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Interdependent Creatures Exploration Algorithm for Solving Optimal Reactive Power Dispatch Problem

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Abstract: **In this paper, a different approach, called called Interdependent Creatures Exploration (ICE) algorithm for solving optimal reactive power dispatch problem has been presented. ICE simulates the interdependent interaction strategies adopted by creatures to endure and promulgate in the ecosystem. The proposed (ICE) algorithm has been tested on standard IEEE 30 bus test system and simulation results show the worthy performance of the proposed algorithm in tumbling the real power loss.**

Keywords: **Optimal Reactive Power, Transmission loss, Interdependent Creatures Exploration, Bio-inspired algorithm.**

I. 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 a novel and commanding algorithm called Interdependent Creatures Exploration (ICE) algorithm for solving optimal reactive power dispatch power problem. This algorithm simulates interdependent communication stratagems that creatures use to endure in the ecosystem. A main advantage of the ICE algorithm over most other metaheuristic algorithms is that algorithm actions need no precise algorithm parameters. The proposed algorithm ICE 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.

II. 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

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

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 ω_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.

III. INTERDEPENDENT CREATURES EXPLORATION ALGORITHM

The proposed ICE algorithm mimics the communicating behavior seen among creatures in nature. Creatures rarely live in seclusion due to dependence on other species for nourishment and even existence. This reliance-based relationship is known as interdependence.

3.1. The basic concept of symbiosis

Interdependent relationships may be either obliges, or two organisms depend on each other for survival [21,22].The most common interdependent relationships found in nature are mutualism, commensalism, and parasitism. Mutualism denotes a interdependent relationship between two dissimilar species in which both profit. Commensalism is an interdependent relationship between two different species in which one benefits and the other is unaffected or unbiased. Parasitism is an interdependent relationship between two different species in which one benefits and the other is vigorously affected. Commonly speaking, creatures develop interdependent relations as a stratagem to adjust to modifications in their environment. Interdependent relationships may also help creatures upsurge fitness and endurance advantage over the long-term. Therefore, it is sensible to accomplish that interdependence has built and endures to shape and tolerate all recent ecosystems.

3.2. Phases of Interdependent Creatures Exploration algorithm

Existing metaheuristic algorithms emulate natural occurrences. For illustration, Artificial Bee Colony mimics the searching behavior of honeybee groups, Particle Swarm Optimization mimics animal flocking deeds, and the Genetic Algorithm mimics the procedure of natural progression. ICE mimics the interdependent communications within a paired organism rapport that are used to exploration for the fittest creature. The projected algorithm was developed primarily to solve numerical optimization over a continuous exploration space. Alike to other population-based algorithms, the projected ICE iteratively uses a population of candidate solutions to encouraging areas in the exploration space in the procedure of seeking the optimal global solution. ICE initiates with an initial population called the ecosystem. In the primary ecosystem, a group of creatures is produced arbitrarily to the exploration space. Each creature epitomizes one candidate solution to the analogous problem. Each creature in the ecosystem is related with a definite fitness value, which imitates degree of alteration to the desired objective. Almost all metaheuristic algorithms apply a sequence of operations to solutions in each iteration in order to produce novel solutions for the subsequent iteration. In ICE, new-fangled solution generation is governed by emulating the biological interaction between two organisms in the ecosystem. Three phases that be similar to the real-world biological interaction model are presented. A. Mutualism phase, B.Commensalism phase, and C.Parasitism phase. The character of the communication describes the chief principle of each phase. Interactions profit both sides in the mutualism phase; profit one side and do not impact the other in the commensalism phase; profit one side and vigorously damage the other in the parasitism phase. Each creature intermingles with the other creature arbitrarily through all phases. The procedure is recurrent until termination criteria are met.

Mutualism phase

An illustration of mutualism, which profits both creature participants, is the rapport between bees and flowers. Bees fly amongst flowers, collecting nectar to turn into honey – an action that profits bees. This movement also profits flowers because bees dispense pollen in the progression, which expedites pollination. This ICE phase imitates such mutualistic relationships. In ICE, X_i is a creature matched to the ith member of the ecosystem. Another creature X_j is then selected arbitrarily from the ecosystem to interrelate with X_i. Both creatures involve in a mutualistic association with the objective of growing joint endurance benefit in the ecosystem. New-fangled candidate solutions for X_i and X_j are calculated based on the mutualistic interdependence between creature X_i and X_j, which is modelled in Equations. (11) and (12).

$$X_{inew} = X_i + rand(0,1) * (X_{best} - mutual\_vector * PF_1) \qquad (11)$$

$$X_{jnew} = X_j + rand(0,1) * (X_{best} - mutual\_vector * PF_2) \qquad (12)$$

$$mutual\_vector = \frac{X_i + X_j}{2} \qquad (13)$$

rand (0,1) in Eqs (11) and (12) is a vector of arbitrary numbers.

The role of PF1 and PF2 is described as follows. In nature, some mutualism relationships might give a superior favourable advantage for just one creature than another creature. In other words, creature A might receive a huge benefit when interacting with creature B. Meanwhile, creature B might only get satisfactory or not so important profit when interrelating with creature A. Here, profit factors (PF1 and PF2) are determined arbitrarily as either 1 or 2. These factors represent level of profit to each creatures, i.e., whether a creature incompletely or completely profits from the relations. Equation (13) shows a vector called ‘‘Mutual_Vector’’ that epitomizes the relationship characteristic between creature X_i and X_j. The part of equation $(X_{best} - mutual\_vector * BF_1)$, is imitating the mutualistic struggle to attain their goal in increasing their endurance advantage. The X_{best} is needed here because X_{best} is representing the highest degree of adaptation. Therefore, we use X_{best}/global solution to model the uppermost degree of alteration as the target point for the fitness increment of both creatures. Finally, creatures are modernized only if their new fitness is better than their pre-interaction fitness.

Commensalism phase

An illustration of commensalism is the association between remora fish and sharks. The remora attaches itself to the shark and eats food remnants, thus receiving a profit. The shark is unaffected by remora fish activities and obtains negligible. Analogous to the mutualism phase, a creature, X_j, is selected arbitrarily from the ecosystem to interact with X_i. In this condition, creature X_i makes efforts to profit from the relations. Conversely, creature X_j itself neither profits nor hurts from the relationship. The new candidate solution of X_i is calculated according to the commensal interdependence between creature X_i and X_j, which is modelled in Eq. (14). Subsequent to the rules, creature X_i is modernized only if its new fitness is better than its pre-interaction fitness.

$$X_{inew} = X_i + rand(-1,1) * \left(X_{best} - X_j\right) \qquad (14)$$

The part of equation $\left(X_{best} - X_j\right)$, is imitating as the favourable advantage provided by X_j to help X_i increasing its endurance advantage in ecosystem to the highest degree in current creature (denoted by X_{best}).

Parasitism phase

An illustration of parasitism is the plasmodium parasite, which uses its relationship with the anopheles mosquito to pass between human hosts. While the parasite flourishes and breeds inside the human body, its human host suffers malaria and can die as an outcome. In ICE, creature X_i is given a role analogous to the anopheles mosquito through the formation of an artificial parasite called ‘‘Parasite_Vector’’. Parasite_Vector is produced in the exploration space by replicating creature X_i, then modifying the arbitrarily selected dimensions using an arbitrary number. Creature X_j is selected arbitrarily from the ecosystem and serves as a host to the parasite vector. Parasite_Vector tries to swap X_j in the ecosystem. Both creatures are then appraised to measure their fitness. If Parasite_Vector has a improved fitness value, it will kill creature X_j and assume its position in the ecosystem. If the fitness value of X_j is superior, X_j will have immunity from the parasite and the Parasite_Vector will no longer be able to live in that ecosystem.

ICE algorithm for solving reactive power dispatch problem

Step 1: Ecosystem Initialization

Number of creatures (eco_size), initial ecosystem, termination criteria, num_iter=0, num_fit_eval=0, max_iter, max_fit_eval

Step 2: Categorize best creature (Xbest)

Select one creature arbitrarily, X_j, where $X_j \neq X_i$

Step 3: Mutualism Phase

Determine mutual relationship vector (Mutual_Vector) and profit factor (PF)

$$\mathrm{mutual\_vector} = \frac{X_i + X_j}{2}$$

PF1= arbitrary number either 1 or 2; PF2= arbitrary number either 1 or 2

Alter creature X_i and X_j based on their mutual relationship

$$X_{inew} = X_i + \mathrm{rand}(0,1) * (X_{best} - \mathrm{mutual\_vector} * PF_1)$$

$$X_{jnew} = X_j + \mathrm{rand}(0,1) * (X_{best} - \mathrm{mutual\_vector} * PF_2)$$

Compute Fitness Value of the modified creatures; num_fit_eval = num_fit_eval + 2

Are the altered creatures fitter than the previous?

If yes accept the modified creatures to swap the previous

If no reject the modified creatures and retain the previous

Step 4: Commensalism Phase

Select one creature arbitrarily, X_j, where $X_j \neq X_i$

Transform creature X_i with the contribution of creature X_j

$X_{inew} = X_i + rand(-1,1) * (X_{best} - X_j)$

Compute Fitness Value of the new creature; num_fit_eval = num_fit_eval + 1

Is the modified creature fitter than the previous?

If yes Accept $X_{i\ new}$ to swap X_i

If no Reject $X_{i\ new}$ and retain X_i

Step 5: Parasitism Phase

Select one creature arbitrarily, X_j, where $X_j \neq X_i$

Generate a Parasite (Parasite_Vector) from Creature X_i

Compute Fitness Value of the new creature; num_fit_eval = num_fit_eval + 1

Is Parasite_Vector fitter than creature X_j?

If yes Swap organism X_j with Parasite_Vector

If no Retain creature Xj and scratch Parasite_Vector

Step 6: i = eco_size?

If yes move to next step7 or go to step step 2

Step7: Is end criteria attained?

(num_iter>max_iter and/or num_fit_eval>max_fit_eval) if yes we get optimal solution or else go to step 1

IV. SIMULATION RESULTS

ICE 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)	**ICE**
V1	1.0308
V2	1.0379
V5	1.0190
V8	1.0289
V11	1.0619
V13	1.0428
T4,12	0.00
T6,9	0.01
T6,10	0.91
T28,27	0.90
Q10	0.11
Q24	0.10
PLOSS	4.5382
VD	0.9089

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 (23)	4.98
PSO (24)	4.9262
LP (25)	5.988
EP (25)	4.963
CGA (25)	4.980
AGA (25)	4.926
CLPSO (25)	4.7208
HSA (26)	4.7624
BB-BC (27)	4.690
ICE	4.5382

V. CONCLUSION

In this paper, the ICE has been successfully implemented to solve Optimal Reactive Power Dispatch problem. The main advantages of the ICE 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 ICE demonstrated its effectiveness and robustness in minimizing the real power loss.

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