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Water Cycle Algorithm For Solving Optimal Reactive Power Dispatch Problem

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ABSTRACT

In this paper, a new approach, called water cycle algorithm (WCA) used for solving optimal reactive power dispatch problem. The design of the WCA as an optimization algorithm was imitative from nature & after probing the whole water cycle process which involves the flow of streams and rivers into the sea in the natural world.The proposed (WCA) algorithm has been tested on standard IEEE 30 bus test system and simulation results shows clearly about the superior performance of the proposed algorithm in dropping the real power loss.

Key Words : Optimal Reactive Power, Transmission loss, voltage stability, Water Cycle Algorithm, Bio-inspired algorithm.

INTRODUCTION

The main objective of optimal reactive power dispatch (ORPD) problem is to minimize the real power loss and bus voltage deviation by fulfilling a set of physical and working constraints imposed by apparatus limitations and security needs. 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 has the difficulty in overseeing inequality constraints. If linear programming is applied then the input- output function has to be articulated as a set of linear functions which mostly lead to loss of correctness. The problem of voltage stability and collapse play a major role in power system planning and operation [8]. Global optimization has received extensive research alertness, and a great number of methods have been applied to solve this problem. Evolutionary algorithms such as genetic algorithm have been already planned 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 stability index. In [13] Biogeography Based algorithm is considered 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], proposes a two-step approach to evaluate Reactive power reserves with respect to operating constraints and voltage stability. In [19], a programming based proposed approach used to solve the optimal reactive power dispatch problem. In [20], presents a probabilistic algorithm for optimal reactive power provision in hybrid electricity markets with uncertain loads. In this study, a new optimization algorithm, acknowledged as the water cycle algorithm (WCA) [21], has been used to solve the optimal reactive power dispatch problem. The inspiration for the idea of WCA was drawn from observing the nature and came from studying the water cycle and observing the way in which the streams and rivers flow downwards into the sea in this natural earth. The proposed algorithm WCA has been evaluated in standard IEEE 30 bus test system & the simulation results shows that our proposed approach outperforms all reported algorithms in minimization of real power loss.

MATERIALS AND METHODS

Problem Formulation

The OPF problem is measured as a general minimization problem with constraints, and can be mathematically written in the following form:

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

$$\text{Subject to } g(x,u)=0 \qquad (2)$$

and

$$h(x, u) \leq 0 \qquad (3)$$

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.

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

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

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

$$u = \left(V_g, T, Q_c\right)^T \qquad (5)$$

or

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

Where Ng, Nt and Nc are the number of generators, number of tap transformers and the number of shunt compensators respectively.

Objective Function

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:

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

(7)

or

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

(8)

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.

Voltage profile improvement

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

$$F = PL + \omega_v \times VD \qquad (9)$$

Where ω_v: is a weighting factor of voltage deviation.
VD is the voltage deviation given by:

$$VD = \sum_{i=1}^{Npq} |V_i - 1| \qquad (10)$$

Equality Constraint

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

$$P_G = P_D + P_L \qquad (11)$$

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

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:

$$P_{gslack}^{min} \le P_{gslack} \le P_{gslack}^{max} \qquad (12)$$

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max}, i \in N_g \qquad (13)$$

Upper and lower bounds on the bus voltage magnitudes:

$$V_i^{min} \le V_i \le V_i^{max}, i \in N \qquad (14)$$

Upper and lower bounds on the transformers tap ratios:

$$T_i^{min} \le T_i \le T_i^{max}, i \in N_T \qquad (15)$$

Upper and lower bounds on the compensators reactive powers:

$$Q_c^{min} \le Q_c \le Q_c^{max}, i \in N_C \qquad (16)$$

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.

The water cycle algorithm

Fundamental conception

As water flows down from upper place to lower one, a river or a stream is formed. As such, most rivers are created at the top of mountains where the melting of snow occurs. In turn, the rivers continuously flow down and along this voyage they are feed with water from rainfall and from other streams before they consequently finish up in the sea. The water in lakes and rivers begin to evaporate. Also during the course of action in photosynthesis plants give off water. Then, the water that is evaporated or transpired goes up into the atmosphere and leads to the creation of clouds that condense in the colder air above. Thus the water is dispersed through precipitation and the formation of rain back to the earth again. This procedure is known as the water cycle [22]. In our natural world, most of the water that comes from the melting of snow or from rainfall seep into the porous layer of rock or soil seditious and is stored there in large amounts. This aquifer is sometimes referred to as groundwater for more explanation. That water in the aquifer flows in a downward direction, seditious in the same way that it flows on the surface of the ground. The underground water could be emptied into a lake, swamp or stream. More clouds are formed through the disappearance of water from streams and rivers, together with transpiration from trees and other vegetation, thus causing more rain to fall, and consequently the cycle go on.

Proposed Water Cycle Algorithm

WCA starts with initial population, which can be compared to the raindrops. Primarily, we start with the postulation that rain or precipitation is available. A sea is selected as the best individual (best raindrop). A number of value raindrops are selected to symbolize a river while the remainder of the raindrops are represented streams flowing into the sea and the rivers. Each river takes in water from the streams according to the force of their flow. Actually, the quantity of water entering a river and sea differs from one stream to another. In addition, the flow of the rivers into the sea is as it at the lowest location.

Generate the initial population

When population-based meta-heuristic methods are engaged to resolve an optimization problem, the problem variables values must be prearranged in form of an array. This array is named "Chromosome" and "Particle location" in Genetic Algorithm and Particle Swarm Optimization terminologies, respectively. Hence, in the proposed method, the array for a single solution is appropriately called a "raindrop". A raindrop is an array of $1 \times N_{var}$ in a N_{var} dimensional optimization problem, and then this array can be defined as:

$$Raindrop = [X_1, X_2, X_3, \ldots, X_n] \quad (17)$$

The raindrop cost could be determined by calculating the function of cost (C) as:

$$c_i = cost_i = \int \left(X_1^i, X_2^i, \ldots, X_{N_{var}}^i\right) i = 1,2,\ldots,N_{pop} \quad (18)$$

Where N_{pop} and N_{var} are represented the number of raindrops (initial population) and design variables. First, N_{pop} raindrops are created. A number of N_{sr} are chosen as the sea and rivers from the best individuals (minimum values). The raindrop with the least value among the rest is taken as a sea. Actually, N_{sr} represents the total Number of Rivers (user parameter) for a single sea as shown in Eq. (18). The remainder of the population (raindrops that compose the streams that flow down directly into the sea or into the rivers) is determined by using Eq. (19).

$$N_{sr} = number\ os\ rivers\ + 1 \quad (18)$$

$$N_{raindrops} = N_{pop} - N_{sr} \quad (19)$$

The following equation is used to assign raindrops into the sea or the rivers concerning about the strength of the flow:

$$NS_n = round\left\{\left|\frac{cost_n}{\sum_{i=1}^{N_{sr}} cost_i}\right| \times N_{rain\ drops}\right\}, n = 1,2, \ldots, N_{sr} \quad (20)$$

This idea can also be applied on rivers that flow into the sea so the new position for the rivers and streams can be given as:

$$X_{stream}^{i+} = X_{stream}^{i} + rand \times c \times \left(X_{River}^{i} - X_{stream}^{i}\right) \quad (21)$$

$$X_{River}^{i+} = X_{River}^{i} + rand \times c \times \left(X_{sea}^{i} - X_{River}^{i}\right) \quad (22)$$

Where C is represented a value between 1 and 2 (Nearer to 2), the best selected value for C is 2.As rand stands for a uniformly distributed random number between 0 and 1, If the solution which is given by a stream is better than its connecting river then the positions of the stream and the river can be exchanged (i.e. the stream becomes the river and vice versa). Similarly, like this exchange may also occur in the position of the sea and the rivers.

Evaporation is a process where d_{max} represents small number (closer to zero). If the distance between the sea and the river is less than d_{max}, it signifies that the river arrived at or linked with the sea. The evaporation process is taken into consideration in this situation and as can be observed in nature, after ample evaporation has taken place, it will begin to rain or precipitation will occur. A large d_{max} value will lower the search but a small value will encourage an intensification of the search close to the sea. As such, the intensity of the search close to the sea (the optimum solution) is controlled by the d_{max}. The value of the d_{max} adapts accordingly and decreases as:

$$d_{max}^{i+1} = d_{max}^{i} - \frac{d_{max}^{i}}{max\ iteration} \quad (23)$$

On completion of the evaporation, the rain process is employed. The raining process involves the formation of streams in various locations by the new raindrops. The following equation is used to specify new locations of the freshly new forming streams:

$$X_{stream}^{new} = LB + rand \times (Ub - LB) \quad (24)$$

Where UB and LB is the upper and lower bounds respectively as identified from the given problem. Eq. (25) is only used for those streams which flow directly into the sea in order to improve the computational performance of the algorithm and the convergence rate of the controlled problems.
The objective of this equation is to foster the creation of the streams that flow straight into the sea in order to increase the search near the sea (the optimum solution) of the feasible area for the controlled problems.

$$X_{stream}^{new} = X_{sea} + \sqrt{\mu} \times randm(1, N_{var}) \qquad (25)$$

Where μ is a coefficient that indicates the range of the search area close to the sea and randn is the normally distributed random number. While the larger value for μ raises the possibility of exiting in the feasible area, the smaller value for μ steers the algorithm to search in a narrow area close to the sea. The suitable value to set for μ is 0.1. From a mathematical perspective, the standard deviation is represented by the term $\sqrt{\mu}$ in Eq. (25) and thus, the concept of variance is accordingly defined as l. By employing these concepts, the individuals that are generated with variance μ are dispersed approximate to the best optimum point which is the (Sea) that has been obtained.

WCA algorithm for solving ORPD problem

- Step 1: select the WCA preliminary parameters:
  $N_{sr}, d_{max}, N_{pop}, \max_{iteration}$.
- Step 2: generate the random preliminary population and form the sea, rivers and preliminary streams (raindrops) by using Equations (18) and (19).
- Step 3: calculate the worth (cost) of each raindrop by using Eq. (17).
- Step 4: find out the concentration of the flow for the sea and rivers by using Eq. (20).
- Step 5: find the flow of the streams into the rivers by using Eq. (21).
- Step 6: find the flow of the rivers into the sea (the most downwards position) by using Eq. (22).
- Step 7: exchange the point of the stream with the river in order to obtain the best solution,.
- Step 8: similar to Step 7, whether the river could find an improved solution than the sea, exchanging the position of the sea with that of the river.
- Step 9: examine about the conditions of the evaporation are satisfied.
- Step 10: check the conditions of the evaporation are satisfied and the rain process will occur by using Equations (24) and (25).
- Step 11: tumbling the value of d, which is measured a defined user parameter by using Eq. (23).
- Step 12: analysis about the criteria of convergence - if the stopping criteria is met, the algorithm will stop or else it will go again to Step 5.

RESULT AND DISCUSSION

WCA algorithm has been tested on standard 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 calculated 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.

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 1: Initial Variables Limits (PU)

Control variables	Min. value	Max. value	Type
Generator: Vg	0.90	1.03	Continuous
Load Bus: VL	0.91	1.00	Continuous
T	0.90	1.37	Discrete
Qc	-0.11	0.30	Discrete

Table 2: Generators Power Limits in MW and MVAR

Bus n°	P_g	P_{gmin}	P_{gmax}	Q_{gmin}
1	94.00	50	200	-20
2	80.00	20	80	-20
5	21.00	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)	WCA
V1	1.0301
V2	1.0303
V5	1.0185
V8	1.0209
V11	1.0601
V13	1.0432
T4,12	0.00
T6,9	0.01
T6,10	0.90
T28,27	0.90
Q10	0.10
Q24	0.10

PLOSS	4.9101
VD	0.9092

The proposed approach succeeds in keeping the dependent variables within their limits.

Table 4 summarizes the results of the optimal solution obtained by PSO, SGA and WCA methods. It reveals the decrease of real power loss after optimization

Table 4: Comparison Results of Different Methods

SGA[9]	PSO[10]	WCA
4.98 Mw	4.9262Mw	4.9101Mw

CONCLUSION

In this paper, the WCA has been effectively implemented to solve ORPD problem. The main reward of the WCA to the ORPD problem are optimization of dissimilar type of objective function - real coded of both continuous, discrete control variables and easily handling nonlinear constraints. The projected algorithm has been tested on the IEEE 30-bus system. The results are compared with the other heuristic methods such as SGA and PSO algorithm reported in the literature and WCA demonstrated its effectiveness and robustness in solving the reactive power dispatch problem.

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