ISSN 2250-3153

Chaotic Particle Swarm Optimization for Congestion Management in an Electricity Market

Dr. V.P. Sakthivel *, S.V.Vijayasundaram**

Department of Electrical Engineering,
Annamalai University
Chidambaram

Abstract- Congestion management is one of the major tasks performed by system operators (SOs) to ensure the operation of transmission system within operating limits. To permit smooth and quality flow of power the problem of congestion has to be solved. The congestion in the transmission line will be removed by generation rescheduling with the cost involved in the rescheduling process should be minimized. T he literature, classical optimization techniques were applied to solve this problem. The main drawbacks of the classical optimization techniques are higher computation time requirement, non-differentiable characteristics of objective function and inferior quality of solutions. To overcome the above mentioned problems, heuristic optimization techniques are widely used. In our project presents Chaotic Particle Swarm Optimization (CPSO) based Congestion Management by optimal rescheduling of active powers of generators. In the proposed method, generators are selected based on their sensitivity to the congested line for efficient utilization. The task of optimally rescheduling the active powers of the participating generators to reduce congestion in the transmission line is attempted by CPSO and conventional PSO. The CPSO and PSO algorithms are tested on the IEEE 30-bus system. Compared with CPSO and PSO, CPSO can better perform the optimal rescheduling of generators to relieve congestion in the transmission line.

Index Terms- Chaotic Particle Swarm Optimization (CPSO), generator sensitivity, particle swarm optimization and Transmission congestion management.

I. INTRODUCTION

A system is said to be congested when producers and consumers of electric energy desire to produce and consume in amounts that would cause the transmission system to operate at or beyond one or more transfer limits. The main challenge faced by the Independent System Operator (ISO) in a deregulated environment is to maintain the security and reliability of the power system by maximizing market efficiency when the system is congested. The ISO, therefore, has to create a set of transparent and robust rules that should not encourage aggressive entities to exploit congestion to create market power and maximize profits at the cost of the market. Congestion in a transmission system cannot be allowed beyond a short duration because this could lead to cascading outages with uncontrolled loss of load. Vinod kumar et al. [1] explained in detail the congestion management and felt that controlling the transmission system so that transfer limits are observed is perhaps the fundamental transmission management problem. In a deregulated environment, all the GENCOs and DISCOs plan their transactions ahead of time. But by the time of implementation of transactions there may be congestion in some of the transmission lines. Hence, ISO has to relieve the congestion so that the system remains in secure state.

Meena and Selvi [2] considered an open transmission dispatch environment in which pool and bilateral/multi lateral dispatches coexist and proceeded to develop a congestion management strategy for this scenario. Dutta et al. [3] presented congestion management techniques applied to various kinds of electricity markets. Kennady and Eberhart [4] reviewed extensively the literature for reporting several techniques of congestion management and informed that the congestion management is one of the major tasks performed by Independent System Operators (ISOs) to ensure the operation of transmission system within operating limits. In the emerging electric power markets, the congestion management becomes extremely important and it can impose a barrier to the electricity trading. Fang and David [5] proposed an efficient zonal congestion management approach using real and reactive power rescheduling based on AC Transmission Congestion Distribution factors considering optimal allocation of reactive power resources. The impact of optimal rescheduling of generators and capacitors has been demonstrated in congestion management.

Ashwani kumar et al. [6] described a coordinating mechanism between generating companies and system operator for congestion management using Benders cuts. Lamont et al. [7] proposed two approaches for a unified management of congestions due to voltage instability and thermal overload in a deregulated environment. Hazra and Sinha [8] discussed a combined frame work for service identification and congestion management while a new approach were applied to identify the services of reactive support and real power loss for managing congestion using the upper bound cost minimization.

Chen and Zhang [9] described the Particle Swarm Optimization (PSO) concept in terms of its precursors, briefly reviewing the stages of its development from social simulation to optimizer and discussed application of the algorithm to the training of artificial neural network weights. Shi et al. [10] research and development of PSO in five categories viz. algorithms, topology, parameters, hybrid PSO algorithms and applications.

In general, the search process of a PSO algorithm should be a process consisted of both contraction and expansion so that it could have the ability to escape from local minima, and eventually find good enough solutions. Yamina and Shahidehpour [11] detailed review of the PSO technique, the basic concepts and different structures and variants, as well as its applications to power system optimization problems. Snider et al. [12] Introduced PSO for solving Optimal Power Flow (OPF) with which congestion management in pool market is practically implemented on IEEE 30 Bus system. Kumar and Srivastava [13] proposed cost efficient generation rescheduling and/or load shedding approach for congestion management in transmission grids using Chaotic Particle Swarm Optimization (CPSO) method.

Fattahi and Ehsan[14] proposed a technique for reducing the number of participating generators and optimum rescheduling of their outputs while managing congestion in a pool at minimum rescheduling cost and explored the ability of PSO technique in solving congestion management problem. An optimal solution for static congestion management using PSO based OPF method. Here, the congestion has been created in the transmission line by loading the lines and it is relieved by placing a Static Synchronous Series Compensator (SSSC) in an optimal location in the transmission line. Masoud Esmaili et al. [15] proposed modified blenders decomposition technique for solving the congestion management in hybrid power markets.

Dutta and Singh [16] demonstrated the successful adaptation of the PSO algorithm to solve various types of economic dispatch (ED) problems in power systems viz. Multi-area ED with tie line limits, ED with multiple fuel options, combined environmental ED and ED of generators with prohibited operating zones. The better computation efficiency and convergence.

Property of the PSO technique shows that it can be applied to a wide range of optimization problems. Christie and Wollenberg [17] PSO method for solving the ED problem with the generator constraints and demonstrated that the PSO method can avoid the shortcoming of premature convergence of Genetic Algorithm (GA) method while obtaining higher quality solution with better computation efficiency and convergence property.

Shahidehpour and Alomoush [18] explained in detail that formulated chaotic particle swarm (CPSO) Optimization Algorithm for optimization process represented by the activity of particle optimization. The algorithm presented has been utilized in this paper for optimal generation of active power of the participating generators. Sakthivel et al. [19] introduced chaotic particle swarm optimization (CPSO) method to overcome the above mentioned drawbacks.

II. Problem Formulation

1) OPF Problem Formulation

The objective function is corresponding to the production cost can be approximated to be a quadratic function of the active power outputs from the generating units. Symbolically, it is represented as

$$\text{Minimize } F_t^{\cos t} = \sum_{i=1}^{N_G} f_i(P_i) \quad (1)$$

Where $f_i(P_i) = a_i p_i^2 + b_i p_i + c_i, \quad i = 1,2,......., N_G$

Is the expression for cost function corresponding to ith generating unit and a_i, b_i and c_i are its cost coefficients. Pi is the real power output (MW) of ith generator. N_G is the number of online generating units.

2) Power Balance Constraints

This constraint is based on the principle of equilibrium between total system generation and total system loads. That is given by set of non-linear power flow equations as

$$P_{G_i} - P_{D_i} - \sum_{j=0}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i - \delta_j) = 0 \quad (2)$$

$$Q_{G_i} - Q_{D_i} - \sum_{j=0}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i - \delta_j) = 0 \quad (3)$$

The real power loss in the system can be modeled a

$$P_{loss} = \sum_{k=1}^{N_l} g_k |V_i|^2 + |V_j|^2 - 2|V_i||V_j| \cos(\delta_i - \delta_j) \quad (4)$$

3) The Generator Constraints

The output power of each generating unit has a lower and upper bound so that it lies in between these bounds. This constraint is represented by a pair of inequality constraints as follows.

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (5)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (6)$$

4) Voltage Limits

The voltage magnitudes of the each and every load buses after conducting the load flow simulation should be verified between its bounds. This voltage magnitude is having its own lower and upper bound and mathematically represented by

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (7)$$

5) Transmission Line Loadings

The line flows of all the transmission lines should be within its line capacity given by MVA ratings. This can be given as

$$S_L \le S_L^{\max} \quad (8)$$

6) OPF Constraints Handling

The equality and inequality constraints of the power dispatch problem are considered in the fitness function (J_{error}) itself by incorporating a penalty function.

$$PF_i = \begin{cases} K_i (U_i - U_i^{\lim})^2 & \text{If violated} \\ 0 & \end{cases} \quad (9)$$

Therefore the objective of the problem is the minimization of generation cost and penalty function due to any constraint violation as defined by the following equation.

$$J_{error} = F_t^{\cost} + \sum_{l=0}^{nc} PF_i \quad (10)$$

7) Determination Of Generator Sensitivity Factor

The generators in the system under consideration have different sensitivities to the power flow on the congested line. A change in real power flow in a transmission line k connected between bus I and bus j due to change in power generation by generator g can be termed as generator sensitivity to congested line (GS). Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_g} \quad (11)$$

8) Congestion Management Problem

It is advisable to select the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling their power outputs. Based on the bids received from the participant generators, the amount of rescheduling required is computed by solving the following optimization problem.

$$C_c = \min \sum_{g}^{N_g} C_g(\Delta P_g)\Delta P_g \quad (12)$$

Subject to

$$\sum_{g}^{N_g}((GS_g \Delta P_g) + PF_k^0 \le PF_k^{\max} \quad (2.13)$$

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max} \quad (2.14)$$

$$\Delta P_g^{\min} = P_g - P_g^{\min} \quad (2.15)$$

$$\Delta P_g^{\max} = P_g^{\max} - P_g \quad (2.16)$$

$$\sum_{g=1}^{N_g} \Delta P_g = 0 \quad (17)$$

Where ΔPg is the real power adjustment at bus-g and Cg (ΔPg) are the incremental and decremented price bids submitted by generators and these generators are willing to adjust their real power outputs. PF_k^0 is the power flow caused by all contracts requesting the transmission service. $PF_k^{\max}$ is the line flow limit of the line connecting bus-i and bus-j. Ng is the number of participating generators, $P_g^{\min}$ and $P_g^{\max}$ denotes respectively the minimum and maximum limits of generator outputs.

III. CHAOTIC PARTICLE SWARM OPTIMIZATION

A. PSO

Kennady and Eberhart first introduced the PSO in the year 1995[4]. PSO is motivated from the simulation of behavior of Social systems such as fish schooling and birds flocking. The PSO algorithm requires less computation time and less memory because of the simplicity inherent in the above systems.

The basic assumption behind the PSO algorithm is, birds find food by flocking and not individually. This leads to the assumption the information is owned jointly in flocking. Basically PSO was developed for two-dimension solution space by Kennedy and Eberhart [4].The position of each individual is represented by XY axis position and its velocity is expressed by V_x in x direction and V_y in y direction. Modification of the individual position is realized by the velocity and position information.

PSO algorithm for N-dimensional problem formulation based on the above concept can be described as follows. Let P be the in a search ‘particle’ coordinates (position) and V its speed (velocity) in a search space.

Consider i as a particle in the total population (swarm).Now the ith particle position can be represented as P_i= (P_{i1}, P $_{i2, Pi3\ldots}$ P_{iN}) in the N-dimensional space. The best previous position of the ith particle is stored and represented as $Pbest_i$= ($Pbest_{i1}$, Pbest $_{i2}$ … Pbest $_{ij}$). All the Pbest are evaluated by using a fitness function, which differs for the different problems. The best particle among all Pbest is represented as gbest.

The velocity of the ith particle is represented as V_i=(V_{i1} ,V_{i2}….V_{ij}).The modified velocity of the each particle can be calculated using the information ,(i) the current velocity(ii)the distance between the current position and Pbest and (iii)the distance between the current position and gbest. This can be formulated as an equation

$$V_{ij}^{(iter+1)} = W * V_{ij}^{(iter)} + c_1 * rand_1 * (Pbest_{ij} - P_{ij}^{(iter)}) + c_2 * rand_2 * (gbest_i - P_{ij}^{(iter)}) \quad (18)$$

$$P_{ij}^{(iter+1)} = P_{ij}^{(iter)} + V_{ij}^{(iter+1)} \quad \text{I =1, 2… N and j =1, 2…} \quad (19)$$

The use of linearly decreasing inertia weight factor w has provided improved performance in all the applications .Its value is decreased linearly from about 0.9 to0.4 during a run. Suitable selection of the inertia weight provides a balance between global and local exploration and exploitation, results in fewer iterations on average to find a sufficiently optimal solution; its value is set according to the following equation:

$$W = \frac{W_{\max} - (W_{\max} - W_{\min}) \times iter}{iter_{\max}} \quad (20)$$

In Equation (20) the first term indicates the current velocity of the particle, second term represents the cognitive part of PSO where the particle change its velocity based on its own thinking and memory. The third term represents the social part of the PSO where the particle changes its velocity based on the social psychological adaption of knowledge.

B. CHAOTIC PARTICLE SWARM OPTIMIZATION

One of the simplest dynamic systems evidencing chaotic behavior is the iterator called the logistic map, whose equation is described as follows:

$$f_k = \mu . f_{k-1} .(1 - f_{k-1}) \quad (21)$$

Where µ is a control parameter and has the real value between [0, 4]. Despite the apparent simplicity of the equation, the solution exhibits a rich variety of behaviors.

The behavior of the system represented by equation is greatly changed with the variation of µ. The value of µ determines whether 'f' stabilizes at a constant size, oscillates between limited sequences of sizes, or behaves chaotically in an unpredictable pattern.

Also the behavior of the system is sensitive to initial value of 'f'. Equation (5) is deterministic, displaying chaotic dynamics when µ = 4.0 and f0 0, 0.25, 0.50, 0.75, 1.0. In this thesis, the new weight is defined as multiplying equation (4) by equation (5) in order to improve the global searching capability as follows:

$$W_{new} = W \times f \quad (22)$$

Whereas, the conventional weight decreases monotonously from Wmax to Wmin, the proposed new weight decreases and oscillates simultaneously for total iteration as shown in figure 3.1.

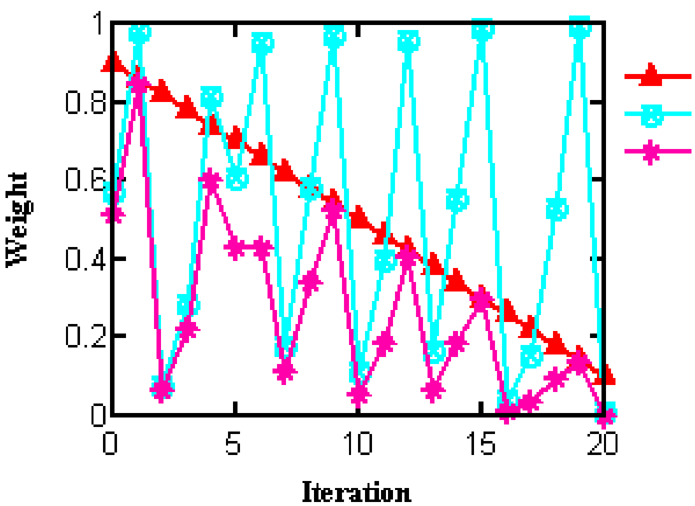


Figure 3.1.comparison of weights by each approach

The CPSO algorithm can be summarized as follows:

Step 1: Initialize parameters Wmax, Wmin, C1, C2 and Itermax.

Step 2: Generate intial population of N particles with random positions and velocities.

Step 3: Calculate fitness: Evaluate the fitness value of current particle.

Step 4: Update personal best: Compare the fitness value of each particle with its pbests. If the current value is better than pbest, then set pbest value to the current value.

Step 5: Update global best: Compare the fitness value of each particle with gbest. If the current value is better than gbest, set gbest to the current particle's value.

Step 6: Update chaotic weight: Calculate weight $W_{new}^{(k+1)}$ using equation.

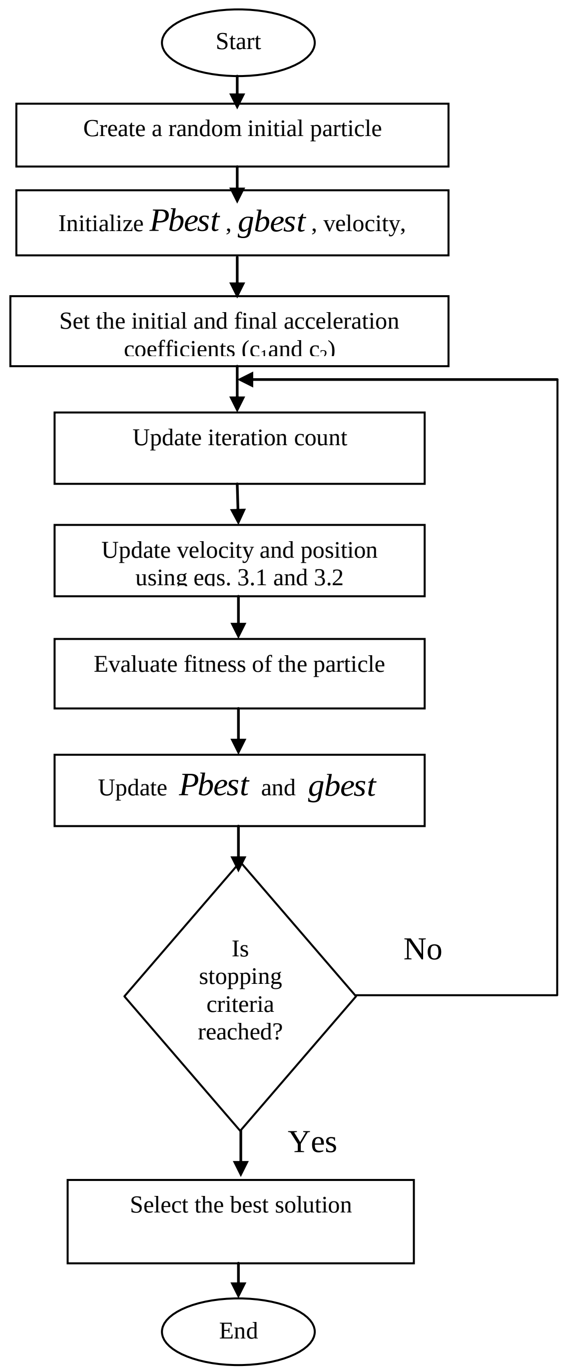
Step 7: Update velocities: Calculate velocities $V_{ij}^{(iter+1)}$ using equation.

Step 8: Update positions: Calculate positions $P_{ij}^{(iter+1)}$ using equation.

Step 9: Return to step (4) until the current iteration reaches the maximum iteration number.

Step 10: Output the optimal solution in the last iteration.

C. FLOW CHART FOR CHAOTIC PARTICLE SWARM OPTIMIZATION



A) *PARAMETER SELECTION OF CPSO ALGORITHM*

Some parameters must be assigned before CPSO is used to solve the parameter estimation problem as follows: Particle size = 20; initial inertia weight W_{max} =0.9; final inertia weight, W_{min} = 0.1; acceleration factor $C_1 = C_2 = 1.5$; maximum iteration, $iter_{max}$ = 50; control parameter of chaotic sequences $\mu = 4.0$ and the initial value of ‘f’ is a random value between [0, 1] except for (0, 0.25, 0.5, 0.75, and 1).

IV. RESULTS AND DISCUSSIONS

The suitability of the CPSO method has been tested for IEEE-30 bus system and compared with PSO algorithm. The IEEE 30 bus system description has been given in Tables 1 and 2. The algorithms are implemented in Matlab-7.12 programming language and the developed software code is executed on 1.67 GHz, 2 GB RAM INTEL(R) ATOM (TM) CPU (N455), DELL computer.

1. optimal power flow

The preferred generation schedule corresponding to the particular load condition is obtained by running a optimal power flow to minimize the generation cost alone and is given in Table 3. The generator outputs except the slack bus generator are considered as the variable for running optimal power flow. The PSO and CPSO algorithms are used to optimize the generation cost. It is giving the minimum generation cost values as 801.843 $/h by CPSO method. The corresponding power generation is taken as the preferred schedule to meet the normal load demand. The bidding cost coefficients are given in Table 4.

2. Congestion removal

The congestion is created in the system by loading at load Bus-14 and is occurred in Line-26 connecting Bus-10 and Bus-17. The real power flow of the Line-26 before and after the congestion management is given in Table 5 and shown in Figure 1. The real power flow obtained in the congested line (line-26) is 7.01 MW. But the real power flow limit of the line is 6.99 MW. The CPSO algorithm is used for finding the necessary change in power generation to remove this congestion on Line 26. The results of rescheduling the generation by PSO and CPSO algorithms are reported in Table 6. The 20 trail is made with both the algorithms and result of best cost, worst cost and mean value of cost is presented in the same table.

Table 1 Description of the Test system

Variables	**30 bus system**
Buses	30
Branches	41
Generators	6

Table 2 Generator cost co-efficient

Bus No.	Real power output limit of generator (MW)		Cost co-efficient		
	Min	Max	a	b	c
1	50	200	0.00375	2.00	0
2	20	80	0.01750	1.75	0
5	15	50	0.06250	1.00	0
8	10	35	0.00834	3.25	0
11	10	30	0.02500	3.00	0
13	12	40	0.02500	3.00	0

Generator Bus No.	Active power generation before congestion management (MW)	
	PSO	CPSO
1	176.93	176.73
2	48.72	48.83
5	21.44	21.47
8	21.60	21.65
11	12.10	12.10
13	12.0	12.0
Cost($/h)	801.844	801.843

Table 3 Active power generation before congestion management

Table 4 Bidding cost

GEN. NO.	1	2	3	4	5	6
BIDS	11	17	19	20	15	10

Table 5 Comparison of line flow before and after congestion management

Branch power flow		Before congestion management active power flow (MW)	After congestion management active power flow (MW)	
From bus	To bus		PSO	CPSO
10	17	7.01	6.93	6.86

Table 6 Active power generation after congestion management

Generator Bus No.	Active power generation after congestion management (MW)	
	PSO	CPSO
1	176.15	176.05
2	47.55	49.54
5	21.45	21.68
8	24.50	23.59
11	14.5	13.55
13	12.0	12.0

Best cost	226.53	220.75
Worst cost	290.11	247.68
Mean cost	260.73	240.63

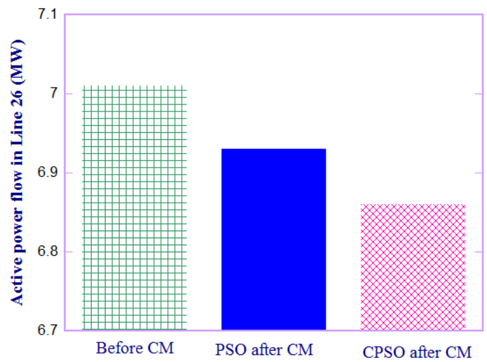


Figure 1 Active power flow in Line 26

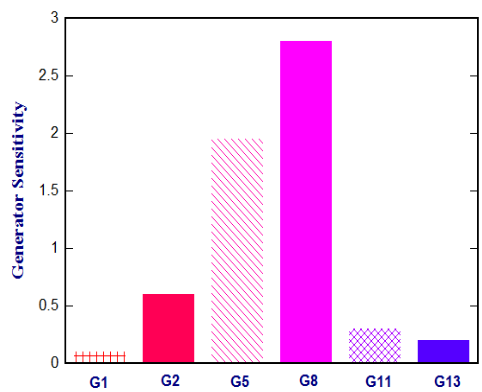


Figure 2 Generator sensitivity factors of Line 26

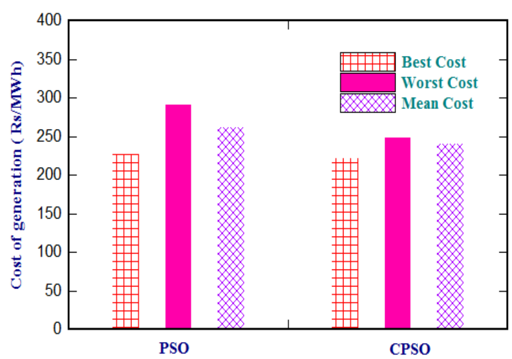


Figure 3 Comparison of cost of generation obtained by PSO and CPSO algorithms

V. CONCLUSION

The congestion management problem has been solved through optimal rescheduling of active powers of generators utilizing PSO and CPSO. The generators have been chosen based on the generator sensitivity to the congested line. The rescheduling has been carried out by taking minimization of cost and satisfaction of line flow limits into consideration. Results obtained by CPSO has been compared with conventional PSO and tested on the IEEE 30-bus. Based on the results, CPSO is the most cost-efficient solution to the congestion management problem compared with conventional PSO.

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AUTHORS

First Author – Dr. V.P. Sakthivel, Assistant Professor, Annamalai University and vp.sakthivel@yahoo.com
.

Second Author – S.V.Vijayasundaram, M.E, Annamalai University and Email id : viayeee02@gmail.com.

Correspondence Author – S.V.Vijayasundaram, M.E, Annamalai University, Email id: viayeee02@gmail.com and ph no. 9442338804