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Priority Algorithm Based Coordinated Voltage Control for Distribution System with Distributed Wind Generators

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Abstract

Different voltage control strategies have been found effective in managing voltage rise issues in the presence of DGs, power factor control (PFC), OLTC control, active power Generation curtailment, and also reactive power compensation. This paper investigates the coordination of control methods to mitigate the voltage rise problem [illegible] a distribution system connected with distributed Wind generators (WDGs). Priority algorithm for voltage control methods are proposed by considering the forecasted wind generation and typical time varying load profiles [illegible] DigSilent p[illegible]ry simulation software is used for the implementation and the results were found satisfactory to [illegible] system voltage within its allowable limits.

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Keywords : Distributed Generation; Power Factor Control; Generation Curtailment.

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1. Introduction

Distribution networks in different parts of the world have gone through significant growth and improvement with the utilization of distributed generation (DGs). This is in line with the policies of government of countries towards the use of renewable energy resources technology. The connection of DGs has created a challenge for the distribution network operators to change their usual passive approach to an active system [1]. Previously, the distribution system has been working [illegible] a unidirectional power flow but with the connection of DGs, the system has to accept bidirectional power flows which resulted in several technical issues such as voltage levels and power flow, protection issues, equipment thermal ratings and fault current levels [2].

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One of the major concerns in the integration of DGs in the distribution systems is the voltage rise issue. This further requires the DNOs to find solutions to the overvoltage problems in ensuring that the customers receive the voltage within its specified limits. Voltage level is particularly influenced by various factors such as; line resistance R, the line reactance X, the DG power output (PDG, QDG), the local load (PL, QL), and the voltage at bus bar i (Ui). Fig. 1 shows the simplified circuit for modelling the relationship between DG penetration and voltage control.

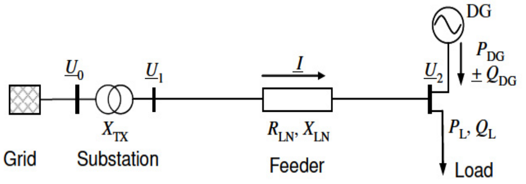


Fig 1 A simple system connected with DG to model voltage rise

The value of voltage at the bus bar connected to the DG can be approximately calculated [illegible] equation [illegible]

$$\Delta U = U1 - U2$$

$$\Delta U = \frac{R(PL - PDG) \quad X(QL + QDG)}{U2} \qquad ([illegible]$$

This equation can be used to qualitatively analyze the relation[illegible]p between voltage at the bus bar connected to the DG and the amount of generation that can be connected to the [illegible]work, as w[illegible]as the impact of alternative control actions to manage the voltage rise [3, 4]. Therefore, network [illegible]ges can b[illegible]anaged in planning timescales by altering R and X or in operational timescales by centrolling P an[illegible] When [illegible] demand for power is low, as in the case in weak rural distribution area, the local ge[illegible]n is all ex[illegible]ack to the primary substation, hence creating a more severe voltage rise issue. This res[illegible]nstable system and losses thus requiring efficient, smart and reliable control system to help manage the[illegible]ue o[illegible]rise.Different voltage control strategies have been found effective in managing voltage rise issue[illegible] presence of DGs [6, 7]. Several studies deal with decentralized voltage control methods, i[illegible] power[illegible]or control (PFC), OLTC, and generation curtailment.

Power factor control (PFC)

In PFC, P/Q is maintained [illegible]ons[illegible] a[illegible]quation 1, any fluctuation in P brings about proportional variation of voltage. If Q ca[illegible] comp[illegible]ed for the voltage variation generated by P by adjusting in the opposite direction, then the voltag[illegible]ation can b[illegible]intained within statutory limits [8]. For voltage rise situation, a more leading power factor is[illegible]qu[illegible]t which the[illegible]is to be connected.

On-load Tap Ch[illegible]ers (OLTCs)

The tap cha[illegible] operation usually[illegible]es 3−10 minutes to move from one position to another, and a several minute time interva[illegible]tween [illegible]quent operations is also required with considering the oxidation of tank oil [9].

In [10] i[illegible]ho[illegible] that the coordination between DG outputs and OLTC tap controls is a necessity in order to allow higher D[illegible]egratio[illegible]therwise, power injection levels can be severely limited if substation voltage is kept co[illegible] the O[illegible] tr[illegible]ormer. In [11] the authors implemented OLTCs/LDCs/AVC relays on a MV feeder and [illegible]ultipl[illegible]V feede[illegible]orks respectively.

[illegible]ent

[illegible]ently, due to the inflexibility of the voltage control strategies, DNOs trip whole DG from the network to solve[illegible]voltage rise problem. This operation largely wastes the potential renewable energy and reduces the profit of DGs[illegible]]. Therefore DG power output curtailment is proposed as a straight forward method to solve voltage variation problems by reducing DG power production. However ’first on last off’ agreement between the DG owners and DNOs adds complexity to the power curtailment technique. According to the stochastic operation mode of wind farm, the most effective way for power curtailment would be increase/decrease the speed of wind turbines by using pitch control.

In this work, local voltage control techniques are suggested to limit the voltage rise in the system. Priority algorithm proposed to implement the voltage control options for time varying load and wind generation. The worst case scenarios also studied. Energy losses could be minimized through voltage control.

2. Problem formulation and priority algorithm

The main objective of this work is to coordinate the DG with the available voltage control equipme[illegible]der to ensure that the steady state voltages can be maintained within the allowed range all the time. The [illegible] obje[illegible] is to minimize the total loss of the system during the voltage control action.

$$\text{Minimise } \{P_{losses} = \textstyle\sum_{l=i}^{n} | I_i |^2 R_i\} *_t$$

where:
t = time of operation in hours
i = Number of lines in the system.
I_i = Line real active current.
R_i = Line resistance.

Several constraints of the power system have been taken into consideration whe[illegible]ing the analysis to get more accurate responds. The setbacks are:

a) Constraint of Voltage bus:

$$V_{\min} \le V_{bus} \le V_{\max}$$

The voltage value for each bus should be within the acceptable li[illegible]hich is i[illegible]tween 0.95 and 1.05 (±5% of rated value).

b) Constraints of Power injection:

$$\sum_{i=1}^{k} P_{DG} < P_{Load} + P_{Losses} \qquad , k = no.of\ DG$$

The total DG output power shall be lowe[illegible] total l[illegible]n the network in order to prevent power injection to the main grid (substation). By doing s[illegible] will e[illegible]ure a co[illegible]uous power flow from the main grid to the whole distribution system.

c) Constraint of Power balance:

$$\sum_{i=1}^{k} P_{DG} + P_{Subst[illegible]} [illegible] P_{Load} + P_{L[illegible]}$$

The amount of power generated [illegible] DG units and substation must be equal to the summation of power load and power losses coin[illegible] with the prin[illegible] of equilibrium where the supply of power must equal to its demand.

d) Constraints [illegible]al and reactive pow[illegible]

$P_{[illegible]} \le P_G \le [illegible]_{max}$

$Q_{Gmin} [illegible] Q_{Gmax}$

P_G - r[illegible]ver ou[illegible] of th[illegible]nerator and Q_G- reactive power output of the generator.

[illegible] Priori[illegible] Algorithm f[illegible]r the Voltage control

[illegible] 1: Read system data, load data and generation data,
Ste[illegible] Classify the DG input power as Low, Medium and High and bus voltages as Low, Mediu[illegible] High and Very high voltage
Step 3: Run the load flow analysis with Distributed generation for the given system
Step 4: If the voltage is low voltage apply PFC
    else if the voltage is medium and high voltage apply PFC + OLTC
        else for very high voltage apply PFC + OLTC + Generation curtailment
Step 5: Repeat the step 4 until the voltage profile is brought within the statutory limits for all the hours.
Step 6: End

The above algorithm shows the implementation of the coordinated voltage control for a distribution network connected with DGs.

3. Test system and simulation

Fig.2 shows the 15 bus test system with base 10 MVA and 6.6 kV is considered for the simulation. A wind farm consists of 4 wind generators considered as DG, each rated with 1.6 MW connected at 13th bus. The line data and load data of the 15 bus system are given in the literature [12]. All Components of the test system are modelled in Dig Silent power factory software. Simulations are carried out on 15 bus test system to see the effectiveness of voltage control schemes i.e., PFC, on load tap changing control and the generation curtailment control methods in distribution networks with DG.

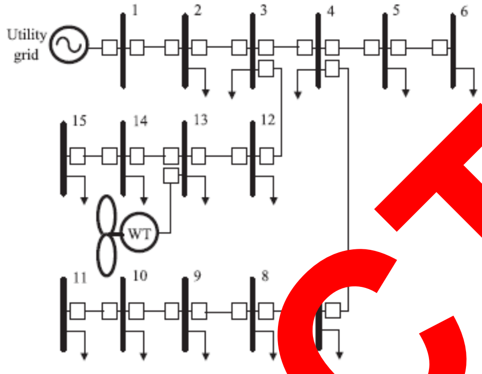


Fig. 2. 15 Bus Test system

For the analysis, two different daily load and wind generation profiles [13, 14] shown in the Fig. 3 and Fig. 4 respectively are considered as case 1 and 2 in the simulation.

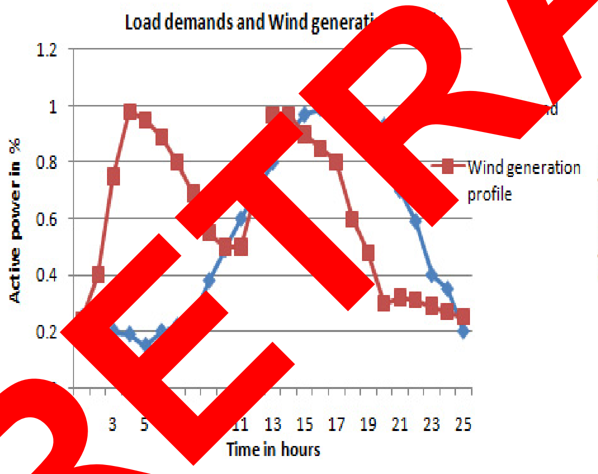


Fig.3 Load and wind generation profile -1

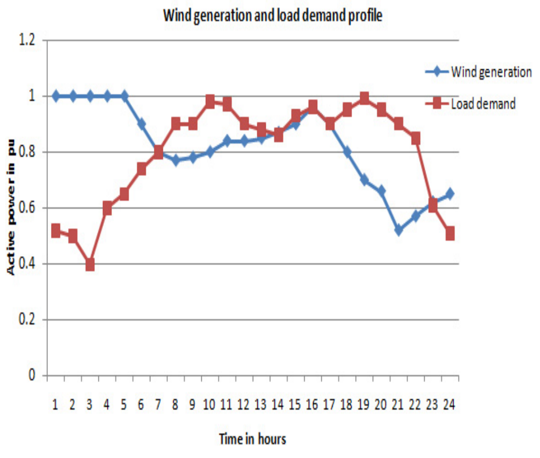


Fig 4. Load and wind generation profile – 2

4. Test results

Fig. 5 and Fig. 6 show the simulation results and it is observed that in both the cases voltage rise effect occurs in most of the hours in a day. Interestingly buses nearer to the DG connection point voltage rises approximately 15% of the rated value. Based on the simulation results, Voltage at the buses are classified into 4 types shown in Table 1.

In order to maintain the voltage within the allowable range (0.95pu-1.05pu), proper coordinated voltage control techniques are proposed in Table 2.

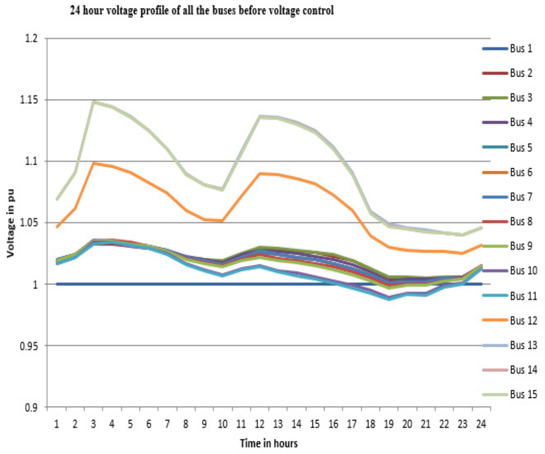


Fig 5 .System voltage case-1

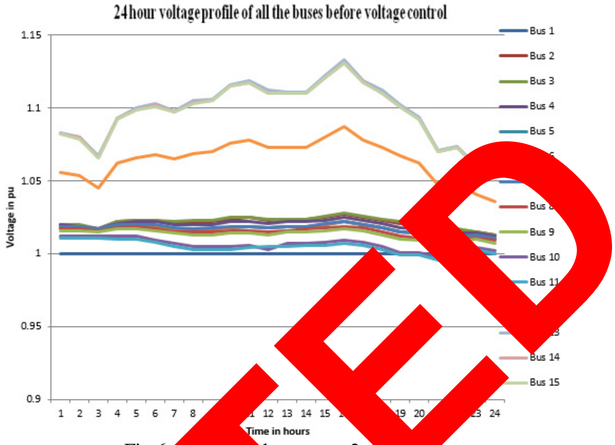


Fig 6 [illegible]ltage case-2

Table 1: Voltage Classification

Type	Voltage Classification	Time in Hours	
		Case 1	Case 2
1	Low Voltage (0.90pu-0.94pu)	--------------	---------------
2	Medium Voltage (0.95pu-1.05pu)	[illegible] 19 [illegible]3	---------------
3	High Volta[illegible] (1.051pu-1[illegible])	[illegible]1, 18	3,21,23,24
4	Very [illegible]h V[illegible] (1[illegible]u-1.15p[illegible]	2, 3, [illegible], 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,17	1,2, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,17,19,20,22

Table 2: [illegible]oposed [illegible]e control method

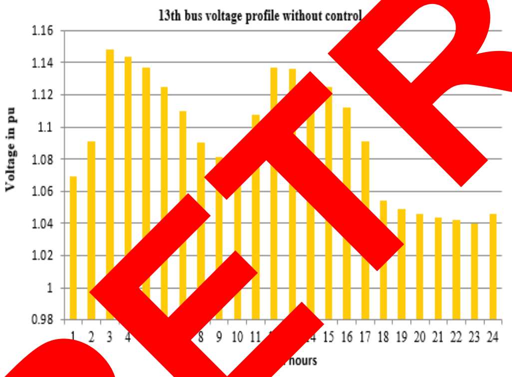
DG i[illegible] p[illegible]	Voltage Classifica[illegible]	Proposed control method	Time in Hours	
			Case 1	Case 2
Low	[illegible]Low Voltage (0.90pu-0.94pu)	DG- Power Factor Control	---------------	-------------
	B=Medium Voltage (0.95pu-1.05pu)	DG- Power Factor Control	0/24, 19, 20, 21, 22, 23	---------------
Medium	C=High Voltage (1.051pu-1.07pu)	DG- Power Factor Control + OLTC Control	1, 18	3, 21,23,24
High	D=Very High Voltage (1.071pu-1.15pu)	DG- Power Factor Control + OLTC control + Generation curtailment	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16,17	1,2,4,5,6,7,8, 9,10,11,12,13,14, 15,16,17,18,19,20,22

The voltage control methods for each case are suggested and are implemented using DigSilent power factory simulation study.

Table 3: Hourly setting of voltage controller in system

Case	Voltage levels	Time In Hours	PFC	OLTC TAP position	Generation curtailment (%)	V_{min} pu	V_{max} pu
1	B	0/24, 19, 20, 21, 22, 23	0.85 lag	------	------	0.99	1.03
	C	1, 18	0.9lag	+2,+1	------	0.98	1.02
	D	2, 3, 4, 5, 6, 7, 8, 9,10, 11, 12, 13, 14, 15, 16,17	0.9lag	+1.+3,+3,+3, +2 +2,+2,+1,+1, +1,+1,+2,+2, +2 ,+1,+1	37,40,37,37, 35,35,37,35,35, 37,37,37,40, 37,35,35	0.97	[illegible]5
2	B	0/24, 19, 20, 21, 22, 23	0.85 lag	------	------	[illegible]----	------
	C	24,23,21,3	0.9lag	+2,+2,+1,+1	[illegible]	0.9[illegible]	[illegible]2
	D	1,2, 4, 5, 6, 7, 8, 9,10, 11, 12, 13, 14,15, 16,17,18,19,20,22	0.9lag	+1.+1,+1,+2, +3,+2,+1,+1, +1,+1,+2,[illegible] +2 ,+1,+[illegible], +1,+1,[illegible]2	[illegible]5,35,36,4[illegible] 40,38,40,40, 40,36,40,38, 40,38,36, 40, 40,35[illegible],35	[illegible].97	1.03

Table 3 gives the optimal settings of the voltage control techniq[illegible]or each [illegible]r in order limit the voltage rise within the specified limits for that particular hour. It i[illegible]rved that f[illegible] voltage only power factor control technique is used with power factor 0.85lag. For hig[illegible] [illegible]urs power factor control and OLTC method are sufficient to limit voltage rise. The very high voltages [illegible] lim[illegible] all control methods i.e, PFC, OLTC and generation curtailment. Maximum of 40% of generation c[illegible]ent is done in order to limit the voltage rise effect.



[illegible]7. Voltag[illegible]f 13th bus without voltage control

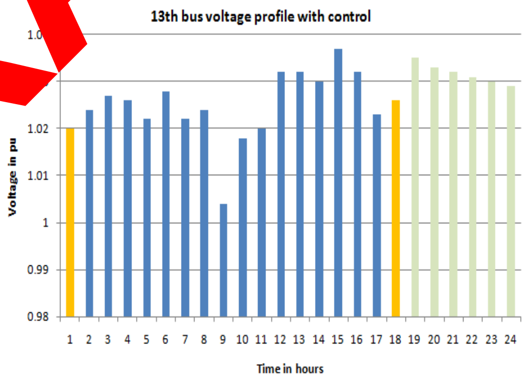


Fig. 8 .Voltage profile of 13th bus with voltage control

▆ PFC + OLTC+ GC 🟨 PFC +OLTC 🟩 PFC

[illegible] Fig. 7, it can be seen that voltage rise problem happens at 13th bus (DG connected bus) i.e, 10-15% above nomi[illegible]alue most of the hours in a day. After the application of coordinated control methods, the voltage in the critical 1[illegible] bus is maintained within the allowable range, which is shown in Fig. 8. Similarly, the voltage profile of other buses with voltage control for case 1 and case 2 are found out.

By comparing the results, it is seen that, according to the priority set in the algorithm, the preferred voltage control methods and their set points shown in the Table 3 are brought enough to maintain the all bus voltages within the statutory limits.

Worst case scenario results

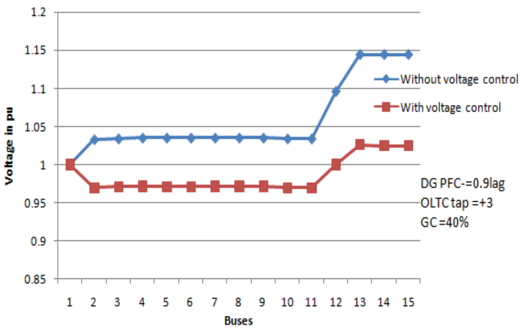


Fig. 9. Voltage profile (1)

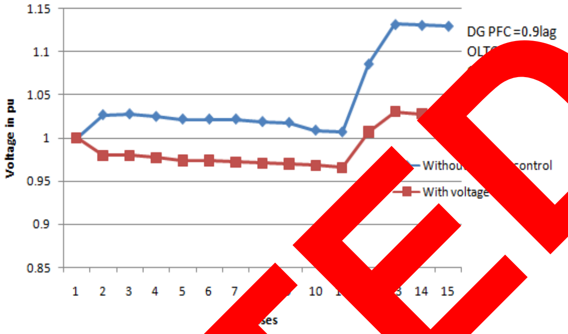


Fig. 1[illegible] [illegible]e profile (2)

Simulations are also carried out for worst case scenarios i.e, (1)maximum g[illegible]tion -minimum load and (2)maximum generation- maximum load condition corresponding [illegible]re shown in [illegible] and 10. It is observed that voltage rise at 13, 14 and 15thbuses. DG PFC - 0.9 lag, OLTC [illegible]p position +3 ,40% of DG power curtailment for the first scenario and for the second case DG PFC 0.9 lag, OL[illegible] tap positio[illegible]2 and 40% DG power curtailment controls are recommended to keep voltage of all buses within li[illegible] Fig.11 s[illegible]s the energy loss in a system for case 2. It is observed that after the voltage control, the system energ[illegible]ses a[illegible]duced to 59.67% and 48% for case 1 and 2 respectively.

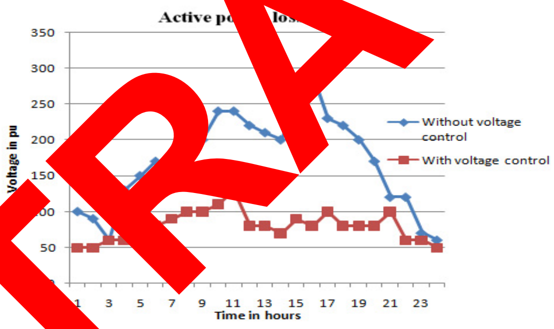


Fig. [illegible] Energy loss before and after voltage control (case 2)

5. Conclusi[illegible]

[illegible]aper, [illegible]le[illegible]ralized voltage control methods are proposed for voltage control of the distribution [illegible]tem. T[illegible] control [illegible]ds the PFC, the on load tap changing control, and the generation curtailment methods are [illegible]sted o[illegible]5-bus system using Dig Silent power factory. The PFC method performed by keeping the generator's p[illegible]actor [illegible]and effective whenever the voltages are medium. This method of voltage control is proven eff[illegible]e to a certain extent, wherein increasing the generator's input power results in high voltage rise. OLTC meth[illegible] found effective whenever the voltages are high. The option of generation curtailment is found to be effective [illegible]henever the voltage values are very high.

Generation curtailment method is applied by reducing input power, with a reduction of the input generation. However, other related issues related to the curtailment issue, such as the duration and cost of curtailment, are important considerations when opting for this method of voltage control. The decentralized voltage controls tested in the simulation and are found to be capable of mitigating voltage rise in a system for a forecasted typical daily load and generation profiles. It has been indicated that the presence of DG needs to be coordinated with the available voltage control equipment, in order to ensure that the steady state voltages can be maintained within the allowed range all the time in a day.

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