0017 -0.0014
0.0000 0.0053 0.0113 0.0012 -0.0025 -0.0038 0.0055 -0.0029
-0.0004 0.0039 0.0012 0.0366 -0.0000 -0.0011 0.0053 0.0011
0.0010 -0.0012 -0.0025 -0.0000 0.0085 0.0097 -0.0027 0.0070
0.0009 -0.0021 -0.0038 -0.0011 0.0097 0.0231 -0.0063 0.0071
-0.0024 0.0017 0.0055 0.0053 -0.0027 -0.0063 0.0832 -0.0011
0.0008 -0.0014 -0.0029 0.0011 0.0070 0.0071 -0.0011 0.0107];
B0= [0.0026 0.0022 0.0006 -0.0007 0.0026 0.0055 -0.0027 0.0018];
B00= [0.0023];

The results of the proposed approach were compared to classical method (lambda iteration method) and genetic algorithm. The comparison results have been demonstrated in Table (2). It is quite evident that the proposed approach gives better results.

To verify the convergence characteristics of the PSO and GA with the selected parameters, the variations in cost with iteration number shown in Fig. (5) and Fig. (6).

6-Conclusions

The PSO and GA algorithms have been investigated for the determination of the global or near-global optimal solution for the economic dispatch (ED) problem. The results of these two methods are compared with conventional lambda iterative method. Since the conventional method depends on the exact adjustment of lambda value, it cannot give the accurate solution for the ED problem. The results show that the PSO and GA provide a global optimal solution than that provided by the Conventional method. By implementation of PSO, computer-processing time can be drastically reduced.The main advantage of PSO over other modern heuristics is modeling flexibility, sure and fast convergence, less computational time than other heuristic methods. In addition, it can be easily coded to work on parallel computers.Simulation results on the 37 Bus, 8-generator system demonstrate the

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Table (1) GA and PSO parameters for best results of economic dispatch.

Classical method	GA method	PSO method
Total system loss = 15.8815 MW	Total system loss = 1.8670 MW	Total system loss = 136.827 KW
Total generation cost = 9753.40 $/h	Total generation cost = 1632.1 $/h	Total generation cost = 1008.679 $/h
Optimal Dispatch of Generation: (MW) 306.7721 61.5731 153.6330 50.0000 68.0129 50.0000 50.0000 50.0000	Optimal Dispatch of Generation: (MW) 155.2453 52.3329 80.5290 51.8792 53.6832 51.3040 50.4463 50.8198	Optimal Dispatch of Generation: (MW) 100.000 50.000 80.000 50.000 50.000 50.000 50.000 50.000

Table (2) the results of the proposed system.

no	Genetic algorithm (GA)		Particle swarm optimization (PSO)	
	Parameters	Values	Parameters	Values
1	Population size	50	Population size	50
2	String size	64	C1	1.99
3	Probability of crossover	0.8	C2	1.99
4	Probability of mutation	0.08	ῴ	0.8
5	Generations	100	Generations	500

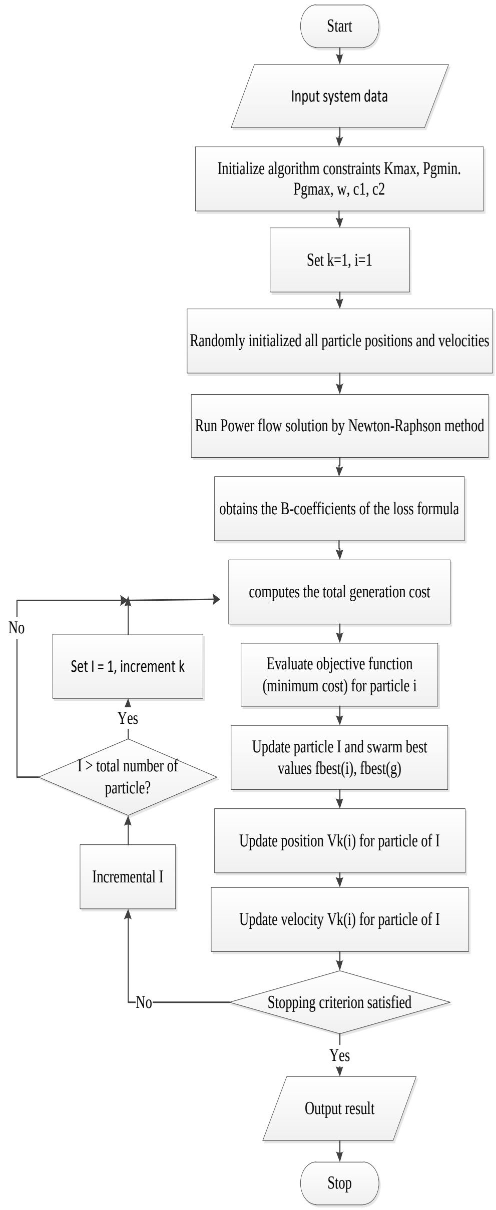

Figure (1) Flow Chart Of Particale Swarm Algorithm

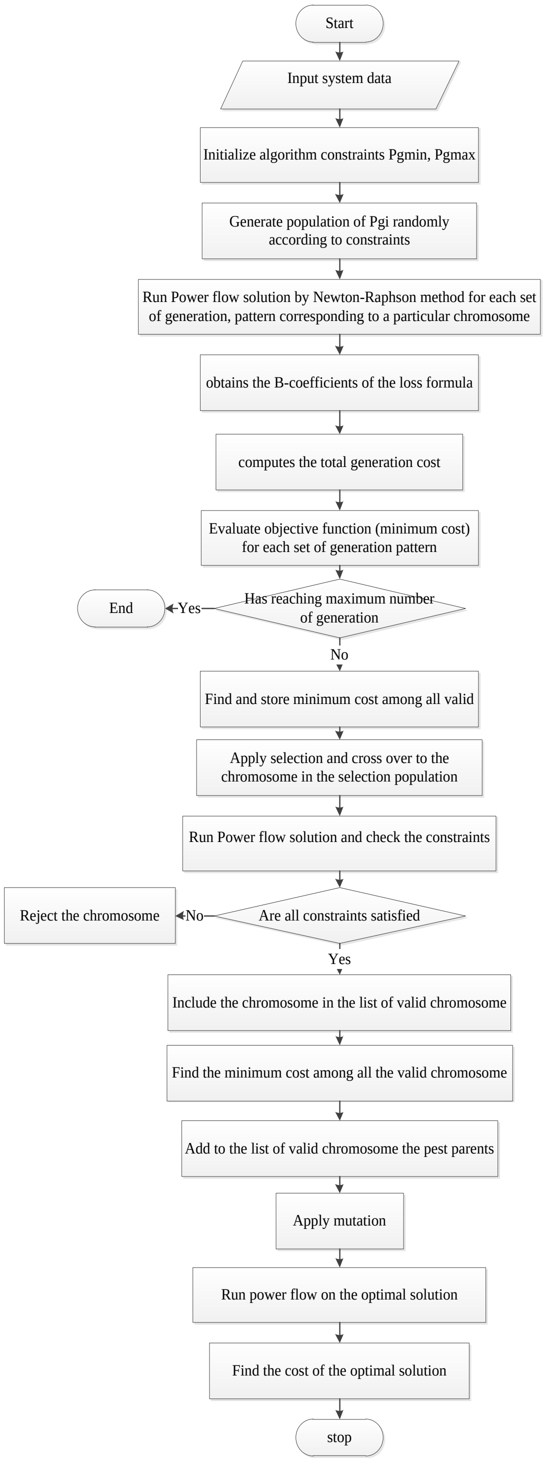

Figure (2) Flow Chart of Genetic Algorithm

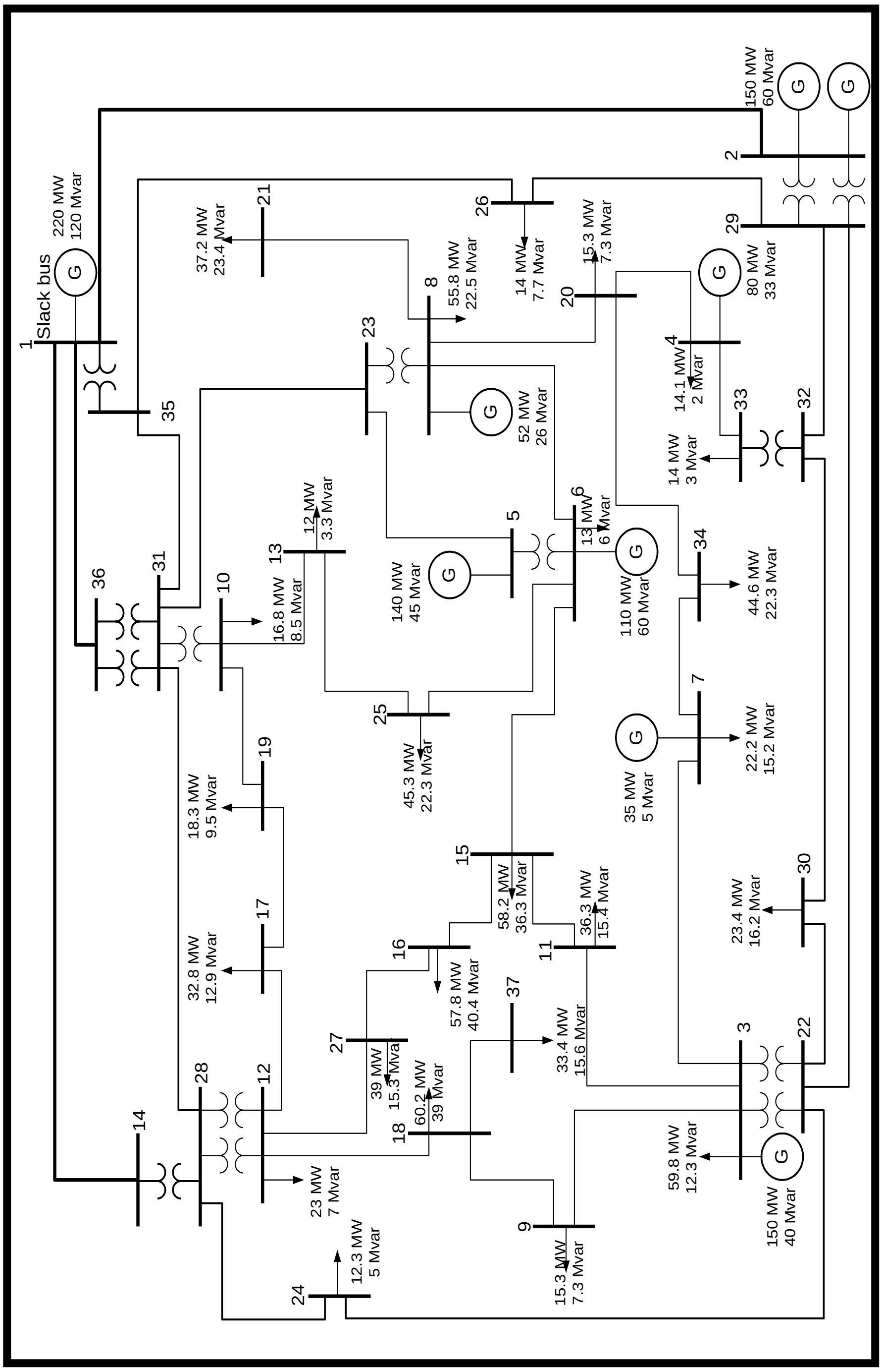

Figure (3) Single line diagram for test system. [19]

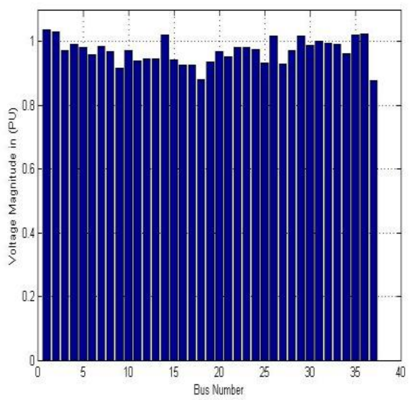

Figure (4) Voltage magnitudes at buses of the system.

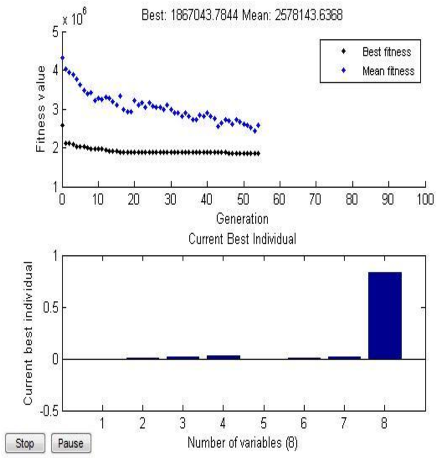

Figure (5) Fitness value for genetic algorithm

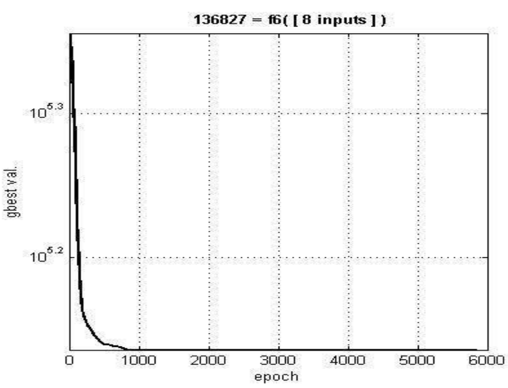

Figure (6) Fitness value for PSO algorithm