Voltage Stability Enhancement Using DSTATCOM Under Contingency Condition

Manjunatha Babu Pattabhi[1*], Bengaluru Rangappa Lakshmikantha[2],
Krishna Shanmukha Sundar[3]
[1*]Research scholar, VTURRC, Belgavi, Karnataka, India
BMS Institute of Technology and Management, Bengaluru, India
[2]Principal & Director, Dayananda Sagar Academy of Technology and Management, Bengaluru, India
[3]Professor, Department of Electrical and Electronics Engineering Dayananda Sagar Academy of Technology and Management, Bengaluru, India

Abstract—Current scenario is modern existence and distribution system that is loaded heavily. Also, it altered a lot due to marvelous surge on distribution system load, surge in renewable supply group, accumulation of solar power systems by residential, manufacturing patrons and production of bulky rechargeable stations. Study on voltage stability distinguished based on distribution system is increasing demand. At some extent, an unintentional line outage puts the system security and reliability in kept under hazard. In this manuscript, the main focus is working on contingency analysis in standard 15 bus system Radial Distribution System. An algorithm shows that forecast the setting and quantity of capacity reduce the development of voltage stability in distribution system. Then, the proposed method is executed on a standard 15 bus system Radial Distribution System and effects indicates that voltage stability of the system enhanced along execution of above method uses DSTATCOM and it is implemented in MATLAB.

Keywords—Stability Index (SI), Voltage Stability Improvement, Radial distribution system, Contingency, Distributed generation.

I. INTRODUCTION

With the introduction of the latest technologies, like distributed generation, solar power plants, heavy electric vehicle charging stations, the stress on the distribution system is increasing so much. Before distribution systems is the transmitting power from the transmission system to customers but today, the distribution systems are injecting active power into the grid [1-4]. Many utilities realized the benefits, like development of voltage stability, power factor, power loss reduction by connecting FACTS and reactive compensation devices in the system [5–8]. Presently, the overhead lines are replaced with cables due to right of way (ROW) issues but the faults experienced by the system increased due to low quality of workmanship and moisture ingress in the cable joints. High financial loss is occurred due to any unplanned power outage also affect the system reliability. The usefulness companies are forced to examine the security of distribution network, delay power outages, service quality development. Contingency analysis is more important because it contains understanding and mitigating potential failure in the network [9].

Voltage contingency, such as loss in line or embedded generator or reactive power device or unplanned care, undergo emergency rise in voltage instability risk [9]. If an unplanned disturbance is not controlled correctly it spreads to the transmission system resulted in grid collapse. When system underwent a contingency, the system operator must know what the actions need to be taken. According to their severity, ranking of insecure contingencies is called contingency ranking [4] that is important for the operators and the planners of power system. When the reserve reactive power sources are finished, if the system is nearer to the verge of voltage instability load shedding can be done to restore the system. In this manuscript, the amount and location of the load is removed, improves voltage stability is presented. A detail literature contingency ranking analysis is implemented in transmission system [10–12] but in distribution system only few of the literatures are accessed. Contingency analysis with respect to loss of line for distribution systems is done in this manuscript.

In the literature, there is not much study is done on load shedding concept for improving the system voltage stability. In [13], the voltage stability improvement is done by load shedding and placement of SVC where load shedding is not possible. In [6] different load characteristics are studied and it was discovered that induction motor loads need to be removed first to increase the voltage stability of the system in case of emergency. In the literature, a novel voltage SI is introduced from the load flow equation to determine bus is more same as the voltage instability is based on radial networks [14]. Forward and backward sweep algorithm given in [15,16] is used for load flow. Voltage SI is executed in [14] is utilized in contingency analysis and deriving the algorithm to find the optimum location and amount of load to be removed to improve the system voltage stability.

II.METHODOLOGY

A. Radial Stability Index (SI)

A voltage SI is built in the presence of solution for the real power and reactive power is presented at the receiving end. Radial system voltage SI is proposed and its equation is given in eqn (1). The electrical equivalent is depicted in fig 1.

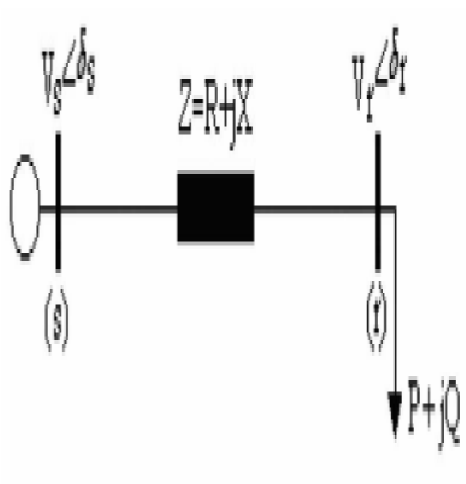

Fig 1: Electrical equivalent

$$SI(m2) = 0.5 * |V(m2)|^2 - P(m2) * R(j) - Q(m2) * X(j) \quad (1)$$

SI (m2) specifies voltage SI for node m2 (m2= 2, 3, 4 ……)

Stable operation for radial distribution network, SI (m2) ≥ 0 , for m2 =2, 3, 4…….

Where,

$V_s$specifies sending end voltage

$\delta_s$specifies phase angle of sending voltages

$\delta_r$specifies phase angle of sending voltages

$V_r$represent receiving end voltage

Z signifies impedance branch

R implies resistance

X implies reactance

P implies loads of active power

Q implies loads of reactive power

B. Derivation of Proposed Real Power Stability Matrix

Real power delta matrix is derived from the voltage stability index SI (m2) is expressed in eqn.1. The change in SI index based on change in the real power is found out by differentiating Equ.1 with respect to real power P at constant reactive power Q.

On differentiation of Equ.1 with respect to P,

$$\frac{\Delta SI(m2)}{\Delta P(m2)} = |V(m2)| * \frac{\Delta|V(m2)|}{\Delta P(m2)} - R = \quad (2)$$

The equation of linearized power flow is expressed as,

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{pmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{pmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \quad (3)$$

$$\Delta P = J_{11}\Delta\theta + J_{12}\Delta V \quad (4)$$

$$\Delta Q = J_{21}\Delta\theta + J_{22}\Delta V \quad (5)$$

As change in reactive power Q is zero, substituting ΔQ = 0 in Equ.5,

$$J_{21}\Delta\theta = -J_{22}\Delta V$$

$$\Delta\theta = -J_{21}^{-1}J_{22}\Delta V \quad (6)$$

Substituting $\Delta\theta$from Equ.6 in Equ.4,

$$\Delta P = -J_{11}J_{21}^{-1}J_{22}\Delta V + J_{12}\Delta V$$

$$\Delta P = [J_{12} - J_{11}J_{22}J_{21}^{-1}]\Delta V \quad = \quad [J_r]\Delta V$$

$$\Delta P = [J_r]^{-1} * \Delta V \quad (7)$$

Now, Equ.4 is rewritten as

$$\frac{\Delta SI(m2)}{\Delta P(m2)} = [|V(m2)| * [J_r]^{-1} - R(j)]$$

$$\Delta SI(m2) = [S_P] * \Delta P(m2) \quad where\ S_P = [|V(m2)| * [J_r]^{-1} - R(j)] \quad (8)$$

Equ.8 gives relationship between the changes in SI index with change in real power. This is used to optimally find out the amount of load and location of the bus where the load shedding is to be done to improve the reliability of the system.

2.3 Contingency Analysis on test system

2.3.1 Line contingency analysis on 15 bus radial system

Fig.2 depicts the line contingency analysis that is carried out on the 15 bus rural electrification distribution system. Appendix A table A.1.is depicted in the line data and load data.

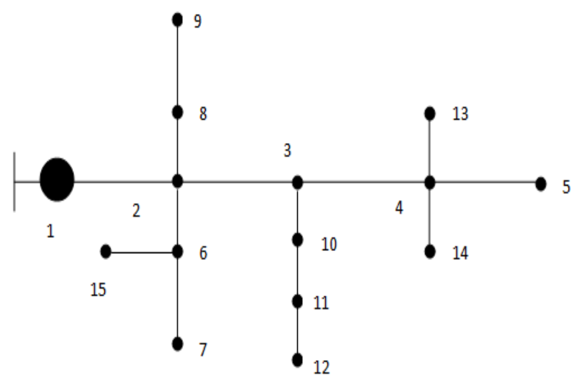

Fig 2: Single line diagram of 15 bus system

Base load given in appendix A is multiplied 5 times for performing contingency analysis. Contingency analysis is done by removing each individual branch, the ranking of the buses is given in the table 1 below. The variation pattern of index with removal index of line between bus 2 – 6 is depicted in fig.3.

Table 1: Rank of the buses when the line connecting bus no. 10 to 11 is removed due to contingency

	Before Contingency Voltages and SI Index values				After Contingency Voltages and SI Index values			
Sl. No.	Bus No.	Bus Voltage (pu)	Rank	SI Index	Bus No.	Bus Voltage (pu)	Ranking	SI Index
1	1	1.000			1	1.000		
2	2	0.797	14	0.317	2	0.833	12	0.346
3	3	0.689	9	0.236	3	0.752	9	0.281
4	4	0.647	7	0.206	4	0.714	5	0.251

5	5	0.640	6	0.200	5	0.707	3	0.245
6	6	0.709	11	0.247	6	0.749	8	0.276
7	7	0.700	10	0.239	7	0.741	7	0.269
8	8	0.777	13	0.297	8	0.813	11	0.326
9	9	0.770	12	0.291	9	0.807	10	0.320
10	10	0.639	5	0.194	10	0.728	6	0.255
11	11	0.606	2	0.179				
12	12	0.596	1	0.172	Line is removed due to contingency			
13	13	0.630	4	0.187	13	0.698	2	0.238
14	14	0.628	3	0.186	14	0.697	1	0.223
15	15	0.694	8	0.230	15	0.735	4	0.248

Table 2: Rank of the buses when the line connecting bus no. 8 to 9 is removed due to contingency

Before Contingency Voltages and SI Index values					After Contingency Voltages and SI Index values			
Sl. No.	Bus No.	Bus Voltage (pu)	Rank	SI Index	Bus No.	Bus Voltage (pu)	Rank	SI Index
1	1	1			1	1		
2	2	0.80	14	0.32	2	0.81	13	0.32
3	3	0.69	9	0.24	3	0.70	9	0.24
4	4	0.65	7	0.21	4	0.66	7	0.21
5	5	0.64	6	0.20	5	0.65	6	0.21
6	6	0.71	11	0.25	6	0.72	11	0.25
7	7	0.70	10	0.24	7	0.71	10	0.25
8	8	0.78	13	0.30	8	0.80	12	0.31
9	9	0.77	12	0.29	9	Line is removed due to contingency		
10	10	0.64	5	0.19	10	0.65	4	0.20
11	11	0.61	2	0.18	11	0.62	3	0.19
12	12	0.60	1	0.17	12	0.61	1	0.18
13	13	0.63	4	0.19	13	0.64	5	0.20
14	14	0.63	3	0.19	14	0.64	2	0.18
15	15	0.69	8	0.23	15	0.71	8	0.24

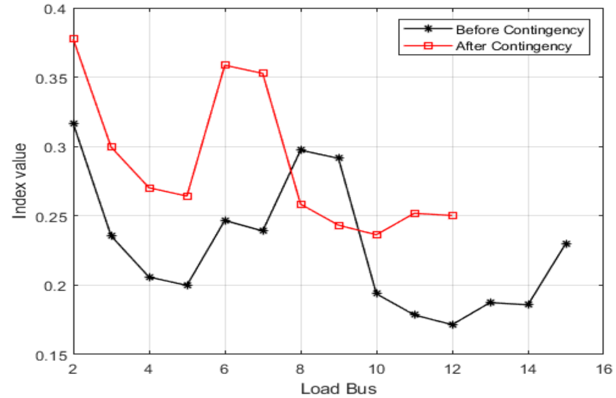

Fig.3: Pattern variation of index with removal index of line is between bus 2 – 6.

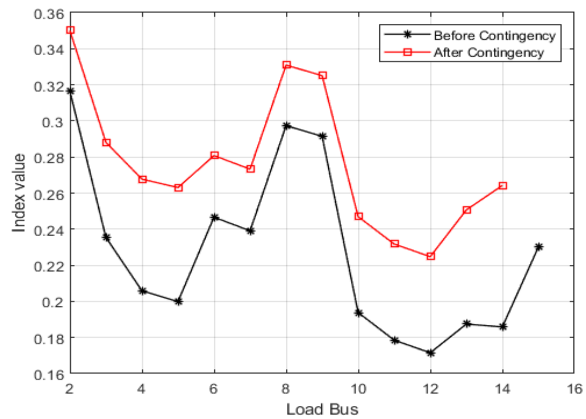

Fig 4: Pattern variation with removal of line between bus 4 – 14.

C. Contingency analysis due to loss of reactive compensation device:

Majority of the distribution systems connect with reactive power compensation devices to increase voltage profile, reduce line losses, improve voltage stability of system. Reactive power compensation device in the system gives more benefits. Sometimes, a sudden unscheduled maintenance or fault in the line causes reactive power compensation device loss in the system. Loss of reactive compensation device in the system drives the system nearer to voltage instability. In order to restore the stabilize the system the operator has to cut down some load on the system. An optimal method is found to less the amount of load cut and raises the voltage stability in the system. In order to simulate this, fifteen bus radial system is depicted in fig 2 is taken. Load connected to bus no.14 is removed and a reactive compensation device of 700 KVAr is connected to bus no. 14. Fig 4 shows the variation pattern with removal of line between the buses 4 – 14. Fig 5 shows the reactive power compensation method linked with 14 bus.

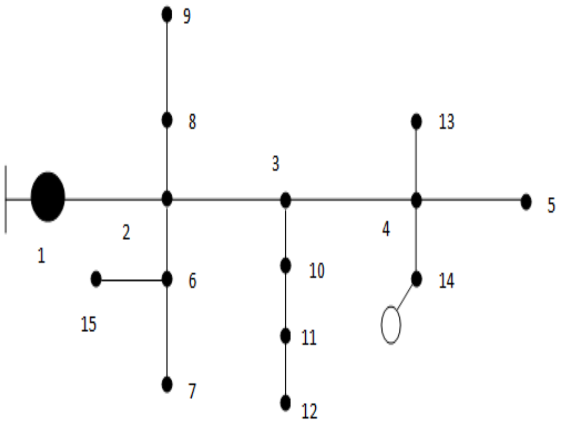

Fig 5: Reactive power compensation method linked with 14 bus.

Table 3: Values of SI Index before and after contingency.

Before Contingency Voltages and SI Index values				After Contingency	
Sl. No.	Bus No.	Bus Voltage (pu)	SI Index	Bus Voltage (pu)	SI Index
1	1	1		1	
2	2	0.85	0.36	0.81	0.33
3	3	0.79	0.31	0.72	0.26
4	4	0.77	0.29	0.69	0.24
5	5	0.76	0.28	0.69	0.23
6	6	0.76	0.28	0.71	0.25
7	7	0.75	0.27	0.70	0.24
8	8	0.83	0.34	0.79	0.31
9	9	0.82	0.33	0.78	0.30
10	10	0.75	0.27	0.67	0.21
11	11	0.74	0.27	0.63	0.19
12	12	0.73	0.26	0.62	0.19
13	13	0.75	0.27	0.67	0.22
14	14	0.77	0.30		
15	15	0.74	0.26	0.70	0.23

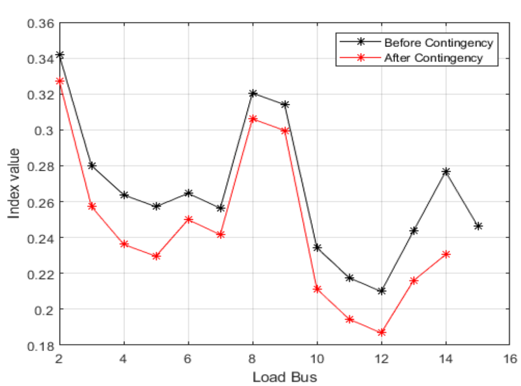

Figure 6: Showing the pattern variation for SI Index before contingency and after contingency.

From table 3 and figure 6, it is observed that the voltage profiles of the bus are reduced and voltage stability of the system is deteriorated due to reactive power compensation device loss that is linked with 14th bus. Real power loss before contingency was 1709KW and real power loss after the contingency increased to 2025KW. It shows the negative impact due to loss of connected reactive power compensation devices on the radial distribution system.

D. A novel algorithm to increase the voltage stability of the system

For improving voltage stability and thereby increase the system reliability, the load on the system needs to be reduced. To optimally reduce the load a new algorithm is developed using linear optimization technique and real power stability matrix developed in section 1.1.

- Run the power flow to get bus voltages.
- Compute the Jacobian matrix for the system under consideration.
- Compute the real power stability matrix from voltages and Jacobian matrix.
- Put a minimum limit to the stability index value.
- Run the linear optimization technique program available in MATLAB.

The above developed algorithm is implemented on the 15 bus system shown in the Figure.6.

Table 4: Location and amount of real power shutdown at a node

Sl. No.	Bus No.	Amount of Real power reduction(KW)
1.	6	461.12
2.	10	465.4

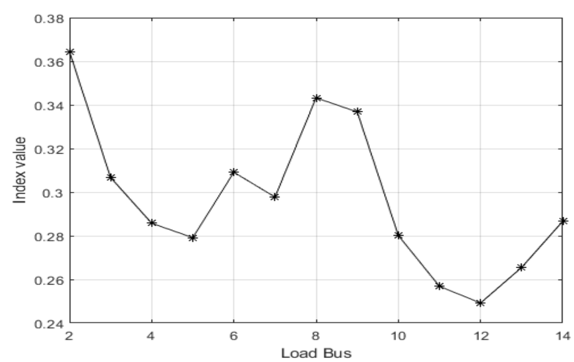

Figure 7: Plot specifies SI Index values after optimization.

The lowest value of voltage SI is 0.19, so bus 12 is prone to voltage instability that is shown in figure 7. Table 4 shows the removing load after implementation of proposed method. Therefore, the lowest value of voltage SI is 0.25. Finally, system voltage stability is improved.

III.CONCLUSION

A detailed study is done in contingency ranking of the distribution system with respect to the loss of line and reactive power compensation device in the system. This manuscript shows that increase in real power loss is because of the loss of reactive power. A new method is developed using the linear optimization technique for improving the voltage stability of the system by experiencing contingency. The proposed algorithm is easily implemented in any bus system. Any sophisticated optimization techniques would give better results is the future scope of this manuscript.

Appendix A

Table A.1 : Line data and nominal load data of fifteen bus radial system

Branch No.	Sending end node	Receiving end node	Branch resistance	Branch reactance	Nominal load Receiving end P (KW)	Nominal load Receiving end Q(KW)
1	1	2	1.35309	1.32349	44.1	44.1
2	2	3	1.17024	1.14464	70	70
3	3	4	0.84111	0.82271	140	140
4	4	5	1.52348	1.02760	44.1	44.1
5	2	8	2.01317	1.35790	70	70
6	8	9	1.68671	1.13770	44.1	44.1
7	2	6	2.55727	1.72490	140	140
8	6	15	1.08820	0.73400	140	140
9	6	7	1.25143	0.84410	70	70
10	3	10	1.79553	1.21110	140	140
11	10	11	2.44845	1.65150	70	70
12	11	12	2.01317	1.35790	44.1	44.1
13	4	13	2.23081	1.50470	70	70
14	4	14	1.19702	0.80740	140	140

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