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Energy savings using D-STATCOM placement in radial distribution system

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Abstract

In this paper optimal location and size of D-STATCOM is determined for radial distribution networks for loss reduction, improvement of voltage profile and overall energy saving. The main contribution of the paper is: (i) Comparison of D-STATCOM allocation for radial distribution network using voltage stability index and power loss index approach (ii) D-STATCOM size calculation by variational technique for radial distribution system, (iii) percentage reduction in power losses with D-STATCOM placement. Based on the reduction in the power losses, the energy savings have been determined. The proposed method is tested for D-STATCOM allocation in IEEE 33-bus radial distribution systems. Results show the considerable reduction in losses and improvement in voltage profile.

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Keywords: *D-STATCOM; Radial distribution system; Optimum location; Optimum size; Power Loss Index; Voltage Stability Index.*

1. Introduction

With the placement of capacitor, custom power devices and penetration of distributed DG in the distribution side, there is need for proper load flow study and find the optimal location of capacitor, custom power devices and DG for better voltage profile management, reduction in losses and overall energy saving. The operation of capacitor, custom

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power devices and DG in distribution system needs to be addressed so that their impact can be studied on the different issues like reactive power management, loss profile management, distribution system pricing, and reserve management during the peak load, and impact of this DG reserve on the peak load distribution pricing structure [1-3]. Most of the loads are reactive loads, such as motors, fans, pumps etc, which increases the reactive power demand in distribution system. Since, these loads draw lagging currents the burden of reactive power increases in the distribution system [4]. Reactive power supplied in distribution systems through optimal capacitor placement.

Nomenclature

CPD	Custom Power Devices
DG	Distributed Generation
D-STATCOM	Distribution static Compensator
DVR	Dynamic Voltage Restorer
UPQC	Unified Power Quality Conditioner
TPL	Total active power loss
TQL	Total reactive power loss
PLI	Power Loss Index
VSI	Voltage Stability Index

But the problem with the capacitors is that their reactive power output is dependent on the system voltage where they are connected and also produce oscillations into the system. The alternative of the fixed or the switched capacitors are the FACTS devices. The devices are originally developed for the transmission system but now they have been in use in the distribution system for the same purpose. They provide the reactive power compensation according to the system needs. They acts like is capacitor when the system requires reactive power and acts like inductor when system has more reactive power. To compensate the reactive power CPD are used such as DVR, D-STATCOM and UPQC. The CPD provide a fast efficient and reliable control over the distribution parameters like voltage, phase angle and line impedance between sending and receiving end node. It has been observed that amongst all, the D-STATCOM serves all the purposes with the required reactive power compensation. D-STATCOM is a shunt connected voltage source converter based static compensator that is used for the improvement of bus voltage profile. It is connected in shunt to the distribution system through a standard power distribution transformer. The D-STATCOM is capable of generating continuously variable reactive power at a level up its maximum MVA rating. The D-STATCOM constantly checks the line waveform with respect to a reference ac signal, and hence, it can offer the precise quantity of leading or lagging reactive current compensation to minimize the amount of voltage variations. The main components of a D-STATCOM are a dc capacitor, an ac filter, one or more inverter modules, a PWM control strategy and a transformer to match the inverter output to the line voltage [5]. D-STATCOM has been utilized to increase the reliability and efficiency of distribution systems due to its various advantages such as low harmonic distortion, small size, low losses, automatic operation, no resonance problems, continuous operations etc [6]. These devices play an important role in improving voltage regulation, voltage balancing and reducing power losses etc of distribution systems under both steady state and dynamic conditions. Many authors reported the placement of D-STATCOM for improving the voltage profile and reducing the losses in the distribution network. S. M. S. Hussain et al. [7] derived the voltage stability indicator for finding optimal bus location for D-STATCOM placement and its size by assuming the voltage magnitude as 1 p.u. at the candidate bus. S. A. Taher et al. [8] proposed biologically inspired immune algorithm for finding optimal location and size of D-STATCOM to reduce the power loss. S. Jazebi et al. [9] used differential evolution algorithm to place D-STATCOM in distribution networks considering reconfiguration. S. Devi et al. [10] show both DG and D-STATCOM placement technique to reduce total power losses and improvement of voltage profile in radial distribution system by Particle Swarm Optimization algorithm. A. Jain et al. [11] proposed an efficient method for D-STATCOM placement in radial distribution system by assuming the voltage magnitude as 1 p.u. at the candidate bus for various load models.

This paper presents comparison of D-STATCOM allocation for radial distribution network using voltage stability index and power loss index approach and corresponding sizes calculation by variational technique [12-13]. It is a very effective method for reduction of line losses and voltage profile improvement. The load flow method used in this paper consists of three main steps which are calculation of load current, formation of BIBC matrix and forward sweep across the line. First the load flow analysis is conducted on radial distribution system for calculating line losses and voltage profile and the bus having the highest VSI and PLI value is selected as candidate bus. After this, the size of D-STATCOM is determined by variational technique. Finally the load flow is carried out by compensating the obtained size of D-STATCOM at the candidate bus for IEEE 33-bus test systems using MATLAB software version 7.8, 2009 [14].

Section 2 explains the VSI and PLI method for determination of optimal location of D-STATCOM. Section 3 describes the optimal size calculation by variational technique for radial distribution system. Section 4 consists of the results and comparison for the IEEE 33 bus test system. Finally the conclusions are made in section 5.

2. Optimal location of D-STATCOM

2.1. Power Loss Index for finding optimal location of D-STATCOM

The candidate bus for the placement of D-STATCOM is found in this section. The PLI approach is an efficient process to select the best location of D-STATCOM, which is sensitive with significant effect on the TPL reduction. In the base case of load flow, TPL and TQL are obtained. At each node, reactive power injections by D-STATCOM are made except source node, load flows are performed and the total active power loss and loss reduction in each case are recorded. The power loss index is calculated from the following equation:

$$PLI\left[g\right]=\frac{M\left[g\right]-Mn}{Mx-Mn} \tag{1}$$

Where N = total number of buses, M = reduction in power loss, Mx = maximum power loss reduction, Mn = minimum power loss reduction, g = 2, 3, 4… N

The bus having the highest PLI value is the most favorable bus and thus selected as candidate bus for D-STATCOM placement. The steps for calculating PLI are described as follows:
Step 1: Read the radial distribution system line data and bus data.
Step 2: Perform the load flow to calculate voltages for all the buses and power losses for all the branches.
Step 3: Perform mathematical modelling of D-STATCOM and calculate reactive power required at all the buses.
Step 4: By compensating the reactive power injections at each bus except source bus, run the load flows and calculate active power losses in each case.
Step 5: Calculate power loss indices using the expression given in equation (1).
Step 6: select the bus having the highest value of PLI as candidate bus.
Step 7: Stop.

2.2. Voltage Stability Index for finding optimal location of D-STATCOM

Optimal location of D-STATCOM is found by calculating the voltage stability index of all the buses. The VSI is calculated from the following equation:

$$VSI=\frac{4R_m(P_n^2+Q_n^2)}{V_m^2P_n} \tag{2}$$

Where V_m and V_n are sending and receiving end voltages respectively; I_m is the branch current; R_m & X_m are branch resistance and reactance respectively.

Voltage stability index has been obtained and the bus with highest value of VSI is most unstable and is selected as candidate bus for D-STATCOM. The steps for calculating VSI are described as follows:

Step 1: Read the radial distribution system line data and bus data.
Step 2: Perform the load flow to calculate voltages for all the buses and power losses for all the branches.
Step 3: Calculate VSI for all the buses using equation (2).
Step 4: Select the candidate bus with highest value of stability index.
Step 5: Stop.

The PLI and VSI values for IEEE 33-bus test systems are shown in Fig.1. For 33-bus test system, 29^{th} bus is getting the highest value of PLI and 30^{th} bus is getting the highest value of VSI as can be seen from Fig.1. Thus it is selected as candidate bus for D-STATCOM placement.

3. Optimal size calculation by variational technique

The size of D-STATCOM is calculated using the variational technique. First the base case load flow is made for finding the losses. Then by following steps is used for finding the optimum size of D-STATCOM. Steps for calculating the optimum size of D-STATCOM by variational technique are as follows:

Step 1: Read the line data and bus data and find the candidate bus for D-STATCOM placement by any sensitivity method (PLI or VSI).
Step 2: Place the D-STATCOM at candidate bus with size varying in steps of 50 KVAR.
Step 3: Find the losses after placement of D-STATCOM.
Step 4: Select the size of D-STATCOM which gives minimum losses.
Step 5: Stop.

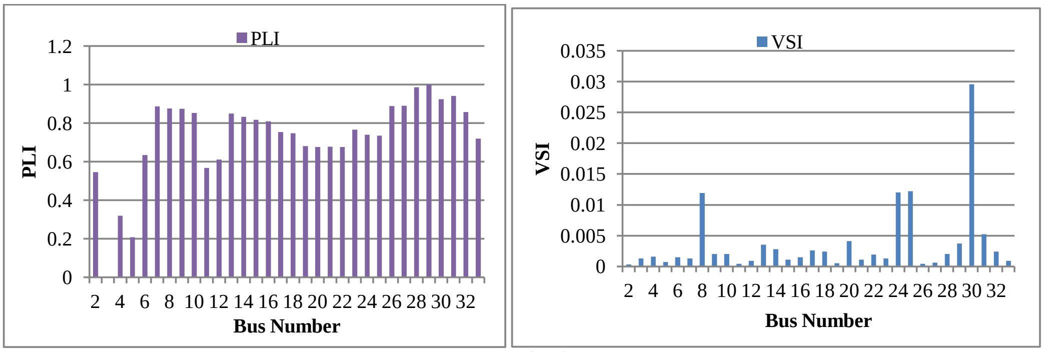

Fig. 1 PLI and VSI profile for 33 bus system

4. Results and discussions

The complete flowchart for determining the optimum size and location of D-STATCOM is given in Fig. 2. It is found that the VSI and PSI is highest at 30th and 29th bus respectively. Hence, the optimum location of D-STATCOM placement is the 29th bus by PLI method and 30th bus by VSI method. Based on PLI and VSI approach, D-STATCOM is placed for voltage profile improvement and reduction of total power losses. The optimum size of D-STATCOM is found by variational technique. The results obtained for IEEE-33 bus radial distribution system with PLI and VSI is compared in Table-1 to demonstrate the effectiveness of both methods. The base MVA and base KV of the system are 10 MVA and 12.66 KV respectively. D-STATCOM is placed at 29th and 30th bus and the variation of real power loss with D-STATCOM size is shown in Fig. 3. Table-2 compares the result obtained by PLI method, VSI method and the results obtained by various author in [7], [8] and [11]. Active Power Losses before installation in KW, Active Power Losses after installation of D-STATCOM in KW, Optimum Size of D-STATCOM in KVAR, Optimum Location of D-STATCOM and % Loss Reduction, loss savings and energy savings is mentioned in Table 2. Fig.4 shows the comparison of annual energy savings for various sizes of D-STATCOM. It is observed that there is considerable annual energy savings with D-STATCOM placed with the proposed technique.

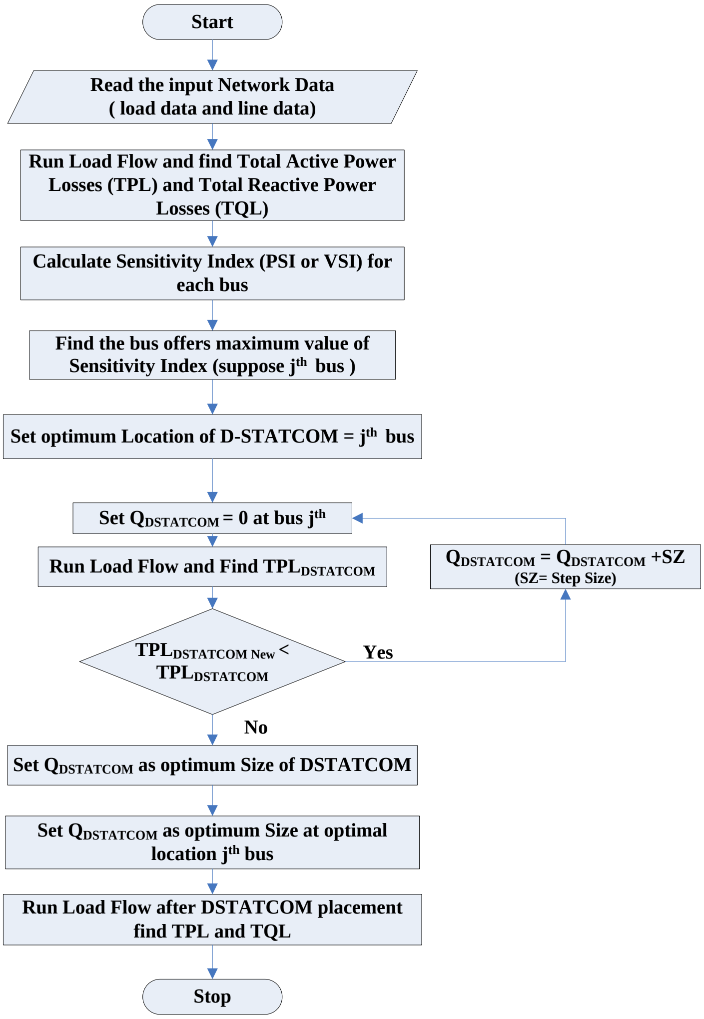

Fig. 2. Flowchart of proposed methodology

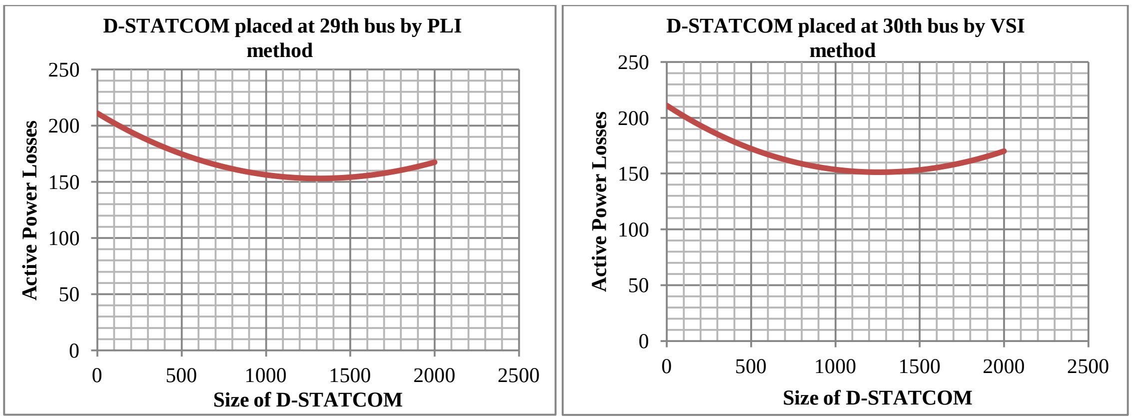

Fig. 3 Size of D-STATCOM vs Active Power Losses by PLI and VSI method

Table 1 Comparison of D-STATCOM size calculation by variational technique

Variational Technique for finding the optimum size of D-STATCOM							
D-STATCOM placed at 29th bus by PLI method				D-STATCOM placed at 30th bus by VSI method			
Size of D-STATCOM in KVAR	Active Power Losses in KW	Size of D-STATCOM in KVAR	Active Power Losses in KW	Size of D-STATCOM in KVAR	Active Power Losses in KW	Size of D-STATCOM in KVAR	Active Power Losses in KW
0	210.98	1050	155.29	0	210.98	1050	152.91
50	206.52	1100	154.53	50	206.18	1100	152.25
100	202.25	1150	153.92	100	201.6	1150	151.78
150	198.17	1200	153.48	150	197.23	1200	151.48
200	194.28	1250	153.2	200	193.07	**1250**	**151.37**
250	190.57	**1300**	**153.07**	250	189.12	1300	151.43
300	187.04	1350	153.11	300	185.37	1350	151.66
350	183.7	1400	153.3	350	181.83	1400	152.07
400	180.54	1450	153.64	400	178.49	1450	152.65
450	177.55	1500	154.14	450	175.36	1500	153.41
500	174.75	1550	154.8	500	172.43	1550	154.33
550	172.12	1600	155.6	550	169.69	1600	155.43
600	169.67	1650	156.56	600	167.15	1650	156.69
650	167.4	1700	157.67	650	164.81	1700	158.12
700	165.29	1750	158.93	700	162.66	1750	159.72
750	163.36	1800	160.34	750	160.7	1800	161.48
800	161.6	1850	161.89	800	158.93	1850	163.41
850	160	1900	163.6	850	157.36	1900	165.5
900	158.58	1950	165.45	900	155.97	1950	167.75
950	157.32	2000	167.44	950	154.76	2000	170.16
1000	156.22	-	-	1000	153.74	-	-

Table 2 Results Comparison

Parameters	PLI method	VSI method	In [11]	In [7]	In [8]
Active Power Losses before installation (KW)	210.98	210.98	210. 99	201.8925	202.68
Active Power Losses after installation (KW)	153.07	151.37	169.79	140.5936	171.81
Optimum Size of D-STATCOM (KVAR)	1300	1250	1993	3386	962.49
Optimum Location of D-STATCOM	29th bus	30th bus	30th bus	30th bus	12th bus
% Loss Reduction	27.44%	28.25%	19.52%	30.36 %	15.23%
Loss Saving (KW)	57.91	59.61	41.2	61.2989	30.87
Annual Energy Saving (KWh)	507291.6	522183.6	360912	536978.36	270421.2

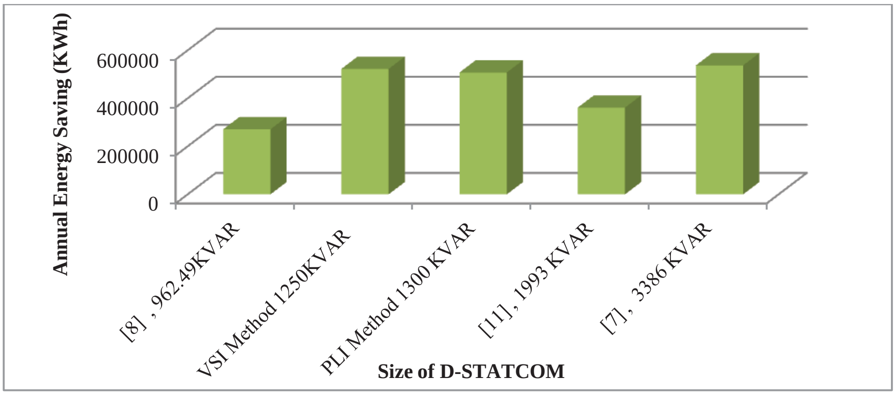

Fig. 4 Comparison of Annual Energy saving with various size of D-STATCOM

5. Conclusion

In this paper variational technique is used for find the optimum size and location of D-STATCOM using different sensitivity methods in the radial distribution system. The losses reduction is obtained with D-STATCOM and the results are also compared with the existing methods. It is observed that the losses reduction in the proposed method with VSI and PLI is better. The D-STATCOM size obtained by proposed method is lower compared to size reported in the results of [11] and [7] also the percentage loss reduction is higher. The D-FACTS can play a vital role in improving voltage profile and reducing losses in the system thereby increasing annual energy saving in the distribution systems. This study can be helpful for better distribution system planning with D-STATCOM for different issues like reactive power management, loss profile management and distribution system pricing.

References

1. IEEE Guide for Identifying and Improving Voltages in power System, *IEEE Std.1250™ -2011;*2011.
2. IEEE Recommended Practice for Monitoring Electric Power Quality, *IEEE Std.1159™ -2009;*2009.
3. IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, *IEEE Std. 1547 ™-2003;*2003.
4. B Singh, and J Solanki, "A Comparison of Control Algorithms for DSTATCOM" *IEEE Transactions on Industrial Electronics.* July 2009:56(7): p. 2738-2745.
5. P. Bapaiah, "Power Quality Improvement by using DSTATCOM" *International Journal of Emerging Trends in Electrical and Electronics.2013;* 2 (4): p.1-12.
6. O P Mahela, A G Shaik," A review of distribution static compensator" *Renewable and Sustainable Energy Reviews*. 2015; 50, p. 531-546.
7. S. M. S. Hussain, N. Visali, "Identification of weak buses using Voltage Stability Indicator and its voltage profile improvement by using DSTATCOM in radial distribution systems", *IOSR Journal of Electrical And Electronics Engineering (IOSRJEEE)*. 2012; 2: p. 17-23.
8. S. A. Taher, S. A. Afsari, "Optimal location and sizing of DSTATCOM in distribution systems by immune algorithm", *Electrical Power and Energy Systems*. 2014, 60, p. 34–44.
9. S. Jazebi, S.H Hosseinian and B. Vahidi, "DSTATCOM allocation in distribution networks considering reconfiguration using differential evolution algorithm" ,*Energy Conversion and Management*. 2011; 52: p. 2777-278.
10. S. Devi, M. Geethanjali, "Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization algorithm", *Electrical Power and Energy Systems*. 2014; 62 : p. 562–570.
11. A. Jain, A. R. Gupta, A. Kumar, "An Efficient Method for D-STATCOM Placement in Radial Distribution System", *6th IEEE India International Conference on Power Electronics*. 2014; p. 1-6.
12. J. B. V Subrahmanyam, C. Radhakrishna, "A Simple Method for Optimal Capacitor Placement in Unbalanced Radial Distribution System", *Electric Power Components and Systems*. 2014; 38, p. 1269-1284.
13. S. Banerjee, C. K. Chanda, S. C. Konar, "Determination of the weakest branch in a radial distribution network using local Voltage Stability Indicator at the proximity of the Voltage Collapse Point", *Third International Conference on Power Systems, Kharagpur, INDIA*. 2009.
14. The MATLAB by Mathworks corporation, MATLAB version 7.8, 2009.