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POLAR PARTICLE SWARM OPTIMIZATION ALGORITHM FOR SOLVING OPTIMAL REACTIVE POWER PROBLEM

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Abstract

This paper presents Polar Particle Swarm optimization (PPSO) algorithm for solving optimal reactive power problem. The standard Particle Swarm Optimization (PSO) algorithm is an innovative evolutionary algorithm in which each particle studies its own previous best solution and the group's previous best to optimize problems. In the proposed PPSO algorithm that enhances the behaviour of PSO and avoids the local minima problem by using a polar function to search for more points in the search space in order to evaluate the efficiency of proposed algorithm, it has been tested on IEEE 30 bus system and compared to other algorithms. Simulation results demonstrate good performance of the Polar Particle Swarm optimization (PPSO) algorithm in solving an optimal reactive power problem.

Keywords: Particle Swarm Optimization; Polar; Optimal Reactive Power; Transmission Loss.

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1. Introduction

Main objective of optimal reactive power problem is to minimize the real power loss and bus voltage deviation. Various mathematical techniques like the gradient method [1-2], Newton method [3] and linear programming [4-7] have been adopted to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the complexity in managing inequality constraints. If linear programming is applied then the input- output function has to be uttered as a set of linear functions which mostly lead to loss of accuracy. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Global optimization has received extensive research awareness, and a great number of methods have been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already proposed to solve the reactive power flow problem [9, 10]. Evolutionary algorithm is a heuristic approach used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [11], Genetic algorithm has been used to solve optimal reactive power flow problem. In [12], Hybrid differential evolution algorithm is proposed to improve the voltage

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stability index. In [13] Biogeography Based algorithm is projected to solve the reactive power dispatch problem. In [14], a fuzzy based method is used to solve the optimal reactive power scheduling method. In [15], an improved evolutionary programming is used to solve the optimal reactive power dispatch problem. In [16], the optimal reactive power flow problem is solved by integrating a genetic algorithm with a nonlinear interior point method. In [17], a pattern algorithm is used to solve ac-dc optimal reactive power flow model with the generator capability limits. In [18], F. Capitanescu proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming-based approach is used to solve the optimal reactive power dispatch problem. In [20], A. Kargarian et al present a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. This paper presents Polar Particle Swarm optimization (PPSO) algorithm for solving optimal reactive power problem. The standard Particle Swarm Optimization (PSO) algorithm is an innovative evolutionary algorithm in which each particle studies its own previous best solution and the group's previous best to optimize problems. The particle swarm optimization (PSO) developed by Eberhart and Kennedy in 1995 is a stochastic global optimization technique enthused by social behaviour of bird flocking, fish schooling, or animals herding where these swarms search for food in a collective manner [21-25]. Each particle in the swarm adjusts its search patterns to search for the comprehensive optimum in the high dimensional space by learning from its own experience and others. Since the PSO comprises a very simple concept and paradigms can be applied more easily with it, it has been proved in certain instances that PSO outperforms other population based evolutionary computing algorithms in many practical engineering fields such as function optimization, artificial neural network training, fuzzy system control, blind source separation as well as machine learning. In the proposed PPSO algorithm that enhances the behaviour of PSO and avoids the local minima problem by using a polar function [26-29] to search for more points in the search space In order to evaluate the efficiency of proposed algorithm, it has been tested on IEEE 30 bus system and compared to other algorithms. Simulation results demonstrate good performance of the Polar Particle Swarm optimization (PPSO) algorithm in solving an optimal reactive power problem.

2. Problem Formulation

The optimal power flow problem is treated as a general minimization problem with constraints, and can be mathematically written in the following form:

$$\text{Minimize } f(x, u) \tag{1}$$

$$\text{subject to } g(x,u)=0 \tag{2}$$

and

$$h(x, u) \leq 0 \tag{3}$$

where f(x,u) is the objective function. g(x.u) and h(x,u) are respectively the set of equality and inequality constraints. x is the vector of state variables, and u is the vector of control variables.

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The state variables are the load buses (PQ buses) voltages, angles, the generator reactive powers and the slack active generator power:

$$x = \left(P_{g1}, \theta_2, .., \theta_N, V_{L1}, ., V_{LNL}, Q_{g1}, .., Q_{gng}\right)^T \tag{4}$$

The control variables are the generator bus voltages, the shunt capacitors/reactors and the transformers tap-settings:

$$u = \left(V_g, T, Q_c\right)^T \tag{5}$$

or

$$u = \left(V_{g1}, \ldots, V_{gng}, T_1, .., T_{Nt}, Q_{c1}, .., Q_{cNc}\right)^T \tag{6}$$

Where ng, nt and nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

3. Objective Function

3.1. 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:

$$F = PL = \sum_{k \in Nbr} g_k \left(V_i^2 + V_j^2 - 2V_i V_j cos\theta_{ij}\right) \tag{7}$$

Or

$$F = PL = \sum_{i \in Ng} P_{gi} - P_d = P_{gslack} + \sum_{i \neq slack}^{Ng} P_{gi} - P_d \tag{8}$$

wheregk: is the conductance of branch between nodes i and j, Nbr: is the total number of transmission lines in power systems. Pd: is the total active power demand, Pgi: is the generator active power of unit i, and Pgsalck: is the generator active power of slack bus.

3.2. Voltage Profile Improvement

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

$$F = PL + \omega_v \times VD \tag{9}$$

Where ωv: is a weighting factor of voltage deviation.

VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \tag{10}$$

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3.3. Equality Constraint

The equality constraint g(x,u) of the Optimal reactive power problem is represented by the power balance equation, where the total power generation must cover the total power demand and the power losses:

$$P_G = P_D + P_L \tag{11}$$

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

3.4. Inequality Constraints

The inequality constraints h(x,u) 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:

$$P_{gslack}^{min} \leq P_{gslack} \leq P_{gslack}^{max} \tag{12}$$

$$Q_{gi}^{min} \leq Q_{gi} \leq Q_{gi}^{max} , i \in N_g \tag{13}$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \leq V_i \leq V_i^{max} , i \in N \tag{14}$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \leq T_i \leq T_i^{max} , i \in N_T \tag{15}$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \leq Q_c \leq Q_C^{max} , i \in N_C \tag{16}$$

Where N is the total number of buses, NT is the total number of Transformers; Ncis the total number of shunt reactive compensators.

4. Polar Particle Swarm Optimization (PPSO) Algorithm

The origin of Polar Coordinates was first described by Harvard professor Julian Lowell Coolidge. Grégoire de Saint-Vincent and Bonaventura Cavalieri independently introduced the concepts in the mid-seventeenth century as described by Coolidge, (1952). Polar coordinates were first used by Cavalieri to solve a problem related to the area within an Archimedean spiral. Blaise Pascal subsequently used polar coordinates to calculate the length of parabolic arcs (Brown, et,. al., 1992).

Also, Sir Isaac Newton examined the transformations between polar coordinates, which he referred to as the "Seventh Manner; For Spirals", and nine other coordinate systems (Boyer, 1949). The

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system of the polar coordinate is a two-dimensional coordinate system where every point on the plane can be determined by an angle from a reference direction and a distance from a reference point. The reference point is called the pole; the polar axis is the ray from the pole in the reference direction. As shown in Figure 1 (a), the pole is 0 and the polar axis is L. We denote to the radial coordinate as an r or ρ and denote to the angular coordinate by θ, ϕ, or t. The radial coordinate or radius is the distance from the pole (0), and the angle is called the angular coordinate. With reference to the figure, the green line's point (3, 60) has a radial coordinate of 3 units and angular coordinate of 60 degrees. The blue line's point (4, 210) has a radial coordinate of 4 units and angular coordinate of 210 degrees. In a polar coordinate grid, see Figure 1 (b), a series of circles extend out from the pole (or origin in a rectangular coordinate grid) with five different lines passing through the pole to represent the angles at which the exact values are known for the trigonometric functions.

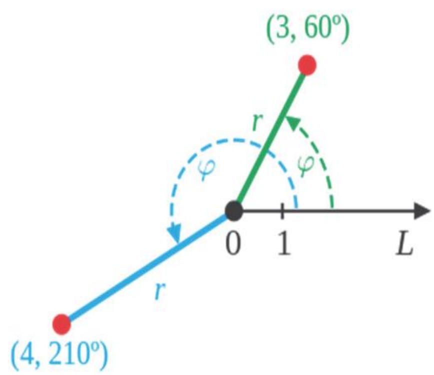

Figure 1: (a) Polar Coordinate Representation

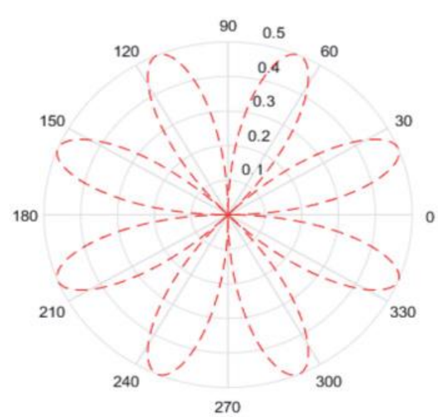

Figure 1: (b) Polar Coordinate Grid (Rose Curve)

Polar coordinates have been widely used to solve many real-life problems, with applications such as collision avoidance between ships and other obstructions, calculating groundwater flow in radial symmetric wells, guiding industrial robots in various production applications, audio pickup patterns for cardioid microphones and in calculations involving aircraft navigation. All these applications for polar coordinates inspire us to think about employing this method to enhance the

PSO behaviour in finding global minimum and applying it to cloud data migration. The behaviours of the polar function; as represented by equation (17); forms a rose graph curve; see Figure 1 (b).

$$\theta = 0{:}\,0.01;\,2 * Pi\,;\, r = a * sin(n * \theta) * cos(n * \theta) \quad (17)$$

Where a≠0 and n is an integer > 1 The formed graph is called a rose curve because the loops that are formed resemble petals. The number of petals that are presented depends on the value of n. The value of "a" determines the length of the petal; see Figure 1 (b). As shown in Figure 2, the PSO moves in one direction toward the global best solution; X_i^k to X_i^(K+1)and it doesn't check for the other points (V_i^K, Pbest i, and Gbest i) while moving.

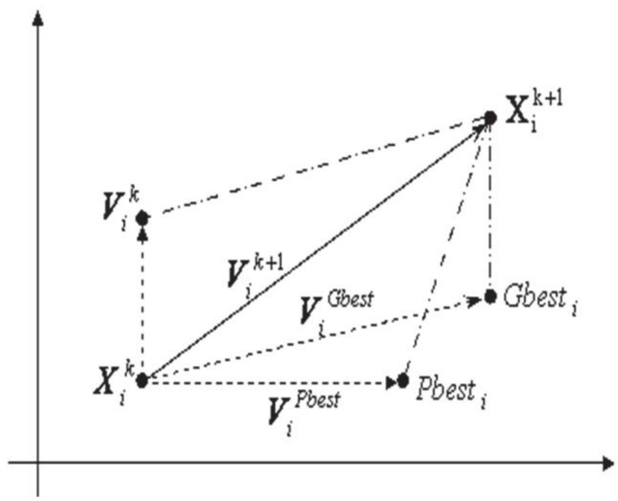

Figure 2: PSO behavior

To improve the PSO search ability we improved the search ability of the PSO at each iteration by employing the polar ability and we added it to PSO ability as described in equation (18) written in Matlab, this hybrid combination has extended the search ability in PSO to include more points and polar direction to the particle movement which increased the possibility to find the global minima and avoid the local minima problem, rather than getting stuck at one local minima point the polar behaviour bypass this obstacle.

$$New\ partcipile\ position = \sin(2 * PBest\ * Pi.01) * cos\ (2 * PBest * Pi.01) * rand(\,) * .01 \quad (18)$$

Where pBest is the local best value found at each iteration of PSO; Pi = 3. 1415.rand(): is a random function that generate numbers between 0 and 1 POLARPSO increases the ability of exploitation and exploration by providing a co-rotating frame during a particle's motion. To define a co-rotating frame, an origin is selected first from the distance r(t) to the particle ahead. An axis of rotation is set up that is perpendicular to the plane of motion of the particle that passes through the origin. Then, at the selected moment t; the PSO particle is moved to new position in a rotation movement that explores many points P1 through P8 ahead and explores more areas; see Figure 3.

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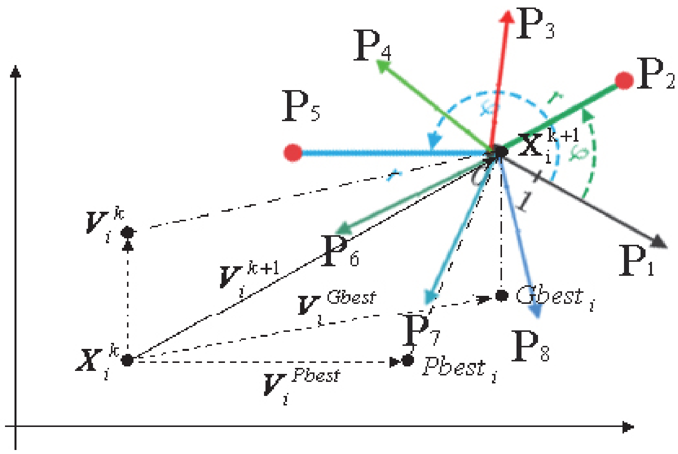

Figure 3: POLARPSO behaviour at each iteration

Upgraded Polar PSO algorithm for solving reactive power problem

1) While a termination criterion is not met do:
2) For each particle i = 1, ..., S do
3) For each particle i = 1, ..., S do
4) Initialize the particle's position with a uniformly distributed random vector: xi ~ U(blo, bup)
5) Initialize the particle's best known position to its initial position: pi ← xi
6) If f(pi) < f(g) then
7) Update the swarm's best known position: g ← pi
8) Initialize the particle's velocity: vi ~ U(-|bup-blo|, |bup-blo|)
9) For each dimension d = 1, ..., n do
10) Pick random numbers: rp, rg ~ U(0,1)
11) Update the particle's velocity: vi,d ← ω vi,d + φp rp (pi,d-xi,d) + φg rg (gd-xi,d)
12) Update the particle's position: xi ← xi + vi
13) If f(xi) < f(pi) then
14) Update the particle's best known position: pi ← xi
15) If f(pi) < f(g) then
16) Update the swarm's best known position: g ← pi
17) Update the particle's position according to equation (18)
18) If f(xi) < f(pi) then
19) Update the particle's best known position: pi ← xi
20) If f(pi) < f(g) then
21) Update the swarm's best known position: g ← pi

5. Simulation Results

Validity of Polar Particle Swarm optimization (PPSO) algorithm has been verified by testing in IEEE 30-bus, 41 branch system and it has 6 generator-bus voltage magnitudes, 4 transformer-tap settings, and 2 bus shunt reactive compensators. Bus 1 is taken as slack bus and 2, 5, 8, 11 and 13 are considered as PV generator buses and others are PQ load buses. Control variables limits are given in Table 1.

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Table 1: Primary Variable Limits (Pu)

Variables	**Min.**	**Max.**	**category**
Generator Bus	0.95	1.1	Continuous
Load Bus	0.95	1.05	Continuous
Transformer-Tap	0.9	1.1	Discrete
Shunt Reactive Compensator	-0.11	0.31	Discrete

In Table 2 the power limits of generators buses are listed.

Table 2: Generators Power Limits

Bus	**Pg**	**Pgmin**	**Pgmax**	**Qgmin**	**Qmax**
1	96.00	49	200	0	10
2	79.00	18	79	-40	50
5	49.00	14	49	-40	40
8	21.00	11	31	-10	40
11	21.00	11	28	-6	24
13	21.00	11	39	-6	24

Table 3 shows the proposed PPSO approach successfully kept the control variables within limits.Table 4 narrates about the performance of the proposed PPSO algorithm. Table 5 list out the overall comparison of the results of optimal solution obtained by various methods.

Table 3: After optimization values of control variables

Control Variables	**PPSO**
V1	1.0242
V2	1.0238
V5	1.0239
V8	1.0226
V11	1.0406
V13	1.0492
T4,12	0.00
T6,9	0.00
T6,10	0.90
T28,27	0.90
Q10	0.10
Q24	0.10
Real power loss	4.2368
Voltage deviation	0.9086

Table 4: Performance of PPSO algorithm

Iterations	31
Time taken (secs)	10.04
Real power loss	4.2368

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Table 5: Comparison of results

Techniques	Real power loss (MW)
SGA(Wu et al., 1998) [30]	4.98
PSO(Zhao et al., 2005) [31]	4.9262
LP(Mahadevan et al., 2010) [32]	5.988
EP(Mahadevan et al., 2010) [32]	4.963
CGA(Mahadevan et al., 2010) [32]	4.980
AGA(Mahadevan et al., 2010) [32]	4.926
CLPSO(Mahadevan et al., 2010) [32]	4.7208
HSA (Khazali et al., 2011) [33]	4.7624
BB-BC (Sakthivel et al., 2013) [34]	4.690
MCS(Tejaswini sharma et al.,2016) [35]	4.87231
Proposed PPSO	4.2368

6. Conclusion

In this paper a novel approach Polar Particle Swarm optimization (PPSO) algorithm successfully solved optimal reactive power problem. In the proposed PPSO algorithm that enhances the behaviour of PSO and avoids the local minima problem by using a polar function to search for more points in the search space In order to evaluate the efficiency of proposed algorithm, it has been tested on IEEE 30 bus system and compared to other algorithms. Simulation results demonstrate good performance of the Polar Particle Swarm optimization (PPSO) algorithm in solving an optimal reactive power problem.

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