INTERNATIONAL JOURNAL OF RESEARCH – GRANTHAALAYAH

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AMELIORATED PARTICLE SWARM OPTIMIZATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER DISPATCH PROBLEM

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Abstract

In this paper, an Ameliorated Particle Swarm Optimization (APSO) algorithm has been proposed to solve the optimal reactive power dispatch problem. Particle Swarm Optimization (PSO) is swarm intelligence-based exploration and optimization algorithm which is used to solve global optimization problems. But due to deficiency of population diversity and early convergence it is often stuck into local optima. Diversity upsurges and avoids premature convergence by using evolutionary operators in PSO. In this paper the intermingling crossover operator is used to upsurge the exploration capability of the swarm in the exploration space. Particle Swarm Optimization uses this crossover method to converge optimum solution in quick manner. Thus the intermingling crossover operator is united with particle swarm optimization to augment the performance and possess the diversity which guides the particles to the global optimum powerfully. Proposed Ameliorated Particle Swarm Optimization (APSO) algorithm has been tested in standard IEEE 30 bus test system and simulation results shows clearly the improved performance of the projected algorithm in reducing the real power loss and static voltage stability margin has been enhanced.

Keywords: Optimal Reactive Power; Transmission Loss; Intermingling Crossover Operator.

1. Introduction

Reactive power optimization plays a key role in optimal operation of power systems. Many numerical methods [1-7] have been applied to solve the optimal reactive power dispatch problem. The problem of voltage stability plays a   strategic role in power system planning and operation [8].   So many Evolutionary algorithms have been already proposed to solve the reactive power flow problem [9-11]. In [12, 13], Hybrid differential evolution algorithm and Biogeography Based algorithm has been projected to solve the reactive power dispatch problem. In [14, 15], a fuzzy based technique and improved evolutionary programming has been applied

to solve the optimal reactive power dispatch problem. In [16, 17] nonlinear interior point method and pattern-based algorithm has been used to solve the reactive power problem. In [18-20], various types of probabilistic algorithms utilized to solve optimal reactive power problem. In this paper, an Ameliorated Particle Swarm Optimization (APSO) algorithm has been proposed to solve the optimal reactive power dispatch problem. Particle Swarm Optimization (PSO) [21] has been used efficaciously in solving many optimization problems, for its simplicity and fast convergence rate. Swarm intelligence is the subdivision of artificial intelligence and based on collective behaviour of self-organized system [22, 23]. The optimize value of the function using Particle Swarm Optimization Algorithm is hang on in the exploration and exploitation of the particles during searching in the exploration space [24].There are also problem in PSO like when it applies to various global optimization problems it may get held in the local optimization due to early convergence because the diversity shrinkages with the time for a large population[25] , So we apply various evolutionary operator to get the global optimal solution[26-31].The intermingling crossover is a crossover operator which is applied in basic PSO to discover the exploration area . The intermingling crossover operator is a improved crossover operator, which is apply to the PSO to optimize the function. The proposed Ameliorated Particle Swarm Optimization (APSO) algorithm has been evaluated in standard IEEE 30 bus test system. The simulation results show   that our proposed methodology outperforms all the entitled reported algorithms in minimization of real power loss.

2. Voltage Stability Evaluation

2.1. Modal Analysis for Voltage Stability Evaluation

Modal analysis is one among best   methods for voltage stability enhancement in power systems. The steady state system power flow equations are 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 = Incremental change in bus real power.
ΔQ = Incremental change in   bus   reactive Power injection
$\Delta\theta$ = incremental change in bus voltage angle.
ΔV = Incremental change in bus voltage Magnitude
$J_{p\theta}$, J_{PV} , $J_{Q\theta}$, J_{QV} jacobian matrix are   the   sub-matrixes   of   the System voltage stability is affected by both P and Q.

To reduce (1), let $\Delta P = 0$, then.

$$\Delta Q = \left[J_{QV} - J_{Q\theta} J_{P\theta^{-1}} J_{PV} \right] \Delta V = J_R \Delta V \tag{2}$$

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

Where

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

J_R is called the reduced Jacobian matrix of the system.

2.2. Modes of Voltage Instability

Voltage Stability characteristics of the system have been identified by computing the Eigen values and Eigen vectors.
Let

$$J_R = \xi \wedge \eta \tag{5}$$

Where,
ξ = right eigenvector matrix of JR
η = left eigenvector matrix of JR
$\wedge$ = diagonal eigenvalue matrix of JR and

$$J_R{}^{-1} = \xi \wedge^{-1} \eta \tag{6}$$

From (5) and (8), we have

$$\Delta V = \xi \wedge^{-1} \eta \Delta Q \tag{7}$$

Or

$$\Delta V = \sum_I \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \tag{8}$$

Where ξi is the ith column right eigenvector and η the ith row left eigenvector of JR.
λi is the ith Eigen value of JR.

The ith modal reactive power variation is,

$$\Delta Q_{mi} = K_i \xi_i \tag{9}$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \tag{10}$$

Where
ξji is the jth element of ξi
The corresponding ith modal voltage variation is

$$\Delta V_{mi} = [1/\lambda_i]\Delta Q_{mi} \tag{11}$$

If $|\ \lambda i\ |\ = 0$ then the ith modal voltage will collapse.

In (10), let $\Delta Q = e_k$ where e_k has all its elements zero except the kth one being 1. Then,

$$\Delta V = \sum_i \frac{\eta_{1k}\,\xi_1}{\lambda_1} \tag{12}$$

η_{1k} k th element of η_1
V –Q sensitivity at bus k

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k}\,\xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \tag{13}$$

3. Problem Formulation

The objectives of the reactive power dispatch problem is to minimize the system real power loss and maximize the static voltage stability margins (SVSM).

3.1. Minimization of Real Power Loss

Minimization of the real power loss (Ploss) in transmission lines is mathematically stated as follows.

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

Where n is the number of transmission lines, gk is the conductance of branch k, Vi and Vj are voltage magnitude at bus i and bus j, and θij is the voltage angle difference between bus i and bus j.

3.2. Minimization of Voltage Deviation

Minimization of the voltage deviation magnitudes (VD) at load buses is mathematically 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 Vk is the voltage magnitude at bus k.

3.3. System Constraints

Objective functions are subjected to these constraints shown below.

Load flow equality constraints:

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

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

where, nb is the number of buses, PG and QG are the real and reactive power of the generator, PD and QD are the real and reactive load of the generator, and Gij and Bij are the mutual conductance and susceptance between bus i and bus j.

Generator bus voltage (VGi) inequality constraint:

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

Load bus voltage (VLi) inequality constraint:

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

Switchable reactive power compensations (QCi) inequality constraint:

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

Reactive power generation (QGi) inequality constraint:

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

Transformers tap setting (Ti) inequality constraint:

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

Transmission line flow (SLi) 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 (PSO)

PSO is a population-based optimization tool, where the system is initialized with a population of random particles and the algorithm searches for optima by updating generations. Suppose that the search space is *D*-dimensional. The position of the *i*-th particle can be represented by a *D*-dimensional vector $X_i = (x_{i1}, x_{i2}, .., x_{iD})$ and the velocity of this particle is $V_i = (v_{i1}, v_{i2}, .., v_{iD})$. The best previously visited position of the *i*-th particle is represented by $P_i = (p_{i1}, p_{i2}, .., p_{iD})$ and the global best position of the swarm found so far is denoted by $P_g = (p_{g1}, p_{g2}, .., p_{gD})$. The fitness of each particle can be evaluated through putting its position into a designated objective function. The particle's velocity and its new position are updated as follows:

$$v_{id}^{t+1} = \omega^t v_{id}^t + c_1 r_1^t (p_{id}^t - x_{id}^t) + c_2 r_2^t (p_{gd}^t - x_{id}^t)$$ (24)

$$x_{id}^{t+1} = x_{id}^t + v_{id}^{t+1}$$ (25)

Where $d \in \{1,2,..,D\}, i \in \{1,2,..,N\}N$ is the population size, the superscript t denotes the iteration number, ω is the inertia weight, r_1 and r_2 are two random values in the range $[0,1]$, c_1 and c_2 are the cognitive and social scaling parameters which are positive constants.

These both equations are used to update the velocity and position of a particle in the exploration space. The equation (24) is used to balance the search abilities of the particle in the search space. The equation (25) uses the velocity obtained in first equation to get the new position of the particle.

Crossover is a Genetic operator which is used after selection in Genetic Algorithm to get the new children using two or more than two parent. It is used to get the healthier solution than current solution. There are various improved version of crossover available to get the value of new-fangled species. Intermingling crossover is also a improved operator which is used to get the new healthier child by using current parent. This operator is applied in PSO to optimize the multi-dimensional function and upsurge the probing capability of the PSO, So that Particle Swarm Optimization optimizes the functions efficiently and did not jammed in the local optima.

5. Proposed Ameliorated Particle Swarm Optimization (APSO) algorithm

Although the crossover operator is a conception of Genetic Algorithm but apart from genetic algorithm it has been used in many algorithms with some alterations. The crossover operator takes two or more than two parent and produce one or more than one child .The produced new child after crossover is superior to their parents. There are various improved crossover technique, The intermingling crossover operator is one of the improved crossover operator in which two particles are used to create a minimum and maximum range values which lies in the function's bounded region and the new particle is produced within the calculated minimum and maximum range values, Then we compute the fitness value of that new particle and compare it with the current particle and modernize the N_POP of the population of the particles.

5.1. Intermingling Crossover

Start
Select two arbitrary particles from N_POP x_1 and x_2
Compute $x_{new} = (x_1 - x_2)$
Compute $k_1 = min(x_1, x_2)$
Compute $k_2 = max(x_1, x_2)$
$k_{min} = k_1 - b*x_{new}$;
$k_{max} = k_2 + b*x_{new}$;
Where "b" is an arbitrary selected integer within range
Now select an arbitrary particle from the range
N_new = $(k_{max} - k_{min})$ *rand + k_{min}
Now compute the fitness of newly produced particle N_new

End

5.2. APSO Algorithm for Solving Optimal Reactive Power Dispatch Problem

Start
Initialize particle with Arbitrary Position and Velocity
Set P_best$_i$=X$_i$,g_best=min(P_best$_i$)
Initialize Generation as g=0; While ($g < \max\_generation$)
For (i=1 to N_POP)
For (j=1 to D_POP)
Computev_{id}^{t+1} using equation (11)
Computex_{id}^{t+1}using equation (12)
If $v_{id}^{t+1}$and $x_{id}^{t+1}$are in exploration range then;
Calculate fitness for corresponding particle x$_i$;
Apply intermingling crossover to compute the new particle N_new
Compute fitness value for newlyproduced particle
Compare the fitness value for x$_i$and N_new;
If Fitness (N_new) is superior than x$_i$ then
Modernize the particle in N_POP g=g+1;
End for
End for
End of while
Print the value of g_best.
End

6. Simulation Results

The efficiency of the proposed Ameliorated Particle Swarm Optimization (APSO) algorithm is demonstrated by testing it on standard IEEE-30 bus system. The IEEE-30 bus system has 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. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results have been presented in Tables 1, 2, 3 &4. And in the Table 5 shows the proposed algorithm powerfully reduces the real power losses when compared to other given algorithms. The optimal values of the control variables along with the minimum loss obtained are given in Table 1. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table 1: Results of APSO – ORPD optimal control variables

Control variables	Variable setting
V1	1.040
V2	1.041
V5	1.045
V8	1.030
V11	1.000
V13	1.030

T11	1.00
T12	1.00
T15	1.00
T36	1.00
Qc10	2
Qc12	2
Qc15	2
Qc17	0
Qc20	2
Qc23	3
Qc24	3
Qc29	2
Real power loss	4.1268
SVSM	0.2472

Optimal Reactive Power Dispatch problem (ORPD) together with voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized simultaneously. Table 2 indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the voltage stability index has increased from 0.2472 to 0.2486, an advance in the system voltage stability. To determine the voltage security of the system, contingency analysis was conducted using the control variable setting obtained in case 1 and case 2. The Eigen values equivalents to the four critical contingencies are given in Table 3. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

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

Control Variables	Variable Setting
V1	1.044
V2	1.046
V5	1.043
V8	1.031
V11	1.000
V13	1.031
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	3
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2

Qc29	3
Real power loss	4.9882
SVSM	0.2486

Table 3: Voltage Stability under Contingency State

Sl.No	Contingency	ORPD Setting	VSCRPD Setting
1	28-27	0.1419	0.1434
2	4-12	0.1642	0.1650
3	1-3	0.1761	0.1772
4	2-4	0.2022	0.2043

Table 4: Limit Violation Checking Of State Variables

State variables	Limits		ORPD	VSCRPD
	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 [32]	5.0159
Genetic algorithm [33]	4.665
Real coded GA with Lindex as SVSM [34]	4.568
Real coded genetic algorithm [35]	4.5015
Proposed APSO method	4.1268

7. Conclusion

Ameliorated Particle Swarm Optimization (APSO) algorithm has been successfully solved optimal reactive power dispatch problem. In this paper the intermingling crossover operator is used to upsurge the exploration capability of the swarm in the exploration space. Particle Swarm Optimization uses this crossover method to converge optimum solution in quick manner. Thus the intermingling crossover operator is united with particle swarm optimization to augment the performance and possess the diversity which guides the particles to the global optimum powerfully. Proposed Ameliorated Particle Swarm Optimization (APSO) algorithm has been tested in standard IEEE 30 bus test system and simulation results shows clearly the improved performance of the projected algorithm in reducing the real power loss and static voltage stability margin has been enhanced.

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