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A Method for Improving Voltage Stability of a Multi-bus Power System Using Network Reconfiguration Method

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Abstract

In this paper a method for improving voltage stability of a power network has been suggested, based on network reconfiguration technique. Network Reconfiguration is proposed to enhance the voltage stability of a multi-bus power network by altering the topological structure of the system. Reactive power sensitivity is proposed as an index for finding out the weakest and strongest load bus in the network. P-V curve have been plotted for finding out the voltage collapse point of the weakest and strongest bus. The proposed Reconfiguration method is applied to the 6-bus 8-line test system. Test results show the effectiveness of the proposed method.

Index Terms— Voltage Stability, (dV/dQ) Index, Voltage Collapse Point, Network Reconfiguration.

I. INTRODUCTION

Voltage stability studies are now receiving special attention in developed power networks due to their increasingly heavy loading [1]. Improvement of voltage stability is very much essential in order to ensure desired power transfer at rated voltage. Voltage stability concerned is with the ability of power system to maintain the acceptable voltages at all system buses under normal conditions as well as when the system is being subjected to a disturbance [2]. To meet ever-increasing electrical load demand, the modern power systems are undergoing numerous changes and becoming more complex from operation, control, stability and maintenance standpoints. The evaluation of voltage stability limit is an important part of study.

The major problem which is associated with such a stressed system is voltage instability or collapse. The voltage collapse phenomenon in power system has been attributed to a lack of sufficient reactive power reserve when the power system experiences heavy load or severe contingencies. In this case,

Voltage magnitude of some system-buses decrease gradually and then rapidly reaches the collapse point [3]. Many recent power system blackouts all over the world have been the consequences of instabilities characterized by sudden voltage collapse phenomena. Most of the incidents of voltage collapse are believed to be related to heavily stressed systems where large amounts of real and reactive power are transported over long extra high voltage (EHV) transmission lines while appropriate reactive power sources are not available to maintain normal voltage profiles at receiving end buses. The other principal causes of voltage instability are too high loading of transmission lines, voltage sources being too far from the load centers, the source voltages being too low and insufficient reactive power compensation [1],[7].

In this paper an attempt has been made to identify first the weakest and strongest load bus in a power system, from the voltage stability point of view. dV/dQ indicator has been employed to identify the weakest bus and strongest bus. V vs. P profile has been plotted at the weakest and strongest bus for a typical 6 bus – 8 line test system under study [4]. The application of network reconfiguration technique for power networks has been proposed for the improvement of voltage stability. The simulation has been developed using N-R method of load flow analysis.

II. DETERMINATION OF WEAKEST BUS USING SENSITIVITY INDICATOR

The basic equation used in Newton-Raphson method is

$$\Delta C = J \Delta X \tag{1}$$

Where, $\Delta C = \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$,

$J = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}$,

$\Delta X = \begin{bmatrix} \Delta \partial \\ \Delta |V| \end{bmatrix}$

The real power flow in an ac system depends on phase-angle difference $\Delta\partial$, and the reactive power flow depends on voltage magnitude differences [6],[8]. The diagonal and off diagonal elements of J4

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|\sin\theta_{ii} - \sum |V_j||Y_{ij}|\sin(\theta_{ij} - \partial i + \partial_j) \tag{2}$$

$$\frac{\partial Q_i}{\partial |V_i|} = -|V_i||Y_{ii}|\sin(\theta_{ij} - \partial i + \partial_j) \quad i \neq j \tag{3}$$

In equation (2) the reactive power sensitivity of i-th bus is indicated in the diagonal element of J_4. $\partial Q_i/\partial|V_i|$ also indicates the degree of weakness for the i-th bus. $\partial|V_i|/\partial Q_i$ became low when $\partial Q_i/\partial|V_i|$ being high, i.e. for variation in Q status of the bus the change of $|V_i|$ is minimum. Thus $\partial Q_i/\partial|V_i|$ being higher, the degree of weakness of i-th bus becomes lesser [3], [4].

III. Voltage Stability Improvement by Network Reconfiguration Method

Power transmissions networks are mostly interconnect and can be configured for effective coordination of their protection systems and load transfer from one feeder to another. The system configuration can be changed by manual or automatic switching operations. A proper reconfiguration scheme can reduce the power loss in the network components and improves voltage stability. Network reconfiguration means restructuring the power lines which connect various buses in a power system. Restructuring of specific network leads to an alternative system configuration. Network reconfiguration can be accomplished by placing line interconnection switches into network. Opening and closing a switch connects or disconnect a line to the existing network [1].

It has been observed that the voltage Stability of a system can be improved if the overall active power loss in the system is minimized. The active power loss comprises of the aggregate of active power losses in each line [1]. During the course of reconfiguration, the following two important criteria must be maintained:

1. No buses can be left out of service.
2. During each operation, active power flow through a line should be within maximum power transfer capability of the line [5]. The improvement of voltage stability is achieved only by altering topological structure of the power lines and does not involve any additional hardware like installation of SVC, capacitor bank, tap-changing transformers etc.

Benefits of network reconfiguration are as follows:

- Network reconfiguration improves the voltage stability of the system.
- Network reconfiguration reduces the power losses and improves the reliability of power supply by changing the status of switches.
- Network reconfiguration also helps smoothening out the peak demands, improving the voltage profile in the feeders and increase network reliability.

IV. Simulation

Simulations were carried out on 6-bus 8-line system. The aim of the simulation was to identify the voltage stability of multi bus power network and its improvement using Network Reconfiguration method. First diagonal elements of J4 are obtained considering base configuration of the network which indicates the reactive power sensitivity of load bus i i.e. $\partial|V_i|/\partial Q_i$. To find the voltage stability we take the inverse of $\partial Q_i/\partial|V_i|$ which indicates the V-Q sensitivity of the load bus. As with $\partial Q_i/\partial|V_i|$ being high, $\partial|V_i|/\partial Q_i$ becomes low indicating minimum change in |Vi| for variation in Q-status of the bus. A positive V-Q sensitivity is an indicator of stable operation, the smaller the sensitivity the more stable the bus. Table -I below gives the bus no. and their corresponding $\partial|V_i|/\partial Q_i$ values under base configuration.

Table I: Bus number and its corresponding dV/dQi values.

Bus no.	$\frac{\partial\|Vi\|}{\partial Qi}$
2	0.083359035
3	0.052650145
4	0.095607778
5	0.074007741
6	0.129947761

From this simulation it is observed that the $\partial|V_i|/\partial Q_i$ value is highest for bus no. 6 whose value is equal to 0.129947761 and the same is lowest for bus 3 which is equal to 0.052599742. So bus no.6 is the weakest bus of the system and bus no. 3 is the strongest bus of the system from the voltage stability point of view.

Table II: System Configuration.

Configuration Number							
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1-6	1-3	1-3	1-3	1-3	1-3	1-3	1-4
2-3	2-4	2-3	2-3	2-3	2-3	2-3	2-3
3-4	3-4	3-6	3-4	3-4	3-4	3-4	3-4
3-5	3-5	3-5	3-5	3-5	3-5	3-5	3-5
4-5	4-5	4-5	4-2	4-5	4-5	4-5	4-5
5-6	5-6	5-6	5-6	5-1	5-6	5-6	5-6
1-2	1-2	1-2	1-2	1-2	1-6	1-2	1-2
2-6	2-6	2-6	2-6	2-6	2-6	2-5	2-6
9	**10**	**11**	**12**	**13**	**14**	**15**	
1-5	1-3	1-3	1-3	1-3	1-3	1-3	
2-3	2-5	2-3	2-3	2-3	2-3	2-3	
3-4	3-4	3-4	3-4	3-4	3-4	3-4	
3-5	3-5	3-5	3-5	3-5	3-5	3-5	
4-5	4-5	4-6	4-5	4-5	4-5	4-5	
5-6	5-6	5-6	5-2	5-6	5-6	5-6	
1-2	1-2	1-2	1-2	1-4	1-5	1-2	
2-6	2-6	2-6	2-6	2-6	2-6	2-4	

Next diagonal element of J4 is determined for every configuration to find out the strongest and weakest bus of the system under different configuration. For finding the voltage stability we take the inverse of diagonal element of J4 in every configuration.

Fig. 1 to Fig. 15 shows graphical representation of reactive power sensitivity index of load buses under different configuration

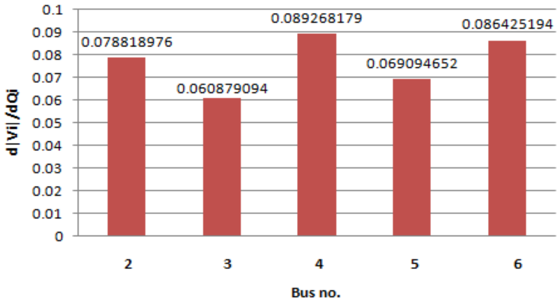

Fig..1: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-1

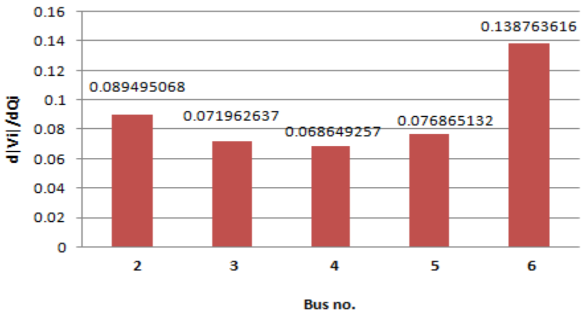

Fig.2: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-2

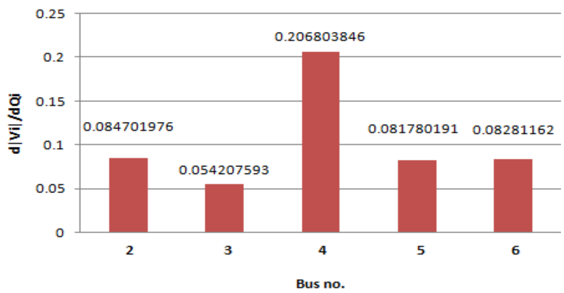

Fig.3: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-3

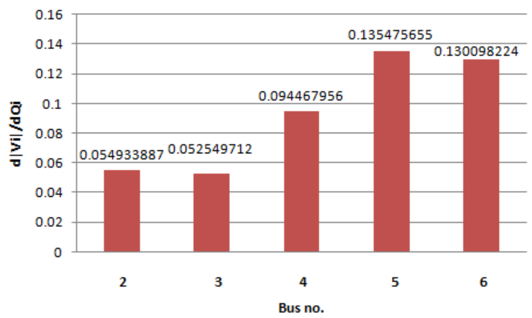

Fig.4: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-4

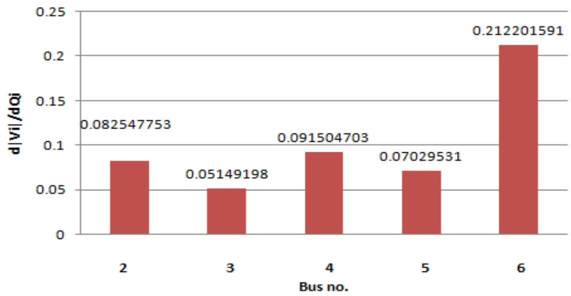

Fig.5: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration -5

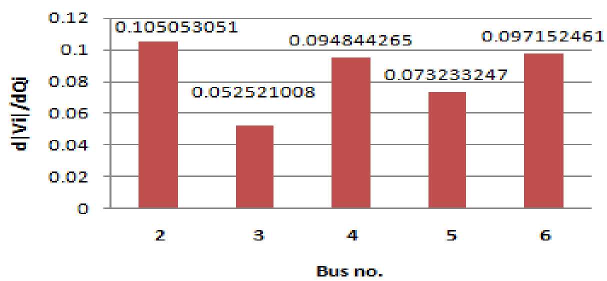

Fig.6: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-6

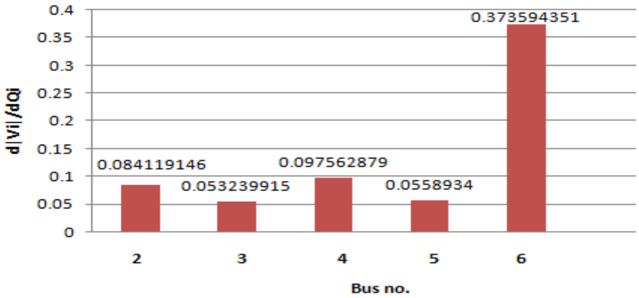

Fig.7: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-7

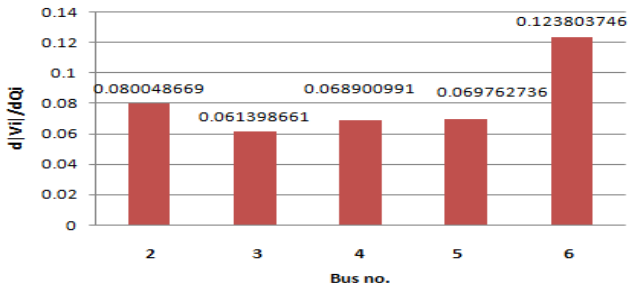

Fig.8: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-8

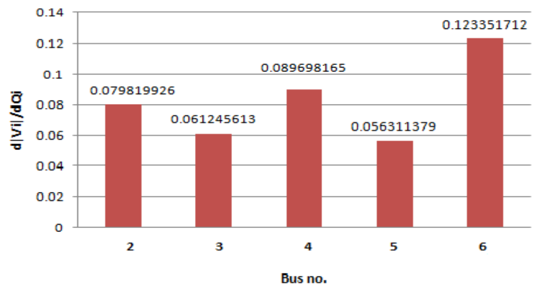

Fig.9: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-9

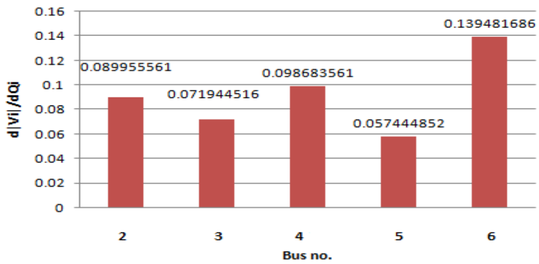

Fig.10: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-10

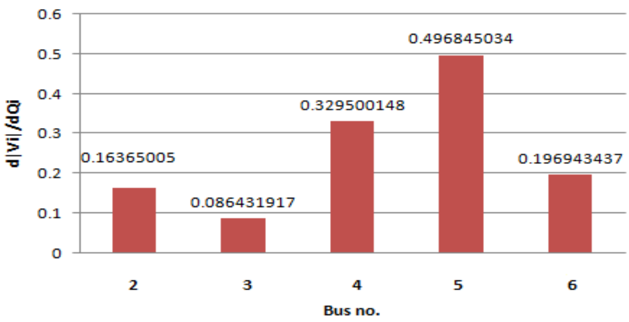

Fig.11: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-11

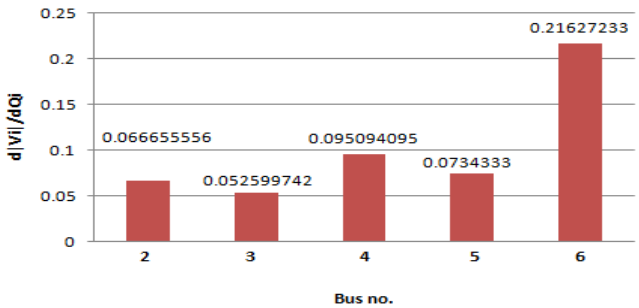

Fig.12: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-12

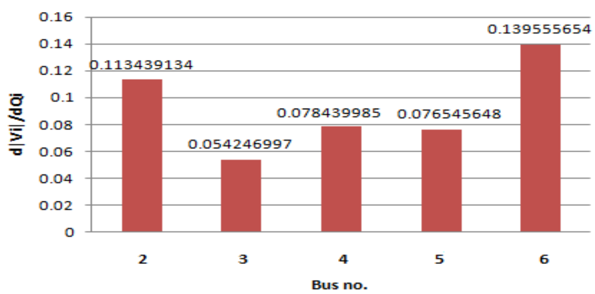

Fig.13: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration -13

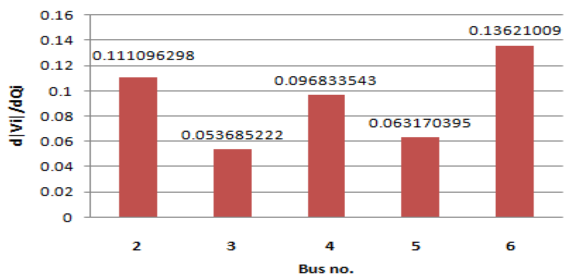

Fig.14: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-14

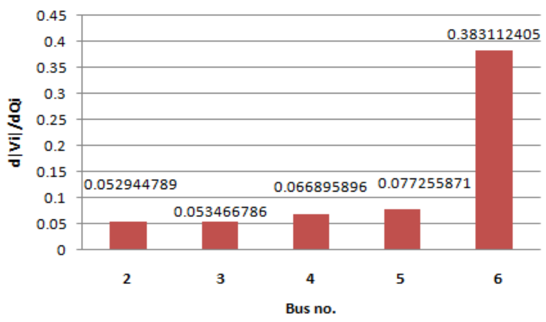

Fig.15: Graphical Representation of Reactive Power Sensitivity Index of Load Buses under Configuration-15

From the above figures it is observed that in some configurations the voltage stability of almost all the buses have been improved as compared to base configuration but stability of one or two buses decreases. In some cases stability of two or three buses has been improved but for rest of the buses it is not. It is also found that in configuration-1 the voltage stability of all the buses have been improved with compare to base configuration. Although in this configuration bus no. 3 does not improve but it is not too much deteriorating. As the stability of all the buses is improved compared to the base configuration, especially the stability of the weak bus no. 6 is improved significantly in this configuration. The value of d|Vi|/dQi of the bus 6 in the base configuration was (0.129947761) but its value in configuration 1 becomes (0.086425194). Also in comparison to other buses this configuration is the best.

Next voltage collapse point is determined from P-V curves. From the base configuration it is seen that the bus no. 3 appears to be strongest and bus no. 6 appears to be weakest and for configuration -1 it is seen that bus 3 appears to be strongest and bus no.4 appears to be weakest. For strongest bus (Bus no.3) under base configuration and configuration-1, the active power loading i.e. P is increased in step keeping Q constant and for each value of P voltage magnitudes for tat load bus is determined from which P-V curves are drawn. These are shown in Fig. 16 and Fig. 17

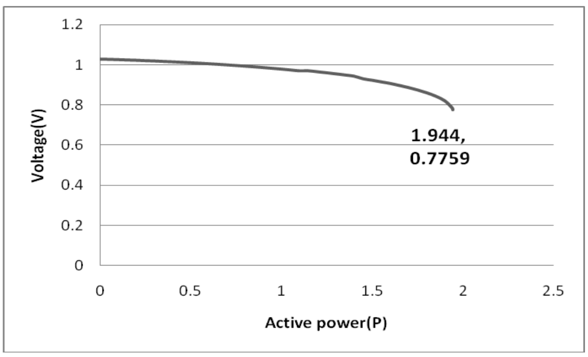

Fig. 16: P vs. V curve of bus no. 3 under base configuration

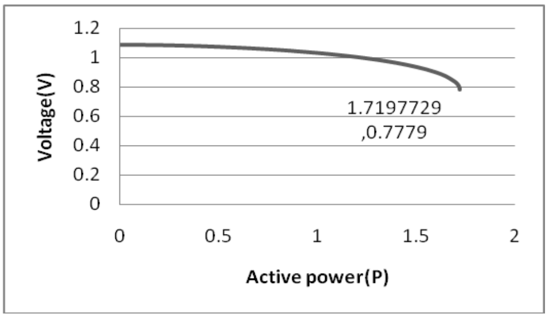

Fig. 17: P vs. curve of bus no. 3 under configuration-1

From Fig. 16 and 17 the critical active power loading i.e. the loading at which voltage collapse occur are determined which are

(P cri)Base=1.944 pu at V=0.7759pu

(Pcri) conf-1=1.7197729 pu at V=0.7779 pu

Similarly the P-V curves for the weakest buses under base configuration and configuration-1 are obtained which are shown in Fig. 18 and Fig.19. The critical values of active power loading as obtained from these curves are given by-

(Pcri)Base=1.0239 Pu at V=0.7078 pu

(Pcri) conf1=1.383474 Pu at V=0.7156pu

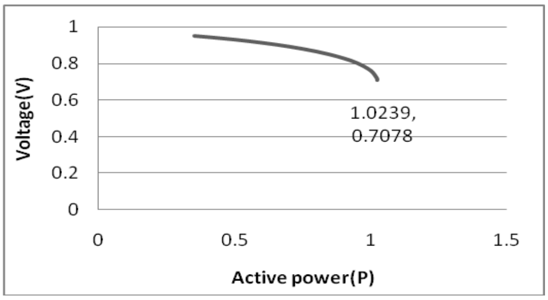

Fig. 18: P vs. V curve of bus no. 6 under base configuration

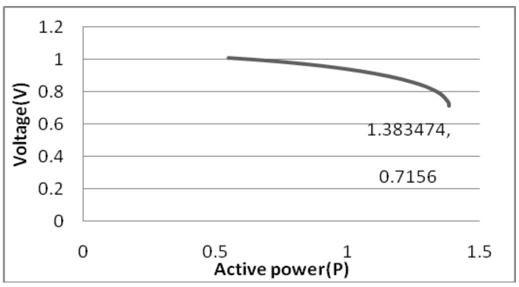

Fig. 19: P vs. V curve of bus no. 4 under configuration-1

From the above result is observed that it is possible to improve the voltage stability by network reconfiguration method.

V. Conclusion

In this investigation, dV/dQ is used as a voltage stability Index. This index has been used to identify the weakest and strongest bus in the test system. P-V characteristic of the weakest and strongest bus are being plotted for finding out the critical values of P and V. In this paper, the application of network reconfiguration technique for power network has been proposed for enhancement of voltage stability. The results obtained from the present study clearly indicate that the change of system configuration has significant impact on the voltage stability. Therefore, restructuring of system topology can improve voltage stability without involving any additional hardware and equipment cost. The present work conclusively

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