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Sensitivity Analysis for 14 Bus Systems in a Distribution Network With Distributed Generators

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Abstract: *There has been a formidable interest in the area of Distributed Generation in recent times. A wide number of loads are addressed by Distributed Generators and have better efficiency too. The major disadvantage in Distributed Generation is voltage control- is highlighted in this paper. The paper addresses voltage control at buses in IEEE 14 Bus system by regulating reactive power. An analysis is carried out by selecting the most optimum location in placing the Distributed Generators through load flow analysis and seeing where the voltage profile rises. Matlab programming is used for simulation of voltage profile in the respective buses after introduction of DG's. A tolerance limit of +/-5% of the base value has to be maintained.To maintain the tolerance limit, 3 methods are used. Sensitivity analysis of 3 methods for voltage control is carried out to determine the priority among the methods.*
Keywords: *Distributed Generators, Distributed System,Reactive Power, Voltage Control, Sensitivity Analysis*

I. Introduction

There is an increase in demand to meet energy requirements daily. Adoption of distributed generators in a distribution network is one way to tackle the energy requirements effectively. A distribution network is extremely sensitive to any changes in reactive power status at the receive.lng end. In order to achieve optimum voltage control, it is required to control the reactive power flow in the network and this is possible by applying reactive power management at different nodes in power system. To maintain steady state operation in a power system, voltage plays a major role and hence its regulation is essential.

Various factors that govern the voltage variations are:-
a) By connecting DGs to the system
b) Load characteristics.
c) Reactive power constraints
d) Increased loading on distribution Feeders,

The introduction of DG's within the distribution system has been a good step forward. But, while it helps by injecting power in the system at different points, it can also cause the voltage at some nodes to shoot up beyond the acceptable level. This project takes up the part of controlling or containing the voltages at all the nodes within a suitable limit.

With the aid of DG, power generation facilities can be kept very close to end users. This reduces transmission losses. If the number of DGs introduced is less, the system can tolerate them. However with a large number of Distributed Generators interconnected to the system, the voltage profile shoots up and exceeds the tolerance limits. But this aggregation of DGs also creates a large area of customer friendly and optimized solutions. The goal of this project was to control the voltage within limits by controlling the reactive power of the DG. Several methods like using capacitor banks and reactors and reduction in DG reactive power are discussed.

Based on tolerance limit as dictated by statute, distribution voltage network are designed [5]. The range of voltage which must be met under a number of different standards does not exceed ±10%, [3-6]. In this paper, the tolerance limit is kept as low as ±5% for an even higher precision. In [6], a generic analytical expression that governs the voltage profile of the distribution with network with DG connected is stated.

There are several other advantages associated with Distributed Generation operation such as improved reliability, low transmission loss, load flow control [1, 4, 5]. Steady state voltage fluctuation, islanding operation, increased fault system level and degradation of power quality and stability of the radial system are the issues that need to be tackled [2]. These factors also depend on the kind of interface used for DG system to interconnect to the grid [3]. However, irrespective of the other demerits, the major cause of worry remains the rise in steady state voltage level of distribution system which has been addressed in this paper. Therefore, if we are able to control the voltage within desirable limits then this system with DGs connected can be favourable to conventional methods due to the vast number of advantages associated with it.

II. Steady State Voltage Rise

In a distribution network when we connect a distribution generator, the active power generated by the generators reduces the flow of power from the primary substation. This can result in a) Maximum system demand and zero generation, b) Maximum generation and minimum system demand c) maximum generation and maximum system demand and maximum generation. For increase in voltage, maximum generation and minimum load withstanding capacity are usually vital for the capacity of Distributed generators [4]. However, it is also essential to analyse the effects of maximum generation and maximum load conditions for providing solution to increase in voltage [5]. The connection of distributed generator to the distribution network are illustrated in Fig.1 (a) and Fig.1 (b) [9].$P_g$and$Q_g$are the active and reactive powers of the generator respectively. The active and reactive powers of the load on the distribution system are represented as $P_L$and $Q_L$respectively. The total current flowing along the line impedance is I_R. The line impedance itself is denoted by$Z = R + jX$andthe total power delivered to the network is denoted by S_R. Vs and Vg are the substation and connection point voltage respectively.

$$S_R = P_R + jQ_R = (P_g + jQ_g) - (P_L + jQ_L) \quad (1)$$

$$S_R = V_g I_R^*,\ I_R = (P_R - jQ_R)/V_g^* \quad (2)$$

$$V_g = V_S + I_R Z = V_S + I_R(R + jX)(P_R - jQ_R)/V_g^*$$
$$= V_S + (P_R R + XQ_R)/V_g^* + j(P_R X - Q_R R)/V_g^* \quad (3)$$

From figure1b) the phasor diagram can be used to arrive at

$$V_g \sin\delta = (P_R X - Q_R R)/V_S \quad (4)$$

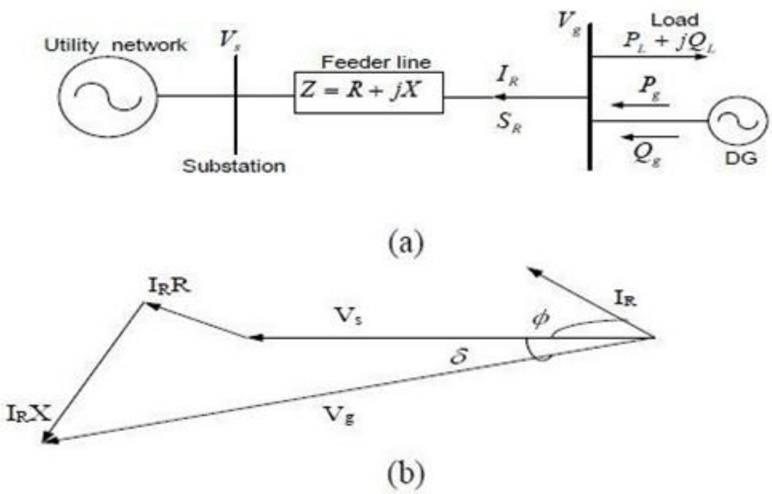

Figure 1(a) Utility network with wind DG system and **Figure1(b)** Phasor Diagram

Since the Voltage angle δ is negligible, the term$(P_R X - Q_R R)/V_g^*$ is also negligible and can be neglected. Magnitude of voltage rise ΔV is approximately given by [9].

$$\Delta V = (P_R R - XQ_R)/V_g^*$$
$$= ((P_g - P_L)R + X(Q_g - Q_L))/V_g^* \quad (5)$$

The induction generator absorbs reactive power, whereas the synchronous generator is able to do both. When it produces active power, it shoots up the voltage, but the reactive power produced can have a twofold purpose: depending on the advancements in DG, it can either increase or decrease voltage profile. These factors, along with the R/X of the radial network and the distribution network characteristics or the load profile help to assess whether the voltage profile at a particular is increasing due to power export from DG or not.

$$\overline{V_{n+1}} = \overline{V_1} - \sum_{k=1}^{n} \frac{(R_k + jX_K)(P_{k+1} - jQ_{k+1})}{\overline{V^*_{k+1}}} \quad (6)$$

The results of some studies that determine the voltage rise issue and the way they can be reduced are shown In [6], . There have been several methods that have been studied – switching off capacitors, switching on reactors, reduction in DG reactive power and controlling the primary substation voltage. The main aim of these methods is to keep the voltage within the tolerance limits to prevent system damage and overloading. The tolerance limits set by statute is ±10%. However this paper has been able to keep it as tight as ±5%.[7]. For determining the efficiency of each method, a sensitivity analysis is carried out in the end.

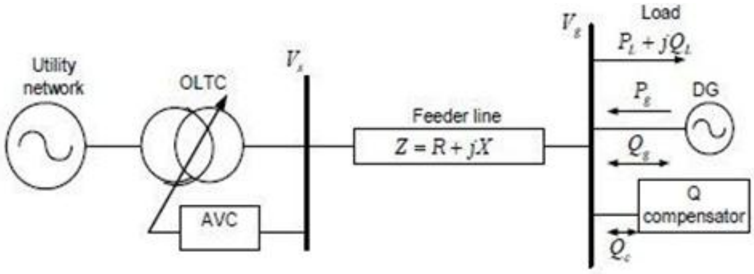

Figure 2 - A simple system illustrating the options for voltage regulation

In Figure 2, a load (P_L, Q_L), distributed generator, DG (P_g, Q_g) and reactive capacitor (Q_C) linked to the distribution system via a distribution feeder that has impedance Z is shown. An on-load tap changer (OLTC) transformer is connected towards the utility end. A DG system which is rotating machine based is used.

III. Voltage Sensitivity Analysis

The impact of changes in system parameters on system performance can be measured by sensitive analysis. Sensitive analysis can also be used to calculate changes in branch flows, losses , bus voltage due to variations in generation and loads. Many cases that deal with reactive power injection, the variation in voltage with respect to change in reactive power injection has been used to calculate sensitivity factor. Sensitivity analysis is a major criterion for determining the priority chart for voltage control in a distribution network with DGs inserted. The sensitivity method has been extensively researched and viable results have been tabulated.
The power flow equations are –

$$P_i = V_i \sum_{j=1}^{n} Vj(G_{ij} \cos\delta_{ij} + Bij\sin\delta_{ij}$$

$$Q_i = V_i \sum_{j=1}^{n} V_j (G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij})$$

Let X= [V ,δ,δ] be set as state vectors,
and U= [P ,Q , P ,Q ,V ,δ] be a set of control vectors, Then the power flow equations can be written as F(X, U) =0.The total derivative of the control vector is

$$\frac{dF}{dU} = \frac{\partial F}{\partial X}\frac{dX}{dU} + \frac{\partial F}{\partial U} = 0$$

For the reactive power output Qg, the total derivative is:

$$\frac{\partial F}{\partial V_L}\frac{\partial V_L}{dQ_g} + \frac{\partial F}{\partial Q_G} = 0$$

Thenthesensitivity dV_l/dQ_{gi} is

$$\frac{\partial V_L}{\partial Q_{gi}}\frac{dV_L}{dQ_g} = -\left[\frac{\partial F}{\partial V_L}\right]\frac{\partial F}{\partial Q_G}$$

When the change of reactive power output occurs, the change of the voltage on the load buses can be calculated. The difference signal is the sensitivity.

IV. Simulation And Results

4.1 Sensitivity Analysis of 14 Bus Systems

For carrying out sensitivity analysis, the change in reactive power and change in peak value of the voltage waveform is noted down. The ratio of these two quantities is what we call the sensitivity factor. Three methods for reduction in Voltage system for a DG connected network are studied. For analysis of sensitivity, sensitivity factor for each method is calculated and then based on the results obtained, a viable conclusion is made.

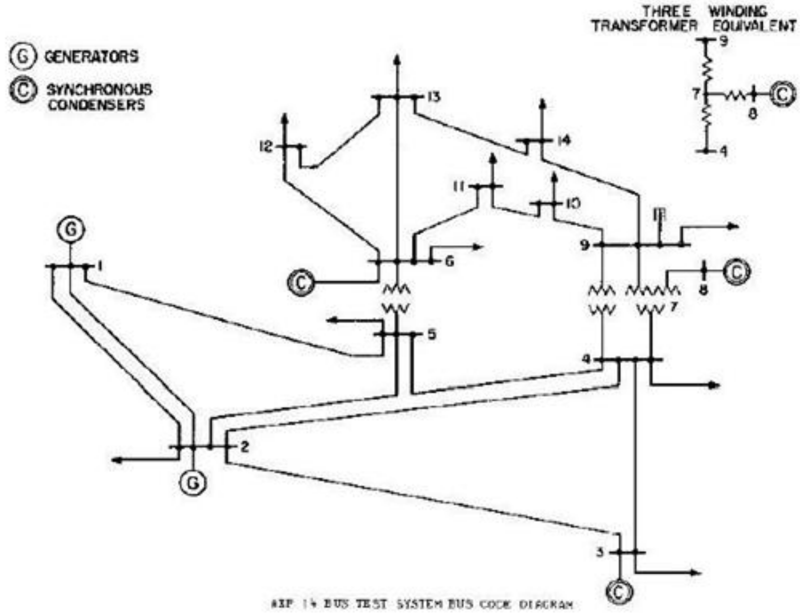

Figure 3: IEEE 14 Bus Single Line Diagram

Table 1: Capacities and Position of DGs inserted in the system

S.no	Capacity (MVA)	Location
DG1	100+80i	Node 1
DG2	148+48.4i	Node 2
DG3	300+200i	Node 3
DG4	250+150i	Node 4
DG 5	200+150i	Node 9

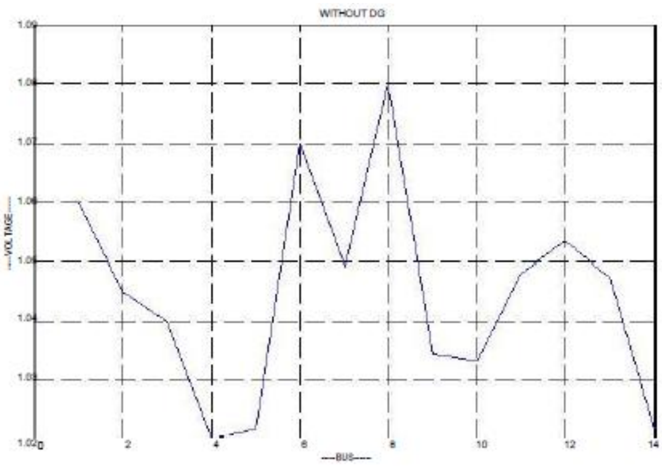

Figure 4: Voltage Profile without DGs

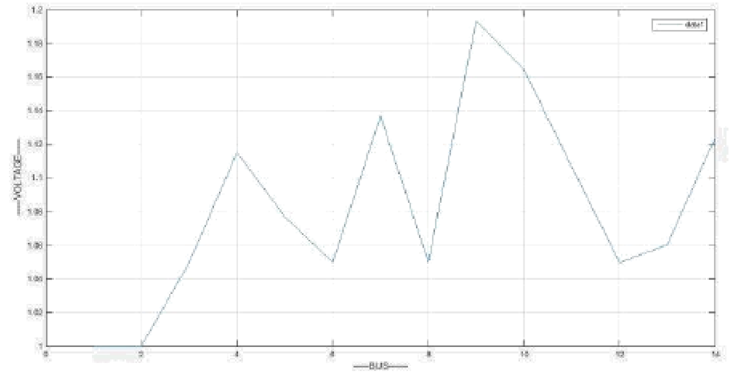

Figure 5: Voltage profile with DG

Fig 4 shows the voltage profile of the system w/o DGs connected. It can be seen that V_{max}= 1.0800 pu and V_{min}= 1.0200 pu. After connecting all 5 DGs to the distribution system the voltage profile of the system can be seen from the Fig 5, which shows V_{max} = 1.194 pu and V_{min} = 1.0 p.u and % of increase in peak voltage as 11.203%. Table 1 shows the DG's size and location in the system. It can be seen that voltage level exceeds the voltage limit (upper limit is 1.05p.u, lower voltage limit is 0.95 p.u).

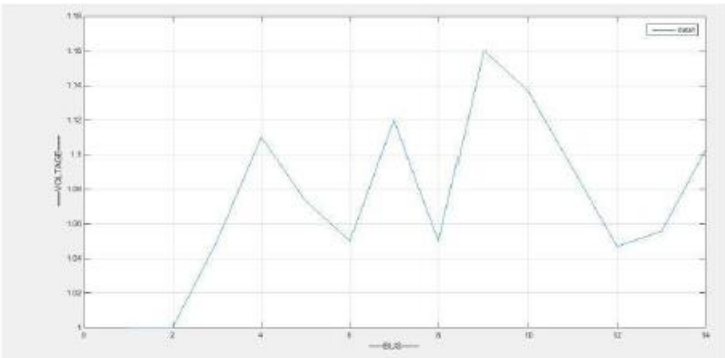

Figure 6: Sensitivity Analysis by Switching on reactors

Net ΔQ= 64i MVAR
ΔV max= 1.194-1.16=0.036 pu Sensitivity Factor μ= ΔV⁄ΔQ =5.625* ê-4.
Fig 6 shows, the voltage profile of the system after switching on all the reactors. It can beseen that the voltage level at all nodes are still not within the limits. V max=1.16p.u and Sensitivity Factor μ= ΔV⁄ΔQ =5.625* ê-4and V min= 1.0 p.u. Thus voltage profile of the system is not within the tolerance limit set (± 5%).

4.2methods For Reduction In Voltage Profile And Carrying Out Sensitivity Analysis
1) Switching on reactors

In this method we introduce reactors to the system at different nodes and analyse the voltage waveforms and evaluate the change in reactive power and ΔV max to calculate the sensitivity factor.

Table No. 2: Capacity of Reactors and their respective location in the distribution network

S.no	Capacities(MVAR)	Location	V max after switching on (pu)
Reactor 1	64i	Node 9	1.04

2) Reduction in DG reactive powers

In this method we reduce the reactive power from every node that contains a distributed generator. The amount of reactive power reduced to get feasible results can be obtained from experimental analysis such that the voltage profile ultimately falls within tolerance limits.

Table No. 3: Reduction in DG capacities

S.no	Capacity (MVA)	Amount of reactive power reduced ΔQ (MVAR)
DG1	100+80i	40i
DG2	148+48.4i	30i
DG3	300+200i	50i
DG4	250+150i	50i
DG 5	200+150i	70i

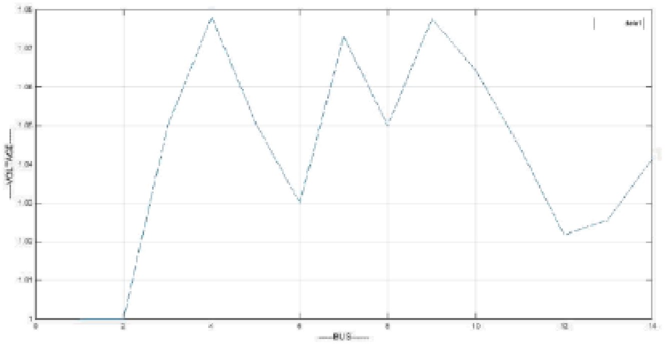

Figure 7: Sensitivity analysis by reduction in DG reactive capacities

Net ΔQ= 40+30+50+50+70= 240iMVAR ΔV max= 1.16-1.078=0.082 pu Sensitivity Factor μ= ΔV/ΔQ =3.41* ê-4

Figure 7 shows the voltage profile of the system after reducing the capacities of all the DGs to required value. It can be seen that V max= 1.078 pu and V min= 1.0pu. Thus voltage profile of the system is still not within the tolerance limit set.

Sensitivity factor using this method μ= ΔV/ΔQ =3.41* ê-4

3) Switch off capacitors

In this method, we are going to switch off all capacitors. We will note its effect on the voltage waveform and note down the peak value of voltage after switching off each capacitor. There will be a considerable drop in the peak value, however it will still violate the limits set and hence we will go for further methods of reduction.

Table 4: Capacity of Capacitors and their respective location in the distribution network

S.no	Capacities(MVAR)	Location
Capacitor 1	100i	Node 5
Capacitor 2	12.2i	Node 6
Capacitor 3	17.4i	Node 8

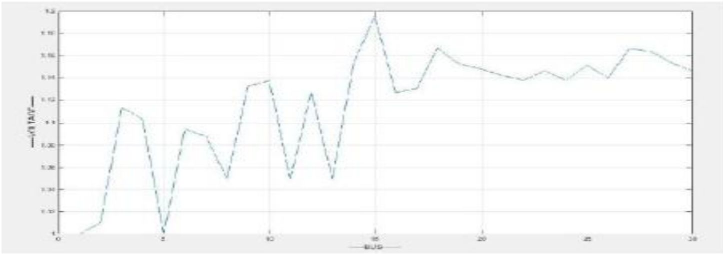

Figure 8: Sensitivity Analysis by switching off capacitors

Net ΔQ = 100+12.2+17.4=129.6 i MVAR ΔV max= 1.078-1.044= 0.081 pu Sensitivity Factor μ= ΔV/ΔQ =2.625*ê-4

Table 4shows the capacitors used along with their location and also the Vmax after switching off each capacitor respectively. Fig.8 shows the voltage profile of the system with switching off all the capacitors. It can be seen that the peak voltage of the system is still crossing the upper voltage limit (1.05 p.u), Vmax is 1.044p.u and sensitivity factor μ=2.625*ê-4.

Table 5: Sensitivity Analysis Chart

S.no	Method	Sensitivity factor
1)	Switching on reactor	5.625×10^{-4}
2)	Reduction in DG reactive	3.41×10^{-4}
	power	
3)	Switching off capacitors	2.625×10^{-4}

From table no 5, we can validate that for reducing the voltage of the system, the first priority should be to switch on the reactors (sensitivity factor highest) and the least priority should be switching off capacitors of DGs (sensitivity factor lowest). These results hold true for the 14 bus system when DG capacities, reactors and capacitors of set values as mentioned before are introduced in the system.

V. Conclusion

In this paper Voltage control for a 14 bus distribution system with DGs connected has been studied. A comprehensive approach for controlling voltage is taken into account by presenting three different methods: Reducing reactive power, introducing reactors and switching off capacitors. The coordinated voltage control based on sensitivity analysis has been done here. It has been observed that sensitivity factor is lowest in case of switching off of capacitors and highest in case of addition of reactors for the 14 bus system. Thus a priority based chart for reactive power control has been established from which it can be easily inferred that in case of a sudden increase in voltage while operation with DGs, the first and foremost priority should be switching on reactors.

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