Proposing a Novel Method for Analyzing Static Voltage Stability

Ali Zare, Ahad Kazemi

Abstract— Various Analyzing methods and different indices have been introduced for considering voltage stability. Each method has its own advantages and disadvantages. In this article, a novel method is suggested for considering voltage stability. This method provides more perfect and more appropriate information related to system condition compared to the existing methods. In addition, the presented index in this method is less influenced by the system conditions and hence has less error. This method has been used for analysis of voltage stability in a 6-bus test system and IEEE 14-bus test system considering the effects of STATCOM on voltage stability.

Index terms – Voltage stability index, Voltage stability margin, Static analysis, FACTS devices

I. INTRODUCTION

In the last two decades, a lot of studies have been allocated to voltage stability. The performed studies from 1985-1998 are collected in [1]. Various methods have been introduced for the analysis of static voltage stability and different indices have also been used. CPF method has been suggested as an appropriate tool for analyzing static voltage stability in [2]. This method has been used in several researches [3]-[8]. In [3], common voltage stability analysis methods such as CPF, modal analysis, singular value decomposition analysis and time simulation are studied. In [9], modal method is introduced for the analysis of voltage stability. In this method, minimum eigenvalue of reduced Jacobian matrix is used as static voltage stability index. Another method of analyzing voltage stability is singular value decomposition which has been described in [10]. Also different Indices have been proposed in various papers. Some of these Indices can be seen in [11]-[14]. Some of these methods were applied for studying the effect of FACTS devices on voltage stability [4]-[8], [15]-[17]. In this article, a novel method is suggested for considering voltage stability and studying the effect of FACTS devices on voltage stability.

In analyzing voltage stability, knee point in PV curve or QV curve is used for finding collapsing point of voltage[18], [19].

A. PV curve

When studying voltage stability, the relationship between transitional power (P) and voltage bus is considered [19]. Voltage stability analysis process depends on transitional power from one point to another point of the system and the amount of its effect on the voltage system.

A common method of analyzing voltage stability is an analysis according to PV curve. A typical PV curve is shown in Fig.1. Here, voltage bus is a function of the total load power. When the load increases, in the knee point of PV curve, power flow will not be converged and the system will be instable. This point is called critical point.

Therefore, PV curve can be used for determining the limit of voltage stability of the system. In general, if operating point of the system is located before critical point of the system, the system will be stable.

B. QV curve

Voltage stability depends on how the deviations in Q and P affect the voltages at the load buses. The effect of reactive power characteristics of the devices at loads (or compensating devices) is more apparent in a QV relationship [19].

Fig.2. shows a typical QV curve. This curve shows the limit of voltage stability in the places where derivative dQ/dV is zero. This point also determines the minimum reactive power required for consistent performance. So, if the operating point of the system is on the right side of the QV curve, the system will be stable, and if the operating point is on the left side of the curve, the system will be instable [19].
The rest of this paper is organized as follows: in section II, the classification of voltage stability analysis methods are introduced. In section III the problem of the common analysis methods are considered. The proposed methodology has been developed and explained in Section IV. The results obtained for the test systems is given and discussed in Section V. Finally, Section VI contains the conclusion.

II. VOLTAGE STABILITY STUDY METHODS

According to utilized PV or QV curves for analyzing voltage stability, voltage stability study methods can be divided into two groups [18]:

i) Methods which evaluated real power limit (or PV analyses)

ii) Methods which evaluated reactive power limit (or QV analyses)

Methods such as CPF, CMLP and RPF belong to the first group and methods like modal analysis and singular value decomposition analysis belong to the second group.

III. DEFINITION OF THE PROBLEM

Used indices for determining voltage stability margin in the two categories of proposed methods of voltage stability analysis in section II are completely different. Analysis methods of the first group are preformed on PV curve and methods of the second group are conducted on QV curve. Consequently, the voltage stability margin calculated for a determined system in these two categories can be completely different (see Fig.3).

Results of each analysis method will depend on:

(a) System conditions

Numbers of nodes, number of generators and compensating elements of reactive power on the obtained voltage stability margin have significant roles in each method. For example, PV analyses in a small system with lots of generators show a good voltage stability margin, but QV analysis may show lower voltage stability margin.

The effect of installing compensating element of reactive power on voltage stability can also be different according to the used method.

(b) Modeling and simulating conditions

In the methods such as OPF, CPF, CMLP and RPF, active power and reactive power of loads are changed simultaneously so that load power factors remain constant.

In QV analysis, it is assumed that real power changes in an operating point are minor and negligible. Therefore, voltage changes depend on reactive power changes, and consequently only reactive power of loads has been used for analyzing voltage stability.

IV. PROPOSED METHODOLOGY

Voltage stability of a power system depends on simultaneous changes of P and Q; Therefore in this paper, using a surface in PQV space is proposed for analyzing voltage stability. This surface shows magnitude of voltage bus according to active power and reactive power of the load. This surface is plotted by using a modified algorithm of computation of the maximum loading point method.

A. Computation of the Maximum Loading Point (CMLP)

In this method, maximum loading point can be calculated by repeating the computation of load flow. Computation of load flow is repeated until power flow is converged. In [21], an algorithm for this purpose is proposed. This algorithm is shown in Fig.4.

B. Modifying the method

In computation of the maximum loading point, time simulation is used in each step and special conditions are
provided so that performing controlling reactive power such as tap changer, compensating reactive power and etc become very easy. In addition, number of commands in each iteration will also decreases. The modified algorithm of the method is shown in Fig. 5.

C. Computation of the Maximum Loading Point in Two Dimensions (CMLPTD)

Calculating the maximum loading point in active power, reactive power and voltage (PQV) space are performed in two steps. In the first step, read load power will be held constant and load reactive power will increases until power flow converges. Then in the second step, load read power increases and again load reactive power increases until power flow converges. The operating point of the system will be calculated with time simulation in each step. The proposed calculating algorithm in this article is shown in Fig. 6.

D. Performance Index

Here, the points located on the lower edge of the surface show the maximum loading points of the system in different states of loading system. The closest point of the lower edge of the surface of the base operating point is minimum voltage stability margin (MVSM). The minimum voltage stability margin represents the amount of the load that matches the system to its stability threshold. Here, index of voltage stability is defined by the difference between complex power of load in base operation point and complex power of load in the closest point of the lower edge of the surface of the base operating point. This index is called MVSM and is defined as follows:

\[
MVSM = \frac{S_{\text{critical}} - S_{\text{base}}}{S_{\text{base}}}
\]  

where

- \(S_{\text{critical}}\): Complex power in the closest point of the lower edge of the surface of the base operating point;
- \(S_{\text{base}}\): Complex power in base operation point.

![Fig. 4. Algorithm of the maximum loading point computation](image1)

![Fig. 5. Modified algorithm of the maximum loading point computation](image2)
V. SIMULATION RESULTS

In this article, two test systems, the 6-bus test system proposed in [5] and the IEEE 14-bus test system, are studied in two conditions: (i) Base case, (ii) when installing a STATCOM in critical bus.

(a) Base case

PV curves of the 6-bus system load buses are shown in Fig. 7. PQV surface of bus number 4, 5 and 6 are shown in Figs. 8, 9 and 10.

![Fig. 8. PQV surface for bus number 4 of 6-bus test system without FACTS](image)

![Fig. 9. PQV surface for bus number 5 of 6-bus test system without FACTS](image)

![Fig. 10. PQV surface for bus number 6 of 6-bus test system without FACTS](image)

Table 1 shows calculated MVSM for the buses and evaluated \( \lambda \) by CMLP method. \( \lambda \) is the same for all buses and critical bus can not be determined by using them. In CMLP method for this condition, critical bus is...
determined according to the PV curve slope. But by using MVSM, it can be observed that two buses 4 and 6 have the least amount of MVSM, hence instability possibility is in its highest level in these two buses and voltage stability limit is \( MVSM = 1.5436 \).

(b) When installing a STATCOM in critical bus

By installing a STATCOM in bus 6 in the 6-bus test system and also in bus 4 in the IEEE 14-bus test system, voltage stability was improved 14.62 percent and 12.33 percent respectively (see tables II and VI). In table V the result of this method is compared with the results of CMPL method and it was observed that CMLPTD results have lower sensitivity due to system condition changes and show the effects of STATCOM in a more reasonable manner.

### TABLE I

<table>
<thead>
<tr>
<th>PV bus number</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MVSM )</td>
<td>1.5436</td>
<td>1.6164</td>
<td>1.5436</td>
</tr>
<tr>
<td>( \lambda )</td>
<td>3.00219</td>
<td>3.00219</td>
<td>3.00219</td>
</tr>
</tbody>
</table>

Table 2 shows calculated MVSM for buses of IEEE 14-bus test system. Here also by using MVSM, it can be seen that bus 4 has the minimum of voltage stability limit and is clearly the weakest bus.

### TABLE II

<table>
<thead>
<tr>
<th>PV bus number</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MVSM )</td>
<td>1.7693</td>
<td>1.8460</td>
<td>1.7693</td>
</tr>
</tbody>
</table>

### TABLE III

<table>
<thead>
<tr>
<th>PV bus number</th>
<th>4</th>
<th>5</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MVSM )</td>
<td>0.2620</td>
<td>1.1687</td>
<td>2.4669</td>
<td>2.3553</td>
<td>2.5219</td>
<td>1.5467</td>
<td>2.6234</td>
<td>2.1023</td>
</tr>
</tbody>
</table>

### TABLE IV

<table>
<thead>
<tr>
<th>PV bus number</th>
<th>4</th>
<th>5</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>( MVSM )</td>
<td>0.2943</td>
<td>1.2630</td>
<td>3.3908</td>
<td>3.4435</td>
<td>3.3593</td>
<td>1.6927</td>
<td>3.0838</td>
<td>2.2894</td>
</tr>
</tbody>
</table>

### TABLE V

<table>
<thead>
<tr>
<th>Method of Analysis</th>
<th>Minimum of MVSM in system without FACTS</th>
<th>Minimum of MVSM in system with FACTS</th>
<th>Percentage of increasing the maximum voltage stability</th>
<th>landa in system without FACTS</th>
<th>landa in system with FACTS</th>
<th>Percentage of increasing the maximum voltage stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-bus test system</td>
<td>1.5436</td>
<td>1.7693</td>
<td>14.62</td>
<td>3.00219</td>
<td>4.2500</td>
<td>41.5</td>
</tr>
<tr>
<td>IEEE 14-bus test system</td>
<td>0.2620</td>
<td>0.2943</td>
<td>12.33</td>
<td>3.900</td>
<td>4.0500</td>
<td>3.85</td>
</tr>
</tbody>
</table>
VI. CONCLUSION

Common voltage stability analysis methods only focused on PV curves or QV curves, so the effects of changes in both active and reactive powers on voltage stability cannot be observed simultaneously. In addition, because of heavy dependence of these methods to system conditions and the type of simulation, the possibility of error is high in these methods. In this article, voltage stability calculating method in two dimensions was proposed for studying voltage stability. Two dimensional voltage stability margin calculating method possesses some advantages in comparison with common methods:

1) Simultaneous observation of the effects of reactive and active power changes on voltage stability.
2) Independence of analysis results related to system conditions, modality and simulation.
3) The introduced index of this method is defined in a way that any changes in loads are covered.

The results of preformed simulation on the 6-bus test system and also on the IEEE 14-bus test system showed more logical results in comparison with common voltage stability analysis methods. The results were also more reasonable related to the effect of installing SATCOM on voltage stability.

REFERENCES


