Loadability Enhancement by Optimal Load Dispatch in Subtransmission Substations: A Genetic Algorithm

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Keywords: Distribution Systems, Loadability, Voltage Stability, Optimal Load Dispatch, Genetic Algorithm

Summary:
Financial, environmental and other constraints cause electric utilities prefer to operation of networks in maximum loadability limit with a sufficient security margin.

In recent decade some researches have been carried out for enhancement of electric network loadability and voltage stability. In the most of these researches installation of reactive power sources such as capacitors, SVC and additional feeders in different place of electric systems is proposed. However expense of these new equipments are constraints for these proposals.

In this paper, we proposed a novel method for enhancement of loadability without using additional equipment. The major idea in this paper is optimal dispatch of load in subtransmission substation using distribution network reconfiguration by switching action in feeders.

In this paper modal method is used to voltage stability analyze. In modal analyze, minimum eigenvalue is a relative measure of how close the system is to the voltage collapse or singular point. Near this collapse point, minimum eigenvalue is close to zero.

General algorithm in proposed method is as follows:

- Determination of Substations Load Transfer Capability Matrix (SLTCM).
- Carry out power flow calculations and identify eigenvalues, right and left eigenvector associate to minimum Jacobian eigenvalue in operating point and base configuration.
- Carry out load transfer with right and left eigenvector and SLTCM by using of efficient method base on genetic algorithm. In genetic algorithm chromosome is as [load in substation 1, load in substation 2, Load in substation n]. Also, fitness function is max loadability in each load level. Subject to load transfer constraints are shown in SLTCM.
- Up to date SLTCM after every load transfer
- Power flow calculation and other process again carry out
- Procedure continue until the minimum Jacobian eigenvalue possibility increased

For evaluation and illustration in detail proposed method is applied to subtransmission (63KV) and distribution (20KV) networks of Hormozgan with satisfactory results.

Genetic based optimization is very accurate but with slow convergence. This optimization method suitable for long-term operation stage and can be applied for feeders configuration.
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Abstract: The loadability enhancement methods usually propose reactive power source installation. In this paper an efficient method for voltage stability and loadability enhancement without installation of new equipments and extra expense is presented. The main idea in this paper is optimal dispatch of loads in subtransmission substation using distribution network reconfiguration by switching actions in primary feeders. For finding optimal loading, an efficient genetic based search algorithm is proposed. Also the singular value is used as voltage stability index. The proposed method is applied to subtransmission (63KV) and primary distribution (20KV) networks of Hormozgan Regional Electric Company (HREC) in Iran with satisfactory results.

Keywords: Distribution Systems, Loadability, Voltage Stability, Optimal Load Dispatch, Genetic Algorithm

1. Introduction

Financial, environmental and other constraints cause electric utilities prefer to operation of networks in maximum loadability limit with a sufficient security margin. In recent decade some researches have been carried out for enhancement of electric network loadability and voltage stability. In the most of these researches installation of reactive power sources such as capacitors, SVC and additional feeders in different place of electric systems are proposed. However cost of these new equipments are main constraints for these proposals [1-5].

In this paper, we have proposed a novel and efficient method for enhancement of loadability without using additional equipment. The major idea in this paper is optimal dispatch of load in subtransmission substation using distribution network reconfiguration by switching actions in primary feeders in distribution systems by use of genetic search method.

Singular value method is used to voltage stability analysis in this research. In singular value decomposition analysis, minimum singular value is a relative measure of how close the system is to the voltage collapse or singular point. Near this collapse point, minimum singular value is close to zero. Furthermore, the singular vectors associated with the singular value have important interpretation. The maximum entries in the right singular vector correspond to critical buses (most sensitive collapse) in the system and the maximum entries in the left singular vector point the most sensitive direction for changes of injection power.

The proposed method is applied to subtransmission (63KV) and distribution (20KV) networks of Hormozgan in Iran with satisfactory results.

In following sections first we describe singular value decomposition methods then loadability enhancement algorithm is proposed.

2. Singular Value index

Singular values have been employed in power systems because of the useful orthonormal decomposition of Jacobian matrices [6,7].

Based on the power flow model, the matrix Jacobian J, contains the first derivatives of active and reactive power mismatch equation equations:

\[
\begin{bmatrix}
\Delta P \\
\Delta Q \\
\Delta \theta \\
\Delta E
\end{bmatrix} =
J
\begin{bmatrix}
\Delta P \\
\Delta Q \\
\Delta \theta \\
\Delta E
\end{bmatrix}
\]  

(1)

Jacobian matrix can be decomposed as follows:
In this equation \( \Delta P, \Delta Q \) are active and reactive power mismatches and \( \Delta E, \Delta \theta \) are variation of voltage magnitudes and angles. Also the singular vectors \( u_i \) and \( v_i \) are the \( i \)-th columns of the unitary matrices \( U \) and \( V \), and \( \Sigma \) is a diagonal matrix of positive real singular values \( \sigma_i \) such that \( \sigma_1 \geq \sigma_2 \geq \ldots \geq \sigma_n \).

In voltage stability assessment, the minimum singular value is a relative measure of how close the system is to the voltage collapse or singular point and used as voltage stability index [8-10].

3 Genetic Algorithm based searching

The G.A is a search algorithm based on the mechanism of natural selection and natural genetics [11]. G.A. also is one of the effective methods for optimization problems and it requires a formalization of problems and a fitness function definition. A constant size population of strings or individuals, representing the possible solutions, are judged and propagated to form the next generation. It is designed such that “fitter” strings survive and propagate into the latter generations. The population is expected to converge to the “fitter” solutions, and, ideally the algorithm ends with a population consisting only of the fit string or the global optimal solution.

Some of the main components of GAs are:

- Coding: representing the problem by strings
- Initialization: initializing the strings
- Fitness Evaluation: determining which strings are fit
- Selection: deciding who mates
- Crossover: exchanging information between two mates
- Mutation: introducing random information

In the following subsections, the main components of G.A. search method for optimal load pattern are addressed.

3.1. Coding

Each possible load level in subtransmission substations is presented as a string by using of right singular vector \( L_{\text{min}} \) associate to reduced load-flow Jacobian. We specify substations associate to elements of \( L_{\text{min}} \). If there is not any connection between substations, we omit corresponding row in \( L_{\text{min}} \). After modification of \( L_{\text{min}} \), the chromosome is built based on modified \( L_{\text{min}} \).

3.2. Initialization

By use of initial load point and sample chromosome, first chromosome is made. Next by generation of random decimal numbers between upper and lower power limit in related substations, initial population is made. First chromosome is include of substation active power in initial load point and since in each new strings or chromosomes, total of gen amplitude must constant, and equal with total of gen amplitude in first chromosome, thus initialization is performed.

3.2. Fitness Evaluation

Whereas G.A in this algorithm is applied for a load duration curve, hence it is necessary that final solution optimize all of load levels corresponding to duration and amount of load. Therefore all chromosomes or strings are evaluated with the same fitness function. The fitness function incorporates the objective function, i.e., total minimum singular values in all of load level in load duration with considering of reconfiguration in first structure and penalties if a string or chromosome violates any of constraints. This has the effect of reducing an infeasible string’s probability of propagation to next generation.

The fitness function, \( f_f \), can be expressed as follows:

\[
ff = \sum_{i=1}^{3} \left( \delta_{\text{min}} (i, j) - \sum_{k=i}^{3} p_k (i, j) \right)
\]
Where \( l \) is number of selected load points in load duration curve \( p_k \) is penalty functions associated with the constraints.

### 3.3. Selection

Stochastic sampling without replacement is used in the selection scheme.

### 3.4. Crossover

With a given crossover probability, mathematical crossover is performed for each string.

### 3.5. Mutation

With a given mutation probability, random alteration of gens in a chromosome or values of a string may occur. For decimal coded string, mutation represent two gen changed as illustrate for Initialization in 3.1.

### 4. General procedure

With respect to above comments general procedure for proposed method is as following:

- **Determination of Substations Load Transfer Capability Matrix (SLTCM).** This matrix represents capabilities of substations for transferring of load that it depends to switching actions capabilities of primary distribution feeders.

- **Carry out power flow calculations for all of load point in load duration curve and identify related minimum singular values \( (\delta_{min}) \) associate to reduced load-flow Jacobians and identify minimum of \( \delta_{min} \).

- **Corresponding to minimum of \( \delta_{min} \), determine critical load point and consider as initial load point.

- **Make first chromosome**

- **Make Initialization**

- **Carry out Crossover**

- **Carry out Mutation**

- **For all Chromosomes, determine rate of load change in each substation and perform this rate for all of load point in load duration curve.**

- **Determine Fitness function for each chromosome**

- **Sort chromosomes with respect to fitness values and select a given number as elite population.**

- **If convergence is not achieved go to step 5.**

- **Determine percent of load change rate based on chromosome corresponding to maximum of fitness function.**

### 5. Case Study

The proposed method is applied for a part of subtransmission network in HREC in south of Iran. The one-line diagram of subtransmission network of HREC is shown in Fig. 1.

The proposed method with Genetic search algorithm is applied for a duration load curve is shown in figure 2. Load that is shown in Fig.2 is total load of network and load of each substation is a given percent of total load with given power factor.

![Fig. 2: The load duration curve.](image)

The chromosome is included active power in substations that can exchange load at least with one of the other substations. This chromosome includes 24 genes.
Fifty chromosomes create as by the way in initialization. The probability in crossover is considered as 0.7 and its value for mutation is 0.1. It is necessary point; the load duration curve in Figure 2 is approximated as three-load level in optimization. The result of case study is shown in table 1. By using of this result load in substations 38, 29, and 33 must be reduced and in substations 31 and 34 increased via load transferring corresponding to table 1. Also voltage stability index is improved in all of load point in load duration curve as shown in table 2.

Table 1: Load transfer in buses

<table>
<thead>
<tr>
<th>Substation No.</th>
<th>Percent of P.U transferred load</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>32</td>
</tr>
<tr>
<td>34</td>
<td>36</td>
</tr>
<tr>
<td>38</td>
<td>-25</td>
</tr>
<tr>
<td>29</td>
<td>-35</td>
</tr>
<tr>
<td>33</td>
<td>-8</td>
</tr>
</tbody>
</table>

Table 4: Voltage stability index in various load level.

<table>
<thead>
<tr>
<th>Status</th>
<th>Voltage stability index (load level 1)</th>
<th>Voltage stability index (load level 2)</th>
<th>Voltage stability index (load level 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial point</td>
<td>1.32</td>
<td>1.2318</td>
<td>2.0</td>
</tr>
<tr>
<td>After load transfer</td>
<td>1.67</td>
<td>1.4126</td>
<td>2.16</td>
</tr>
</tbody>
</table>

6. Conclusion

In this paper, load transferring in subtransmission substation for loadability enhancement is proposed. This can be achieved by determination of optimal loading of substations and switching actions in primary distribution feeders. The singular value for voltage stability analysis is used. Also in proposed algorithm GA is used for finding optimal loading. The results of case study
in a real network in Iran confirmed validity of method.

About application of proposed method in planning and operation of distribution systems as we know Genetic based optimization is very accurate but with slow convergence. Consequently for applying this procedure in operation stage in electric systems in distribution network with ADS (Automation Distribution Systems) it is necessary we use network-partitioning methods for fast searching. However optimization method is suitable for planning in feeder configuration planning stage for both systems with and without ADS.

7. References:


