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AMENDED PARTICLE SWARM OPTIMIZATION ALGORITHM FOR REAL POWER LOSS REDUCTION AND STATIC VOLTAGE STABILITY MARGIN INDEX ENHANCEMENT

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Abstract

In this paper, Amended Particle Swarm Optimization Algorithm (APSOA) is proposed with the combination of Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA) for solving the optimal reactive power dispatch Problem. PSO is one of the most widely used evolutionary algorithms in hybrid methods due to its simplicity, convergence speed, an ability of searching Global optimum. GSA has many advantages such as, adaptive learning rate, memory-less algorithm and, good and fast convergence. Proposed hybridized algorithm is aimed at reduce the probability of trapping in local optimum. In order to assess the efficiency of proposed algorithm, it has been tested on Standard IEEE 30 system and compared to other standard algorithms. The simulation results demonstrate worthy performance of the Amended Particle Swarm Optimization Algorithm (APSOA) in solving optimal reactive power dispatch problem.

Keywords: Gravitational Search Algorithm (GSA); Particle Swarm Optimization (PSO); Optimal Reactive Power Dispatch.

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1. Introduction

In recent years the optimal reactive power dispatch (ORPD) problem has received great attention as a result of the improvement on economy and security of power system operation. Gradient method [1, 2] Newton method [3] and linear programming [4-6] like various mathematical techniques have been adopted to solve the optimal reactive power dispatch problem. But they have difficulty in handling inequality constraints. Many Evolutionary algorithms such as have been proposed to solve the reactive power dispatch problem [7-10]. In this paper, Amended Particle Swarm Optimization Algorithm (APSOA) is proposed with the combination of Particle Swarm Optimization (PSO) and Gravitational Search Algorithm (GSA) for solving the optimal reactive power dispatch Problem. Merging the optimization algorithms is a way to balance the

overall exploration and Exploitation ability. PSO is one of the most widely used evolutionary algorithms in hybrid methods due to its simplicity, convergence speed, an ability of searching Global optimum. GSA has many advantages [11] such as, adaptive learning rate, memory-less algorithm and, good and fast convergence. There are some studies in the literature [12-19] which have been done to synthesize PSO with other algorithms. These hybrid algorithms are aimed at reducing the probability of trapping in local optimum. PSO is one of the most widely used evolutionary algorithms in hybrid methods due to its simplicity, convergence speed, an ability of searching Global optimum. GSA has many advantages such as, adaptive learning rate, memory-less algorithm and, good and fast convergence. This hybridized algorithm is aimed at reduce the probability of trapping in local optimum. In order to assess the efficiency of proposed algorithm, it has been tested on Standard IEEE 30 system and compared to other standard algorithms. The simulation results demonstrate worthy performance of the Amended Particle Swarm Optimization Algorithm (APSOA) in solving optimal reactive power dispatch problem.

2. Voltage Stability Evaluation

2.1. Modal Analysis for Voltage Stability Evaluation

Power flow equations of the steady state system is given by,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{p\theta} & J_{pv} \\ J_{q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} \tag{1}$$

Where
ΔP = bus real power change incrementally.
ΔQ = bus reactive Power injection change incrementally.
$\Delta \theta$ = bus voltage angle change incrementally.
ΔV = bus voltage Magnitude change incrementally.
$J_{p\theta}$, JPV , JQθ , JQV are sub-matrixes of the System voltage stability in jacobian matrix and both P and Q get affected by this.

Presume $\Delta P = 0$, then equation (1) can be written as, $\Delta Q = \left[J_{QV} - J_{Q\theta} J_{P\theta^{-1}} J_{PV} \right] \Delta V = J_R \Delta V$ $\quad$ (2)

$$\Delta V = J^{-1} - \Delta Q \tag{3}$$

Where

$$J_R = \left(J_{QV} - J_{Q\theta} J_{P\theta^{-1}} JPV \right) \tag{4}$$

J_R denote the reduced Jacobian matrix of the system.

2.2. Modes of Voltage Instability

Voltage Stability characteristics of the system have been identified through computation of the Eigen values and Eigen vectors.
$$J_R = \xi \wedge \eta \tag{5}$$

Where,

ξ denote the right eigenvector matrix of JR, η denote the left eigenvector matrix of JR, $\wedge$ denote the diagonal eigenvalue matrix of JR.

$$J_{R^{-1}} = \xi \wedge^{-1} \eta \qquad (6)$$

From the equations (5) and (6),

$$\Delta V = \xi \wedge^{-1} \eta \Delta Q \qquad (7)$$

Or

$$\Delta V = \sum_I \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \qquad (8)$$

ξ_i denote the ith column right eigenvector & η is the ith row left eigenvector of JR.
λ_i indicate the ith Eigen value of JR.

reactive power variation of the ith modal is given by,

$$\Delta Q_{mi} = K_i \xi_i \qquad (9)$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \qquad (10)$$

Where ξ_{ji} is the jth element of ξ_i
ith modal voltage variation is mathematically given by,

$$\Delta V_{mi} = [1/\lambda_i] \Delta Q_{mi} \qquad (11)$$

When the value of $| \lambda_i | = 0$ then the ith modal voltage will get collapsed.

In equation (8), when $\Delta Q = ek$ is assumed , then ek has all its elements zero except the kth one being 1. Then ΔV can be formulated as follows,

$$\Delta V = \sum_i \frac{\eta_{1k} \xi_1}{\lambda_1} \qquad (12)$$

η_{1k} is k th element of η_1
At bus k V –Q sensitivity is given by,

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k} \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \qquad (13)$$

3. Problem Formulation

To minimize the real power loss and also to maximize the static voltage stability margin (SVSM) is the key objectives of the reactive power dispatch problem.

3.1. Minimization of Real Power Loss

Real power loss (Ploss) minimization in transmission lines is mathematically given as,

$$P_{loss} = \sum_{\substack{k=1 \\ k=(i,j)}}^{n} g_{k(V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij})} \tag{14}$$

Where n is the number of transmission lines, g_k is the conductance of branch k, V_i and V_j are voltage magnitude at bus i and bus j, and θ_{ij} is the voltage angle difference between bus i and bus j.

3.2. Minimization of Voltage Deviation

At load buses minimization of the voltage deviation magnitudes (VD) is stated as follows,

$$\text{Minimize VD} = \sum_{k=1}^{nl} |V_k - 1.0| \tag{15}$$

Where nl is the number of load busses and V_k is the voltage magnitude at bus k.

3.3. System Constraints

These are the following constraints subjected to objective function as given below,
Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_i \sum_{j=1}^{nb} V_j \begin{bmatrix} G_{ij} & \cos \theta_{ij} \\ +B_{ij} & \sin \theta_{ij} \end{bmatrix} = 0, i = 1,2 \dots, nb \tag{16}$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{nb} V_j \begin{bmatrix} G_{ij} & \sin \theta_{ij} \\ +B_{ij} & \cos \theta_{ij} \end{bmatrix} = 0, i = 1,2 \dots, nb \tag{17}$$

where, nb is the number of buses, P_G and Q_G are the real and reactive power of the generator, P_D and Q_D are the real and reactive load of the generator, and G_{ij} and B_{ij} are the mutual conductance and susceptance between bus i and bus j.

Generator bus voltage (V_{Gi}) inequality constraint:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \tag{18}$$

Load bus voltage (V_{Li}) inequality constraint:

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \tag{19}$$

Switchable reactive power compensations (Q_{Ci}) inequality constraint:

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \tag{20}$$

Reactive power generation (Q_{Gi}) inequality constraint:

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \tag{21}$$

Transformers tap setting (T_i) inequality constraint:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt \tag{22}$$

Transmission line flow (S_{Li}) inequality constraint:

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \tag{23}$$

Where, nc, ng and nt are numbers of the switchable reactive power sources, generators and transformers.

4. Particle Swarm Optimization

Particle Swarm Optimization (PSO) is an evolutionary computation technique which is inspired from social behavior of bird flocking. It uses a number of particles (candidate solutions) which fly around in the search space to find best solution. Meanwhile, they all look at the best particle (best solution) in their paths. In other words, particles consider their own best solutions as well as the best solution has found so far. Each particle in PSO should consider the current position, the current velocity, the distance to *pbest*, and the distance to *gbest* to modify its position. PSO was mathematically modeled as follow:

$$v_i^{t+1} = wv_i^t + c_1 \times rand \times (pbest_i - x_i^t) + c_2 \times rand \times (gbest - x_i^t) \tag{24}$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} \tag{25}$$

The PSO starts with randomly placing the particles in a problem space. In each iteration, the velocities of particles are calculated using equation (24). After defining the velocities, the position of masses can be calculated by equation (25). The process of changing particles' position will continue until meeting an end criterion.

5. Gravitational Search Algorithm

Gravitational Search Algorithm (GSA) is a novel heuristic optimization method which is inspired from is the Newton's theory that states: Every particle in the universe attracts every other particle with a force that is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. GSA can be considered as a collection of agents

(candidate solutions) whose have masses proportional to their value of fitness function. During generations, all masses attract each other by the gravity forces between them. A heavier mass has the bigger attraction force. Therefore, the heavier masses which are probably close to the global Optimum attract the other masses proportional to their Distances. The GSA was mathematically modeled as follow. Suppose a system with N agents. The algorithm starts with randomly placing all agents in search space. During all epochs, the gravitational forces from agent j on agent i at a Specific time t is defined as follows;

$$F_{ij}^d(t) = G(t) \frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) + \epsilon} \left(x_j^d(t) - x_i^d(t) \right) \qquad (26)$$

The G(t) is calculated as (27):

$$G(t) = G_0 \times \exp(-a \times \frac{iter}{maxiter}) \qquad (27)$$

In a problem space with the dimension d, the total force that acts on agent i is calculated as the following equation:

$$F_i^d(t) = \sum_{i=1, j \neq i}^{N} rand_j F_{ij}^d(t) \qquad (28)$$

According to the law of motion, the acceleration of an agent is proportional to the result force and inverse of its mass, so the acceleration of all agents should be calculated as follow:

$$ac_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \qquad (29)$$

The velocity and position of agents are calculated as follows:

$$vel_i^d(t+1) = rand_i \times vel_i^d(t) + ac_i^d(t) \qquad (30)$$

$$x_i^d(t+1) = x_i^d(t) + vel_i^d(t+1) \qquad (31)$$

In GSA, at first all masses are initialized with random Values. Each mass is a candidate solution. After Initialization, velocities for all masses are defined using (30). Meanwhile the gravitational constant, total forces, and accelerations are calculated as (27), (28), and (29) respectively. The positions of masses are calculated using (31). Finally GSA will be stopped by meeting an end criterion.

6. Amended Particle Swarm Optimization Algorithm (APSOA)

Two algorithms can be hybridized in high-level or low-level with relay or co evolutionary method as homogeneous or heterogeneous. In this paper, we hybridize PSO with GSA using low-level co evolutionary heterogeneous hybrid. The hybrid is low-level because we combine the functionality of both algorithms. It is co-evolutionary because we do not use both algorithm one after another. In other words, they run in parallel. It is heterogeneous because there are two different algorithms that are involved to produce final results. The basic idea of proposed

algorithm is to combine the ability of social thinking (*gbest*) in PSO with the local search Capability of GSA. In order to combine these algorithms, (32) is proposed as follow:

$$V_i(t+1) = w \times V_i(t) + C_1' \times rand \times ac_i(t) + C_2' \times rand \times (gbest - X_i(t)) \qquad (32)$$

In each iteration, the positions of particles are updated as follow:

$$X_i(t+1) = X_i(t) + V_i(t+1) \qquad (33)$$

In the proposed algorithm, at first, all agents are randomly initialized. Each agent is considered as a candidate solution. After initialization, Gravitational force, gravitational constant, and resultant forces among agents are calculated using (26), (27), and (28) respectively. After that, the accelerations of particles are defined as (29). In each iteration, the best solution so far should be updated. After calculating the accelerations and with updating the best solution so far, the velocities of all agents can be calculated using (32). Finally, the positions of agents are defined as (33). The process of updating velocities and positions will be stopped by meeting an end criterion. The steps of hybridized algorithm are represented in fig.1.
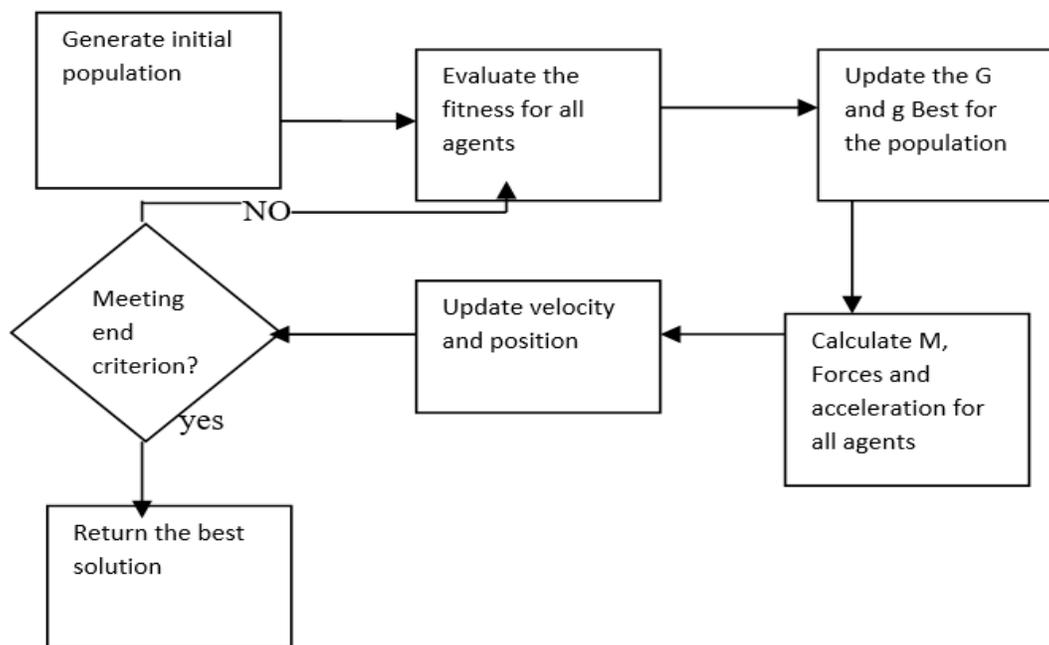
Figure 1: Steps of Hybridized PSO & GSA algorithm

In Amended Particle Swarm Optimization Algorithm (APSOA), the quality of solutions (fitness) is considered in the updating procedure. The agents near good solutions try to attract the other agents which are exploring the search space. When all agents are near a good solution, they move very slowly. In this case, the gBest help them to exploit the global best. Amended Particle Swarm Optimization Algorithm (APSOA) use a memory (gBest) to save the best solution has found so far, so it is accessible anytime.

7. Simulation Results

The efficiency of the proposed Amended Particle Swarm Optimization Algorithm (APSOA) is demonstrated by testing it on standard IEEE-30 bus system. 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers in standard IEEE-30 bus system. Lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses, for PQ buses & reference bus it is 1.05 p.u.. Comparisons of results are shown in Table 5. In Table 1 optimal values of the control variables are given.

Table 1: Results of APSOA – ORPD optimal control variables

Control variables	Values of Variable setting
V1	1.0402
V2	1.0411
V5	1.0420
V8	1.0301
V11	1.0020
V13	1.0301
T11	1.000
T12	1.000
T15	1.010
T36	1.010
Qc10	2
Qc12	3
Qc15	2
Qc17	0
Qc20	2
Qc23	2
Qc24	3
Qc29	2
Real power loss	4.2006
SVSM	0.2486

Table 2 indicates the optimal values of the control variables & there is no limit violations in state variables. Mainly static voltage stability margin (SVSM) has increased from 0.2486 to 0.2498. contingency analysis was conducted using the control variable setting obtained in case 1 and case 2 to determine the voltage security of the system. In Table 3 the Eigen values equivalents to the four critical contingencies are given. Result reveal about the Eigen value has been improved considerably for all contingencies in the second case.

Table 2: Results of   APSOA -Voltage Stability Control Reactive Power Dispatch Optimal
Control Variables

Control Variables	Values of Variable Setting
V1	1.0450
V2	1.0471
V5	1.0480
V8	1.0300
V11	1.0032
V13	1.0324
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	2
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9892
SVSM	0.2498

Table 3: Voltage Stability under Contingency State

Sl.No	Contingency	Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
1	28-27	0.1419	0.1424
2	4-12	0.1642	0.1651
3	1-3	0.1761	0.1764
4	2-4	0.2022	0.2052

Table 4: Limit Violation Checking Of State Variables

State variables	Limits		Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
	Lower	Upper		
Q1	-20	152	1.3422	-1.3269
Q2	-20	61	8.9900	9.8232
Q5	-15	49.92	25.920	26.001
Q8	-10	63.52	38.8200	40.802
Q11	-15	42	2.9300	5.002
Q13	-15	48	8.1025	6.033
V3	0.95	1.05	1.0372	1.0392
V4	0.95	1.05	1.0307	1.0328
V6	0.95	1.05	1.0282	1.0298
V7	0.95	1.05	1.0101	1.0152
V9	0.95	1.05	1.0462	1.0412

V10	0.95	1.05	1.0482	1.0498
V12	0.95	1.05	1.0400	1.0466
V14	0.95	1.05	1.0474	1.0443
V15	0.95	1.05	1.0457	1.0413
V16	0.95	1.05	1.0426	1.0405
V17	0.95	1.05	1.0382	1.0396
V18	0.95	1.05	1.0392	1.0400
V19	0.95	1.05	1.0381	1.0394
V20	0.95	1.05	1.0112	1.0194
V21	0.95	1.05	1.0435	1.0243
V22	0.95	1.05	1.0448	1.0396
V23	0.95	1.05	1.0472	1.0372
V24	0.95	1.05	1.0484	1.0372
V25	0.95	1.05	1.0142	1.0192
V26	0.95	1.05	1.0494	1.0422
V27	0.95	1.05	1.0472	1.0452
V28	0.95	1.05	1.0243	1.0283
V29	0.95	1.05	1.0439	1.0419
V30	0.95	1.05	1.0418	1.0397

Table 5: Comparison of Real Power Loss

Method	Minimum loss
Evolutionary programming [20]	5.0159
Genetic algorithm [21]	4.665
Real coded GA with Lindex as SVSM[22]	4.568
Real coded genetic algorithm [23]	4.5015
Proposed APSOA method	4.2006

8. Conclusion

In this paper, Amended Particle Swarm Optimization Algorithm (APSOA) has been successfully solved the optimal reactive power dispatch problem. Proposed hybridized algorithm is aimed at reduce the probability of trapping in local optimum. In order to assess the efficiency of proposed algorithm, it has been tested on Standard IEEE 30 system and compared to other standard algorithms. The simulation results demonstrate worthy performance of the Amended Particle Swarm Optimization Algorithm (APSOA) in solving optimal reactive power dispatch problem. Real power loss has been reduced & static voltage stability margin index has been enhanced.

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