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# Enriched Particle Swarm Optimization for Solving Optimal Reactive Power Dispatch Problem

Mr. K. Lenin* Dr.B.Ravindhranath Reddy Dr.M.Surya Kalavathi
Jawaharlal Nehru Technological University Kukatpally, Hyderabad 500 085, India
*Corresponding author Email: gklenin@gmail.com

**Abstract:**

In this paper, a different approach, Enriched particle Swarm optimization (EPSO) Algorithm for solving optimal reactive power dispatch problem has been presented. Particle swarm optimization is affected by early convergence, no assurance in finding optimal solution. This paper proposes EPSO using multiple sub swarm PSO in blend with multi exploration space algorithm. The particles are alienated into equal parts and arrayed into the number of sub swarms available. Multi-exploration space algorithm is used to obtain an optimum solution for each sub swarm and these solutions are then arrayed yet into a new swarm to obtain the best of all the solution. The proposed EPSO algorithm has been tested on standard IEEE 30 bus test system and simulation results show the commendable performance of the proposed algorithm in reducing the real power loss.

**Keywords:**Optimal Reactive Power, Transmission loss, Enriched particle Swarm optimization, Multi-exploration

## 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. This paper introduces Enriched particle Swarm optimization (EPSO) Algorithm for solving optimal reactive power dispatch power problem. Particle Swarm Optimization (PSO) is an optimization method that belongs to the swarm intelligence family that has proved to be very successful [21].It is a biologically inspired computational search and optimization method based on the social behaviors of birds flocking or fish schooling, thus animal societies that don't have any leader in their group. It consists of a swarm of particles, where each particle represents a potential solution to an objective [22]. PSO algorithm was originally designed by Kennedy and Eberhart [23].The PSO combines self-experiences with social experiences. The proposed EPSO algorithm has been evaluated in standard IEEE 30 bus test system & the simulation results show that our proposed approach outperforms all reported algorithms in minimization of real power loss.

## 2. Problem Formulation

### 2.1 Active power loss

The objective of the reactive power dispatch is to minimize the active power loss in the transmission network, which can be described as follows:

$$F = PL = \sum_{k \in Nbr} g_k \left( V_i^2 + V_j^2 - 2V_iV_j cos\theta_{ij} \right) \qquad (1)$$

or

$$F = PL = \sum_{i \in N_g} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \qquad (2)$$

Where $g_k$ : is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. $P_d$: is the total active power demand, $P_{gi}$: is the generator active power of unit i, and $P_{gsalck}$: is the generator active power of slack bus.

### 2.2 Voltage profile improvement

For minimizing the voltage deviation in PQ buses, the objective function becomes:

$$F = PL + \omega_v \times VD \qquad (3)$$

Where $\omega_v$: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \qquad (4)$$

### 2.3 Equality Constraint

The equality constraint of the optimal reactive power dispatch power (ORPD) problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$$P_G = P_D + P_L \qquad (5)$$

This equation is solved by running Newton Raphson load flow method, by calculating the active power of slack bus to determine active power loss.

### 2.4 Inequality Constraints

The inequality constraints reflect the limits on components in the power system as well as the limits created to ensure system security. Upper and lower bounds on the active power of slack bus, and reactive power of generators:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \qquad (6)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \qquad (7)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \qquad (8)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \qquad (9)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \le Q_c \le Q_C^{max}, i \in N_C \qquad (10)$$

Where N is the total number of buses, $N_T$ is the total number of Transformers; $N_c$ is the total number of shunt reactive compensators.

### 3. Basic Particle Swarm Optimization

PSO like other arbitrary optimization algorithm is prone to be limited into local optimal solution especially in complicated optimization problems [24].In the original particle swarm optimization, there is a deficiency of solution, because it is very easy to move to local optima. In certain conditions, where a new-fangled position of the particle equal to global best and local best then the particle will not change its position. If that particle is the global best of the complete swarm then all the other particles will tend to move in the direction of this particle. The finish result is the swarm converging prematurely to a local optimum. If the new position of the particle is pretty far from global best and local best, then the velocity will be changing rapidly turning into a great value. This will directly affect the particle's position in the next step. For now the particle will have an updated position of great value, as a result, the particle may be out of bounds the exploration area. With their exploration and exploitation, the particle of the swarm flies through hyperspace and have two essential reasoning capabilities: the memory of their own best position -local best (lb) and knowledge of the global or their neighbourhood's best - global best (gb). Position of the particle is prejudiced by velocity $V_i$. Let $x_i(t)$ represent the position of particle in the exploration space at time step t. The position epitomizes a solution suggested by the particle while velocity is the rate of changes of the next position with respect to current position. Initially these two values (position and velocity) are arbitrarily initialized and consequently updated by using equation (12). The position of the particle is changed by adding a velocity $V_i(t)$, to the current position of the particle $x_i(t)$ [22].
Thus initial position $x_i(t)$ is

$$x_i(t) = x_i(t) + v_i(t) \qquad (11)$$

Modernized position $x_i(t + 1)$ is

$$x_i(t + 1) = x_i(t) + v_i(t + 1) \qquad (12)$$

Where:

$v_i(t) = wv_i(t - 1) + c_1r_1 (lb(t) - x_i(t - 1)) + c_2r_2 (gb(t) - x_i(t -1))$ (13)

$w$ is the inertia weights method which controls particles momentum so that, they can avoid continuing to explore the wide exploration space and switch to fine tuning when a good area is found [21].$c_1$ and $c_2$, respectively, are learning rates for individual capability and social influence respectively. The value of $c_1$ and $c_2$ is usually 2. $r_1$ and $r_2$ are uniformly distributed random numbers in the intervals of 0 and 1 different at each iteration. $i$ is particle's number ($i$ = 1,..,N; N: number of particles in the swarm) It has been detected that great performance is obtained using the following values of $w$ = 0.36 and $c_1$= $c_2$=1.9.For equation (13), the first part represents the inertia of the preceding velocity, the second part is the "cognition" part, which represents the particle's thinking by itself and the third part is the "social" part which represents the cooperation among the particles[25]. One of the PSO problems is its tendency to a fast and premature convergence in mid optimum points.

*PSO Algorithm*

1. Prepare each particle with arbitrary position and velocity.
2. Position particles.
3. Calculate all particle's position and update all particles with their own best position (local best); if superior than present position.
4. Define the global best position and update all particles' position to global best position using eqn. 12.
5. Compute and modernize each particle's velocity using eqn.13.
6. Check for stopping criteria: if not satisfied, repeat from step 2 else optimal solution has been attained then stop [26].

## 4. Enriched particle Swarm optimization

We propose an Enriched PSO that makes use of multiple sub swarm PSO in combination with multi search space algorithm. The particles are divided into m equal parts and deployed into the n number of sub swarms (the whole exploration space is divided into n sub swarms). Multi search space algorithm is used to obtain an optimum solution for each sub swarm and these solutions are then deployed yet into a new swarm to obtain the best of all the solutions. Since the particle position and velocity are arbitrary modified and there is possibility that running the procedure multiple times can generate multiple different results. It is therefore advised to run this procedure multiple times to ensure that local optima are overcome.

*EPSO Algorithm*

1. Produce N swarms with m number of particles for each swarm.
2. Set the largest number of iterations, inertia weight and acceleration constant.
3. Set each particle with uniform probability distribution, arbitrary position and velocity.
4. Calculate each particle's fitness.
5. Arrange particles.
6. Calculate all particle's position and update all particles with their own best position (local best); if superior than present position.
7. Define the global best position and update all particles' position to global best position using eqn. 12 independently for each sub swarm.
8. Compute and modernize each particle's velocity using eqn. 13 independently for each sub swarm.
9. Check for stopping criteria: if not satisfied, repeat from step 4 else optimal solution has been attained.

## 5. Simulation Results

EPSO algorithm has been tested on the IEEE 30-bus, 41 branch system. It has a total of 13 control variables as follows: 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. Bus 1 is the slack bus, 2, 5, 8, 11 and 13 are taken as PV generator buses and the rest are PQ load buses. The measured security constraints are the voltage magnitudes of all buses, the reactive power limits of the shunt VAR compensators and the transformers tap settings limits. The variables limits are listed in Table 1.

Table 1: Initial Variables Limits (PU)

| ***Control variables*** | ***Min. value*** | ***Max. value*** | ***Type*** |
|---|---|---|---|
| Generator: Vg | 0.92 | 1.08 | Continuous |
| Load Bus: VL | 0.90 | 1.01 | Continuous |
| T | 0.90 | 1.40 | Discrete |
| Qc | -0.11 | 0.30 | Discrete |

The transformer taps and the reactive power source installation are discrete with the changes step of 0.01. The power limits generators buses are represented in Table2. Generators buses are: PV buses 2,5,8,11,13 and slack bus is 1.the others are PQ-buses.

Table 2: Generators Power Limits in MW and MVAR

| ***Bus n°*** | $P_g$ | $P_{gmin}$ | $P_{gmax}$ | $Q_{gmin}$ |
|---|---|---|---|---|
| 1 | 97.00 | 50 | 200 | -20 |
| 2 | 80.00 | 20 | 80 | -20 |
| 5 | 52.00 | 15 | 55 | -13 |
| 8 | 20.00 | 10 | 31 | -13 |
| 11 | 20.00 | 10 | 25 | -10 |
| 13 | 20.00 | 11 | 40 | -13 |

Table 3: Values of Control Variables after Optimization and Active Power Loss

| Control Variables (p.u) | EPSO |
|---|---|
| V1 | 1.0301 |
| V2 | 1.0371 |
| V5 | 1.0187 |
| V8 | 1.0281 |
| V11 | 1.0610 |
| V13 | 1.0420 |
| T4,12 | 0.00 |
| T6,9 | 0.01 |
| T6,10 | 0.90 |
| T28,27 | 0.90 |
| Q10 | 0.10 |
| Q24 | 0.10 |
| PLOSS | 4.5371 |
| VD | 0.9080 |

Table 3 show that the proposed approach succeeds in keeping the dependent variables within their limits.

Table 4 summarizes the results of the optimal solution by different methods. It reveals the reduction of real power loss after optimization.

Table 4: Comparison Results of Different Methods

| Methods | Ploss (MW) |
|---|---|
| SGA (27) | 4.98 |
| PSO (28) | 4.9262 |
| LP (29) | 5.988 |
| EP (29) | 4.963 |
| CGA (29) | 4.980 |
| AGA (29) | 4.926 |
| CLPSO (29) | 4.7208 |
| HSA (30) | 4.7624 |
| BB-BC (31) | 4.690 |
| EPSO | 4.5371 |

## 6. Conclusion

In this paper, the EPSO has been effectively applied to solve Optimal Reactive Power Dispatch problem. The main advantages of the EPSO are easily handling of non-linear constraints. The proposed algorithm has been tested on the IEEE 30-bus system to minimize the active power loss. The optimal setting of control variables are well within the limits. The results were compared with the other heuristic methods and proposed EPSO demonstrated its effectiveness and robustness in minimizing the real power loss.

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K. Lenin has received his B.E., Degree, electrical and electronics engineering in 1999 from university of madras, Chennai, India and M.E., Degree in power systems in 2000 from Annamalai University, TamilNadu, India. At present pursuing Ph.D., degree at JNTU, Hyderabad,India.

Bhumanapally. RavindhranathReddy, Born on 3rd September,1969. Got his B.Tech in Electrical & Electronics Engineering from the J.N.T.U. College of Engg., Anantapur in the year 1991. Completed his M.Tech in Energy Systems in IPGSR of J.N.T.University Hyderabad in the year 1997. Obtained his doctoral degree from JNTUA,Anantapur University in the field of Electrical Power Systems. Published 12 Research Papers and presently guiding 6 Ph.D. Scholars. He was specialized in Power Systems, High Voltage Engineering and Control Systems. His research interests include Simulation studies on Transients of different power system equipment.

M. Surya Kalavathi has received her B.Tech. Electrical and Electronics Engineering from SVU, Andhra Pradesh, India and M.Tech, power system operation and control from SVU, Andhra Pradesh, India. she received her Phd. Degree from JNTU, hyderabad and Post doc. From CMU – USA. Currently she is Professor and Head of the electrical and electronics engineering department in JNTU, Hyderabad, India and she has Published 16 Research Papers and presently guiding 5 Ph.D. Scholars. She has specialised in Power Systems, High Voltage Engineering and Control Systems. Her research interests include Simulation studies on Transients of different power system equipment. She has 18 years of experience. She has invited for various lectures in institutes.