A Review on Voltage Stability Margin Improvement with Distributed Generation

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Abstract – With the expansion of economy, the rapidly increasing load demands in distribution systems are the forceful factors for intensification of distribution generation (DG) installation in power distribution system. There is an assortment of beneficial aspects of DG implementation, where maximum voltage support is one of the technical beneficial aspects. On the other hand, DG penetration is a main concern when go through voltage stability problem to avoid superfluous load demand. Here, the different techniques are going to be described to get optimal siting of DG units and their preliminary sizes to improve voltage stability margin so that it may enhance and power distribution system becomes more reliable.

Index Terms – distributed generation (DG); voltage stability margin (VSM); continuation power flow (CPF); power distribution system; optimal location; voltage collapse.

1. INTRODUCTION

Distributed Generation (DG) is a small scale renewable electric power resource of ratings few KWs to few MWs. which is associated directly to the distribution network at utility feeder and provides better services to customer level. DG technologies include reciprocating engines, combined heat and power plants, micro-turbine, photovoltaic cells, fuel-cells, wind turbine etc which are free from carbon dioxide emissions and provide more green power. Although these technologies are more expensive than the conventional central generation technology, but there are many beneficial aspects in terms of techno-economic, environmental and customer point of view. Therefore, they improve system voltage and reduce power losses by supporting distribution network, decrease transmission and distribution raising cost and produce more reliable power [1].

The problem of voltage stability due to heavily loaded systems is very common when deals with power distribution system. There are distinct conventional methods used to overcome the same. The network reconfiguration of radial distribution system for voltage stability increment is one which is initiated without DG penetration [2]. To find the most susceptible buses to voltage collapse in radial network, a novel voltage-stability index concept is initiated by load-flow equations [3]. All these methods are the straight-forward voltage control methods analyzed by simple measurements.

The novel technology based on DG technology is introduced to diminish the voltage stability problem created by probabilistic nature of load. Voltage instability mainly occurs due to voltage collapse at the most susceptible buses as a result of highly load demand associated with these buses. This trouble can be defeated by DG penetration in power distribution system. The assessment of voltage stability can be accomplished by PV curve, QV curve and bifurcation analysis as they only gives information about reactive margin and maximum transfer loadability, facilitates to evaluate voltage stability margin (VSM) [4], [5]. At the same time, it is necessary to get the optimal location, sizing, and maximum penetration level of DG units. The DG unit must be placed at the bus which has lowest voltage during voltage collapse to recover and augment VSM. The penetration level and size of DG units should be such that they don't exceed the load demand.

The residue of this paper is assembled as, section II reviews the problem associated with voltage stability in power distribution system. Section III demonstrates voltage stability evaluation on the basis of PV curve and QV curve. Section IV describes voltage stability improvement with DG implementation in power distribution system in which VSM is raised with DG installation in distribution network and bifurcation analysis has been discussed to evaluate VSM. The various approaches such as separated optimization technique, DG location index etc., is presented in section V to find the optimal sizing and location of DG units. And, section VI concludes this paper.

2. THE PROBLEM OF VOLTAGE STABILITY IN DISTRIBUTION SYSTEM

The problem of voltage stability is a main issue when comes under distribution system and has been realized for many years. It has been occurring in many countries due to massively loaded systems. The main reason of voltage instability is load fluctuations so it is also known as load instability. It causes voltage sags in densely loaded system where local distribution network systems do not have reactive power resources and accordingly can't supply better voltage profile to the system. This scarcity of reactive power brings about voltage stability problems and blackout, has arisen in several countries [6]. For example, voltage stability problem caused a serious blackout in the S/SE Brazilian system in 1997 [7]. Thus, voltage levels in distribution network are controlled by the use of tap-changing transformers at substations and through feeder capacitors and voltage regulators. But due to dynamic nature of voltage, it is quite difficult to analyze these problems.

3. Voltage Stability Estimation using PV & QV Curves

Voltage collapse is the main phenomenon in power distribution system which can be seen under the heavily loaded conditions. It may lead to the widespread collapse cause blackout in power system. Therefore, voltage collapse creates voltage stability problems in power distribution system. To maintain a reliable distribution system free from these problems, it is necessary to assess the PV and QV curves. These PV and QV characteristics can analyses the voltage stability problems and gives information about voltage stability properties.

PV curve is a non-linear relationship between voltage and MW transfer where full power flow solution series are used to increase MW transfer and monitors system voltage. The critical operating point S as depicted in figure 1 shows the maximum loadability point in which acceptable operating conditions represented by the points above S.

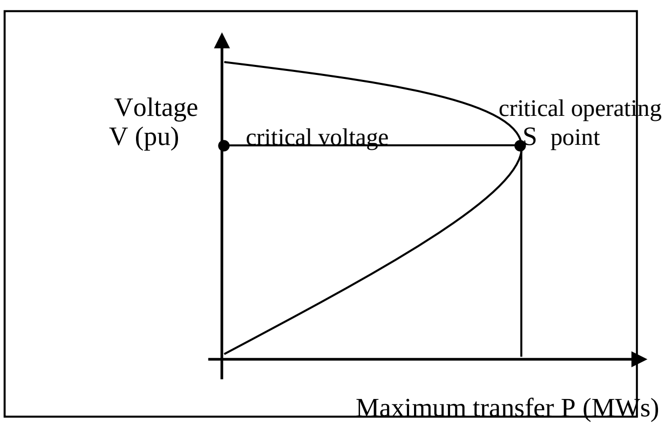

Fig.1 PV curve

On the other hand, QV curve shown in figure 2 represents the relationship of bus voltage variations and sensitivity with respect to reactive power either absorption or injection. The voltage stability limit is represented by the minimum in this QV curve. Hence, stable region of the system is present where $dQ/dV > 0$ [4]. These curves are able to trace by solving a huge amount of power flow algorithms using conventional methods. But conventional methods have some drawbacks because it fails to congregate in front of loadability limits.

In distinction with the conventional approach, the continuation approach can be used to generate PV and QV curve, which is an iterative algorithm having predictor and corrector steps [8].

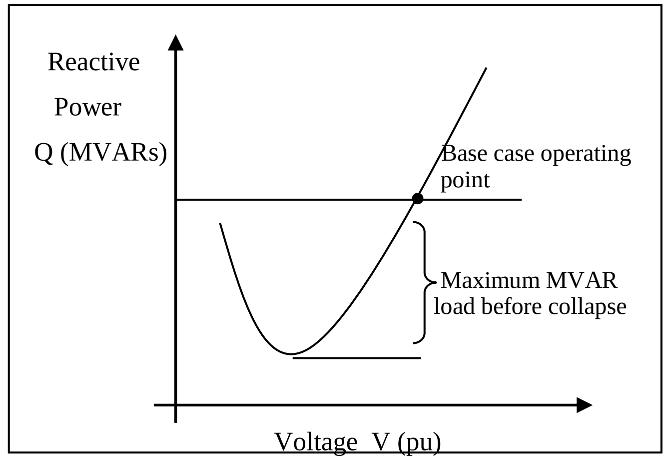

Fig.2 QV curve

In this continuation method, power flow Jacobian can be reformulated to calculate tangent predictor as:

$$\begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} = [J]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \quad (1)$$

Where θ is bus voltage angle vector and V is bus voltage magnitude vector. Let the initial active and reactive powers at every bus be stated as:

$$P = P_O(1 + \Delta\lambda) \quad (2)$$

$$Q = Q_O(1 + \Delta\lambda) \quad (3)$$

Where, $\Delta\lambda$ is step size variation.

Then, by using equations (1), (2) and (3), the tangent vector can be expressed as:

$$TV = \begin{bmatrix} \frac{\Delta\theta}{\Delta\lambda} \\ \frac{\Delta V}{\Delta\lambda} \end{bmatrix} = [J]^{-1} \begin{bmatrix} P_O \\ Q_O \end{bmatrix} \quad (4)$$

And step size variation is:

$$\Delta\lambda = \frac{K}{||TV||} \quad (5)$$

Where K is velocity adjusting parameter and ||TV|| symbolizes tangent vector Euclidian norm. The step size variation controls the step size of parameters and weakens the reaches a bifurcation point. The above equation (5) helps the predictor step problem where corrected steps correct the each step during the whole process. This congregates quickly for the real solution [8].

4. VSM IMPROVEMENT WITH DG UNIT AND BIFURCATION ANALYSIS

Recently, work is going on to locate DG units in distribution system to improve and enhance the voltage stability. The allocation of DG units should be at the most responsive buses sensitive to voltage collapse to maximize the voltage stability margin (VSM) so that loadability increases under normal and contingency conditions as well as this results in reduction in power losses [9]. There may be problem regarding with DG units locations because these units are dispatchable. Therefore, with the purpose of improving and enhancing the voltage stability in power distribution network, complexity of continuous power flow, probabilistic nature of the load and the resources of DG units are the main things which are considered. Hence, a modified voltage stability index method has been proposed with the above conditions in which bus voltage and feeder currents are two important constraints should be within limits [9].

Voltage stability analysis has been going on since many years. It is basically done with the help of PV curve in which saddle node bifurcation point represented by λ_{max} corresponds to the maximum loading of the system. In PV curve, the distance between the operating point and critical voltage collapse point measured by VSM if there is any load increment. It is a proficient index for the assessment of voltage stability. The deciding factor of VSM by PV curve is the penetration level of DG units in distribution system further depends upon power factors at which DG units run. Basically, the range 0.95 lagging to 0.95 leading of power factor has been taken to provide better VSM. Fig. 3 shows the DG unit impact on voltage stability. Here, λ is a scaling factor in MWs representing loadability and V is voltage in pu. The presence of DG units enhancing the operating point of V_1 to V_2 and also increases the loadability from λ_1 to λ_2 [9].

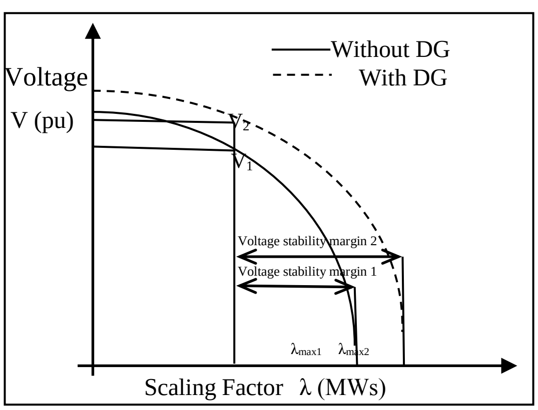

Fig. 3 DG unit impact on (VSM) [9]

Another approach to estimate voltage stability is bifurcation analysis in which Continuation Power Flow (CPF) is taken as a tool in the load domain [5]. The power of loads and generators can be increased from base case value after applying the loading parameter of λ in CPF as:

$$P_D = P_D^{BC} + \lambda P_D^{CPF} \quad (6)$$

$$Q_D = Q_D^{BC} + \lambda Q_D^{CPF} \quad (7)$$

$$P_G = P_G^{BC} + (\lambda + k_G).\, P_G^{CPF} \quad (8)$$

where P_D^{BC}, Q_D^{BC}, and P_G^{BC} are base case powers of loads and generators, P_D^{CPF}, Q_D^{CPF}, and P_G^{CPF} are loads and generators power increment directions in the CPF [10], and k_G is a parameter that balances power losses when load and generation are changed.

There are a variety of voltage stability bifurcations which further depends on power system limits, basically on reactive power limits which are encountered or not in CPF. The Saddle-node bifurcation (SNB) is one of them, and the other one is Limit-Induced Bifurcations (LIB). In these techniques, VSM is measured from base case to the operating point and consequently, used to reduce the same to avoid voltage collapse [5].

As observed, the location and rating of DG units are deciding parameters and reactive power limits are the functional limits when deals with voltage stability analysis, all of them have a theatrical effect on voltage stability in power distribution system. However, there is possibility that VSM can be enhanced by adjusting the suitable siting and sizing of DG installations in distribution systems considering their reactive limits. In the upcoming section, optimal location and sizing of DG units are going to discuss to boost VSM.

5. OPTIMAL LOCATION AND SIZING OF DG UNITS

The location of DG units and their preliminary sizes are the essential factors which can be formulated by multi-objective functions such as VSM increment, improvement of voltage profile, voltage reliability improvement, line loss minimization, etc [11]. There are various approaches to find DG placement and their ratings which are given below:

A. Separately Optimization Technique

To determine DG location, a CPF always run to see the most defenseless voltage buses which have lower voltage during voltage collapse, this bus is the best applicant to place DG unit in this technique. The two individual objective functions VSM and power losses (PLoss) are combined together into a single one in this approach to examine the optimal rating of DG units. The objective function is optimized which is specified below:

$$F_i(P_{DGi}) = w_1 \times \frac{VSM_i(P_{DGi})}{VSM_{BC}} - w_2 \times \frac{PLoss_i(P_{DGi})}{PLoss_{BC}} \quad (9)$$

where w_1 and w_2 weighting factors for VSM and PLoss; VSM_{BC} and $PLoss_{BC}$are the base case values before placing DG; VSM_i and $PLoss_i$are the objective functions of P_{DGi} for ith bus and F_i is the maximized weighted objective function of multi-objectives as a function of P_{DGi} [5].

Here, it is possible to scale dissimilar of VSM and power losses by their base case values into similar ranges and after that combine them into a single objective function which provides a best optimum size for DG [5]. The objective of F_i is to be maximized; it can be possible if loss term minimizes losses. In present equation (9), w_1 and w_2 are weighting factors having greatly importance to increase VSM and reduce power losses, as they are adjusted according to the requirement of getting best solution.

B. DG Location Index

A location index of DG can be derived by using Thevenin equivalent at highly sensitive bus to voltage collapse. Thevenin equivalent model can be visualized in fig.4.

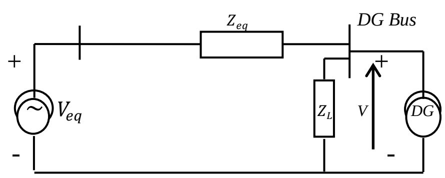

Fig. 4 Thevenin equivalent model at DG bus

As Thevenin equivalent voltage helps in calculate location index value as:

$$L_S^{DG} = \frac{4}{E^4}\{VE\ cos\delta - V^2\ cos^2\delta\} \quad (10)$$

where δ is the angle between Thevenin equivalent voltage and bus voltage and cosδ ≈1. Then equation (5) becomes;

$$L_S^{DG} = \frac{4V}{E^4}\{VE - V^2\} \leq 1 \quad (11)$$

where E is the Thevenin voltage at DG bus, and V is bus voltage.

Therefore, location index specifies the voltage collapse immediacy. If the location index value gets nearer 1, then there is possibility that the bus voltage under taken is most vulnerable to voltage collapse. And, it leads to voltage instability. The DG location can be examined by location index for every bus in considering area in the distribution network. The bus having maximum value of location index is selected to locate a DG unit to get rid of voltage collapse and supports VSM [1].

C. Dynamic Programming (DP) Approach

Dynamic Programming is a proficient tool to find out optimal solution of any problem regarding power system and broadly used in power system applications. Here, optimal size of DG units can be attained by applying this approach. It is assumed that there are 'N' DG units present and the optimal capacity of DG unit are considered as objective function. The problem constraints are grouping of 'N' DG units. It can be solution to the problem so that DG units will not beat the total load demand. In this approach, DG unit is considered as state and each state is exemplified by decision variables as:

$$F_k = P_{DG1}, P_{DG2}, \dots \dots ., P_{DGN} \quad (12)$$

where F_k is objective function value.

Each state has its own VSM estimated by bifurcation analysis. All suitable state values are applied in DP and state having value of highest objective function is chosen as global optimal solution [5]. Hence, DP approach can be implemented in power distribution system problem to reach optimal size of DG in large scale.

D. Continuation Power Flow (CPF) Method

A CPF is an iterative method for DG implementation with maximum loading capacity. Initially, the bus which is the most susceptible at voltage collapse is chosen as a candidate bus for DG installation [12]. The remaining buses are considered as the participating buses are determined by their modal analysis. According to their size and topologies like eigen values; more in number provide best optimized results, and participation factors; highest value is opted as another candidate bus for DG locating. Then, a new CPF process is taken out on the distribution network with the implemented DG. This process is repeated for all the candidate buses.

6. SUMMARY

This paper basically focuses on how to improve and enhance VSM with DG implementation in power distribution system. Initially, the problems regarding with voltage instability has discussed, as voltage stability issue has been occurring for many years due to increase in load demands. The PV curve assesses the critical operating point for voltage stability and maximum transfer loadability, while QV curve represents the base case operating point of bus voltage variations with respect to reactive power, which further help in estimation of VSM. Bifurcation analysis is another approach to estimate voltage stability which is based on reactive limits used to reduce VSM to eliminate voltage collapse. These voltage collapses can be reduced with DG installation without reducing VSM. Therefore, the foremost techniques to get optimal location and size of DG units such as a CPF method, DP approach etc. are conversed in this review paper. The global optimal solution of DG placement and rating helps to improve and boost VSM can be found by using these techniques. Thus, to abolish voltage collapse at the most vulnerable buses DG units are added to these buses to recover load instability. Optimal DG unit's location and size are discussed to provide maximum VSM.

REFERENCES

[1] D. T. Le, M. A. Kashem, M. Negnevitsky, and G. Ledwich, "Maximizing Voltage Support in Distribution Systems by Distributed Generation," TENCON 2005 IEEE Region 10, 21-24 Nov. 2005.

[2] M. Arun and P. Aravindhababu, "A New Reconfiguration Scheme for Voltage Stability Enhancement of Radial Distribution Systems," Int. J. Energy Convers. Manage., vol. 50, 2009, pp.2148-2151.

[3] M. Chakravorty and D. Das, "Voltage Stability Analysis of Radial Distribution Networks." Int. J. Elect. Power Energy Syst., vol. 23, Feb. 2001, pp. 129-135.

[4] Adriana Batista Almeida, Eliane Valence De Lorenci, Rafael Coradi Leme, Antonio Carlos Zambroni de Souza, Benedito Isaias Lima Lopes, and Kwok Lo, "Probabilistic Voltage Stability Assessment Considering Renewable Sources with the help of the PV and QV Curves," IET Renewable Power Generation,vol. 7, issue 5, 2013, pp. 521-530.

[5] Masoud Esmaili, EsmailChatkan Firozaee, and Heidar Ali Shayanfar, "Optimal Placement of Distributed Generations Considering Voltage Stability and Power Losses with Observing Voltage-Related Constraints," Applied Energy, 2014, pp.1252-1260.

[6] U.S.-Canada power System Outage Task Force, Final Report on the August 14, 2003 blackout in the United States and Canada: Causes and recommendations, Tech. Rep., Apr. 2004.

[7] R. B. Prada and L. J. Souza, "Voltage Stability and Thermal Limit: Constraints on the Maximum Loading of Electrical Energy Distribution Feeders," Proc. Inst. Electr. Eng.-Gen. Transm. Distrib., vol 145, 1998, pp. 573-577.

[8] Mohn, F.W., Zambroni de Souza, A.C., "Tracing PV and QV Curves with the help of a CRIC Continuation Method," IEEE Trans. Power Syst., vol. 21, issue 3, 2006, pp. 1115-1122.

[9] R. S. Al Abri, Ehab F. El-Saadany, and Yasser M. Atwa, "Optimal Placement and Sizing Method to Improve the Voltage Stability Margin in a Distribution System Using Distribution Generation," IEEE Trans. on Power Systems, vol. 28, no. 1, Feb. 2013, pp. 326-334.

[10] Milano F., "An Open Source Power System Analysis Toolbox," IEEE Trans. Power Syst., vol 20, 2005, pp.-199-206.

[11] M. Ettehadi, H. Ghasemi, and S. Vaez-Zadeh, " Voltage Stability-Based Placement in Distribution Networks," IEEE Trans. On Power Delivery, vol. 28,no. 1, Jan. 2013, pp. 171-178.

[12] H. Hedayati, S. A. Nabaviniaki, and A. Akbarimajd, "A Method for Placement of DG Units in Distribution Networks," IEEE Trans. Power Del., vol. 23, Jul. 2008, pp. 1620-1628.