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ACTIVE POWER LOSS REDUCTION AND IMPROVEMENT OF STATIC VOLTAGE STABILITY MARGIN INDEX BY WATERWAY ALGORITHM

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Abstract -- *In this paper, the Waterway Algorithm (WA) is used for Active Power Loss Reduction and improvement of Static Voltage Stability Margin Index. The design of the Waterway Algorithm (WA) is imitated from nature and the whole waterway process which involves the flow of streams and rivers into the sea in the natural world. The proposed Waterway Algorithm (WA) algorithm has been tested on standard IEEE 30 bus test system and simulation results show clearly about the superior performance of the proposed algorithm in reducing the real power loss and upgrading the Static Voltage Stability Margin Index.*

Keywords: *Optimal Reactive Power; Transmission loss; Voltage stability; Waterway Algorithm; Bio-inspired algorithm.*

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INTRODUCTION

In recent years the optimal reactive power dispatch (ORPD) problem has received great attention as a result of the improvement on economy and security of power system operation. Gradient method (Abido and Bakhashwain, 2003; Abdullah et al., 1998), Newton method (Lee, Park and Ortiz, 1994) and linear programming (Granville, 1994; Deeb and Shahidehpour, 1998; Grudinin, 1998) like various mathematical techniques have been adopted to solve the optimal reactive power dispatch problem.

But, they have difficulty in handling inequality constraints. Many Evolutionary algorithms such as have been proposed to solve the reactive power dispatch problem (Abido, 2002; Abou et al., 2011; Miranda and Fonseca, 2002; Canizares et al., 1996). In this paper, Waterway Algorithm (WA) used for Active Power Loss Reduction & Upgrading the Static Voltage Stability Margin Index.

The design of the Waterway Algorithm (WA) is imitated from nature & the whole waterway process (Eskandar et al., 2012; David, 1993) which involves the flow of streams and rivers into the sea in the natural world.

The proposed Waterway Algorithm (WA) 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 reducing the real power loss and upgrading the Static Voltage Stability Margin Index.

METHOD

Voltage Stability Evaluation

a. Modal analysis for voltage stability evaluation

Power flow equations of the steady state system is given by Equ. (1):

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix} = \begin{bmatrix} J_{p\theta} & J_{pv}\\ J_{q\theta} & J_{QV}\end{bmatrix} \begin{bmatrix}\Delta\theta\\ \Delta V\end{bmatrix} \quad (1)$$

where:

- ΔP = bus real power change incrementally.
- ΔQ = bus reactive Power injection change incrementally
- $\Delta\theta$ = bus voltage angle change incrementally.
- ΔV = bus voltage Magnitude change incrementally. $J_{p\theta}$, JPV , $JQ\theta$, JQV are sub-matrixes of the System voltage stability in jacobian matrix and both P and Q get affected by this.

Presume $\Delta P = 0$, then Equ. (1) can be written as,

$$\Delta Q = \left[J_{QV} - J_{Q\theta} J_{P\theta^{-1}} J_{PV}\right]\Delta V = J_R \Delta V \quad (2)$$

$$\Delta V = J^{-1} - \Delta Q \quad (3)$$

where:

$$J_R = \left(J_{QV} - J_{Q\theta} J_{P\theta^{-1}} JPV\right) \quad (4)$$

J_R denote the reduced Jacobian matrix of the system.

b. Modes of Voltage instability

Voltage Stability characteristics of the system have been identified through computation of the Eigen values and Eigen vectors.

$$J_R = \xi \wedge \eta \quad (5)$$

where, ξ denote the right eigenvector matrix of JR, η denote the left eigenvector matrix of JR, ∧ denote the diagonal eigenvalue matrix of JR.

$$J_{R^{-1}} = \xi \wedge^{-1} \eta \quad (6)$$

From the Equ. (5) and (6),

$$\Delta V = \xi \wedge^{-1} \eta \Delta Q \quad (7)$$

or

$$\Delta V = \sum_I \frac{\xi_i \eta_i}{\lambda_i} \Delta Q \quad (8)$$

ξi denote the ith column right eigenvector and η is the ith row left eigenvector of JR and λi indicate the ith Eigen value of JR.

Reactive power variation of the ith modal is given by,

$$\Delta Q_{mi} = K_i \xi_i \quad (9)$$

where,

$$K_i = \sum_j \xi_{ij^2} - 1 \quad (10)$$

where ξji is the jth element of ξi and ith modal voltage variation is mathematically given by,

$$\Delta V_{mi} = [1/\lambda_i] \Delta Q_{mi} \quad (11)$$

When the value of | λi | =0 then the ith modal voltage will get collapsed.

In Equ. (8), when ΔQ = ek is assumed , then ek has all its elements zero except the kth one being 1. Then ΔV can be formulated as follows,

$$\Delta V = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} \quad (12)$$

η_{1k} is k th element of η_1

At bus k V –Q sensitivity is given by,

$$\frac{\partial V_K}{\partial Q_K} = \sum_i \frac{\eta_{1k}\ \xi_1}{\lambda_1} = \sum_i \frac{P_{ki}}{\lambda_1} \quad (13)$$

Problem Formulation

To minimize the real power loss and also to maximize the static voltage stability margin (SVSM) is the key objectives of the reactive power dispatch problem.

a. Minimization of Real Power Loss

Real power loss (Ploss) minimization in transmission lines is mathematically given as,

$$P_{loss=} \sum^{n}_{\substack{k=1 \\ k=(i,j)}} g_{k(V_i^2 + V_j^2 - 2V_i V_j \cos\theta_{ij})} \quad (14)$$

Where n is the number of transmission lines, gk is the conductance of branch k, Vi and Vj are voltage magnitude at bus i and bus j, and θij is the voltage angle difference between bus i and bus j.

b. Minimization of Voltage Deviation

At load buses minimization of the voltage deviation magnitudes (VD) is stated as follows,

$$\text{Minimize VD} = \sum_{k=1}^{nl} |V_k - 1.0| \quad (15)$$

Where nl is the number of load busses and Vk is the voltage magnitude at bus k.

c. System Constraints

These are the following constraints subjected to objective function as given below,

Load flow equality constraints:

$$P_{Gi} - P_{Di} - V_{i \sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \cos\theta_{ij} \\ +B_{ij} & \sin\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (16)$$

$$Q_{Gi} - Q_{Di} - V_{i \sum_{j=1}^{nb} V_j} \begin{bmatrix} G_{ij} & \sin\theta_{ij} \\ +B_{ij} & \cos\theta_{ij} \end{bmatrix} = 0, i = 1,2 \ldots., nb \quad (17)$$

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:

$$V_{Gi}^{min} \le V_{Gi} \le V_{Gi}^{max}, i \in ng \quad (18)$$

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

$$V_{Li}^{min} \le V_{Li} \le V_{Li}^{max}, i \in nl \quad (19)$$

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

$$Q_{Ci}^{min} \le Q_{Ci} \le Q_{Ci}^{max}, i \in nc \quad (20)$$

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

$$Q_{Gi}^{min} \le Q_{Gi} \le Q_{Gi}^{max}, i \in ng \quad (21)$$

Transformers tap setting (T_i) inequality constraint:

$$T_i^{min} \le T_i \le T_i^{max}, i \in nt \quad (22)$$

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

$$S_{Li}^{min} \le S_{Li}^{max}, i \in nl \quad (23)$$

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

The Waterway Algorithm

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 waterway. 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.

Waterway Algorithm (WA) 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.

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:

$$Raindrop = [X_1, X_2, X_3, .., X_n] \quad (24)$$

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

$$c_i = cost_i = \int (X_1^i, X_2^i, .., X_{N_{var}}^i) \; i = 1,2, .., N_{pop} \quad (25)$$

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. (26). 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 Equ. (27).

$$N_{sr} = number\ os\ rivers + 1 \quad (26)$$

$$N_{raindrops} = N_{pop} - N_{sr} \quad (27)$$

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

$$NS_n = round \left\{ \left| \frac{cost_n}{\sum_{i=1}^{N_{sr}} cost_i} \right| \times N_{rain\ drops} \right\}, n = 1,2, .., N_{sr} \quad (28)$$

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:

$$X_{stream}^{i+} = X_{stream}^i + rand \times c \times (X_{River}^i - X_{stream}^i) \quad (29)$$

$$X_{River}^{i+} = X_{River}^i + rand \times c \times (X_{sea}^i - X_{River}^i) \quad (30)$$

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:

$$d_{max}^{i+1} = d_{max}^{i} - \frac{d_{max}^{i}}{maxiteration} \quad (31)$$

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:

$$X_{stream}^{new} = LB + rand \times (Ub - LB) \quad (32)$$

Where UB and LB is the upper and lower bounds respectively as identified from the given problem. Eq. (33) 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.

$$X_{stream}^{new} = X_{sea} + \sqrt{\mu} \times randm(1, N_{var}) \quad (33)$$

Where μ is a coefficient that indicates the range of the search area close to the sea and rand m 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.

Waterway Algorithm (WA) for solving optimal reactive power problem

Step 1: select the WA 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)

Step 3: calculate the worth (cost) of each raindrop.

Step 4: find out the concentration of the flow for the sea and rivers.

Step 5: find the flow of the streams into the rivers.

Step 6: find the flow of the rivers into the sea (the most downwards position)

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.

Step 11: tumbling the value of d_{max}, which is measured a defined user parameter.

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.

RESULTS AND DISCUSSION

The efficiency of the proposed Waterway Algorithm (WA) is demonstrated by testing it on standard IEEE-30 bus system. 6 generator buses, 24 load buses and 41 transmission lines of which four branches are (6-9), (6-10) , (4-12) and (28-27) - are with the tap setting transformers in standard IEEE-30 bus system. Lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses, for PQ buses & reference bus it is 1.05 p.u. Comparisons of results are shown in Table 5. In Table 1 optimal values of the control variables are given.

Table 1.Results of WA – ORPD optimal control variables

Control variables	Values of Variable setting
V1	1.0424
V2	1.0421
V5	1.0432
V8	1.0302
V11	1.0044
V13	1.0311
T11	1.000
T12	1.000
T15	1.010
T36	1.010
Qc10	2
Qc12	3
Qc15	2
Qc17	0
Qc20	2
Qc23	2
Qc24	3
Qc29	2
Real power loss	4.1364
SVSM	0.2486

Table 2 indicates the optimal values of the control variables & there is no limit violations in state variables. Mainly static voltage stability margin (SVSM) has increased from 0.2486 to 0.2498. contingency analysis was conducted using the control variable setting obtained in case 1 and case 2 to determine the voltage security of the system.

In Table 3 the Eigen values equivalents to the four critical contingencies are given. Result reveal about the Eigen value has been improved considerably for all contingencies in the second case, as listed in Table 4 and Table 5.

Table 2.Results of WA -Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

Control Variables	Values of Variable Setting
V1	1.0452
V2	1.0473
V5	1.0482
V8	1.0303
V11	1.0036
V13	1.0328
T11	0.090
T12	0.090
T15	0.090
T36	0.090
Qc10	3
Qc12	2
Qc15	2
Qc17	3
Qc20	0
Qc23	2
Qc24	2
Qc29	3
Real power loss	4.9890
SVSM	0.2498

Table 3. Voltage Stability under Contingency State

Sl.No	Contingency	Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
1	28-27	0.1419	0.1424
2	4-12	0.1642	0.1651
3	1-3	0.1761	0.1764
4	2-4	0.2022	0.2052

Table 4. Limit Violation Checking Of State Variables

State variables	Limits		Optimal Reactive Power Dispatch Setting	Voltage Stability Control Reactive Power Dispatch Setting
	Lower	Upper		
Q1	-20	152	1.3422	-1.3269
Q2	-20	61	8.9900	9.8232
Q5	-15	49.92	25.920	26.001
Q8	-10	63.52	38.8200	40.802
Q11	-15	42	2.9300	5.002
Q13	-15	48	8.1025	6.033
V3	0.95	1.05	1.0372	1.0392
V4	0.95	1.05	1.0307	1.0328
V6	0.95	1.05	1.0282	1.0298
V7	0.95	1.05	1.0101	1.0152
V9	0.95	1.05	1.0462	1.0412
V10	0.95	1.05	1.0482	1.0498
V12	0.95	1.05	1.0400	1.0466
V14	0.95	1.05	1.0474	1.0443
V15	0.95	1.05	1.0457	1.0413
V16	0.95	1.05	1.0426	1.0405
V17	0.95	1.05	1.0382	1.0396
V18	0.95	1.05	1.0392	1.0400
V19	0.95	1.05	1.0381	1.0394
V20	0.95	1.05	1.0112	1.0194
V21	0.95	1.05	1.0435	1.0243
V22	0.95	1.05	1.0448	1.0396
V23	0.95	1.05	1.0472	1.0372
V24	0.95	1.05	1.0484	1.0372
V25	0.95	1.05	1.0142	1.0192
V26	0.95	1.05	1.0494	1.0422
V27	0.95	1.05	1.0472	1.0452
V28	0.95	1.05	1.0243	1.0283
V29	0.95	1.05	1.0439	1.0419
V30	0.95	1.05	1.0418	1.0397

Table 5. Comparison of Real Power Loss

Method	Minimum loss
Evolutionary programming (Wu et al., 1995)	5.0159
Genetic algorithm (Durairaj et al., 2006)	4.6650
Real coded GA with Lindex as SVSM (Devaraj, 2007)	4.5680
Real coded genetic algorithm (Jeyanthy and Devaraj, 2010)	4.5015
Proposed WA method	4.1364

CONCLUSION

In this paper, Waterway Algorithm (WA) has been effectively solved optimal reactive power dispatch problem. The design of the Waterway Algorithm (WA) is imitated from nature & the whole waterway process which involves the flow of streams and rivers into the sea in the natural world.

The proposed Waterway Algorithm (WA) 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 reducing the real power loss and Upgrading the Static Voltage Stability Margin Index.

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