Brain Storm Optimization Algorithm for Solving Optimal Reactive Power Dispatch Problem

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I. Introduction

Power system constancy is related through security, and it refers to steadiness of service, reliability in frequency and specified voltage restrictions. Main task is to sustain the voltage profiles within the limits by increase or decrease in reactive power. Choosing the ideal parameter of reactive power resources is one of the centreways for the protected function of transmission structure. The scanty regulation of reactive power sources confines the active power transmission, which can be basis for uncontrolled declined in voltage and tension fall down in the load buses. Optimal reactive power dispatch is one among the main subject for the operation and control of power systems, and it should be carried out properly such that system dependability should not get affected. The gradient method [1, 2], Newton method [3] and linear programming [4-7] experience from the complexity of managing the inequality constraints. In recent times widespread Optimization techniques such as genetic algorithms have been proposed to solve the reactive power flow problem [8, 9]. In recent years, the difficulty of voltage stability and voltage fall down has become most important concern in power system development and function. This paper presents the reactive power dispatch problem as multi-objective optimization problem with real power loss minimization and maximization of static voltage stability margin (SVSM). Voltage stability evaluation is done by using modal analysis [10] and it is used as the pointer of voltage stability. The meta-heuristic algorithms have extraordinary features that differs them from the gradient based methods. In the field of structural optimization, genetic algorithms (GA) [11-12], particle swarm optimization (PSO) [13-14] and Ant colony optimization (ACO) [15-16] are very recent algorithms used to solve a variety of optimization problems. In a swarm intelligence algorithm, it is the cooperative behaviour of all individuals that make the algorithm to be successful in problem optimization. All individuals collaborate and move in a group towards the superior areas in the solution of explore space. These individuals symbolize objects such as birds in PSO, ants in ACO, bacteria in BFO, etc. Human beings are social animals and are the most intellectual animals in the world. It is natural to imagine that an optimization algorithm inspired by human creative problem solving process will be a high-quality optimization algorithm. In this paper, we will introduce a new optimization algorithm inspired by the human thought generation procedure – brainstorming procedure. In this paper is Brain Storm Optimization Algorithm (BSOA) [17] used to solve the optimal reactive power problem. The performance of BSOA has been evaluated in standard IEEE 30 bus test system and the simulation results show that our proposed method outperforms all approaches investigated in this paper.

II. Voltage Stability Evaluation

A. Modal analysis for voltage stability evaluation

The linearized steady state system power flow equations are given by,

$$\Delta P = \frac{\partial P}{\partial Q}$$

Where

- $\Delta P$ = Incremental change in bus real power.
- $\Delta Q$ = Incremental change in bus reactive power
- Power injection
- $\Delta V$ = Incremental change in bus voltage angle.
- $J_{pq}$, $J_{pv}$, $J_{qV}$, $J_{qV}^T$: Jacobian matrix are the sub-matrices of the System voltage stability affected by both $P$ and $Q$.

However, at each operational point we keep $P$ constant and evaluate voltage stability by considering incremental relationship between $Q$ and $V$.

To reduce (1), let $\Delta P = 0$, then,

$$\Delta Q = \Delta V$$

$$\Delta V = J^{-1} \Delta Q$$

Where

$$J = \begin{bmatrix} J_{qV} & -J_{qV} J_{pV} \end{bmatrix}$$

$J_R$ is called the reduced Jacobian matrix of the system.
B. Modes of Voltage instability:

Voltage Stability characteristics are computed by the Eigen values and Eigen vectors.

Let

\[ J_R = \xi \Lambda \eta \]  \hspace{1cm} (5)

Where,

\[ \xi = \text{right eigenvector matrix of } J_R \]

\[ \eta = \text{left eigenvector matrix of } J_R \]

\[ \Lambda = \text{diagonal Eigenvalue matrix of } J_R \]

\[ J_R^{-1} = \xi \Lambda^{-1} \eta \]  \hspace{1cm} (6)

From (3) and (6), we have

\[ \Delta V = \xi \Lambda^{-1} \eta \Delta Q \]  \hspace{1cm} (7)

or

\[ \Delta V = \sum \frac{\xi_i}{\lambda_i} \Delta Q \]  \hspace{1cm} (8)

Where \( \xi_i \) is the ith column right Eigenvector and \( \eta \) the ith row left eigenvector of \( J_R \).

\( \lambda_i \) is the ith eigen value of \( J_R \).

The ith modal reactive power variation is,

\[ \Delta Q_{mi} = K_i \xi_i \]  \hspace{1cm} (9)

where,

\[ K_i = \sum_j \xi_{ij}^2 - 1 \]  \hspace{1cm} (10)

Where

\( \xi_{ij} \) is the jth element of \( \xi_i \)

The corresponding ith modal voltage variation is

\[ \Delta V_{mi} = \frac{1}{\lambda_i} \Delta Q_{mi} \]  \hspace{1cm} (11)

In (8), let \( \Delta Q = e_k \) where \( e_k \) has all its elements zero except the kth one being 1. Then,

\[ \Delta V = \sum \frac{\xi_i}{\lambda_i} \delta_{ik} \]  \hspace{1cm} (12)

\( \delta_{ik} \) kth element of \( \delta_{ik} \)

\( \delta_{ik} \) V sensitivity at bus k

\[ \frac{\delta V}{\delta Q_k} = \sum \frac{\xi_i}{\lambda_i} = \sum \frac{\delta V}{\delta Q_k} \]  \hspace{1cm} (13)

III. Problem Formulation

The objective of the reactive power dispatch problem is to control the real power loss and maximize the static voltage stability margins (SVSM) index.

A. Minimization of Real Power Loss

Minimization of real power loss (Ploss) in transmission lines is mathematically stated as follows.

\[ P_{\text{loss}} = \sum_{k=1}^{n} g_k (v_i^2 + v_j^2 - 2v_i v_j \cos \theta_{ij}) \]  \hspace{1cm} (14)

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 \( \theta_{ij} \) is the voltage angle difference between bus \( i \) and bus \( j \).

B. Minimization of Voltage Deviation

Minimization of Deviations in voltage magnitudes (VD) at load buses is mathematically stated as follows.

Minimize \( VD = \sum_{k=1}^{n_l} |V_k - 1.0| \)  \hspace{1cm} (15)

Where \( n_l \) is the number of load buses and \( V_k \) is the voltage magnitude at bus \( k \).

C. System Constraints

Objective functions are subjected to the following constraints.

Load flow equality constraints:

\[ P_{ei} - P_{di} - V_i v_j - \frac{G_{ij} \cos \theta_{ij}}{2} + \frac{B_{ij} \sin \theta_{ij}}{2} = 0, i = 1, 2, ..., n_b \]  \hspace{1cm} (16)

\[ Q_{ei} - Q_{di} - V_i v_j - \frac{G_{ij} \cos \theta_{ij}}{2} + \frac{B_{ij} \sin \theta_{ij}}{2} = 0, i = 1, 2, ..., n_b \]  \hspace{1cm} (17)

where, \( n_b \) is the number of buses, \( P_G \) and \( Q_G \) are the real and reactive power of the generator. \( P_S \) and \( Q_S \) 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 (\( V_G \)) inequality constraint:

\[ V_{G_{mi}} \leq V_G \leq V_{G_{mi}}^{\text{max}}, i \in n_G \]  \hspace{1cm} (18)

Load bus voltage (\( V_L \)) inequality constraint:

\[ V_{L_{mi}} \leq V_L \leq V_{L_{mi}}^{\text{max}}, i \in n_L \]  \hspace{1cm} (19)

Switchable reactive power compensations (\( Q_S \)) inequality constraint:

\[ Q_{S_{mi}} \leq Q_S \leq Q_{S_{mi}}^{\text{max}}, i \in n_c \]  \hspace{1cm} (20)

Reactive power generation (\( Q_G \)) inequality constraint:


IV. Brainstorming Procedure

We all have experienced that, when we face a difficult problem which, single person can’t solve, a group of persons, particularly with dissimilarenvironment, get together to brainstorm and the problem can frequently be solved with high possibility. Enormous and un-expectable intelligence can happen from interactive teamwork of human beings. One way to help human beings to interactively team up to generate great ideas is to acquirejointly a group of people to brainstorm. A brainstorming procedure normally described as follows,

- Rule 1. Acquire jointly a brainstorming group of people with dissimilarbackground as feasible.
- Rule 2. Generate many ideas.
- Rule 3. Contain a number of, like 4 or 5, clientele perform as the owners of the problem. To pick up a number of i.e. one from every owner, information as superior ideas for solving the problem.
- Rule 4. Use the ideas selected up in the rule 3 with superiorpossibility than other information as clues, and produce more ideas.
- Rule 5. Encompass the owners to choose up several better ideas generated as did in rule 3.
- Rule 6. Arbitrarily choose an object and make use of the functions and appearance of the object as clues, and produce more ideas.
- Rule 7. Enclose the owners to pick up several healthier ideas;
- Rule 8. Optimistically a high-quality solution can be obtained by taking into account or by merging theideas generated.

In a brainstorming procedure, usually there are a catalyst, a brainstorming cluster of people, and numerous owners of the problem to be solved. The role of the catalyst is to facilitate the idea production (brainstorming) procedure by enforcing the brainstorming cluster to obey the Osborn’s [18] original four rules of idea generation in a brainstorming procedure. The catalyst shouldn’t be caught up in generating ideas itself, but facilitate the brainstorming procedure only. The rule for selecting catalyst or facilitator is to have a catalyst to have facilitation knowledge, but have less proficiency on the background knowledge connected to the problem to be solved as possible. The purpose of this is to have generated ideas to have less, if not nothing, then biases from the catalyst.

Osborn’s Original Rules for Idea Generation in a Brainstorming Process are as follows,

A. Rule 1. Defer verdict
B. Rule 2. Everything Goes
C. Rule 3. Cross-fertilize
D. Rule 4. Go for capacity

- Rule 1 says that there is no idea can be seen as bad idea. All ideas are high-quality ideas only. It is ill-advised to judge whether a projected idea is a high-quality or dreadful idea. Any decision or censure must be held back until at least the conclusion of the brainstorming process.
- Rule 2 says that everything coming to your mind in the period of the brainstorming process is an idea merit to be pooled and recorded. Don’t let any idea or contemplation mistreated.
- Rule 3 says that bunch of ideas be capable and should be based on ideas previously generated. Every generated idea be capable and should dish up as a clue to generate more ideas.
- Rule 4 says that it is essential to generate lots of ideas as possible. We primary go for amount of generated ideas. The superiority will come from quantity obviously. Lacking in generating large quantity of ideas, it is difficult or impossible, to come out ideas with high-quality.

Brain Storm Optimization Algorithm (BSOA) for solving the multi-objective reactive power dispatch problem.

Step 1. Arbitrarily produce n potential solutions (individuals);
Step 2. Huddle n individuals into m clusters;
Step 3. Calculate the n individuals;
Step 4. Grade the individuals in every cluster and document the best individual as cluster centre in each cluster;
Step 5. Arbitrarily generate a value between 0 and 1;
   a) If the value is smaller than a predestined probability then.
      i. Arbitrarily select a cluster centre;
      ii. Arbitrarily generate an individual to substitute the selected cluster centre;
Step 6. Create new individuals,
   a) Arbitrarily generate a value between 0 and 1;
   b) If the value is less than a probability then,
      i. Arbitrarily select a cluster with a probability;
      ii. Create a random value between 0 and 1;
      iii. If the value is smaller than a predestined probability then,
         1) Choose the cluster centre and include random values to it to
create a new individual.

iv. Or else arbitrarily select an individual from this cluster and include random value to the individual to create new individual.

c) Or else arbitrarily select two clusters to create new individual

i. Generate a random value;

ii. If it is less than a predestined probability, then the two cluster centres are pooled together and then added with random values to create new individual;

iii. Or else, two individuals from every selected cluster are arbitrarily selected has to be combined and added with random values to create new individual.

d) The newly created individual is compared with the lively individual with the same individual catalogue. The superior one is kept and recorded as the new individual.

Step 7. If n new individuals have been created, then go to step 8 or else go to step 6;

Step 8. Conclude if predestined maximum number of iterations has been reached or else go to step 2.

V. Simulation Results

The accuracy of the proposed BSOA and Algorithm method is demonstrated by testing it on standard IEEE-30 bus system. The IEEE-30 bus system has 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. The lower voltage magnitude limits at all buses are 0.95 p.u. and the upper limits are 1.1 for all the PV buses and 1.05 p.u. for all the PQ buses and the reference bus. The simulation results have been presented in Tables I, II, III & IV. And in the Table V shows the proposed algorithm powerfully reduces the real power losses when compared to other given algorithms. The optimal values of the control variables along with the minimum loss obtained are given in Table I. Corresponding to this control variable setting, it was found that there are no limit violations in any of the state variables.

Table 1: Results of BSOA – ORPD Optimal Control Variables

<table>
<thead>
<tr>
<th>Control variables</th>
<th>Variable Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>1.040</td>
</tr>
<tr>
<td>V2</td>
<td>1.041</td>
</tr>
<tr>
<td>V5</td>
<td>1.043</td>
</tr>
<tr>
<td>V8</td>
<td>1.032</td>
</tr>
<tr>
<td>V11</td>
<td>1.003</td>
</tr>
<tr>
<td>V13</td>
<td>1.040</td>
</tr>
<tr>
<td>T11</td>
<td>1.05</td>
</tr>
<tr>
<td>T12</td>
<td>1.02</td>
</tr>
<tr>
<td>T15</td>
<td>1.00</td>
</tr>
<tr>
<td>T36</td>
<td>1.00</td>
</tr>
<tr>
<td>Qc10</td>
<td>3</td>
</tr>
<tr>
<td>Qc12</td>
<td>4</td>
</tr>
<tr>
<td>Qc15</td>
<td>2</td>
</tr>
<tr>
<td>Qc17</td>
<td>0</td>
</tr>
<tr>
<td>Qc20</td>
<td>3</td>
</tr>
<tr>
<td>Qc23</td>
<td>4</td>
</tr>
<tr>
<td>Qc24</td>
<td>3</td>
</tr>
</tbody>
</table>

Real power loss 4.3899

SVSM 0.2489

ORPD together with voltage stability constraint problem was handled in this case as a multi-objective optimization problem where both power loss and maximum voltage stability margin of the system were optimized simultaneously. Table II indicates the optimal values of these control variables. Also it is found that there are no limit violations of the state variables. It indicates the voltage stability index has increased from 0.2489 to 0.2498, an advance in the system voltage stability. The Eigen values equivalents to the four critical contingencies are given in Table III. From this result it is observed that the Eigen value has been improved considerably for all contingencies in the second case.

Table II: Results of BSOA - Voltage Stability Control Reactive Power Dispatch Optimal Control Variables

<table>
<thead>
<tr>
<th>Control Variables</th>
<th>Variable Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>V1</td>
<td>1.045</td>
</tr>
<tr>
<td>V2</td>
<td>1.043</td>
</tr>
<tr>
<td>V5</td>
<td>1.041</td>
</tr>
<tr>
<td>V8</td>
<td>1.033</td>
</tr>
<tr>
<td>V11</td>
<td>1.008</td>
</tr>
<tr>
<td>V13</td>
<td>1.034</td>
</tr>
<tr>
<td>T11</td>
<td>0.090</td>
</tr>
<tr>
<td>T12</td>
<td>0.090</td>
</tr>
<tr>
<td>T15</td>
<td>0.090</td>
</tr>
<tr>
<td>T36</td>
<td>0.090</td>
</tr>
<tr>
<td>Qc10</td>
<td>4</td>
</tr>
<tr>
<td>Qc12</td>
<td>3</td>
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<tr>
<td>Qc15</td>
<td>2</td>
</tr>
<tr>
<td>Qc17</td>
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</tr>
<tr>
<td>Qc20</td>
<td>0</td>
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<td>Qc23</td>
<td>4</td>
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<td>Qc24</td>
<td>4</td>
</tr>
<tr>
<td>Qc29</td>
<td>4</td>
</tr>
</tbody>
</table>

Real power loss 4.9900

SVSM 0.2498

Table III. Voltage Stability Under Contingency State

<table>
<thead>
<tr>
<th>SL.No</th>
<th>Contingency</th>
<th>O R P Setting</th>
<th>D V S C R P D Setting</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28-27</td>
<td>0.1410</td>
<td>0.1430</td>
</tr>
<tr>
<td>2</td>
<td>4-12</td>
<td>0.1658</td>
<td>0.1661</td>
</tr>
<tr>
<td>3</td>
<td>1-3</td>
<td>0.1774</td>
<td>0.1773</td>
</tr>
<tr>
<td>4</td>
<td>2-4</td>
<td>0.2032</td>
<td>0.2041</td>
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</table>

Table IV. Limit Violation Checking of State Variables

<table>
<thead>
<tr>
<th>State Variables</th>
<th>limits</th>
<th>ORPD</th>
<th>VSCRPD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>upper</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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particular limits. These limits have been considerably reduced and the voltage profile index within the bus system. Simulation results show that the real power loss has been demonstrated on the IEEE 30-bus system. The efficiency of the proposed method has been established well through its voltage stability evaluation by modal analysis and is effectual at various instants following system contingencies. The performance of the designed algorithm has been well through its mixed integer non-linear optimization problem. The planned method formulates the reactive power dispatch problem as a mixed integer non-linear optimization problem. In this BSOA algorithm is used to solve the optimal reactive power dispatch problem by including various generator constraints.

VI. Conclusion

In this BSOA algorithm is used to solve optimal reactive power dispatch problem by including various generator constraints. The planned method formulates the reactive power dispatch problem as a mixed integer non-linear optimization problem. The performance of the designed algorithm has been well through its voltage stability evaluation by modal analysis and is effectual at various instants following system contingencies. The efficiency of the proposed method has been demonstrated on the IEEE 30-bus system. Simulation results show that the real power loss has been considerably reduced and the voltage profile index within the particular limits.

Table V: Comparison Of Real Power Loss

<table>
<thead>
<tr>
<th>Method</th>
<th>Minimum loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evolutionary programming[19]</td>
<td>5.0159</td>
</tr>
<tr>
<td>Genetic algorithm[20]</td>
<td>4.665</td>
</tr>
<tr>
<td>Real coded GA with Lindex as SVSM[21]</td>
<td>4.568</td>
</tr>
<tr>
<td>Real coded genetic algorithm[22]</td>
<td>4.5015</td>
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<tr>
<td>Proposed BSOA method</td>
<td>4.3899</td>
</tr>
</tbody>
</table>

References

[15] Camp CV, Bichon BJ. Design of space trusses using ant...


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