Incorporation of Dstatcom in Radial Distribution Systems

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ABSTRACT

In this paper presents a method to determine the weakest bus in a radial distribution system. A unique& novel voltagestability indicator (VSI) can identify the condition of load buses with voltage collapse point of view.The voltage stability indicator is derived from the voltage equation of radial distribution system. The weakest bus voltage profile is improved by placing a DSTATCOM. The DSTATCOM is modeled to supply the required reactive power for compensation and to maintain the voltage magnitude of the node where DSTATCOM is placed as 1 p.u. The validity of the proposed VSI and DSTATCOM modeling is examined by a standard 33 bus radial distribution system. The results validate the proposed VSI and DSTATCOM models in large distribution systems.

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KEYWORDS: *Distribution system,DSTATCOM,load flow, voltage stability, voltage stability indicator (VSI), Load modelling.*

I. NOMENCLATURE

P_i, Q_i Active and Reactive sending end power respectively
P_{i+1}, Q_{i+1} Active and Reactive receiving end power
V_i, V_{i+1} Sending end and Receiving end voltage
L_d Proposed voltage stability indicator
L_e Existing indicator
P_L, Q_L Active and Reactive power losses respectively

II. INTRODUCTION

In recent days, there is a growing interest in operation and control of distribution networks. The most of the distributionsystems are radial in nature. The Radial distribution networks [2,4,8, 9] having a combination of industrial, commercial,residential and lightning loads are generally weak in nature because of high resistance to reactance ratio.The Voltage stability is an important factor to be considered in power system operation and planning since voltage instability would lead to system collapse. The problem of voltage stability [4] has been defined as inability of the power system to provide the reactive power or non-uniform consumption of reactive power bythe system itself. So, the voltage stability is a major concern in planning and assessment of security of large power systems in contingency situation, especially in developing countries because of non -uniform growth of load demand in the reactive power management side [3]. The loads generally play a key role in voltage stability analysis. So, the voltage stability is known as load stability.

The radial distribution systems have high resistance to reactance ratio, which may cause high power loss in radial system. In power system, the radial distribution system is one which may suffer from voltage instability.In this paper a new technique used for determination of voltage stability at load bus. By using this Voltage Stability indicator, the buses of the system which are weak in nature can be identified easily. So far much attention was paid on voltage stability analysis of transmission lines, researchers have paid very little attention to develop a voltage stability indicator for radial distribution systems [1,2,6]. In case of the radial distribution system,providing demanding power to the entire load while maintaining voltage magnitude at an acceptable range is one of the major system constraints. There are two principal conventional means of maintaining voltages at an acceptable range in distribution systems are series voltage regulators and shunt capacitors. Conventional series voltage regulators are commonly used for voltage regulation in distribution system [7,8,9]. But these devices cannot generate reactive power and by its operation only force the source togenerate requested reactive power and they have quite slow response as these operations are step by step [10].Shunt capacitors can supply reactive power to the system but they are not capable to generate continuous variable reactive power. Another difficulty associated with the application of distribution capacitors is the natural oscillatory behavior of capacitors when they are used in the same circuit with inductive components. Which results in the well-known phenomena of ferroresonance and/or self-excitation of induction machinery [10].

The FACTS devices concept was originally developed for transmission systems, but the similar idea has been started to be applied to distribution systems. The Distribution STATCOM (D-STATCOM) is a shunt connected voltage source converter which has been utilized to compensate power quality problems such as unbalanced load, voltage sag, voltage fluctuation and voltage unbalance. D-STATCOM is also utilized for the improvement of another aspect of power quality, i.e. voltage compensation in long term. In section 2 presents the derivation of Voltage stability indicator, load flow of radial distribution system and mathematical modeling of DSTATCOM and in the section3 the VSI and DSTATCOM are tested on a 33 bus radial distribution system and results are analysed. Section 4 summarizes the load modelling process of different- types load model in distribution systems Section 5 summarizes the main points and results of the paper.

III. BASIC THEORY

3.1 Mathematical derivation of voltage-stability indicator

The VSI is derived from voltage equation of the radial distribution system. The proposed indicator is given below considering a line of impedance R+jX is connected between two nodes as shown in the following Fig.1 where i and j are respectively two nodes of the branch and node I is sending end node[V(i)] and node j is receiving end node[V(j)]. Therefore, power flow direction is from node i to node j. The load at node j is{P(j)+jQ(j)}.The impedance of the branch is R(i)+jQ(i) if line shunt admittances are neglected, the current flowing through the line is given by:

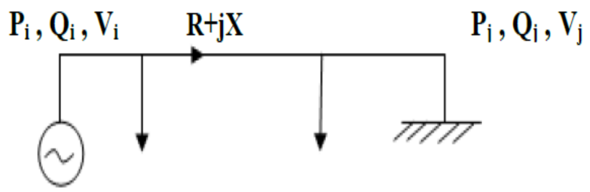

Figure 1: Radial system

$$I(i) = \frac{V_i\angle\theta_i - V_j\angle\theta_j}{R_i + jX_i} \qquad (1)$$

The complex power is given as: S=VI^*

$$I(i) = \frac{P(j) - jQ(j)}{V^*(j)} \qquad (2)$$

Equating (1) and (2)

$$\frac{V_i\angle\theta_i - V_j\angle\theta_j}{R_i + jX_i} = \frac{P(j)-jQ(j)}{V_j\angle-\theta_j}$$

$$[V(i)\angle\theta_i - V(j)\angle\theta_j][V(j)\angle-\theta_j]=[P(j)-jQ(j)][R(i)+jX(i)] \qquad (3)$$

Equating real& imaginary parts of (3) we get

$$V(i)*V(j)\cos(\theta_i - \theta_j)-V(j)^2 = P(j)*R(i)+Q(j)*X(i) \quad (4)$$

$$X(i)*P(j)-R(i)*Q(j) = V(i)*V(j)\sin(\theta_i - \theta_j) \qquad (5)$$

As in radial distribution systems voltage angles are negligible, hence $(\theta_i - \theta_j)\approx 0$,equation (4),(5) becomes

$$V(i)*V(j)-V(j)^2 = P(j)*R(i)+Q(j)*X(i) \qquad (6)$$

$$X(i) = \frac{R(i)*Q(j)}{P(j)} \qquad (7)$$

From equation (6),(7)

$$V(j)^2-V(i)*V(j)+P(j)R(j)+\frac{R(i)*Q(j)2}{P(j)} = 0 \qquad (8)$$

$$V(j)^2-V(i)*V(j)+\frac{R(i)[P(j)2+Q(j)2]}{P(j)} = 0 \qquad (9)$$

The roots of equation (6) are real if

$$V(i)^2-\frac{4R(i)[P(j)2+Q(j)2]}{P(j)} \geq 0$$

$$\frac{4R(i)[P(j)2+Q(j)2]}{V(i)2P(j)} \leq 0 \qquad (10)$$

$$VSI=\frac{4R(i)[P(j)2+Q(j)2]}{P(j)} \qquad (11)$$

Hence equation (11) is termed as voltage stability indicator (VSI).For stability of particular node the value of VSI must be VSI≤1. The range of VSI values is 0<VSI≤1. If the value of VSI approaches or greater than unity, then that node is highly unstable.

3.2 Load flow technique

In this paper, backward forward sweep load flow technique is used to compute voltages and power flow for a radial distribution system. Several methods have been developed based on the concept of doing backward forward sweeps of radial distribution networks [11,12,13].

Forward backward sweep based power flow algorithms generally take advantage of the radial network topology and consist of forward or backward sweep processes. In these algorithms, forward sweep is mainly the node voltage calculation from sending end to the far end of the feeder and laterals, and the backward sweep is primarily the branch current or power summation from far end to sending end of the feeder and laterals.Thefirst step to perform load flow is to create a matrix M (with columns as nodes and nodes as branches). For a particular branch (row) the sending end node of a branch is assigned -1 and receiving end as +1, remaining elements as zero. From that M matrix the column which doesn't have -1 represents end node. After identifying all end nodes, the back propagation path from end node to source node must be identified. After finding end node corresponding row gives the branch attached to it and in this row, -1 value is identified. The corresponding column gives the sending end node to the studied branch. This process continues until the algorithm reaches a column which has no element equal to 1 this represents source node. Hence the end nodes and back propagation paths for end nodes are calculated then employ KVL and KCL to radial distribution system, the power flow algorithms calculate node voltages in forward and backward processes. The radial part is solved by a straight forward two-step procedure in which branch currents are first computed (backward sweep) and then bus voltages are updated (forward sweep).

The voltage at node i can be expressed as

$$V(i) = V(i-1)-I(i)Z(i) \qquad (12)$$

The current at node i can be expressed as

$$I_L=\frac{PL(i)-QL(i)2}{V*(i)} \qquad (13)$$

Branch current can be given as

$$I(i) = I_i(i)+\sum_{j\in\beta i} I(j) \qquad (14)$$

Algorithm for radial distribution system load flow:

[1] Read the distribution system line data& load data.
[2] From the node & branch matrix M.
[3] Get the end nodes& back propagation paths.
[4] Obtain the value of β of equation (14) by calculating the downstream nodes of every node.
[5] Make a flat start by assuming the voltage profile of all buses to be 1 p.u.
[6] Calculate load current IL(i) of each bus using equation (13)
[7] Summation of all the load currents corresponding to the nodes which are downstream to the desired node, as well as its own node; gives the current injected I(i) at that node.
[8] After calculating the current injected to each bus, calculate the voltage of each bus using equation (12).
[9] Compare the difference between each consecutive voltages values of every node. This gives deviation.
[10] If deviation is less than or equal to tolerance limit,then update new voltage values and go to step 6.Else display absolute value of voltage and the phase angle.
[11] Stop.

3.3 Mathematical modelling of DSTATCOM

The D-STATCOM is used for voltage regulation in the steady-state condition and can inject only reactive power to the system. Consequently, $\mathbf{I_{dstat}}$ must be kept in quadrature with voltage of the system. By installing DSTATCOM in distribution system, all nodes voltages, especially the neighboring nodes of

D-STATCOM location, and branch current of the network, change the steady state condition. The diagram of buses *i* and *j* of the distribution systems, when D-STATCOM is installed for voltage regulation in bus j is shown in shown Fig.2 -STATCOM location, and branches current of the network,change in the steady-state condition. The diagram of buses *i* and *j* of the distribution systems, when D-STATCOM is installed for voltage regulation in bus. The phasor diagram of these buses with D-STATCOM placement is shown in Fig.3. The voltage of bus *j* changes from *Vj* to *Vjnew* after D-STATCOM. For simplicity, the angle of voltage *Vi* is assumed to be zero.

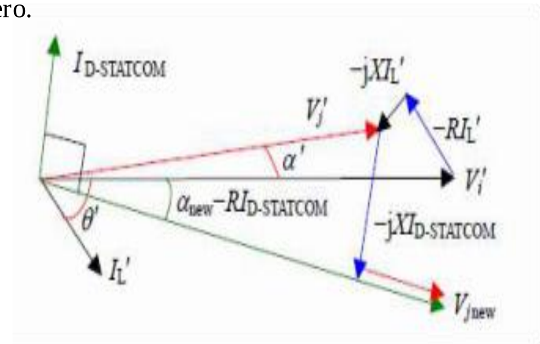

Figure 2: Single line diagram of two buses with DSTATCOM

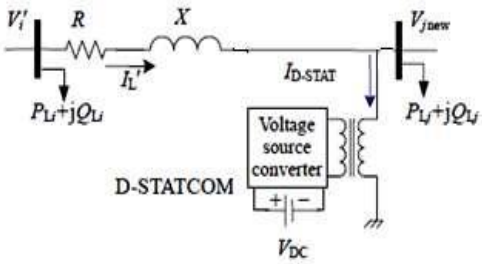

Figure 3 : Phasor diagram of voltages and currents

$V(j)\angle\alpha_{new} = Vi\angle\delta - (R+jX)IL\angle\theta - (R+jX)I_{dsat}(\angle\alpha_{new}+\pi/2)$ (15)

by equating imaginary and real parts the above equation(15) we obtain,

$Vj_{new}\cos\alpha_{new} = Re(Vi\angle\delta - Re(RI_L\angle\theta) + XI_{dsat}\sin(\angle\alpha_{new}+\pi/2) - RI_{dsat}\cos(\angle\alpha_{new}+\pi/2)$ (16)

$Vj_{new}\sin\alpha_{new} = Im(Vi\angle\delta - Im(RI_L\angle\theta) + XI_{dsat}\cos(\angle\alpha_{new}+\pi/2) - RI_{dsat}\sin(\angle\alpha_{new}+\pi/2$ (17)

$a = Re(Vi\angle\delta - Re(RI_L\angle\theta)$

$b = Im(Vi\angle\delta - Im(RX\angle\theta$

$c_1 = -R,\ c_2 = -X,\ d = Vj_{new}$

$x_1 = I_{dsat},\ x_2 = \alpha_{new}$

From equations (16), (17)

$d\cos x_2 = a - c_1x_1\sin x_1 - c_2x_1\cos x_2$ (18)

$d\sin x_2 = a - c_2x_1\sin x_2 - c_1x_1\cos x_2$ (19)

a, b, c_1, c_2 are constants, we need to calculate x_1, x_2.

$x_1 = \frac{d\cos x2 - a}{-C1\sin x2 - c2\cos x2}$, $x_1 = \frac{d\sin x2 - b}{-C2\sin x2 - c1\cos x2}$ (20)

Considering $x=\sin x_2$, Equating above equation(20) we get

$(K_1^2 + K_2^2)x^2 + (2k_1dc_1)x + (d^2c_1^2 - K_2^2) = 0$ (21)

Where,

$k_1 = a_1c_2 - a_2c_1,\ k_2 = a_1c_1 - a_2c_2$

The solution of equation (21) is given as,

$x = (-2k_1dc_1 \pm \sqrt{\{(2k_1dc_1)^2 - 4(K_1^2 + K_2^2)(d^2c_1^2 - K_2^2)\}}$

$\alpha_{new} = x_2 = \sin{-1}\ x$

Now the injected reactive power and voltage and current at node where is installed given as,

$Vj_{new} = Vj_{new}\angle\alpha_{new}$ (23)

$Idsat = (\angle\alpha new+\pi/2)$ (24)

$jQ_{stat} = V_{jnew}I^{*}d_{stat}$ (25)

and * denotes conjugate of complex variable.

The DSTATCOM is modeled such that the voltage magnitude of the node where DSTATCOM is located to set to 1p.u. The phase of the node where DSTATCOM is located is calculated by using equation (22), and the current flowing in DSTATCOM i.e., Idstat is calculated from equation (24). Finally injected by DSTATCOM is calculated by equation (25).

Algorithm for radial distribution system load flow with DSTATCOM:

[1] Read the distribution system line data and bus data.
[2] Run the load flow of distribution system as in section 3. Select the candidate bus as in section 2.1
[3] Assume the voltage profile of candidate bus as 1 p.u.
[4] Calculate the injected reactive power of DSTATCOM and phase angle of the candidate bus using equations
[5] (22), (25).
[6] Update the reactive power and voltage phase angle of compensated bus.
[7] Run the load flow of distribution system with updated reactive power and phase angle of candidate bus.
[8] Stop.

IV. LOAD MODELLING

A load model in this paper is a mathematical representation of the relationship between power and voltage, where the power is either active or reactive and the output from the model. The voltage (magnitude and/or frequency) is the input to the model. The load model could be a static or dynamic load model or a combination of both. Load models are used for analyzing power system stability problems, such as steady state stability, transient stability, long term stability and voltage control. It isnot said that the same load model is appropriate for different stability analysis. In order to obtain a model which is as simple as possible, it is important to choose a load model structure which is appropriate for the studied problem"For dynamic performance analysis, the transient and steady-state variation of the load P and Q with changes in bus voltage and frequency must be modeled" [15]. For power system analysis load can be thought as real and reactive power launched to lower voltage distribution system at buses represented as network model. Among lots of devices and appliances being connected to the system and considered as a load, one should include inter relating distribution systems feeders shunt capacitors, transformers etc. as well as voltage controlling devices or voltage regulators. The simplest load model is static model. A static load model expresses the characteristics of the load at any instant of time as algebraic functions of bus voltage magnitude and frequency at that instant. The load modelling of the active& reactive power is given by

$P = P_o(V^a)$ (26)

$Q = Q_o(V^a)$ (27)

From equations (26) & (27)

If a = 0 Constant power load model.
a = 1 Constant current load model.
a = 2 Constant impedance load model.

V. RESULTS AND DISCUSSION

With the help of MATLAB program, the effectiveness of the proposed VSI and DSTATCOM performance is tested on 12.66 KV, 100MVA radial distribution system consisting of 33 buses. The single linediagram of 33-bus system is shown in figure 4 and its data is given in [11].

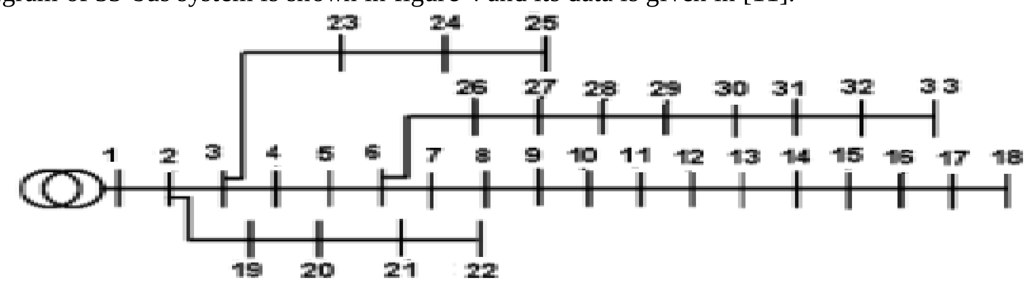

FIG.4: Single line diagram of 33-bus distribution system

The load flow of the 33 bus system is carried out and the voltages at each node and the Voltage Stability Indicator (VSI) are calculated and results shown in table below:

TABLE1: Bus voltages and VSI values from load flow

BUS	Voltage (p.u.) without DSTATCOM	Voltage Stability Indicator	Voltage (p.u.) with DSTATCOM at bus 30
1	1.0000	-	1.0000
2	0.9970	0.0003	0.9983
3	0.9830	0.0014	0.9909
4	0.9755	0.0017	0.9885
5	0.9682	0.0008	0.9863
6	0.9498	0.0015	0.9861
7	0.9463	0.0013	0.9831
8	0.9415	0.0050	0.9784
9	0.9352	0.0020	0.9726
10	0.9294	0.0020	0.9671
11	0.9286	0.0004	0.9663
12	0.9271	0.0009	0.9648
13	0.9210	0.0035	0.9591
14	0.9187	0.0028	0.9571
15	0.9173	0.0011	0.9558
16	0.9160	0.0015	0.9546
17	0.9140	0.0026	0.9528
18	0.9134	0.0024	0.9522
19	0.9965	0.0004	0.9978
20	0.9929	0.0041	0.9942
21	0.9922	0.0011	0.9935
22	0.9916	0.0019	0.9929
23	0.9794	0.0014	0.9874
24	0.9727	0.0122	0.9808
25	0.9694	0.0123	0.9775
26	0.9479	0.0004	0.9870
27	0.9453	0.0006	0.9884
28	0.9339	0.0020	1.0005
29	0.9257	0.0038	1.0002
30	0.9222	0.0298	1.0010
31	0.9180	0.0053	1.0005
32	0.9171	0.0024	1.0097
33	0.9168	0.0009	1.0095

From the TABLE 1, it is noticed that the bus 30 has the highest value of VSI. Hence Bus 30 is considered to be the weak bus. And also bus 18 has the lowest voltage. The upper and lower limit of voltage magnitudes are 0.95 p.u. and 1.05 p.u. 21 out of 33 nodes have under voltage or over voltage problem when thereis no DSATACOM installed.

In order to improve the voltage profile of the system the DSTATCOM is placed at the weak bus 30. DSTATCOM is modeled such that it injects the required reactive power to maintain the voltage at 1 p.u. at the node where it is connected and improve voltage profile of other nodes. The load flow is carried out after placingDSTATCOM at node 30. TABLE 1 shows that after DSTATCOM improves the voltage of all the nodes having under voltage problems in distribution system. The result shows that the DSTATCOM installation in this node strongly improves the voltage of neighboring nodes.

TABLE 2: Active power loss of distribution system with& without DSTATCOM

	Without DSTATCOM	**With DSTATCOM at bus 30**
Size of DSTATCOM (MVA)	-	3.386 MVAR
No. buses with under or over	21	0
Total Active Power losses (kw)	201.8925	143.0350
% loss reduction	-	29.15%

TABLE 2 shows the total Active power loss without DSTATCOM is 201.8925 KW, when DSTATCOM is placed at bus 30 the active power losses are reduced by 58.8575 KW. The active power loss reduction after DSTATCOM placement is 29.15%. The results in TABLE 1 and 2 are achieved based on assumption that DSTATCOM has no capacity limit for reactive power injection to voltage compensation. And the size of DSTATCOM installed at bus 30 is 3.386 MVA. In the below fig.5 shows the bus voltages in p.u. corresponding to with & without applying 3MVAR DSTATCOM at bus 30.

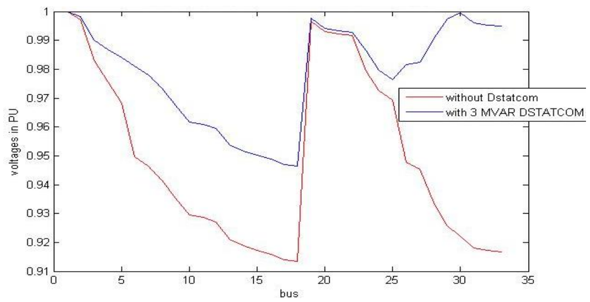

FIG.5: Voltages of with and without 3 MVAR DSTATCOM at bus 30

The below fig.6 shows the active power losses of the with& without placing 3MVAR DSATCOM at bus 30

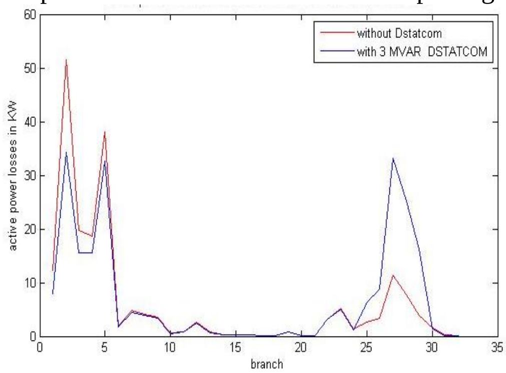

FIG.6: Active power losses of the with and without 3MVAR DSTATCOM at bus 30

IV. CONCLUSION

From the above simulation results, it is observed that node 30 has the highest value of VSI which is the weakest bus of 33 bus radial distribution system. Hence the DSTATCOM is placed at the weakest bus. After the placement of DSTATCOM the voltage profile of all the buses is improved. The DSTATCOM is modeled such that it maintains voltage 1 p.u. at the bus where it is installed. Hence the voltage profile of the system is improved and system losses are minimized. As an extension of the work, the load multiplier factor may be increased and check the VSI performance.The DSTATCOM in this paper is modeled for fixed voltage and no capacity limit which may result in high MVA ratings. So, our proposed idea for estimation of voltage stability indicator is good method for the operating personal to bring back the voltage level within the estimated range. The proposed estimation method is helpful in power system voltage stability limit in post contingency conditions.

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