Optimal Generator Redispatching for Congestion Management Using PSO-TVAC

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Abstract— *This paper proposes the optimal generator redispatching approach for congestion management by particle swarm optimization with time varying acceleration coefficients (PSO-TVAC). The system cost and generator redispatching minimization is concerned. In congestion management process, redispatched generators are indicated by generator sensitivity (GS) technique. It aims to reduce in number of participating generators. The IEEE 30-bus and 118-bus systems are used to illustrate the proposed approach. The simulation results show the PSO-TVAC could provide better solutions than the other PSO schemes for the congestion management problem. The proposed approach is useful for the system operator (SO) to manage the transmission congestion in deregulated environment.*

Keywords— **Congestion management, deregulated market, generator redispatching, PSO, sensitivity factor and transmission system.**

1. INTRODUCTION

In the deregulated environment, power system is operated nearly to the limits at given time in order to achieve maximum power transfer. Three crucial power transfer limits are thermal limit, voltage limit and stability limit. When power transfers over such limits, the congested problems occur in the system. Therefore, congestion management becomes major tasks for the SO in deregulated market.

Several researchers have addressed where the system is the most sensitive of the power transfer over the limits. In [1]-[3], the technique called transmission congestion distribution factors (TCDFs) was discussed. Nevertheless, in this technique, all buses are required to participate in the computation. In [4], relative electrical distance (RED) concept was introduced to mitigate the overload by generation redispatching.

The reviews on optimal power flow (OPF) for congestion management scheme are interested for several researches. In [5] has been expressed the based OPF approach for minimized cost of congestion and service costs. OPF for coordination between generating companies (GENCOs) and the independent system operator (ISO) using the bender cuts has been discussed in [6]. In [7] has been used OPF for the least cost to adjust the power injection in the market-based and optimal curtail transactions due to voltage instability and thermal overload.

PSO has been used to solve several power system optimization problems. In [8], considering the economic dispatch problem, PSO could provide higher quality solution compared with genetic algorithm (GA). In [9], PSO was applied to the voltage security assessment for reactive power and voltage control. In [10]-[12] have been proved the effectiveness for PSO's various strategies.

This study proposes the congestion management using the active power redispatching by the optimal generators adjustment. The participating generators are selected by GS technique. It purposes to reduce the complexity of computation during congestion management process. The objective function is to minimize the redispatching cost while satisfied congestion constrains. The different PSO schemes are introduced of the ability to find optimal solution in congestion management. The paper illustrates the effectiveness of proposed technique considering IEEE 30-bus and 118-bus systems.

The organizations of this paper are as follows: Section 3 discusses the problem formulation. Section 4 introduces the GS approach to indicate the optimal generator for redispatching. In Section 5, several PSO schemes are expressed. Section 6 shows the steps of algorithm in this study. Section 7 reveals the numerical examples and results of congestion management problem through both considered systems. Section 8 concludes this paper.

2. PROBLEM FORMULATION

The objective function is formulated based on the minimum system cost and minimum of active power redispatching which is expressed as

$$Minimize \sum_{g}^{Ng} C_g\left(\Delta P_g\right)\Delta P_g \tag{1}$$

$$\Delta P_g^{\min} \le \Delta P_g \le \Delta P_g^{\max};\ g=1,2,\ldots,N_g \tag{2}$$

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

$$\sum_{g=1}^{Ng} \Delta P_g = 0 \tag{3}$$

$$\sum_{g=1}^{Ng}\left(\left(GS_g^{k}\right)\Delta P_g\right) + F_l^{0} \le F_l^{\max};\ l=1,2,\ldots,n_l \tag{4}$$

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Although (3) maintains power balance and includes change in active power at slack bus, the last generation allocation at slack bus is contained at the end of optimization processes which hold on the system losses.

3. CONGESTION MANAGEMENT APPROACH

The GS value indicates the change of active power flow in line *k* due to change in active power generation by generator g^{th}. Mathematically, GS value by generator g^{th} of line *k* can be written as

$$GS_g^k = \frac{\Delta P_{ij}}{\Delta P_{G_g}} \tag{5}$$

Following (5) can be expanded as

$$GS_g^k = \frac{\partial P_{ij}}{\partial \theta_i}\frac{\partial \theta_i}{\partial P_{G_g}} + \frac{\partial P_{ji}}{\partial \theta_j}\frac{\partial \theta_j}{\partial P_{G_g}} \tag{6}$$

The power flow equation on congested line can be calculated by

$$P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij}\cos(\theta_i - \theta_j) + V_i V_j B_{ij}\sin(\theta_i - \theta_j) \tag{7}$$

The differentiations of (7) with respect to θ_i and θ_j are contained in (8) and (9)

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_i V_j G_{ij}\sin(\theta_i - \theta_j) + V_i V_j B_{ij}\cos(\theta_i - \theta_j) \tag{8}$$

$$\frac{\partial P_{ij}}{\partial \theta_j} = +V_i V_j G_{ij}\sin(\theta_i - \theta_j) - V_i V_j B_{ij}\cos(\theta_i - \theta_j) = -\frac{\partial P_{ij}}{\partial \theta_i} \tag{9}$$

The active power injected at a bus-s which refers to any bus in the system can be explicated as

$$\begin{aligned} P_s &= |V_s|\sum_{t=1}^{n}\{(G_{st}\cos(\theta_s - \theta_t) + B_{st}\sin(\theta_s - \theta_t))|V_t|\} \\ &= |V_s|^2 G_{ss} + |V_s|\sum_{\substack{t=1 \\ t\neq s}}^{n}\{(G_{st}\cos(\theta_s - \theta_t) + B_{st}\sin(\theta_s - \theta_t))|V_t|\} \end{aligned} \tag{10}$$

The further calculation can be linked by differentiating (10) as contained in (11) and (12)

$$\frac{\partial P_s}{\partial \theta_t} = |V_s||V_t|\{G_{st}\sin(\theta_s - \theta_t) + B_{st}\cos(\theta_s - \theta_t)\} \tag{11}$$

$$\frac{\partial P_s}{\partial \theta_s} = |V_s|\sum_{\substack{t=1 \\ t\neq s}}^{n}\{(-G_{st}\sin(\theta_s - \theta_t) + B_{st}\cos(\theta_s - \theta_t))|V_t|\} \tag{12}$$

By neglecting P-V coupling, the relation between the change in active power at system buses and the phase angles of voltages can be formulated as matrix as shown below

$$\underset{n\times 1}{[\mathbf{\Delta P}]} = \underset{n\times n}{[\mathbf{H}]}\underset{n\times 1}{[\mathbf{\Delta \theta}]} \tag{13}$$

$$\underset{n\times n}{[\mathbf{H}]} = \begin{bmatrix} \frac{\partial \mathbf{P_1}}{\partial \boldsymbol{\theta}_1} & \frac{\partial \mathbf{P_1}}{\partial \boldsymbol{\theta}_2} & \cdots & \frac{\partial \mathbf{P_1}}{\partial \boldsymbol{\theta}_n} \\ \frac{\partial \mathbf{P_2}}{\partial \boldsymbol{\theta}_1} & \frac{\partial \mathbf{P_2}}{\partial \boldsymbol{\theta}_2} & \cdots & \frac{\partial \mathbf{P_2}}{\partial \boldsymbol{\theta}_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \mathbf{P_n}}{\partial \boldsymbol{\theta}_1} & \frac{\partial \mathbf{P_n}}{\partial \boldsymbol{\theta}_2} & \cdots & \frac{\partial \mathbf{P_n}}{\partial \boldsymbol{\theta}_n} \end{bmatrix}_{n\times n} \tag{14}$$

Given

$$[\mathbf{M}] = [\mathbf{H}]^{-1} \tag{15}$$

Thus

$$[\mathbf{\Delta \theta}] = [\mathbf{M}][\mathbf{\Delta P}] \tag{16}$$

As bus 1 is the reference bus, the first row and first column can be eliminated. Therefore, (16) is written as

$$\underset{n\times 1}{[\mathbf{\Delta \theta}]} = \underset{n\times n}{\begin{bmatrix} \mathbf{0} & \mathbf{0} \\ \mathbf{0} & [\mathbf{M_{-1}}] \end{bmatrix}}\underset{n\times 1}{[\mathbf{\Delta P}]} \tag{17}$$

All GSs in the system are computed and to indicate that how much the active power flow on line *k* would changes due to active power injection from generator g^{th}. When GSs are non-uniform and large magnitude, they would be selected by the SO to participate in active power output adjustment.

4. PSO SCHEMES

PSO adopts "velocity-position" searching models. Each particle represents a potential solution to a problem in d^{th}-dimensional spaces, whose superior or inferior degree can be evaluated by calculating its fitness. Velocity, $V_p = (v_{p1}, v_{p2}, \dots, v_{pd})$, determine particle p^{th} searching direction and step length for each iteration in d^{th}-dimensional space.

Position of particle, $X_p = (x_{p1}, x_{p2}, \dots, x_{pd})$, are evaluated relative to a goal (fitness) at every iteration, and all particles share memories of their own "best" positions $pbest_p = (p_{p1}, p_{p2}, \dots, p_{pd})$ and their "best" position $gbest_g = (g_{g1}, g_{g2}, \dots, g_{gd})$ to adjust their own velocities, and thus subsequent positions.

A. Classical PSO (CPSO)

CPSO is mathematically defined as [12]

$$\begin{aligned} v_{pd}^{q+1} &= w \times v_{pd}^{q} + c_1 \times rand_1 \times (pbest_{pd} - x_{pd}) \\ &+ c_2 \times rand_2 \times (gbest_{gd} - x_{pd}) \end{aligned} \tag{18}$$

$$x_{pd}^{q+1} = x_{pd} + v_{pd}^{q+1} \qquad (19)$$

B. PSO with Time Varying Inertia Weight (PSO-TVIW)

Though the concept of PSO-TVIW is same with CPSO with respect to algorithm used, some parameters for update velocity are adapted by using inertia weight. The equation can be expressed as [11]

$$v_{pd}^{q+1} = C\left\{\begin{aligned} & w \times v_{pd}^{q} + c_1 \times rand_1 \times \left(pbest_{pd} - x_{pd}\right) \\ & \qquad + c_2 \times rand_2 \times \left(gbest_{gd} - x_{pd}\right) \end{aligned}\right\} \qquad (20)$$

$$C = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}, \text{ where } 4.1 \le \varphi \le 4.2 \qquad (21)$$

$$w = \left(w_{\max} - w_{\min}\right) \times \frac{\left(q_{\max} - q\right)}{q_{\max}} + w_{\min} \qquad (22)$$

C. PSO with Time Varying Acceleration Coefficients (PSO-TVAC)

In order to have the ability of PSO to fine tune the optimal solution, cognitive and social components are adapted with time. The velocity update of PSO-TVAC can be described as [10]

$$v_{pd}^{q+1} = C\left\{\begin{aligned} & w \times v_{pd}^{q} + \left(c_{1f} - c_{1i}\right)\frac{q}{q_{\max}} + c_{1i} \times rand_1 \times \left(pbest_{pd} - x_{pd}\right) \\ & \qquad + \left(c_{2f} - c_{2i}\right)\frac{q}{q_{\max}} + c_{2i} \times rand_2 \times \left(gbest_{gd} - x_{pd}\right) \end{aligned}\right\} \qquad (23)$$

5. SOLUTION ALGORITHM

The processes of congestion management by PSO algorithm are as follows.

Step 1: Identify congested lines by power flow equation.

Step 2: Calculate GS values follow section 2 to select the optimal generator participants. These generators would be d^{th}-dimensions parameter in PSO algorithm.

Step 3: Set parameters of PSO.

Step 4: Initialize the active power output redispatching.

Step 5: The values of position best and global best are defined by evaluating the objective function.

Step 6: Update the velocity and particles until exceed the maximum iteration.

Step 7: If the objective function is satisfied, the program is stopped, otherwise return to step 4.

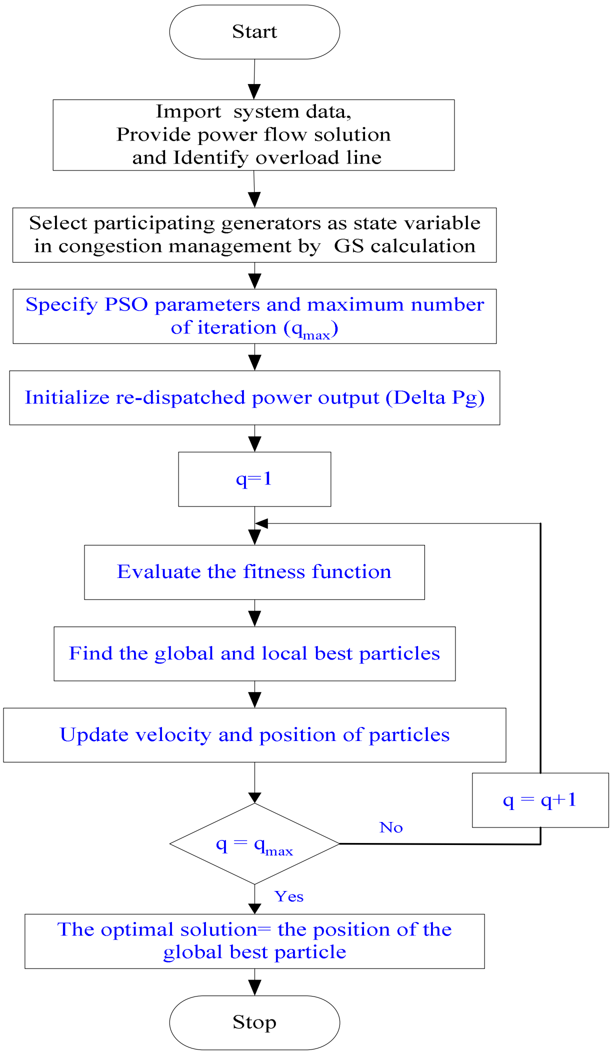

Fig. 1. Flow chart of congestion management by PSO

6. NUMERICAL RESULTS

A. IEEE 30-bus system

The IEEE 30-bus system in [13] consists of six generating units, 24 load buses and 41 lines. The reference bus is bus 1. The MVA base of 100 MVA is used.

Table 1. Congested line case study in IEEE 30-bus system

Congested line	Active Power Flow (MW)	Line Limit (MW)	Over the limit (MW)
1 to 2	170	130	40

The congested line 1-2 is over the limit by 40 MW as introduced in Table 1. All the generators are influent because the magnitudes of all GSs are large excluding slack bus. Figure 2 can clearly shows significance of GSs. GS of the reference bus is usually zero, and this bus is always participated. So, all of the generators are taken part in redispatching of active power output.

The PSO algorithm is responsible after selected participating generators. The six dimensions are given with regard to the selected generators. The particle size set as 70 particles with 400 iterations. The parameters set up by three different PSO schemes are tabulated.

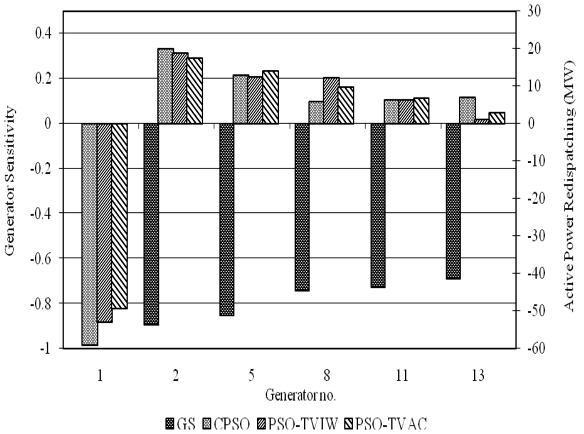

Fig.2. Selected GSs for active power redispatching in IEEE 30-bus system.

Table 2. Parameters of PSO

Parameters	CPSO	PSO-TVIW	PSO-TVAC
c_1	2	2	$c_{1i} = 2.5$ $c_{1f} = 0.2$
c_2	2	2	$c_{2i} = 0.2$ $c_{2f} = 2.5$
W	0.5	$w_{min} = 0.4$ $w_{max} = 0.9$	$w_{min} = 0.4$ $w_{max} = 0.9$
C	-	$\varphi = 4.1$	$\varphi = 4.1$

Table 3. Solutions by PSO schemes in IEEE 30-bus system

	GS	CPSO[14]	PSO-TVIW	PSO-TVAC
ΔP_1 (MW)	0	-59	-52.79	-49.25
ΔP_2 (MW)	-0.8908	19.9	18.87	17.51
ΔP_5 (MW)	-0.8527	13	12.49	14.02
ΔP_8 (MW)	-0.7394	6	12.36	9.88
ΔP_{11} (MW)	-0.7258	6.5	6.41	6.8
ΔP_{13} (MW)	-0.6869	7	1.10	3.01
Total redispatching (MW)		111.4	104.02	100.47
Cost ($/hr)		269	252.50	246.22

The GSs can indicate direction of active power adjustment. The power adjustment and the sign of GSs are opposite due to (4). The GSs with negative sign affect to increase in active power output, and the amount of active power increasing is also sensitive to GSs as shown in Figure 2. Although there is no any positive sign for GS, the reference bus with zero GS could be representative in decreasing active power output to balance the power injection. The trend of active power adjustment is similarly sensitive to GS for all PSO schemes.

The solutions by PSO schemes on congestion management are presented in Table 3. The inertia weight with varying to iteration time could search to the optimal solution with the lower cost of redispatching by $16.5/hr compared to classical PSO scheme in [14]. However, the results found that the two acceleration coefficients pull the solution to the most optimal point in search space with $23/hr cost reduction. Therefore, PSO-TVAC is the best capable to fine the optimal solution among other two PSO schemes.

B. IEEE 118-bus system

The IEEE 118-bus system in [15]-[17] is tested to highlight the advantage of GS technique and to reveal the ability of PSO algorithm schemes on the representative practical system for the congestion management. It involves with 54 generating buses and 186 lines. Following to the previous study, bus 1 is assigned as a reference bus. The 100 MVA based is also used.

The congested line occurred between bus 89 and 90 by 60 MW as presented in Table 4. The selected generators would contain the large magnitude of GS comparing with all the generators as computed in Table 5. The participating generators can be obviously observed in Figure 3. The generators number 85, 87, 89, 90 and 91 have non uniform GSs, and the magnitudes of GSs are also much larger. Thus, they are selected to participate in redispatching active power output. The reference bus is also chosen for participating in order to balance power adjustment. The only 6 generating units are taken part for congestion management while the numbers of all generators in the system are 54 units. This is proved the advantage of GS technique that it is extremely reduced in number of participating generators. Moreover, the generator number 89 is the maximum positive sensitivity value whereas the generator number 90 is the minimum negative sensitivity values. It is interested to note that they both represent the same bus of congested line.

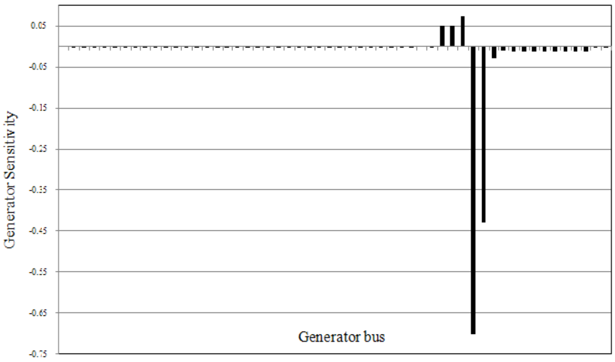

Fig.3. GS values of 54 units in IEEE 118-bus system

Table 4. Congested line case study in IEEE 118-bus system

Congested line	Active Power Flow (MW)	Line Limit (MW)	Over the limit (MW)
89 to 90	260	200	60

Table 5: GS values of 54 units in 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

The task to fine the optimum solution can be done by PSO algorithm with different parameters schemes in Table 2. However, in this system vary by 600 iterations and the number of particles is given by 70 particles. With respect to the selected generators, there are six dimensions in search space. The comparisons in Table 6 propose the indication of GS. Increase in active power output of participating generators would be obtained the negative GS sign while participating generators contains the positive GS sign would decrease power adjustment. This can be distinctly illustrated by Figure 4. It is shown the sensitive of active power adjustment to GS compared among same sign of GSs.

Table 6. Solutions by PSO schemes in IEEE 118-bus system

	GS	CPSO	PSO-TVIW	PSO-TVAC
ΔP_1 (MW)	0	-7.03	-0.08	-3.08
ΔP_{85} (MW)	0.050068	-16.62	-14.86	-18.02
ΔP_{87} (MW)	0.050654	-30.4	-30.27	-25.28
ΔP_{89} (MW)	0.074455	-51.73	-51.72	-43.34
ΔP_{90} (MW)	-0.70150	55.81	58.16	68.41
ΔP_{91} (MW)	-0.42790	45.32	39.57	21.22
Total redispatching (MW)		206.94	194.66	179.34
Cost ($/hr)		1042.28	971.59	887.09

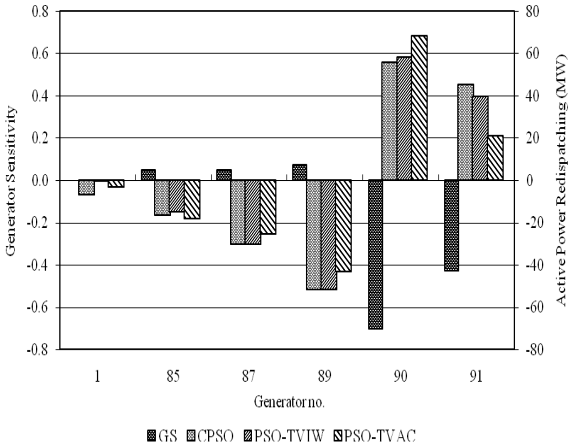

Fig. 4. Selected GSs for active power redispatching in IEEE 118-bus system.

The results from comparing PSO schemes are similarly trended with previous study. The PSO-TVIW is more capable to search the minimum cost than CPSO with $71/hr. Nevertheless, the achievement of PSO-TVAC proposed method is investigated in fine tune to optimal solution by $155/hr as compared to classical scheme.

7. CONCLUSION

This paper proposes the technique for congestion management in deregulated market using PSO-TVAC. The results are tested on IEEE 30-bus and 118-bus systems. The selection of optimal generators to participate in congestion management can be indicated by GS values. The GS technique provides the direction of active power adjustment. It also implies the sensitive of active power redispatching to GS values. The radical decrease in number of participating generators is aimed for GS benefit as investigated in the last study. The results for both systems show that PSO-TVAC is an efficient approach to find the optimal solution with the lowest cost and the minimum active power redispatching. The proposed approach is applicable for the SO to manage the transmission congestion in deregulated market.

NOMENCLATURE

The notations used in this paper are given below.

N_g	Number of participating generators.
ΔP_g	Active power adjustment at bus g where generator g^{th} is installed.
C_g	Incremental and decremented priced bids.
P_g	Active power operating output.
$\Delta P_g^{\min}$	Minimum limit of the generator outputs.
$\Delta P_g^{\max}$	Maximum limit of the generator outputs.
F_l^0	Power flow caused by all contracts requesting the transmission service.
$F_l^{\max}$	Power flow limit of line *l*.
n_l	Number of transmission lines in the system.
k	Congested line connected between buses *i-j*.
ΔP_{ij}	Changed in active power flow on line *k*.
ΔP_{G_g}	Changed in active power of g^{th} generator.
V_i, V_j	Voltage mag. at buses *i* and *j* respectively.
θ_i, θ_j	Phase angle at buses *i* and *j* respectively.
G_{ij}	Conductance of line *k*.
B_{ij}	Susceptance of line *k*.
n	Number of all the buses in the system.
q	Current iteration number.
$q_{\max}$	Maximum number of iterations.
w	Inertia weight.
$w_{\min}$	Minimum inertia weight.
$w_{\max}$	Maximum inertia weight.
C	Constriction factor.
c_1	Cognitive acceleration coefficient.
c_{1i}, c_{1f}	Initial and final values of c_1.
c_2	Social acceleration coefficient.
c_{2i}, c_{2f}	Initial and final values of c_2.
$rand_i$	Random numbers between 0 and 1, *i* =1, 2.

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