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A New Particle Swarm Optimization Solution to Power Flow Regulation for Unsolvable Case

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Abstract

This paper proposes a regulation algorithm for the power flow regulation of a power system. The proposed method employs nodes unbalanced powers, which serves to assess the unsolvable status of the power system and to guide the corrective control strategy. Particle swarm optimization is applied to find the optimal control action, where the objective functions to be optimized are nodes unbalanced powers and load shedding. The method is applied on the New-England 39-bus test system. The proposed approach results have been compared to those that reported in the literature recently. The results are promising and show the effectiveness and robustness of the proposed approach.

Keywords: Artificial intelligence; unsolvable power flow; unbalanced powers; particle swarm optimization; chaos

1. Introduction

With the rapid development of modern power system, long-range, heavy duty, large regional networking features become more apparent. In this context, network planning and severe contingencies lead to many of unsolvable power flows. At this point it should be taken to adjust the generator output, transformer tap and even removal of part of the load and other measures to make the system back to a feasible solution domain. The approach presented in [1] is based on both the Newton-Raphson method and the information provided by the left eigenvector associated with the null eigenvalue of the Jacobian matrix. Based on [1], Literature [2] comprehensive consideration of the adjustment range and economic factors makes the results more realistic. Brazilian scholars Barboza proposes a nonlinear interior-point method to calculate the unsolvable problem of power flow [3]-[5].

In the iterative calculation process does not require solving the current equation, so the method does not rely on any trend of convergence of the algorithm. The sensitivity of virtual critical point is made using fault-based continuous power flow in [6], to gain control of sensitivity for prevention and control.
strategies. The reasons of the unsolvable power flow can be attributed to one or a few weak transmission channels over its transmission limit [7]. The paper proposes that the weakest transmission channel is obtained by lowering load power, and with sensitivity to adjust the generator output, removal of part of the load, the convergence solution of the power flow is obtained. Pattern analysis method is used to study participation factors of the voltage instability mode corresponds to reactive power injected. The use of participation factors contributes to the priority to adjust the load removal and generator output, and with the original - dual interior point method power flow is solved [8].

Some failure modes, such as generator reactive load breaking or heavier line breaking, most algorithms can not deal with all, but the algorithm in this paper can adapt to all modes of recovery the power flow insolvability. The unbalanced power of the node and the minimum amount of load shedding are as the objective function in this paper, and the mechanism of pheromone-based particle swarm optimization algorithm is applied to find the optimal control action [9-11]. The algorithm first establishes optimization model based on node-based unbalanced power and the minimum amount of load shedding. The power balance equation in the conventional optimization problem is turn into node-based unbalanced power, as the optimization target is processed. And the inequality constraints are handled as penalty functions. In the search early, according to the sequence are random and chaotic characteristics of periodicity, chaotic sequence is used to initialize the position of each particle. Second, the method can effectively determine of premature stagnation is embedded in the PSO. After several iterations, nearby points are made the rapid separation to jump out of local optimum. Finally, numerical example systems are used to verify the correctness of the proposed method.

2. Formulation Of Unsolvable Power Flow Problem

2.1. Objective Function

In actual operation, when there is no solution, you need to restore the system using a variety of control methods to feasible solution, and try to meet the control measures of economic indicators. The main means of control to adjust the generator output, load removed, capacitor bank switching, load tap-tap of choice is usually the case, the load removal costs than other means of control. Especially in the electricity market conditions, there is not easy to allow removal of the load. Therefore, restoration measures adjust the generator output priority, followed by adjustment OLTC and shunt compensation equipment, and finally removal of the load.

The objective function is described as follows:

\[
\min f = \omega_1 \left( \sum_{i=1}^{N} \Delta p_i^2 \right) + \omega_2 \sum_{j=1}^{M} \left( \Delta q_j^2 \right) + \omega_3 \sum_{k=1}^{S_L} f_{\text{load}}(\varphi_k) + \omega_4 F(x)
\]

(1)

Where: \( i = 1, 2, \cdots, N \) is the number of active power equation; \( j = 1, 2, \cdots, M \) is the number of reactive power equation; \( \Delta p, \Delta q \) are active and reactive nodes unbalanced power; \( \omega_1, \omega_2, \omega_3 \) are weight coefficient of respectively, nodes power unbalanced power, shedding load and the inequality penalty function; \( S_L \) is the load set can be cut for the collection. Not all of the load in the electricity market environment can be removed, it must be determined before the optimization of the load is removed which. Under normal circumstances, all of the loads can all be removed: \( f_{\text{load}} \) is the amount of load removal; \( \varphi_k \) is the proportion of load removed; \( F(x) \) is the penalty function that inequality limits over limits, the specific form in the next section in detail.
Constraints include voltage limits for all nodes, Generator output limits, Adjustable transformer tap limits and reactive power compensation equipment capacity restrictions:

2.2. Power Balance Equation

The equality constraint of the general optimization model is the power balance equation. The total generated power should be the same as the total load demand plus the total line loss. When traditional PSO method [12-14] and other artificial intelligence methods [15,16] solve optimal power flow, they randomly generates control variables first, then call the load flow program to calculate the state variables, and then treat the objective function and inequality constraints when the state variables meet the requirements. It essentially requires that the initial particles must be the points of the feasible region. It is too demanding on the initial conditions and affects the calculation speed.

Mathematically speaking, the main task of the load flow is to calculate in a certain range of iterations made by the node does not match the weight down to a very small magnitude. Load flow calculation does not converge in the two cases [17]: one is called the value of the divergence. The performance is the mismatch of power equality equation with the rapid increasing by the number of iterations increases. Other is known identification of divergent. It looks mismatch for the flow equations vary with the number of iterations increases, maintained at a small value, namely one or more nodes of the voltage-controlled type conversion occurs frequently, can not stop. The main problems of power flow no solution to correction is appropriate to adjust the parameters so that node mismatching power can be in the acceptable range.

In general, restoring solutions for unsolvable power flow define the degree of no solution first [18]: To increase the probability of search space to feasible solutions, and to reduce the amount of programming and computing, the nodes unbalanced power are defined as:

$$MIS = \sqrt{\left[ S - f(x) \right]^T \left[ S - f(x) \right]}$$  \hspace{1cm} (2)

The nodes unbalanced powers are conceded as the shortest distance from unfeasible domain to the feasible region in this paper. It would be as objective function, as the optimal adjustment of the direction. Restoring solutions for unsolvable power flow is as a nonlinear optimization problem solving. It uses particle swarm optimization parallel random search strategy to deal with large-scale complex nonlinear optimization problems, in order to get rid of the traditional method using a single search mechanism, nonlinear systems solve large-scale computing for a long time, poor robustness flaws.

3. Improved PSO With Pheromone Sharing Mechanism, Chaotic Sequences And Chaotic Strategy

3.1. Improved PSO with pheromone sharing mechanism

Improved PSO with pheromone sharing mechanism [16] draws ACO pheromone sharing mechanisms. It first establishes shared pheromone matrix; and then, uses the normal integration of the information in the pheromone matrix to provide the basis for the particle update; finally, use position correction, perturbation and other methods to enhance the group's ability to make use of information. The method to solve the restoring solutions for unsolvable power flow of such large-scale, with a large number of constraints, the objective function with non-convex nonlinear optimization problems characterized, is more effective.

3.2. Initial position of the particle distribution of Chaos sequences
Standard particle swarm optimization initialization method commonly used random distribution; it is difficult to ensure a better initial particle swarm ergodicity. Considering the chaotic sequence has the characteristics of chaotic motion, and thus has better randomness and ergodicity. Therefore, the sequence of the characteristics of chaos the initial distribution of particle swarm can greatly enhance the diversity of the search algorithm.

4. Implementation Of Improved PSO Algorithm For Power Flow Regulation For Unsolvable Case

The use of nodes unbalanced power for restoring regulation for unsolvable case is as follows:

Step 1: Initialize the original parameters. Input control variables include generator active power, generator terminal voltage, load transformer tap, adjustable capacitor, load and remove the dimension ratio, the lower limit, set the state variables including the PQ node voltages, generator reactive power and balance contribute to the active node limit; set the size of the particle groups, the largest number of iterations, the inertia factor, weight factor, the maximum speed of the particle update, the lower limit on the decision variables and other parameters.

Step 2: the location of m particles are initialized based on the chaos sequences. Then equation (1) is as the fitness function for each particle's initial position to evaluate the position to calculate the fitness value of each particle; whichever is the minimum optimal solution for the current group and record the corresponding position, and take the current position of individual particles for the current optimal solution.

Step 3: updates the pheromone of particles and particle location.

Step 4: Check the group particles overlap situation, if the particle overlap (the distance is less than a given error), then a particle unchanged, other particles as described in Section III given by chaotic motion.

Step 5: Re-use of the fitness function (1) evaluation of the particle, the particle's fitness to be; for a particle, if the current fitness value is less than the current optimal solution corresponding to the individual fitness value, then current position as the individual particle current optimal solution; to take all the individual particles in the optimal solution to the minimum optimal solution as the current group.

Step 6: Determine whether the stagnation of the evolution of algebra. If it is premature stagnation, overcome of the chaos optimization has to be done.

Step 7: Determine whether the current iteration number reaches the maximum number of iterations, if not meet the conditions, the number of iterations plus 1 go to Step 3; If it meet the conditions, the output is optimized results.

5. Numerical Tests

The New England 10 machine 39-bus system is used to verify the effectiveness of the proposed recovery algorithm. The detailed data see in [8]. It takes the particle population size of 50, inspired factor 0.7, the weights c1 is 0.8, c2 is 0.2, correction factor c3 is 1, impact factor c4 is 0.7, the control factor is 0.35, set to 30 the number of chaotic optimization. The generator active output, the generator terminal voltage and load-shedding factor are optimization variables.

In order to compare with the literature [8], the analyses take into account the convergence of the power flow as along as the system voltage level. System with initial conditions the same as [8], when the line 2-3 disconnected (fault 1) and 14-15 disconnection (fault 2), considering the generator reactive power limit, the system is unsolvable power flow. After controlling in accordance with this article algorithm, the power flow recovery solvability, and all nodes voltage constraints are satisfied 0.94-1.06.

Tables 1 and 2, respectively, are the optimized generator active and reactive power amount and load shedding amount. When fault 1, the removal of load of this paper is 179.03 + j624.80, and removal of the
load capacity of [8] is 421.6+j420.45. When fault 2, the removal of load of this paper is 151.96 + j628.68, and removal of the load capacity of [8] is 157.54 + j370.73. This proposed algorithm in the fault 1 and fault 2 is superior to the amount of active load removal [8].

Table 1 Active and Reactive power generation after optimization under contingency

<table>
<thead>
<tr>
<th>BUS</th>
<th>Active power output/MW</th>
<th>Reactive power output /MVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fault 1</td>
<td>Fault 2</td>
</tr>
<tr>
<td>30</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>31</td>
<td>760.66</td>
<td>320.68</td>
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<tr>
<td>37</td>
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<td>700</td>
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<td>38</td>
<td>1000</td>
<td>1000</td>
</tr>
<tr>
<td>39</td>
<td>0</td>
<td>0</td>
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</table>

Table 2 Load shedding in New England 39

<table>
<thead>
<tr>
<th>Fault</th>
<th>Load-shedding bus</th>
<th>Active power output/MW</th>
<th>Reactive power output /MVAR</th>
<th>Total active power output/MW</th>
<th>Total reactive power output /MVAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>56.69</td>
<td>582.98</td>
<td>179.03</td>
<td>624.80</td>
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<td></td>
<td>23</td>
<td>122.34</td>
<td>41.82</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td>56.71</td>
<td>583.16</td>
<td>151.96</td>
<td>628.68</td>
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<tr>
<td></td>
<td>15</td>
<td>95.25</td>
<td>45.52</td>
<td></td>
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</tr>
</tbody>
</table>
6. Conclusions

This paper proposes a restoring solution for unsolvable cases via node-based power unbalanced and the minimum amount of load shedding. The algorithm establishes an optimization model based on nodes unbalanced power and the minimum amount of load shedding. The conventional power balance equation is turn into nodes unbalanced power, as the optimization target processing, handling inequality constraints with penalty functions. This method can process of the various constraints. New England 39 is used to verify the effectiveness of the proposed method.

References