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Improved Invasive Weed Optimization for Solving Optimal Reactive Power Problem

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Abstract; This paper presents Improved Invasive Weed Optimization (IIWO) for solving optimal reactive power problem. Particle Swarm Optimization (PSO) has been combined with Invasive weed optimization (IWO) to enhance exploration & exploitation capability for solving the optimal reactive power Problem. In this paper, the idea of intelligent swarming, social cooperation, competition, and reproduction in an optimization meta-algorithm has been merged.In order to evaluate the efficiency of the proposed algorithm; it has been tested on IEEE 57 bus system and simulation results reveals about the best performance of the proposed algorithm in reducing the real power loss.

Keywords; Invasive weed, optimal reactive Power dispatch,Transmission loss.

I. Introduction

Reactive power optimization places an important role in optimal operation of power systems. Various numerical methods like the gradient method [1,2], Newton method [3] and linear programming [4-7] have been implemented to solve the optimal reactive power dispatch problem. Both the gradient and Newton methods have the intricacy in managing inequality constraints. The problem of voltage stability and collapse play a key role in power system planning and operation [8] Evolutionary algorithms such as genetic algorithm have been already projected to solve the reactive power flow problem [9-11]. Evolutionary algorithm is a heuristic methodology used for minimization problems by utilizing nonlinear and non-differentiable continuous space functions. In [12], Hybrid differential evolution algorithm is projected to increase the voltage 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 elucidate 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 [18-20] proposes a two-step approach to calculate Reactive power reserves with respect to operating constraints and voltage stability. **This** paper presents Improved Invasive Weed Optimization (IIWO) for solving optimal reactive power problem. Particle Swarm Optimization (PSO) [21, 22] has been combined with Invasive weed optimization (IWO) [23-25] to enhance exploration & exploitation capability for solving the optimal reactive power Problem. In this paper, the idea of intelligent swarming, social cooperation, competition, and reproduction in an optimization meta-algorithm has been merged.In order to evaluate the efficiency of the proposed algorithm; it has been tested on IEEE 57 bus system and simulation results reveals about the best performance of the proposed algorithm in reducing the real power loss.

II. Problem formulation

The objective of the optimal reactive power problem is to minimize one or more objective functions while satisfying a number of constraints such as load flow, generator bus voltages, load bus voltages, switchable reactive power compensations, reactive power generation, transformer tap setting and transmission line flow.

A.Minimization of Real Power Loss

It is aimed in this objective that minimizing of the real power loss (Ploss) in transmission lines of a power system. This is mathematically stated as follows.

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

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.

B. Minimization of Voltage Deviation

It is aimed in this objective that minimizing of the Deviations in voltage magnitudes (VD) at load buses. This is mathematically stated as follows.

$$\text{Minimize VD} = \sum_{k=1}^{nl} |V_k - 1.0| \quad (2)$$

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

C. System Constraints

In the minimization process of objective functions, some problem constraints which one is equality and others are inequality had to be met. Objective functions are subjected to these constraints shown below.

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (3)$$

$$Q_{Gi} - Q_{Di}\, V_{i\sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (4)$$

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:

$$V_{Gi}^{min} \leq V_{Gi} \leq V_{Gi}^{max}, i \in ng \quad (5)$$

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

$$V_{Li}^{min} \leq V_{Li} \leq V_{Li}^{max}, i \in nl \quad (6)$$

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

$$Q_{Ci}^{min} \leq Q_{Ci} \leq Q_{Ci}^{max}, i \in nc \quad (7)$$

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

$$Q_{Gi}^{min} \leq Q_{Gi} \leq Q_{Gi}^{max}, i \in ng \quad (8)$$

Transformers tap setting (T_i) inequality constraint:

$$T_i^{min} \leq T_i \leq T_i^{max}, i \in nt \quad (9)$$

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

$$S_{Li}^{min} \leq S_{Li}^{max}, i \in nl \quad (10)$$

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

III. Particle Swarm Optimization

Particle Swarm Optimization (PSO) aims to mimic foraging trend and communication behaviour in flocks of birds when they are flying. Contrary to traditional evolutionary algorithms which only keep track of position, PSO maintains information regarding position and velocity. The equations for calculating the next particle velocity and position are presented in (11) and (12).

$$V_i(t+1) = \omega V_i(t) + c_1 * \varphi_1 * \left(P_i(t) - X_i(t)\right) + c_2 * \varphi_2 * \left(P_g(t) - X_i(t)\right) \quad (11)$$

$$X_i(t+1) = X_i(t) + V_i(t+1) \quad (12)$$

P_i is the best previous position for that particle, and P_g is the position of the best particle in the whole swarm up to that iteration. c_1 and c_2 called learning factors, are constants that determine the balance between acceleration toward local best (individual’s experience, cognition, exploration) or global best (social collaboration or interaction, exploitation). φ_1 and φ_2 are uniform random numbers in the range of [0, 1]. ω is an inertia weight which determines the influence of velocity memory and is employed on the favour of global or local search. It is also suggested to restrict the velocity to a specified range [-V_{max},V_{max}] . Until now, numerous versions of PSO with selection, reproduction, recombination, and mutation operators have been developed and the way on the improvement of PSO and generally swarm intelligence seems to be continued.

IV. Invasive Weed Optimization

Invasive weed optimization (IWO) is a bio inspired numerical optimization algorithm that simply simulates natural behaviour of weeds in colonizing and finding suitable place for growth and reproduction. Some of the distinctive properties of IWO in comparison with other evolutionary algorithms are the way of reproduction, spatial dispersal, and competitive exclusion. In Invasive Weed Optimization algorithm, the process begins with initializing a population. It means that a population of initial solutions is randomly generated over the problem space. Then members of the population produce seeds depending on their relative fitness in the population. In other words, the number of seeds for each member is beginning with the value of S_{min} for the worst member and increases linearly to S_{max} for the best member. For the third step, these seeds are randomly scattered over the search space by normally distributed random numbers with mean equal to zero and an adaptive standard deviation. The equation for determining the standard deviation (SD) for each generation is presented in (13).

$$\sigma_{iter} = \frac{(iter_{max} - iter)^n}{(iter_{max})^n} \left(\sigma_{initial} - \sigma_{final}\right) + \sigma_{final} \quad (13)$$

Where $iter_{max}$ is the maximum number of iterations, σ_{iter} is the SD at the current iteration and n is the nonlinear modulation index. The produced seeds, accompanied by their parents are considered as the potential solutions for the next generation. Finally, a competitive exclusion is conducted in the algorithm,

i.e., after a number of iterations the population reaches its maximum, and an elimination mechanism should be employed. To this end, the seeds and their parents are ranked together and those with better fitness survive and become reproductive.

V. Improved Invasive Weed Optimization (IIWO)

From the two previous sections it can be concluded that Particle Swarm Optimization (PSO) & Invasive weed optimization (IWO) have two different approaches for optimization. IWO offers good exploration and diversity, while PSO is an algorithm with fairly deliberate and to the point movements in each iteration. In this section, two algorithms and present a hybridized algorithm. In hybrid IWO/PSO algorithm, colonization is beginning in the same way as IWO, however, the seeds are located like the equations in PSO for flying particles. It means that after reproducing the seeds, the velocity is updated with (14), and temporary position of seeds is estimated by (15), and finally these seeds are randomly distributed the same as the process used in IWO to construct the next population.

$$V_{i,s}(t+1) = \omega V_i(t) + c_1 * \varphi_{1,s} * \left(P_i(t) - X_i(t)\right) + c_2 * \varphi_{2,s} * \left(P_g(t) - X_i(t)\right) \quad (14)$$

$$X_{i,s}(t+1) = X_i(t) + V_{i,s}(t+1) \quad (15)$$

$V_{i,s}$ and $X_{i,s}$ are the velocity and position for the sth seed of the ith member.

Improved Invasive Weed Optimization (IIWO) for Solving Optimal Reactive Power Problem

1. Generate random population of N_0 solutions;
2. For iter = 1 to the maximum number of generations;
    a. Calculate fitness for each individual;
    b. Compute maximum and minimum fitness in the colony;
    c. Set P_g as the best position of all individuals;
    d. For each individual $w \in W$;
        i. Set P_i as the best position of individual w in comparison with its predecessors;
        ii. Compute number of seeds of w, corresponding to its fitness;
        iii. For each seed s ;
            1) Calculate the velocity according to (14);
            2) Update the position according to (15);
        iv. Randomly distribute generated seeds over the search space with normal distribution around the parent plant (w);
        v. Add the generated seeds to the solution set, W ;
    e. If $(|w| = N) > P_{max}$;
        i. Sort the population W in descending order of their fitness;
        ii. Truncate population of weeds with smaller fitness until $N = P_{max}$
3. Next iter :

VI. Simulation Results

Proposed Improved Invasive Weed Optimization (IIWO) has been tested in standard IEEE-57 bus power system. The reactive power compensation buses are 18, 25 and 53. Bus 2, 3, 6, 8, 9 and 12 are PV buses and bus 1 is selected as slack-bus. The system variable limits are given in Table 1.

The preliminary conditions for the IEEE-57 bus power system are given as follows:

P_{load}= 12.012 p.u. Q_{load} = 3.016 p.u.

The total initial generations and power losses are obtained as follows:

$\sum P_G$ = 12.5518 p.u. $\sum Q_G$ = 3.3204 p.u.

P_{loss}= 0.25716 p.u. Q_{loss} = -1.2012 p.u.

Table 2 shows the various system control variables & Table 3, shows the comparison of optimum results.

Table 1. Variable limits

Reactive Power Generation Limits							
Bus no	1	2	3	6	8	9	12
Qgmin	-1.4	-.015	-.02	-0.04	-1.3	-0.03	-0.4
Qgmax	1	0.3	0.4	0.21	1	0.04	1.50
Voltage And Tap Setting Limits							
vgmin	**Vgmax**	**vpqmin**	**Vpqmax**	**tkmin**	**tkmax**		
0.9	1.0	0.91	1.05	0.9	1.0		
Shunt Capacitor Limits							
Bus no	18	25	53				

Qcmin	0	0	0
Qcmax	10	5.2	6.1

Table 2. Control variables obtained after optimization

Control Variables	IIWO
V1	1.1
V2	1.038
V3	1.039
V6	1.030
V8	1.029
V9	1.010
V12	1.021
Qc18	0.0672
Qc25	0.201
Qc53	0.0472
T4-18	1.010
T21-20	1.061
T24-25	0.882
T24-26	0.872
T7-29	1.060
T34-32	0.880
T11-41	1.020
T15-45	1.039
T14-46	0.910
T10-51	1.021
T13-49	1.060
T11-43	0.910
T40-56	0.900
T39-57	0.950
T9-55	0.950

Table 3. Comparison results

S.No.	Optimization Algorithm	Finest Solution	Poorest Solution	Normal Solution
1	NLP [26]	0.25902	0.30854	0.27858
2	CGA [26]	0.25244	0.27507	0.26293
3	AGA [26]	0.24564	0.26671	0.25127
4	PSO-w [26]	0.24270	0.26152	0.24725
5	PSO-cf [26]	0.24280	0.26032	0.24698
6	CLPSO [26]	0.24515	0.24780	0.24673
7	SPSO-07 [26]	0.24430	0.25457	0.24752
8	L-DE [26]	0.27812	0.41909	0.33177
9	L-SACP-DE [26]	0.27915	0.36978	0.31032
10	L-SaDE [26]	0.24267	0.24391	0.24311
11	SOA [26]	0.24265	0.24280	0.24270
12	LM [27]	0.2484	0.2922	0.2641
13	MBEP1 [27]	0.2474	0.2848	0.2643
14	MBEP2 [27]	0.2482	0.283	0.2592
15	BES100 [27]	0.2438	0.263	0.2541
16	BES200 [27]	0.3417	0.2486	0.2443
17	Proposed IIWO	0.22118	0.23124	0.22136

VII. Conclusion

In this paper, Improved Invasive Weed Optimization (IIWO) successfully solved optimal reactive power problem. Particle Swarm Optimization (PSO) has been combined with Invasive weed optimization (IWO) to enhance exploration & exploitation capability for solving the optimal reactive power Problem. In this paper, the idea of intelligent swarming, social cooperation, competition, and reproduction in an optimization meta-algorithm has been merged.In order to evaluate the efficiency of the proposed algorithm; it has been tested on IEEE 57 bus system and simulation results reveals about the best performance of the proposed algorithm in reducing the real power loss.

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