DETERMINATION OF THE PERFORMANCE OF THE DISTRIBUTION STATIC COMPENSATOR (D-STATCOM) IN DISTRIBUTION NETWORK

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ABSTRACT

The Distribution Static Compensator (D-STATCOM) coupled with a transformer is connected in shunt with a distribution network. This paper presents the best locations and ratings of a D-STATCOM in a radial distribution network. For this purpose, the backward/forward algorithm sweep has been carried out to compute the realistic system operation states and evaluate the control performance of the D-STATOM. In this paper D-STATCOM is utilized for improved voltage profile and reduction in power losses. A numerical result based on 33 bus distribution network is given to show the computational performance of the Backward/Forward power flow algorithm with incorporation of the D-STATCOM model.

INTRODUCTION

To maximize the utilization of the existing power system capacities, new power electronic controllers such as FACTS and custom power devices are installed. With custom power solutions in place, the end-user sees law harmonic, improved voltage profile, minimum power interruptions, and reduction in power losses and so on.
With the practical applications of converter-based DFACTS controllers such as the DVR, D-STATCOM and UPQC, modeling and analysis of these DFACTS controllers in power-system operation and control is of great interest. It is well known that power flow solution is the most frequently performed routine power network calculations, which can be used in power system planning, operational planning, and operation/control [1, 2].
However, it is found that, in the past, much effort has been paid in the effects of D-STATCOM modeling on compensation of power quality problems such as reduce voltage fluctuations, regulate voltage distribution feeders or load compensation in unbalanced distribution system and power factor correction [3-5]. Almost all of the previous studies have considered control algorithm of D-STACOM or presented switching control scheme, because the performance of D-STACOM depends on the control algorithm. For this purpose, many control schemes are reported in literatures [6]. The models reported in the past for the D-STATCOM utilized in a two-bus distribution system, since, have been presented the effects of D-STATCOM on large distribution system [7]. In reference [8], rating of the D-STATCOM for voltage compensation is derived by the phasor diagram method. But in this model D-STATOCM installed on branches and its method is proper for this situation.
Since, in this paper, considering that the general structure of D-STATCOM is similar to STATCOM, it is reasonable to consider that for the purpose of power flow analysis the D-STATCOM modeling like STATCOM and represented by a synchronous voltage source with maximum and minimum voltage magnitudes limits. The bus at which the D-STATCOM is connected is represented as PQ bus. Two main subjects in selection and installation of a D-STATCOM in a distribution network are the selection of the best installing location and the best rating of D-STATCOM so, this paper presents the best locations and ratings of a D-STATCOM in a radial distribution network. For this purpose, the backward/forward load flow algorithm has been carried out to compute the realistic system operation states and evaluate the control performance of the D-STATOM. Numerical results based on 33 bus distribution networks are given to show the computational performance of the Backward/Forward power flow algorithm with incorporation of the D-STATCOM model.

MODEL OF THE D-STATCOM FOR POWER FLOW ANALYSIS

Operating Principles of STATCOM and D-STATCOM

A STATCOM usually consists of a coupling transformer, an inverter, and capacitor or energy storage. As shown in Fig.1, the STATCOM is shunt connected with a power grid through the coupling transformer [1]. When the STATCOM is applied in distribution system is called DSTACOM (Distribution-STACOM) and its configuration is the same. A D-STACOM is the most important controller for distribution networks. It has been widely used since the 1990s to precisely regulate system voltage, improve voltage profile, reduce voltage harmonics, load compensation and power factor correction. To increase the dynamic rating in the capacitive range, a fixed capacitor/filter can be used in parallel with D-STATCOM. By connecting an energy storage device, D-STATCOM is capable of injecting active power in addition to reactive power for a limited time (during momentary interruptions or large voltage sags). Therefore, for steady state application, D-STATCOM consists of a capacitor instead of energy storage, and reactive power is exchanged between D-STATCOM and AC system [9-11]. The phasor diagram of D-STATCOM is shown in Fig.2. Considering a sinusoidal voltage at the bus k, of magnitude V_k and phase angles θ_k and the D-STATCOM voltage is taken to be a variable voltage source E_{vR}, whose magnitude V_{vR} and phase angle δ_{vR}. The phasor diagram is shown for leading and lagging VAR compensation in Fig. 2(a) and 2(b), respectively.

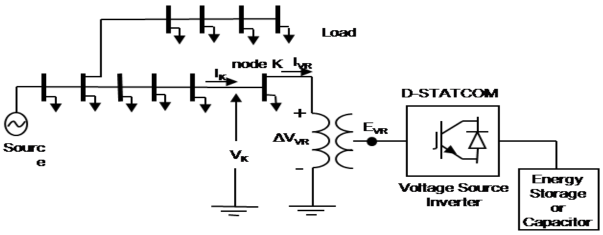

Fig.1. Schematic representation of the D-STATCOM as a custom power controller

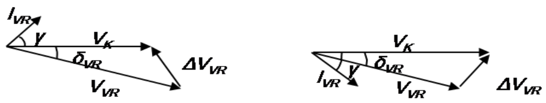

Fig.2. Phasor diagram, (a) lagging operation and (b) leading operation

Operating Principales of STATCOM and D-STATCOM

An equivalent circuit of the D-STATCOM as shown in Fig.3 can be derived based on the operation principle of the D-STATCOM and the phasor diagram illustrated in Fig.2. In the equivalent, the D-STATCOM is represented by a voltage source V_{VR} in series with transformer's impedance. In the practical operation of the D-STATCOM, V_{VR} can be regulated to control voltage of bus *k* or *m*.

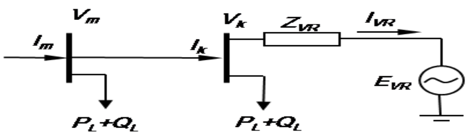

Fig.3. Distribution Static compensator (D-STATCOM) equivalent circuit

IMPLEMENTATION OF THE D-STATCOM EQUIVALENT MODEL IN BACKWARD/FORWARD SWEEP

Radial Distribution System Load Flow

The effectiveness of the backward/forward sweep method in the analysis of radial distribution systems has already been proven by comparing it to the traditional Gauss-Seidel and Newton-Raphson methods. The backward/forward sweep method is an iterative method that is considered root node be the slack node with known voltage magnitude and angle[12]. The initial voltage for all other nodes is considered to be equal to the root node voltage and the power loss for all branches is equal to zero. At each iteration, the following computational stages are performed:

Stage1:

Backward sweep is mainly the branch power calculation, starting from the end buses and moving toward the root node, the power in branch *n* is:

$$S_n = S_i + \sum_{m \in M} S_m + Loss_n \quad (1)$$

Where, S_n is the power of branch *n*, *i* is the ending node of branch *n*, S_i is the absorbed power by the connected load at the ending node of branch *n*, S_m is the power of branch *m* and $Loss_n$ is the power loss of branch *n*. Initial power loss for all branches is equal to zero.

Stage2:

Forward sweep begins from the first branch, which is connected to the slack bus, and moving toward the ending branches, currents are calculated in sending bus of branch *n* (means bus *j*) and also voltages in receiving bus of branch *n* (means bus *i*):

$$J_n = \left(\frac{S_n}{V^j}\right)^* \quad (2)$$

$$V^i = V^j - Z_n.J_n \quad (3)$$

Power loss for branch *n* is calculated by equation (4):

$$Loss_n = (V^i - V^j).I_n^* \quad (4)$$

Stage3:

The voltage mismatches for all buses are calculated during each iteration as follows:

$$\Delta V^{i(k)} = \left|V^{i(k)}\right| - \left|V^{i(k-1)}\right| \quad (5)$$

Where, *k* denotes the iteration number. If any of these voltage mismatches is greater than a convergence criterion, the two first steps are repeated until convergence is achieved[13].

Model of the D-STATCOM in Power Flow

In this paper, it is assumed that the injected reactive power of D-STATCOM is set to its maximum rating. It is considered as a negative constant value in load model in node *K* [1]. In order to indicate and compare the effects of D-STATOM implementing in the distribution system, different locations are selected for the installation of D-STATCOM. Also, rating of D-STACOM is changed in any procedures.

NUMERICAL RESULTS

Test system

In this paper, numerical results are carried out on the 33-bus system. In the test, the convergence criterion is that, in successive iteration the maximum difference in voltage magnitude must be less than 1×10^{-5}p.u. The single line diagram of the 12.66 kV, 33-bus, 4-latrreal radial distribution system is shown in Figure 4. The data of the system is obtained from [14]. The load of the system is considered as (3715+2300j) KVA. Therefore, we considered maximum rating of D-STATCOM equal with reactive power of load.

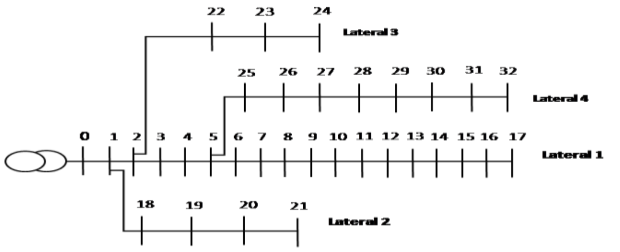

Fig.4. Single line diagram of 33-bus distribution system

Power flow, voltage and power loss control by D-STATCOM

In order to show the capability of the D-STATCOM and the performance of the backward/forward sweep algorithm, the following cases based on the 33-bus system are carried out.

Case 1: This is a base case 33-bus system

Case 2: This similar to case 1 except that there is a D-STATCOM installed for control of voltage profile. Therefore, ΔV is defined as follows:

$$\Delta V=\sum_{i=1}^{n}\left|1-V_i\right| \tag{6}$$

Which calculate difference of voltage magnitude of buses (V_i) from 1 p.u. Different locations are selected for the installation of D-STATCOM. The rating of D-STATCOM changed in five modes to compensate reactive power of the system.

Case 3: This is similar to case 2 except that the rating of D-STATCOM changed from 0 KVA to 2300 KVA and D-STATCOM is installed in 6 buses.

Case 4: This is similar to case 2 except that there is a D-STATCOM installed for control of power loss.

Power loss is defined as follows:

$$\Delta P=\sum_{i=1}^{n}R_i I_i^2 \tag{7}$$

Case 5: This is similar to case 3 except that there is a D-STATCOM installed for control of power loss.

The result of case 1 is illustrated in Table 1. A summary of load flow solution before D-STATCOM installation is presented in this table. The voltage magnitudes of buses are assumed between 1.05p.u and 0.95p.u for the lower and upper limits, respectively. Therefore, 54.54% nodes of the distribution system are under voltage constraint.

Table.1. Voltage magnitude and phase angle in 33-bus distribution system without implementing D-STATCOM

Node no.	Voltage magnitude (P.U.)	Phase angle (°)	Node no.	Voltage magnitude (P.U.)	Phase angle (°)
0	1	0	17	0.9131	-0.4926
1	0.997	0.0145	18	0.9965	0.0037
2	0.9829	0.0965	19	0.9929	-0.0633
3	0.9755	0.1636	20	0.9922	-0.0827
4	0.9681	0.2327	21	0.9916	-0.1032
5	0.9497	0.1473	22	0.9794	0.0662
6	0.9462	-0.082	23	0.9727	-0.0216
7	0.9413	-0.0467	24	0.9694	-0.0655
8	0.935	-0.1205	25	0.9477	0.1873
9	0.9292	-0.1845	26	0.9452	0.2445
10	0.9284	-0.1776	27	0.9337	0.3334
11	0.9269	-0.1667	28	0.9255	0.4173
12	0.9208	-0.2602	29	0.922	0.5257
13	0.9185	-0.3402	30	0.9178	0.4461
14	0.9171	-0.3789	31	0.9169	0.424
15	0.9157	-0.4033	32	0.9166	0.4165
16	0.9137	-0.4823			

As shown in Fig.5 nodes 15 to 17 have the least ΔV, hence to improve voltage profile it is suggested that D-STATCOM installed on these nodes.

According to Fig.5 and Fig.6, D-STATCOM installation near the feeder has no considerable influence on improving voltage profile even by increasing reactive power rating of D-STATCOM.

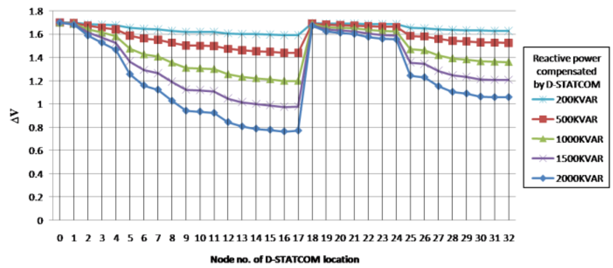

Fig.5. Results of case 2

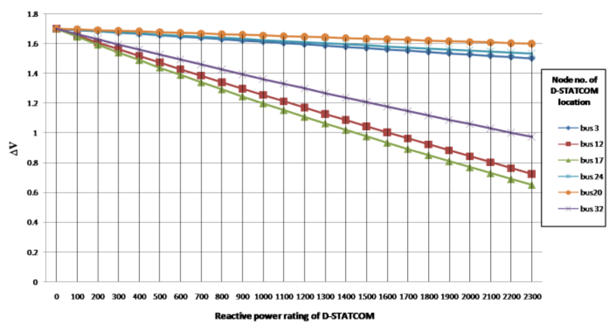

Fig.6. Results of case 3

As shown in Fig.7, 8 increasing reactive power rating of D-STATCOM generally make increasing power loss. To lessen this power loss, installing D-STATCOM on lateral

4 (nodes 25 to 32) is suggested.

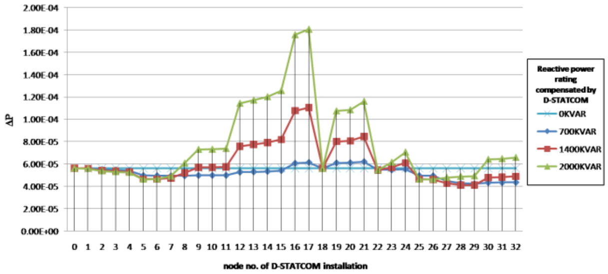

Fig.7. Results of case 4

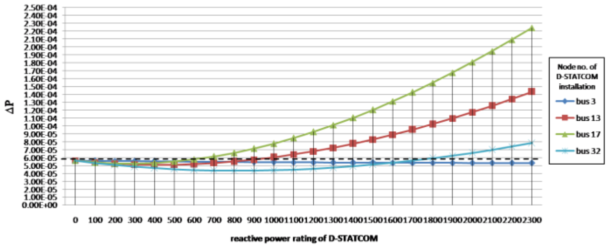

Fig.8. Results of case 5

CONCLUSION

This paper has described Distribution static compensator (D-STATCOM) and described steady-state model of D-STATCOM based on STATCOM model. In this work, the problems associated with determination of proper D-STATCOM location and proper D-STATCOM reactive power rating, are considered. Therefore, D-STATCOM was applied on the 33-bus power system and implemented using the MATLAB® software package. The numerical results show that installation D-STACOM near by the feeder has no influence on power loss and voltage profile. While the minimum ΔV is achieved by installation of D-STATCOM on nodes 15 to 17, the maximum power loss happens in these nodes. According to these results, installation of D-STATCOM on lateral 4 is suggested. This causes improving voltage profile and power loss reduction.

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