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OPTIMAL CONGEST MANAGEMENT BASED VEPSO ON ELECTRICITY MARKET

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Abstract- In this paper, optimal Congest Management (CM) problem by the Vector Evaluated Particle Swarm Optimization (VEPSO) in the deregulated electricity market is present. The CM problem is formulated as an optimization problem according to the generator sensitivity by objective function to minimizing re-dispatch cost which is solved by the VEPSO technique that has a strong ability to find the most optimistic results. In the proposed VEPSO technique, generators are choosing based on their sensitivity for efficient utilization on line congested. The task of optimal rescheduling active powers of participating generators to reduce transmission line congestion is attempted by VEPSO. The proposed algorithm applied on different test standard power system. The effectiveness of the proposed method is compared with CPSO, PSO-TVAC and PSO-TVIW. Results showed the efficiency of the proposed algorithm.

Keywords: VEPSO, Congest Management, Generator Sensitivity.

I. INTRODUCTION

The privatization and deregulation of electricity markets has a very important goal, especially on modern power systems around the world. Competitive electricity markets are complicate systems with many operators who buy and sell electricity [1]. Most of the complexity arises from the limitations of the underlying transmission systems and the fact that supply and demand must be in balance at all times. The Independent System Operator (ISO) is a regulating entity independent from the electric companies and optimizes the overall system operation [2].

Actually, in competitive market, the security of power system plays an important role from the market/system operator's point of view. When the producers and consumers of electric energy desire to produce and consume, this action leads to creation of some problems and calculation for transmission system to operate according to the transfer limits, which called the system is congested. Congestion management is about controlling the transmission system so that transfer limits are observed and is perhaps the most fundamental transmission management problem [3]. Congestion before deregulation was treated in terms of steady-state security and the basic objective was to control the generators' output so that system remained secure (no limits were violated) at the lowest cost as seen by the mutually agreeing vertically integrated utilities. However, applying the deregulation in power system, the congestion has become a term in conjunction with power systems and competition. When there is congestion in a transmission system, locational prices can be significantly different from those of unconstrained optimal solutions. Hence, congestion alleviation is very important issue and is an active area of research [4, 5].

Kumar et al, in [6] defined number of Congestion management approaches. The proposed CM problem based congestion factor method of distribution network describe in [7-9]. In the other hand, authors for this references used Ranking zone categorized by sensitivity index to divided active and reactive power. This method in computational aspect is complex. Also, it takes long simulation time to obtain the solution. Optimal Power Flow (OPF) technique with minimization congestion cost and service are presented in [10]. The [11] described OPF for synchronization between the producing company and ISO using disconnected port. Also OPF can be injected power to adjust the system condition for instability state and over load heat [12]. In [13], the concept of Relative Electrical Distance (RED) to alleviate overloaded lines by the timing of active power is described. This method minimized system Loss and improved voltage profile. However, in this paper has been not raised schedule cost. In [14], the method of production scheduling optimization considering scheduling based on cost minimization objective PSO is presented.

The PSO technique is proposed to improve optimization synthesis such that the global optima are guaranteed and the speed of algorithms convergence is extremely improved, too. PSO algorithm can be used to solve many of the same kinds of problems as GA and does not suffer from of GA's difficulties [5]. Generally, PSO is characterized as a simple concept, easy to implement, and computationally efficient. Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities.

This concept was used for the Vector Evaluated PSO (VEPSO) [15]. In VEPSO, which is inspired by VEGA, each swarm is exclusively evaluated with one of the objective functions; however information coming from other swarm(s) is used to influence a swarm's motion in the search space. Information communicated to each of the other swarms contains the global best particle found by each of the swarms. In the proposed method re-dispatched system with congestion management to minimize cost, congestion lines for overload condition and satisfied production constraints and generator loads. The results of simulation compared with CPSO, PSO-TVAC and PSO-TVIW [16]. Proposed method has a high convergence rate and placed in local areas.

II. THE CM FORMULATION

The optimal congestion management minimizing re-dispatch cost can be expressed as [8].

$$\min \sum_{g=1}^{Ng} Ic_g(\Delta P_g)\Delta P_g \quad (1)$$

where Ic_g is incremental and decremental cost of generator g, ΔP_g is Active power adjustment at bus g, g is participating generator and N_g is number of participating generators.

subject to:

- Power balance constraint:

$$\sum_{g=1}^{Ng} \Delta P_g = 0 \quad (2)$$

Operating limit constraints:

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max}; g = 1,2,\ldots, Ng \quad (3)$$

where $\Delta P_g^{\min} = P_g - P_g^{\min}, \Delta P_g^{\max} = P_g^{\max} - P_g$.

- Line flow constraints:

$$\sum_{g=1}^{Ng} (GS_g^{ij}.\Delta P_g) + F_l^0 \le F_l^{\max} \quad , l=1,2,\ldots,n \quad (4)$$

Selecting Redispatched Generators: The Generator Sensitivity (GS) technique indicates the change of active power flow due to change in active power generation. The GS value of generator g on the line connected between buses i and j can be written as [8].

$$GS_g^{ij} = \frac{\Delta P_{ij}}{\Delta P_{Gg}} = \frac{\partial P_{ij}}{\partial \theta_i}.\frac{\partial \theta_i}{\partial P_{Gg}} + \frac{\partial P_{ji}}{\partial \theta_j}.\frac{\partial \theta_j}{\partial P_{Gg}} \quad (5)$$

The power flow equation on congested lines can be calculated by:

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_i V_j G_{ij} \sin(\theta_i - \theta_j) + V_i V_j B_{ij} \cos(\theta_i - \theta_j) \quad (6)$$

$$\frac{\partial P_{ij}}{\partial \theta_j} = +V_i V_j G_{ij} \sin(\theta_i - \theta_j) + V_i V_j B_{ij} \cos(\theta_j - \theta_i) = -\frac{\partial P_{ij}}{\partial \theta_i} \quad (7)$$

The relation between the change in active power at each bus and voltage phase angles can be written as:

$$[\Delta P]_{n\times 1} = [H]_{n\times n} \times [\Delta\theta]_{n\times 1}$$

$$[H]_{n\times n} = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_1} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ : & : & & : \\ . & . & & . \\ \frac{\partial P_n}{\partial \theta_1} & \frac{\partial P_n}{\partial \theta_2} & \cdots & \frac{\partial P_n}{\partial \theta_n} \end{bmatrix}_{n\times n} \quad (8)$$

where $[M] = [H]^{-1}$ therefore $[\Delta\theta]_{n\times 1} = [M]_{n\times n} \times [\Delta P]_{n\times 1}$.

Since bus 1 is the reference bus, the first row and first column of $[M]$ can be eliminated. Therefore, the modified $[M]$ is written as:

$$[\Delta\theta]_{n\times 1} = \begin{bmatrix} 0 & 0 \\ 0 & [M-1] \end{bmatrix}_{n\times n} \times [\Delta P]_{n\times 1} \quad (9)$$

The modified [M] represents the values of $\frac{\partial \theta_i}{\partial P_{Gg}}$ and $\frac{\partial \theta_j}{\partial P_{Gg}}$ to calculate GS values. Large GS generators will be selected for redispatched since they are more influential on the congested line.

III. PARTICLE SWARM OPTIMIZATION

A. Standard PSO

The standard of the PSO are best describe as sociologically inspired, since the original algorithm was based on the sociological behavior associated with bird flocking [16, 17]. PSO is simple in concept, few in parameters, and easy in implementation, besides it has an excellent optimization performance. At first, PSO was introduced for continuous search spaces and because of the aforementioned features; it has been widely applied to many optimization problems soon after its introduction [18].

To explain how PSO algorithm works, an optimization problem which requires optimization of N variables simultaneously is considered here. PSO is initialized with a population of solutions, called "particles". At first, a random position and velocity is assigned to each particle. The position of each particle corresponds to a possible solution for the optimization problem. A fitness number is assigned to each particle which shows how good its position is. During the optimization process, each particle moves through the N-dimensional search space with a velocity that is dynamically adjusted according to its own and its companion's previous behavior. Updating the particle velocity is based on three terms, namely the "social" the "cognitive" and the "inertia" terms. The "social" part is the term guiding the particle to the best position achieved by the whole swarm of particles so far (*gbest*), the "cognitive" part guides it to the best position achieved by itself so far (*pbest*), and the "inertia" part is the memory of its previous velocity ($\omega . v_n$). The following formulae demonstrate the updating process of a particle position (x_n) and its velocity (v_n) in the nth dimension in an N-dimensional optimization space [17]:

$$v_i^{k+1} = \omega v_i^k + c_1 R_1 \left(pbest_i^k - x_i^k \right) + c_2 R_2 \left(gbest^k - x_i^k \right) \quad (10)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (11)$$

In Equation (11), R_1 and R_2 are random numbers uniformly distributed between 0 and 1. c_1 and c_2 are acceleration constants and ω is the inertia weight. These three parameters determine the tendency of the particles to the related terms. Moreover, another parameter is used to limit the maximum velocity of a particle (V_{max}). All these parameters directly affect the optimization behavior; for example, the inertia weight controls the exploration ability of the process while the acceleration constants and maximum velocity are parameters for controlling the convergence rate [16, 17]. The iterative procedure of updating the velocities and positions of particles continues until the best position achieved by the whole swarm of particles (*gbest*) does not change over several iteration. Figure 1 shows this process of PSO method to CM problem.

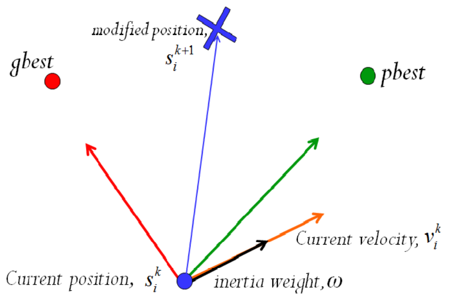


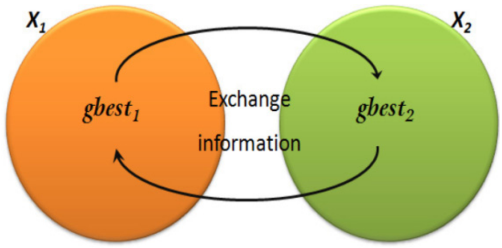
Figure 1. Velocity and location of particle updating process

B. VEPSO

The vector evaluated approach can be classified as a criterion-based multi-objective strategy, where different stages of the optimization process consider different objectives [15].

The actual implementation involves assigning each objective function to one of multiple populations for optimization. Information with respect to the different populations is exchanged in an algorithm-dependent fashion resulting in the simultaneous optimization of the various objective functions. As previously stated, the advantage of this approach lies in reduced computational complexity, which is a desirable property when solving a complex combinatorial problem where the fitness function evaluations are in them computationally expensive.

The basic concept of VEPSO algorithm is illustrated in Figure 2. As an example, for the case of two objective functions, X_1 and X_2 are swarm 1 and swarm 2, respectively, while $gbest_1$ and $gbest_2$ are the *gbest* for swarm 1 and swarm 2, respectively. As usual, v_1, v_2, s_1, and s_2 are the velocities and positions of each swarm.



$$v_1^{k+1} = \omega v_1^k + c_1 r_1 (pbest_1 - s_1^k) + c_2 r_2 (gbest_2 - s_1^k)$$

$$v_2^{k+1} = \omega v_2^k + c_1 r_1 (pbest_2 - s_2^k) + c_2 r_2 (gbest_1 - s_2^k)$$

Figure 2. The basic concept of VEPSO

The X_1 evaluates the objective function f_1 and X_2 evaluates the objective function f_2. There is no necessity for a complicated information migration scheme between the swarms as only two swarms are employed. Each swarm is exclusively evaluated according to the respective objective function. The *gbest* of the second swarm (X_2) is used for the calculation of the new velocities of the first swarm's (X_1) particles and accordingly, *gbest* of the first swarm (X_1) is used for the calculation of new velocities of the second swarm (X_2).

The VEPSO assumes that the search behaviour of a swarm is affected by a neighbouring swarm. The procedure of exchanging information among swarms can be clearly viewed as a migration scheme in a parallel computation framework. The flow chart is given as Figure 3.

IV. SIMULATION AND RESULTS

Different methods discussed earlier are applied to two cases to find out the minimum cost for any demand. One is IEEE 30-bus and other is 118-bus systems [15]. Results of proposed ABC algorithm are compared with Particle Swarm Optimization (CPSO [16], PSO-TVAC [16] and PSO-TVIW [16]). All the simulation has been calculated on Matlab 7.6 environment.

A. IEEE 30-Bus System

In the first case study, the IEEE 30-bus system with six generators and forty one lines is used. The system configuration of the proposed case study is shown in Figure 4 and the system data can be found in [15]. In this case, Bus 1 is considered as the reference bus or slack. A congested line between buses 1 and 2 exists as shown in Table 1. The maximum number of iterations and honey bee are set as 200 and 30, respectively. Table 2 shows the GS values of 6 generation units. Considering GS values, all generators are selected for re-dispatched.

Table 1. A congested line on first case study

Congested line	Active power flow (MW)	Line limit (MVA)	Overload (MW)
1 to 2	170	130	40

Table 2. Generation sensitivity of 6 units on the IEEE 30-bus system

Gen no	1	3	5	8	11	13
GS 1-2	0	-0.8908	-0.8527	-0.7394	-0.7258	-0.6869

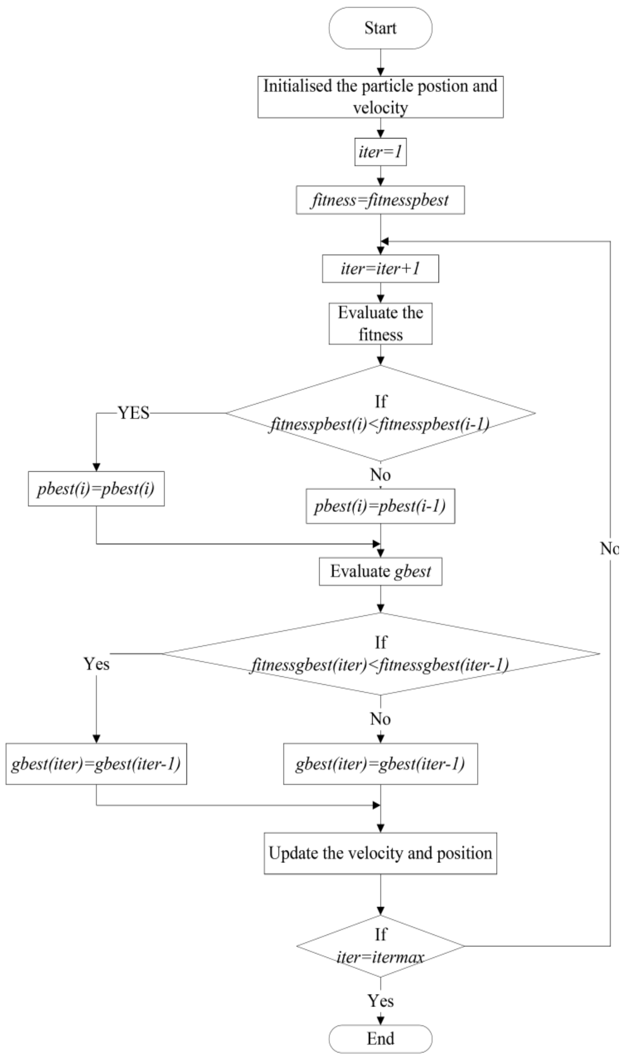


Figure 3. Flowchart for CM problem

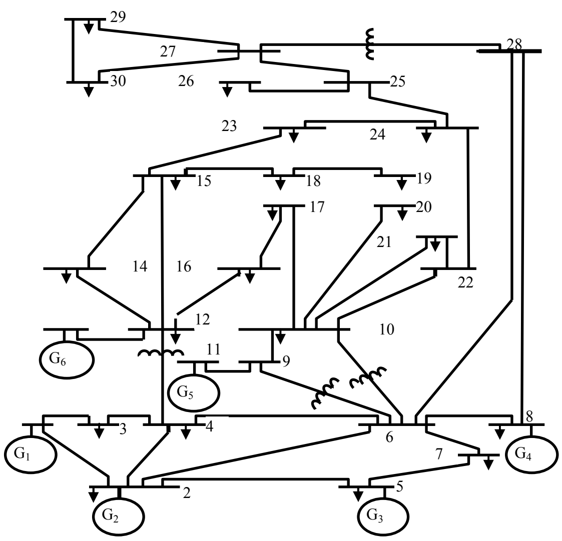


Figure 4. The IEEE 30-bus system configuration

The GS values of all six generators in the IEEE 30-bus system are high therefore it is needed to use all generators for re-dispatch to relieve the congested line. To achieve this goal, selected group of generators having the largest GS values may be used to save the computational effort. In Figure 5, the average active power adjustment and GS values of each generator have been shown. With 50 trial simulation, statistical results with VEPSO approaches are compared in Table 3. VEPSO provides the minimum re-dispatch cost solution of $ 232.35, whereas PSO-TVAC $ 237.9/h, CPSO and PSO-TVIW provide $ 240.3/h and $ 239.2/h, respectively. In addition, the solutions of VEPSO optimization have the lowest standard deviation 1.432; whereas this value in PSO-TVAC is 1.6, in CPSO and PSO-TVIW provide 48.2 and 3.8, respectively.

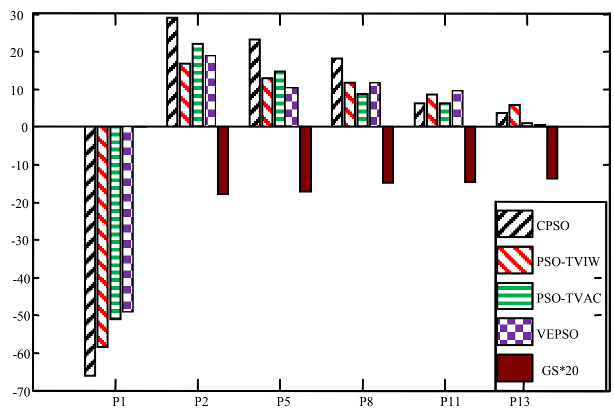


Figure 5. GS values and generation redispatch on the IEEE 30-bus system

B. IEEE 118-Bus System

The system configuration of the IEEE 118-bus system with 54 generators and 186 lines [16] is used as second case study. Bus 1 is assigned as the reference bus. The congested line data is shown in Table 4.

Table 3. A congested line on the IEEE 118-bus system

Congested line	Active power flow (MW)	Line limit (MVA)	Overload (MW)
89 to 90	260	200	60

Table. 4. Comparison of VEPSO solutions on the IEEE 30-bus system

MW	ΔP_1	ΔP_2	ΔP_5	ΔP_8	ΔP_{11}	ΔP_{13}	Total ΔP	*Cost* ($ /h)
				CPSO				
Max	-66.1	28.9	23.3	18.1	6.2	3.7	146.3	403.1
Min	-47.9	18.6	16.5	11.3	2.8	0.1	97.2	240.3
Mean	-55.9	22.6	16.2	10.5	5.6	2.6	113.2	287.1
SD	8.3	7.6	3.5	3.3	3.2	3.3	15.9	48.2
				PSO-TVIW				
Max	-58.5	16.7	13.0	11.8	8.6	5.7	114.2	288.0
Min	-47.3	20.1	14.5	10.5	4.8	0.5	97.7	239.2
Mean	-50.1	18.9	13.2	9.2	5.9	4.1	101.4	253.1
SD	2.8	3.5	5.4	3.3	3.5	6.1	13.3	3.8
				PSO-TVAC				
Max	-51.1	22.0	14.7	8.8	6.2	1.0	103.8	254.9
Min	-47.3	25.1	16.0	7.6	0.6	0.0	96.7	237.9
Mean	-49.3	17.5	14.0	9.9	6.8	3.0	100.5	247.5
SD	0.8	2.1	2.1	2.2	2.3	2.4	4.6	1.6
				VEPSO				
Max	-50.4	20.9	12.8	9.1	7.2	0.5	101.2	250.65
Min	-46.3	20.6	15.4	7.3	3.3	0.3	92.1	232.35
Mean	-50.1	19.2	15.8	9.2	3.5	2.2	98.85	244.76
SD	0.75	2.3	2.09	2.05	2.2	2.1	4.32	1.432

The GS values are shown in the Figure 6, the results of GS values for all generator buses are presented in Table 5. This results show, the generator buses 85, 87, 89, 90, and 91 are among the largest magnitude of GS. This implies that these generators could significantly affect to the congested line. Thus, they are chosen as re-dispatched generators. Using the largest GS values, only 6 generators out of 54 are used for re-dispatching by VEPSO algorithm, requiring a much less computational effort.

With 50-trial simulation, the solutions from VEPSO algorithm and different PSO approaches are shown in Table 6. From the results, VEPSO algorithm provides the lowest re-dispatch cost of $ 820.1h, while PSO-TVAC is 820.76/h and CPSO and PSO-TVIW provide the minimum $ 875.0/h and $ 853.8/h, respectively. Mean and standard deviation values of ABC algorithm is 94.34, however PSO-TVAC is 94, CPSO and PSO-TVIW provide 196.4 and 165.8, respectively.

The relationship between GS values and power re-dispatch shown in the Figure 7. As the GS at bus 85, 87, and 89 are positive, the generation output at these buses is reduced. By contrast, the generators at bus 90 and 91 have negative GS values, thus the generation is increased. Moreover, the GS magnitude affects the amount of active power adjustment. The reference bus is used to maintain the power balance.

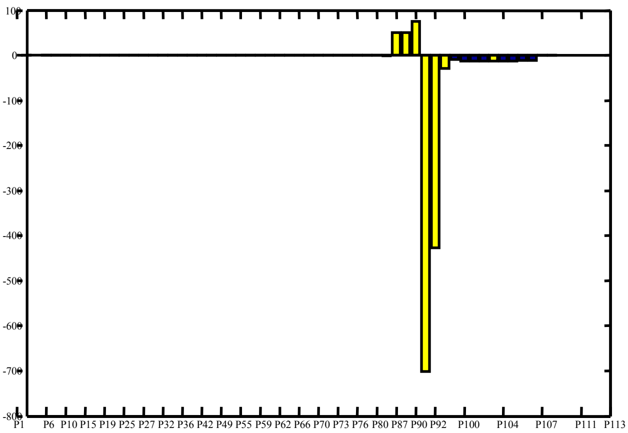


Figure 6. GS values of 54 units on the IEEE 118-bus system

Table 5. GS values of 54 generators on the IEEE 118-bus system

Gen no.	GS (10^{-3})	Gen no.	GS (10^{-3})	Gen no.	GS (10^{-3})
1	0	42	-0.0375	80	-0.9250
4	-0.0005	46	-0.0242	85	50.068
6	-0.0001	49	-0.0460	87	50.654
8	-0.0014	54	-0.0838	89	74.455
10	-0.0014	55	-0.0871	90	-701.15
12	0.0004	56	-0.0854	91	-427.90
15	0.0021	59	-0.1100	92	-28.411
18	0.0051	61	-0.1160	99	-9.391
19	0.0046	62	-0.1130	100	-12.915
24	0.1350	65	-0.1350	103	-12.737
25	0.0484	66	-0.0983	104	-12.854
26	0.0337	69	0.2120	105	-12.772
27	0.0451	70	0.3690	107	-12.202
31	0.0339	72	0.2326	110	-12.274
32	0.0477	73	0.3400	111	-12.07
34	-0.0323	74	0.5410	112	-11.747
36	-0.0329	76	0.8650	113	0.0110
40	-0.0343	77	0.0012	116	-0.1750

Table 6. Comparison of VEPSO solutions on the IEEE 118-bus system

MW	ΔP_1	ΔP_{85}	ΔP_{87}	ΔP_{89}	ΔP_{90}	ΔP_{91}	Total ΔP	Cost ($ /h)
CPSO								
Max	-5.1	-6.4	-8.6	-122.9	117.8	18.9	279.8	1604.5
Min	-5.1	-27.3	-27.5	-28.9	68.1	25.9	182.7	875.0
Mean	-5.9	-15.3	-31.5	-62.0	85.1	26.8	226.6	1183.8
SD	4.4	8.4	11.4	17.5	23.2	14.6	30.5	196.4
PSO-TVIW								
Max	-2.7	-13.8	-23.4	-97.7	121.4	10.4	269.4	1497.8
Min	-6.8	-18.2	-28.2	-33.1	78.3	8.9	173.5	853.8
Mean	-5.5	-12.1	-28.2	-59.8	76.4	29.8	211.7	1088.4
SD	4.3	6.7	10.7	16.9	21.1	13.5	26.3	165.8
PSO-TVAC								
Max	-5.9	-6.2	-6.5	-96.2	80.1	30.5	225.5	1229.6
Min	-0.8	-12.1	-13.9	-52.3	81.6	3.3	163.8	829.5
Mean	-4.4	-10.3	-22.0	-58.5	69.4	24.7	189.3	970.7
SD	2.9	5.0	10.0	15.1	9.8	16.1	16.5	94.5
VEPSO								
Max	-5.1	-6.1	-6.7	-96.8	83.3	31.8	227.55	1217.4
Min	-0.75	-11.3	-14.1	-50.7	85.8	3.23	165.76	820.76
Mean	-4.8	-9.9	-22.7	-60.5	75.5	26.5	198.67	969.87
SD	2.83	4.6	9.4	15.12	9.72	15.8	16.562	93.56

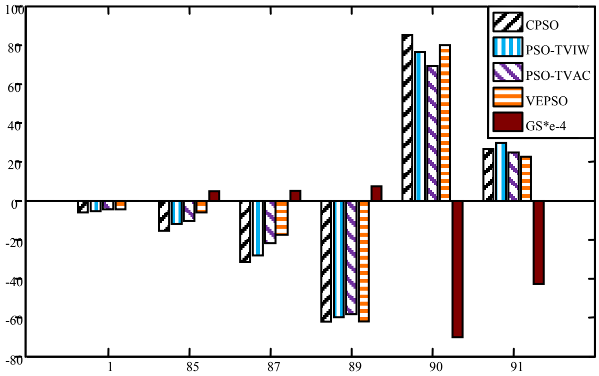


Figure 7. GS values and power redispatch on the IEEE 118-bus system

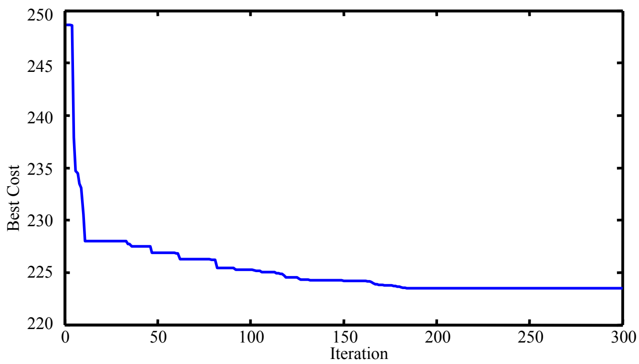


Figure 8. Convergence characteristics of VEPSO: IEEE 30-bus

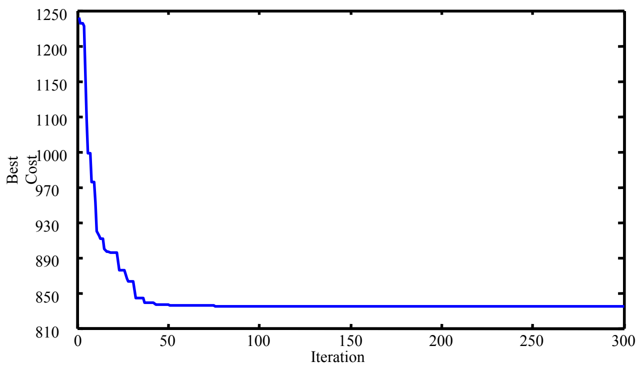


Figure 9. Convergence characteristics of VEPSO: IEEE 118-bus

In Figures 8 and 9, convergence characteristics of VEPSO are shown. The maximum iteration limit is set to 300. To demonstrate the robustness and effectiveness of the proposed technique, Table 7 shows the results of several runs.

Table 7. Results for some run in IEEE 30 bus

No. Run	Max	Mean	Min	Iteration
1	250.65	244.76	232.35	192
2	250.76	244.75	232.36	190
3	250.68	244.79	232.37	189
4	250.64	244.74	232.35	193
5	250.63	244.76	232.36	195
6	250.68	244.76	232.35	201
7	250.67	244.73	232.36	197
8	250.64	244.76	232.35	195
9	250.65	244.79	232.38	196
10	250.66	244.81	232.35	194
S.D	0.0353	0.0233	0.0098	3.31

V. CONCLUSIONS

In this paper describes the implementation of the VEPSO technique to develop a market-based approach to the problem of transmission congestion management in a electricity Market. In the other hand, the VEPSO technique has been used to simulate the considered market models and the congestion problems. The IEEE 30-bus and the IEEE 118-bus test systems have been used to demonstrate the robustness of the approaches. The objectives of congestion management are different in different market. The proposed method convergence rate is really less than in comparison other methods in solving complex mathematical problems. The numerical results demonstrate that the proposed method has better ability in finding optimal answers and possibility of particle placed in local zone. Moreover, the proposed strategy has simple structure, easy to implement and tune and therefore it is recommended to generate good quality and reliable electric energy in the restructured power systems.

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