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Impact of DG and D-STATCOM placement on improving the reactive loading capability of mesh distribution system

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Abstract

In this paper, Distribution Generation (DG) and Distribution STATic COMpensator (D-STATCOM) are optimally placed in mesh distribution systems using sensitivity approaches. The objective of this paper is to improve the reactive loading capability of the network with maintaining voltage profile in an acceptable limit. Optimal locations of DG and D-STATCOM are determined using Voltage Stability Index and Combined Power Loss Sensitivity approaches respectively. The size of DG and D-STATCOM are determined by variational algorithm subjected to minimization of total power loss. In order to quantitatively analyze the impact of DG and D-STATCOM on voltage stability margin, Q-V curves are drawn using continuation power flow method. In this study the impact of simultaneous placement of DG and D-STATCOM is investigated separately for large industrial motor load as well as industrial load. Also, load growth scenario is considered for better planning of the system. The results are obtained on standard IEEE-33 and 69-bus mesh distribution systems to check the feasibility of proposed methodology.

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Keywords: DG; D-STATCOM; Mesh Distribution system; Optimum location; Optimum size; Voltage Stability Index

1. Main text

Most of the power system loads such as motors, fans, pumps etc, are reactive in nature, which demand reactive power. Since, these loads draw lagging currents the burden of reactive power increases in the distribution system. The reactive power demand increases more in the presence of unbalanced loads. More reactive power demand

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increases feeder losses and also it reduces the capability of active power flow in the distribution system, whereas unbalancing also affects the operation of transformers and generators [1]. As the reactive loading of distribution system increases, voltage profile of the network becomes poor. Voltage collapse is the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system [2]. Voltage profile of distribution system can be maintained within an acceptable limit by providing reactive power from external compensating devices like capacitor banks, voltage regulators or custom power devices such as static synchronous series compensators (SSSC), D-STATCOM and unified power quality conditioner (UPQC). Among all compensating devices, D-STATCOM has several features, like low power losses, compact size and low cost [3]. Voltage stability is the ability of power system to maintain steady acceptable voltage at all buses in the system at normal operating conditions and after being subjected to a disturbance. A voltage stability indicator is proposed for analysis of voltage stability of distribution system in [4]. DG provides several advantages, such as, economical, environmental and technical and plays a vital role in improving the voltage profile of distribution network [5]. A Q-V curve is used as a technique of voltage stability measurement as in [6, 7]. Voltage stability improvement by placement of wind and solar based DG in distribution system is explained in [8]. Voltage profile of distributed wind generation can be improved with D-STATCOM as in [9].

From the literature survey, it is found that authors have proposed separate placement of DG as well as D-STATCOM in radial distribution system for voltage stability analysis. But, voltage stability analysis for finding critical loading condition with simultaneous placement of DG and D-STATCOM in mesh distribution system (MDS) is hardly available. In this paper, optimal placement of DG and D-STATCOM in MDS is presented using sensitivity approaches for voltage stability analysis to find out the critical loading condition with voltage dependent load models including load growth.

2. Voltage Stability Analysis

Voltage stability is the ability of power system to maintain steady acceptable voltage at all buses in the system at normal operating conditions and after being subjected to a disturbance. Voltage collapse is the catastrophic result of a sequence of events leading to a low-voltage profile suddenly in a major part of the power system. A power system network becomes unstable when voltages uncontrollably decrease due to outage of equipments (generators, lines, bus bars, any major compensating devices etc.), increment of load etc. Main factor causing voltage instability is the inability of the power system to meet the demands for reactive power in the heavily stressed system to keep desired voltages. The mathematical equation of voltage stability analysis is derived in [10]. In this study, Impact of voltage dependent load models and load growth are also considered on the voltage stability analysis. Continuation load flow method is applied to determine critical voltage stability limits in the presence of DG and D-STATCOM.

3. Load Model

Load model will affect voltage instability, reactive power imbalance, power system planning, and availability of shunt devices. Common static load models for active and reactive power are expressed in a polynomial or an exponential form. The characteristic of the exponential load models can be given as:

$$P = P_o \left(\frac{V}{V_o} \right)^{n_p} \tag{1}$$

$$Q = Q_o \left(\frac{V}{V_o} \right)^{n_q} \tag{2}$$

where, n_p and n_q stand for load exponents, P_o and Q_o stand for the values of the active and reactive powers at the nominal voltages. V and V_o stand for load bus voltage and load nominal voltage, respectively. The load exponents for different components are given in [11]. The load growth equation [12] can be given as:

$$Load_i = Load \times (1 + \mathrm{r})^{\mathrm{m}} \tag{3}$$

where, r =annual growth rate, m=plan period in years. In this paper, r=7% and m=5

4. Optimal location and size determination of DG and D-STATCOM

Optimal locations of D-STATCOM and DG are determined using Voltage Stability Index as in [13] and Combined Power Loss Sensitivity approaches as in [14] respectively. VSI suggests that 30th and 60th buses are best location for D-STATCOM placement and CPLS suggests that 25th and 60th buses are best for DG placement for IEEE 33 and 69 bus meshed distribution systems respectively. The optimal size of DG and D-STATCOM are determined by variational algorithm subjected to minimization of total power loss as in [15] and presented in Table 1 and Table 2 for IEEE 33 and 69 buses mesh distribution systems respectively.

Table 1: Optimal size of DG and D-STATCOM for 33 bus mesh distribution systems

Load Model	Device	Base Case	with D-STATCOM	with DG	with D-STATCOM and DG
CP Load Model	D-STATCOM Size (kVAr)	--	1150	--	1150
	DG Size (kW)	--	--	2200	2200
Load Growth	D-STATCOM Size (kVAr)	--	2100	--	2100
	DG Size (kW)	--	--	3150	3150
Industrial Load Model	D-STATCOM Size (kVAr)	--	1250	--	1250
	DG Size (kW)	--	--	2075	2075
Large Industrial Motors	D-STATCOM Size (kVAr)	--	1475	--	1475
	DG Size (kW)	--	--	2200	2200

Table 2: Optimal size of DG and D-STATCOM for 69 bus mesh distribution systems

Load Model	Device	Base Case	with D-STATCOM	with DG	with D-STATCOM and DG
CP Load Model	D-STATCOM Size (kVAr)	--	1100	--	1100
	DG Size (kW)	--	--	1950	1950
Load Growth	D-STATCOM Size (kVAr)	--	1950	--	1950
	DG Size (kW)	--	--	2750	2750
Industrial Load Model	D-STATCOM Size (kVAr)	--	1150	--	1150
	DG Size (kW)	--	--	1825	1825
Large Industrial Motors	D-STATCOM Size (kVAr)	--	1100	--	1100
	DG Size (kW)	--	--	1950	1950

5. Methodology

The basic equation of load flow analysis used for mesh distribution systems, consist of five loops are taken from [11] for analysis and the results are obtained with DG and D-STATCOM placement for IEEE 33 and 69 bus MDS using MATLAB software version 7.8, 2009 [16]. The realistic voltage dependent load models such as large industrial motor and industrial load models are taken for the analysis. Load growth is also considered in this study which is essential parameter for power system planning. The complete methodology used for obtaining the results for following considered cases is described by the flowchart given in Fig.1.

Case 1: Base case
Case 2: With D-STATCOM
Case 3: With DG
Case 4: With DG and D-STATCOM

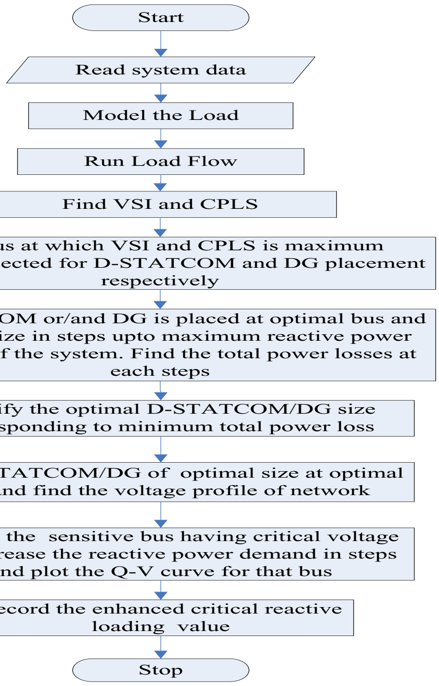

Fig.1. Flow chart of proposed methodology

6. Results and Discussions

In this study, the purpose of DG and D-STATCOM placement is to improve the critical reactive loading capability of MDS by providing active and reactive power support respectively. Q-V curves are drawn with installation of DG and D-STATCOM to determine the critical loading values in each case. In this study, critical voltage is taken as 0.9 p.u and increment in the reactive power demand is considered at the sensitive node only. Q-V curves for 33 bus meshed distribution systems with constant power load are shown in Fig.2 and it can be seen that the critical reactive loading capability with base case is 0.0479 p.u and after D-STATCOM (1150 kVAr) placement it improves and reaches up to 0.0595 p.u, after DG (2200 kW) placement it reaches to 0.0722 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.0837 p.u.

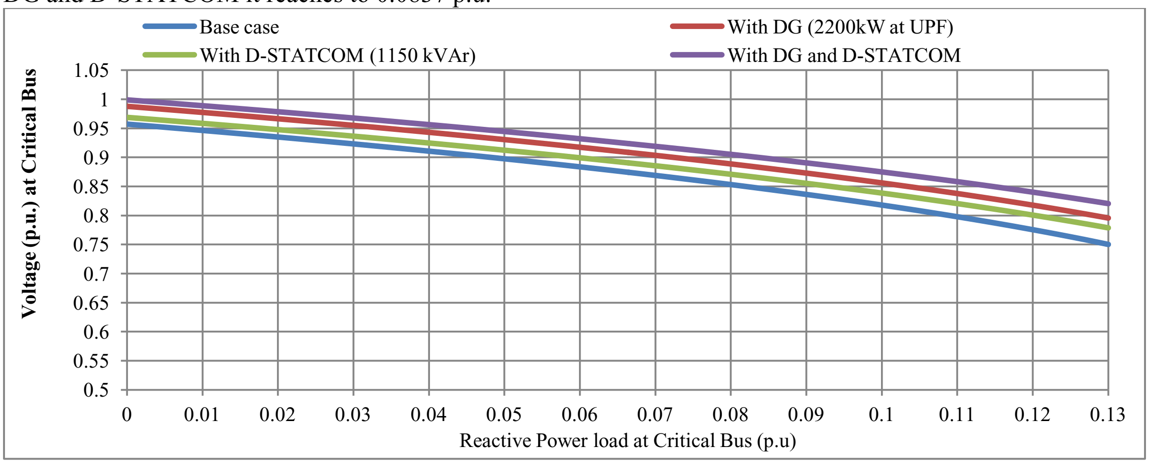

Fig.2: Q-V curves for 33-bus meshed distribution system

Similarly, Q-V curves for 69 bus meshed distribution systems with constant power load are shown in Fig.3 and it can be seen that the critical reactive loading capability with base case is 0.0771 p.u and after D-STATCOM (1100 kVAr) placement it improves and reaches to 0.0881 p.u, after DG (1950 kW) placement it reaches to 0.1028 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.1138 p.u. Q-V curves for 33 bus meshed distribution systems after considering load growth of 7 % for 5 years are shown in Fig.4 and it shows that the critical reactive loading capability with base case is 0.0325 p.u and after D-STATCOM (2100 kVAr) placement it improves and reaches 0.0535 p.u, after DG (3150 kW) placement it reaches to 0.0677 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.0887 p.u. Similarly, Q-V curves for 69 bus meshed distribution systems after considering load growth of 7 % for 5 years are shown in Fig.5 and it shows that the critical reactive loading capability with base case is 0.0599 p.u and after D-STATCOM (1950 kVAr) placement it improves and reaches 0.0794 p.u, after DG (2750 kW) placement it reaches to 0.0969 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.1164 p.u. Q-V curves for 33 bus meshed distribution systems with industrial load are shown in Fig.6 and it shows that the critical reactive loading capability with base case is 0.1016 p.u and after D-STATCOM (1250 kVAr) placement it improves and reaches 0.1251 p.u, after DG (2075 kW) placement it reaches to 0.1320 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.1556 p.u.

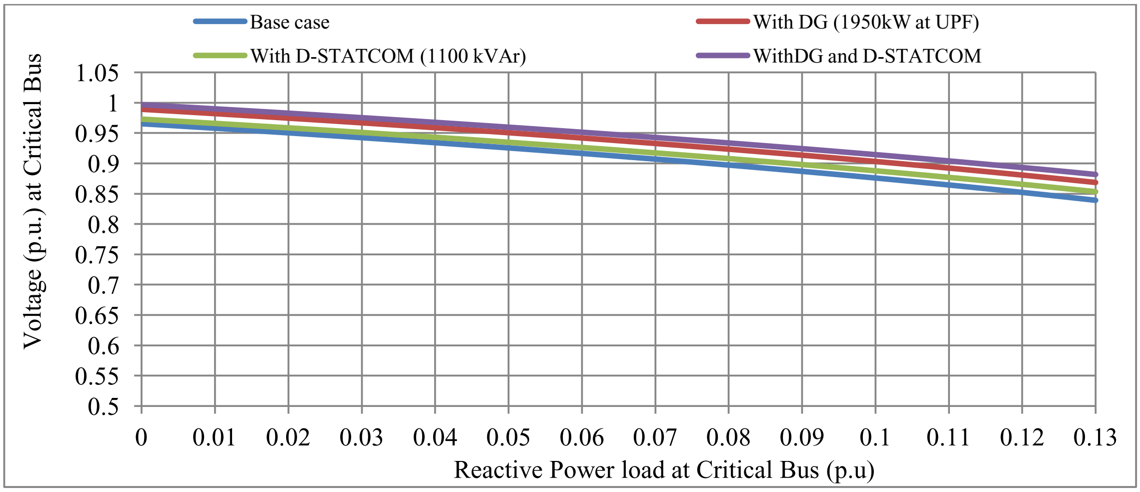

Fig.3: Q-V curves for 69 bus meshed distribution system

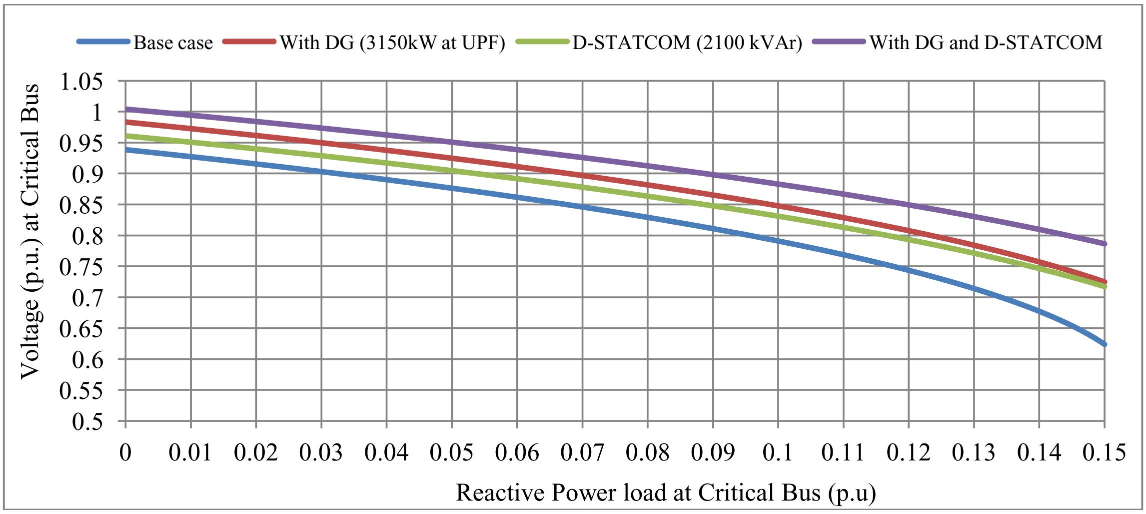

Fig.4: Q-V curve for 33-bus mesh distribution system with load growth

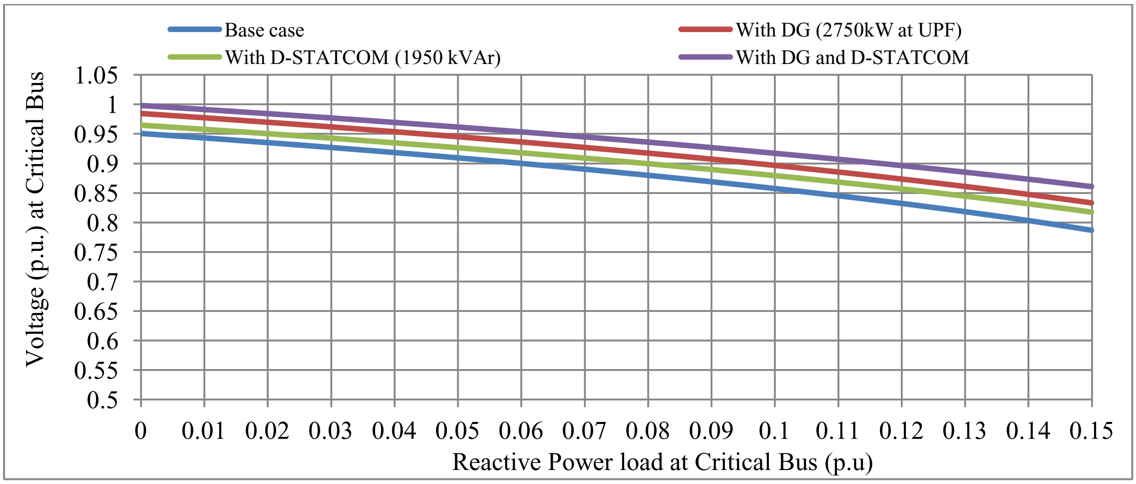

Fig.5: Q-V curve for 69-bus mesh distribution system with load growth

Similarly, Q-V curves for 69 bus meshed distribution systems with industrial load are represented in Fig.7 and it shows that the critical reactive loading capability with base case is 0.1021 p.u and after D-STATCOM (1150 kVAr) placement it improves and reaches 0.1237 p.u, after DG (1827 kW) placement it reaches to 0.1483 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.17 p.u.

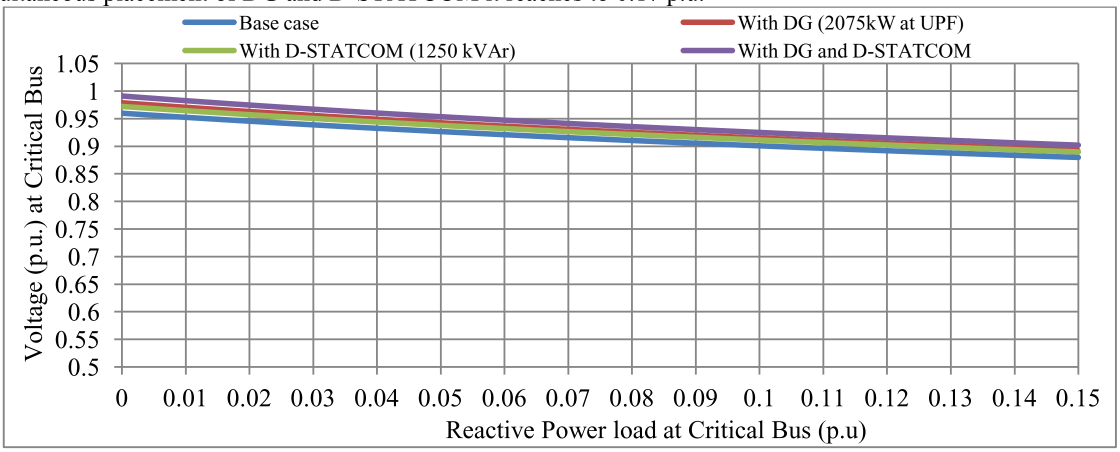

Fig.6: Q-V curves for 33-bus mesh distribution system with industrial load

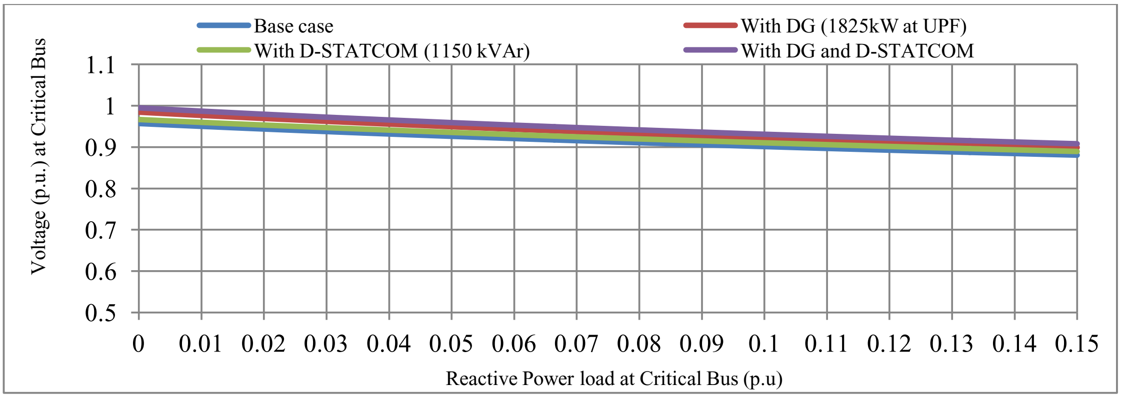

Fig.7: Q-V curves for 69-bus mesh distribution system with industrial load

Q-V curves for 33 bus meshed distribution systems with large industrial motor load are shown in Fig.8 and it shows that the critical reactive loading capability with base case is 0.0513 p.u and after D-STATCOM (1475 kVAr) placement it improves and reaches 0.0669 p.u, after DG (2200 kW) placement it reaches to 0.0695 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.0851 p.u. Similarly, Q-V curves for 69 bus meshed distribution systems with large industrial motor load are shown in Fig.9 and it shows that the critical reactive loading capability with base case is 0.0512 p.u and after D-STATCOM (1100 kVAr) placement it improves and reaches 0.0628 p.u, after DG (1950 kW) placement it reaches to 0.0786 p.u and after simultaneous placement of DG and D-STATCOM it reaches to 0.0903 p.u. Critical reactive loading capability is recorded for each case and presented in Table 3.

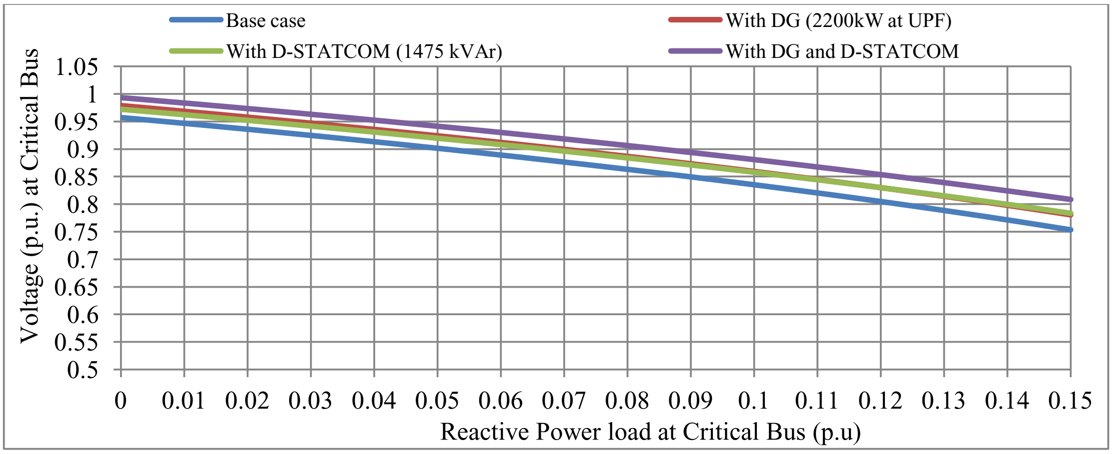

Fig.8: Q-V curves for 33-bus mesh distribution system with large industrial motor load

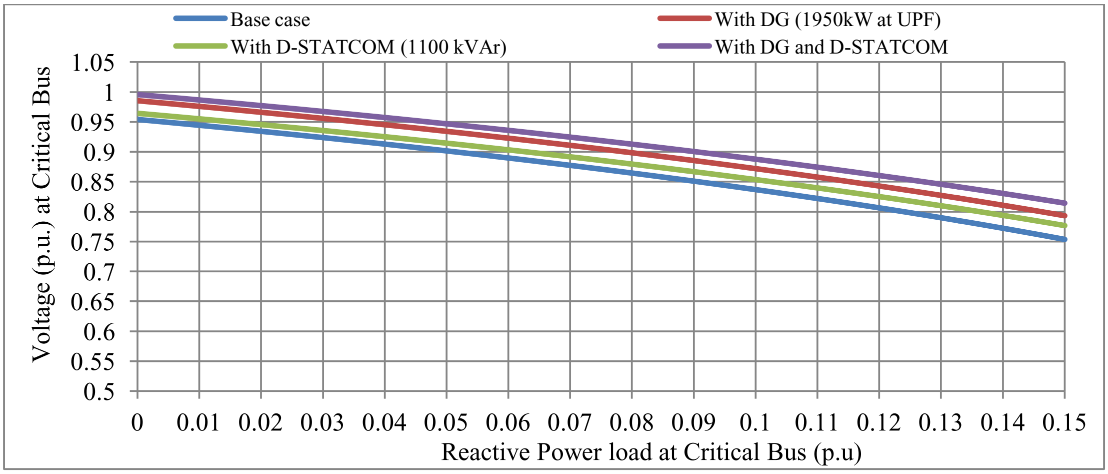

Fig.9: Q-V curves for 69-bus mesh distribution system with large industrial motor load

Table 3: Critical Loading Values in p.u for 33 and 69-bus mesh distribution systems

33-bus mesh distribution systems				
	CP Load Model	Industrial Load Model	Large Industrial Motors	Load Growth
Base Case	0.0479	0.1016	0.0513	0.0325
With D-STATCOM	0.0595	0.1251	0.0669	0.0535
With DG	0.0722	0.1320	0.0695	0.0677
With DG and D-STATCOM	0.0837	0.1556	0.0851	0.0887
69-bus mesh distribution systems				

Base Case	0.0771	0.1021	0.0512	0.0599
With D-STATCOM	0.0881	0.1237	0.0628	0.0794
With DG	0.1028	0.1483	0.0786	0.0969
With DG and D-STATCOM	0.1138	0.1700	0.0903	0.1164

It can be clearly observed from the Q-V curves that, voltage stability limit are increased with optimal installation of DG and D-STATCOM. This is due to; a part of the total power demand is locally deployed by these compensating devices. A significant amount of feeder capacity is released after placement of either DG or D-STATCOM or both. However, the released feeders capacity as well as critical loading capability is higher with the two compensating devices are operating simultaneously.

5. Conclusions

This paper proposed an effective approach for improving the critical reactive loading capability of mesh distribution system with separate as well as simultaneous placement of DG and D-STATCOM. Results show that, the improvement of voltage stability as well as obtained critical reactive loading capability is higher with simultaneous placement of DG and D-STATCOM with all loading conditions including load growth. Power losses increases with load growth as the load demand increases. Accordingly, the rating of required DG and D-STATCOM also increases. This proposed technique will help the distribution network operator to plan the expansion of distribution system with DG and D-STATCOM.

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