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Research Article

Voltage Profile Analysis in Smart Grids Using Online Estimation Algorithm

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Voltage rise is the main obstacle to prevent the increase of distributed generators (DGs) in low-voltage (LV) distribution grids. In order to maintain the power quality and voltage levels within the tolerance limit, new measurement techniques and intelligent devices along with digital communications should be used for better utilization of the distribution grid. This paper presents a real-time sensor-based online voltage profile estimation technique and coordinated Volt/VAR control in smart grids with distributed generator interconnection. An algorithm is developed for voltage profile estimation using real-time sensor remote terminal unit (RTU) which takes into account topological characteristics, such as radial structure and high R/X ratio, of the smart distribution grid with DG systems. A coordinated operation of multiple generators with on-load tap changing (OLTC) transformer for Volt/VAR control in smart grids has been presented. Direct voltage sensitivity analysis is used to select a single DG system for reactive power support in multi-DG environment. The on-load tap changing transformer is employed for voltage regulation when generators' reactive power contributions are not enough to regulate the voltages. Simulation results show that the reported method is capable of maintaining voltage levels within the tolerance limit by coordinated operation of DG systems and on-load tap changing transformer.

1. Introduction

Proliferation of distributed generation is expected to change the operation and control of existing power grids. Interconnection of distributed generators at low voltage levels improves network reliability, power quality, and efficiency and reduces overall power loss. In order to achieve these benefits with large penetration of DG source in existing utility networks, several technical problems are to be faced such as voltage regulation, islanding of DG, degradation of system reliability, power quality problems, and protection and stability of the network [1, 2]. Voltage rise problem is the main obstacle for the growth of distributed generators in low-voltage distribution grids [3]. This is very important as traditional distribution networks are designed to maintain customer voltage constant within the tolerance limit. Therefore, new measurement techniques and intelligent devices along with digital communications should be employed in low-voltage distribution grids in order to maintain the power quality and voltage levels within the tolerance limit. Emerging smart grid technologies will address the enormous challenges to be faced by the integration of high levels of DG sources into future distribution grids. A key feature of a smart grid system is the use of communication infrastructure and advanced technologies such as smart meters and sensors that provide system operators with relevant, real-time information [4–6]. This research work mainly addresses real-time sensor-based online voltage profile estimation and coordinated control in smart grids with distributed generation systems.

It is important to obtain system parameters, such as voltage magnitudes and power flows, for the operation and control of distribution system regulating devices. Many methods have been proposed in the literature to estimate voltage profile of a radial distribution system [7–12]. The methods presented in [7, 8] estimate the voltages without considering any generators in the distribution system. In [9–12], a new voltage estimation methodology was presented based on RTU readings. Based on the estimated voltage values, voltage regulation is carried out using single on-load tap changing transformer. In these methods, reactive power support through the generators as well as mechanical stress on the transformer taps is not considered.

One of the challenging aspects of the active distribution networks is the coordinated voltage control. The fundamental idea behind coordinated control approach is to coordinate the operation of the DG sources and voltage regulating devices such as on-load tap changing transformer and capacitor [13–17]. In [13], coordinated and uncoordinated control scheme with and without considering the DG in voltage control was investigated. The results show that involvement of DG in voltage regulation reduces number of tap charger operations of transformer. A coordinated control action using a genetic algorithm was presented in [14], where the control devices include shunt capacitor (SC), step voltage regulation (SVR), load ratio control transformer (LRT), shunt reactor, and static VAR compensator (SVC). Volt/VAR control in distribution networks utilizing optimal reactive power injection through the distributed generator was presented in [15]. The control interactions among multiple DG units and other voltage regulating devices, such as transformer and capacitors, were examined in [16]. In these schemes, it is not very clearly addressed how to obtain real-time system parameters and utilize them effectively for operation and control of distribution grids. Voltage control for distribution networks via coordinated regulation of active and reactive power of DGs was proposed in [18]. Active power curtailment of DGs in voltage regulation process leads to underutilization of DG sites. Many coordinated voltage regulation schemes for distribution systems with distributed generation and energy storage systems were proposed in [19–23]. However, control algorithms used in these voltage control schemes assume that voltage profile of the system is readily available, and based on available node voltages, control actions will be initiated for voltage regulating devices in the system.

In this paper, an algorithm is developed for voltage profile estimation in smart distribution networks using real-time sensor remote terminal unit (RTU). The developed algorithm takes into account topological characteristics such as radial structure and high R/X ratio of the smart distribution networks. The RTU sensors are placed at only DG connected and lateral originating node points. The magnitudes of voltage values estimated are compared with the forward/backward sweep load flow method. A coordinated Volt/VAR control method using multiple DG systems and on-load tap changing transformer is presented. The direct voltage sensitivity analysis is carried out for selection of individual DG system in multiple DG environments. On-load tap changing transformer is employed in voltage regulation when generators' reactive power support is not enough to maintain voltage levels. The validation is carried out using the IEEE 69-bus radial distribution system. The reported simulation results show that coordinated operation of generators and on-load tap changing transformer can effectively solve voltage rise problem while maintaining voltage levels within tolerance limit.

The rest of the paper is organized as follows. Section 2 details the voltage rise in distribution system with DG. Section 3 gives online voltage profile estimation methodology. Section 4 describes the system structure of RTU. Section 5 presents developed voltage sensitivity analysis. Section 6 discusses the DG selection for reactive power support. Finally, Section 7 reports simulation results associated with case study and conclusions of the work are drawn in Section 8.

2. Voltage Rise in a Distribution System with DG

When a DG source is connected to the distribution system, its active power export reduces the power flow from the primary substation and hence reduces the voltage drop. However, with the significant increased penetration of generators, the power flows may become reversed and cause the system voltage to rise.

Figure 1 illustrates a connection of DG source to the distribution network. P_G and Q_G are active and reactive powers of the DG source, respectively. P_L and Q_L represent the active and reactive power of the load connected to the distribution system. V_S and V_G are substation voltage and connection point voltage, respectively. I is the net current through the line impedance, and $Z = R + jX$. The net power injected to network (S) is given by

$$S = P + jQ = P_G \pm jQ_G - P_L - jQ_L. \quad (1)$$

The connection point voltage is given by

$$V_G = V_S + I.Z. \quad (2)$$

The net current through the line impedance is given by

$$I = \left(\frac{S}{V_G}\right)^* = \frac{(P - jQ)}{V_G^*}. \quad (3)$$

Substituting (3) into (2) gives

$$\begin{aligned} V_G &= V_S + \frac{(P - jQ)(R + jX)}{V_G^*}, \\ V_G &= V_S + \frac{(PR - QX)}{V_G^*} + j\frac{(PX - QR)}{V_G^*}. \end{aligned} \quad (4)$$

Considering the phasor diagram in Figure 1 gives

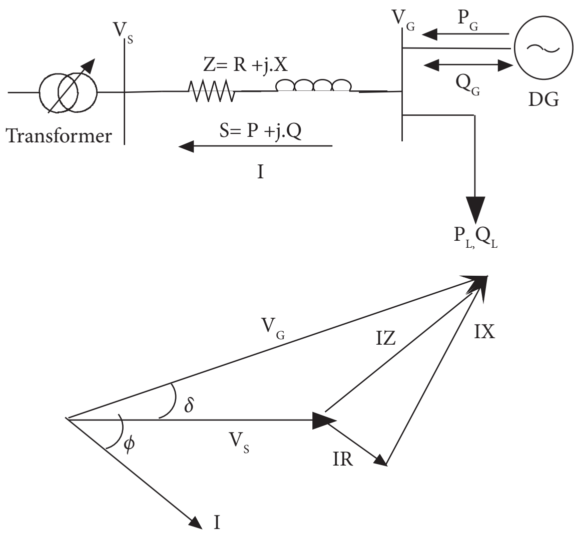

Figure 1: Voltage rise from a DG source.

$$V_G \sin \delta = \frac{(PX - QR)}{V_G}. \quad (5)$$

In light of the fact that the voltage angle δ is so modest,

$$\frac{(PX - QR)}{V_G}. \quad (6)$$

As a result, it is easy to overlook. The magnitude of the increase in voltage is given by

$$\Delta V = \frac{(PR + QX)}{V_G^*}, \quad (7)$$

where $P = (P_G - P_L)$ and $Q = (\pm Q_G - Q_L)$. V_G is expressed in per unit. The magnitude of the voltage rise is approximately given by

$$\Delta V = (P_G - P_L)R + (\pm Q_G - Q_L). \quad (8)$$

The above equation gives that the magnitude of voltage rise depends on amount of DG source active power exports, whereas the DG source reactive power can be further increased or reduced depending on the type of DG technology. If the voltage rise problem is alleviated, then higher DG levels can be integrated on distribution grids.

3. Online Voltage Profile Estimation

The main objective of design of the distribution network is to maintain the customer voltage constant, within the tolerance limit. Distribution network operation and control require the value of voltage magnitude at different sections of the grid. Therefore, in order to maintain the voltage levels, voltage profile of the system needs to be estimated first. Based on the voltage profile of the system over a certain period of time, the voltage regulating devices take control actions.

3.1. Maximum Voltage Values. Typically, in a distribution network, the magnitude of voltage value is maximum at substation bus or at any nodes which are having active sources such as DG and capacitor banks. By connecting RTUs at these nodes, maximum voltage values can be estimated.

3.2. Minimum Voltage Values. Minimum voltage values for distribution feeders can usually be at the end node of the feeder as well as in between any two DG connected nodes. Voltage at the end node is directly obtained by connecting a RTU. Voltage between two DG connected buses needs to be estimated. For estimating the minimum voltage value, this paper assumes that loads are concentrated at the mid-point between DG units. Figure 2 shows a part of the distribution system.

The value of minimum voltage between two DG sources, as calculated byDG_1, can be given by

$$V_{\text{est},DG_1} = V_1 - \left(P_1\frac{r}{2} + Q_1\frac{x}{2}\right). \quad (9)$$

Also, the value of minimum voltage between two DG sources, as calculated by DG_2, can be given by

$$V_{est,DG_2} = V_2 + \left(P_2\frac{r}{2} + Q_2\frac{x}{2}\right). \quad (10)$$

Take the average of (9) and (10) to get a better estimation:

$$V_{\text{est}} = \frac{V_{\text{est},DG_1} + V_{\text{est},DG2}}{2}, \quad (11)$$

where V_{est} is the estimated minimum voltage value between two DG sources.

4. System Structure of RTU

RTU is a data collecting device used in smart distribution grids. The RTU's primary job is to collect data at its own node, process it mathematically, and then transmit it to another RTU or control station over a communication link for analysis. The distribution network is assumed to include a wide range of communication infrastructure. The RTU system structure is shown in Figure 3. RTUs are equipped at each DG or capacitor connected node points and lateral originating node points in the system. Dotted lines illustrate the communication links between RTUs. Each RTU must take local measurements, do computations, and communicate with its neighbor RTUs. Figure 4 shows the view of parameters measured by each RTU. There is no requirement to measure the voltages of the immediate neighboring buses other than the model proposed in [11]. Consequently, the number of measurements and the amount of computation required by each RTU are lowered [12].

The RTU algorithm is designed to convey the magnitude of the min and max voltage values of every feeder to its neighbor RTU or control station. Let RTU_n be the RTU connected to a certain DG at node "n." Assume that RTU_{n-1} and RTU_{n+1} are upstream and downstream RTUs connected at $(n-1)$ and $(n+1)$ nodes, respectively. The most remote RTU_{n+1} at $(n+1)$ node assumes its own DG voltage as maximum voltage value and estimates minimum voltage

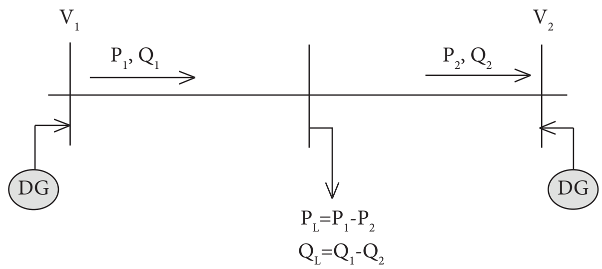

Figure 2: Part of a distribution system.

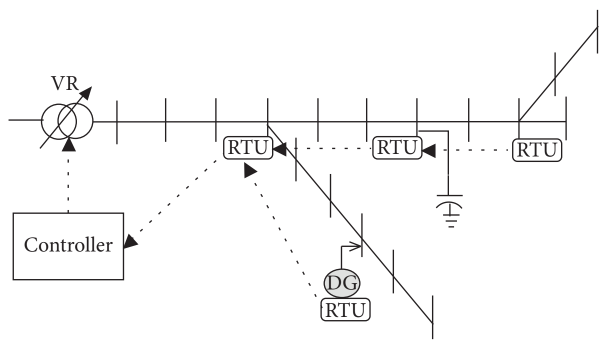

Figure 3: RTU's system architecture.

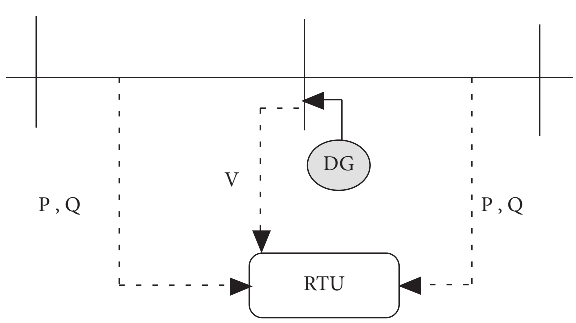

Figure 4: Details of RTU measurements.

value. RTU_{n+1} sends the information of min and max voltage value to upstream RTU_n. As soon as these data are received, RTU_n checks to see if the voltage at its own node exceeds the value obtained from the downstream RTU_{n+1} and accordingly updates the maximum voltage value. For more accurate estimation, RTU_n calculates the minimum voltage and then averages that value. Each RTU along the way records the feeder's maximum and minimum voltage values. As a result, control station will receive the maximum and minimum voltage values of the system. According to Homaee et al. [12], the RTU algorithm's flowchart is depicted in Figure 5.

5. Direct Voltage Sensitivity Analysis

Voltage sensitivity theory in high-voltage networks is based on the Jacobian matrix's inverse [24–26]. It is possible to represent the Jacobian matrix as a function of nodal phasor voltages by

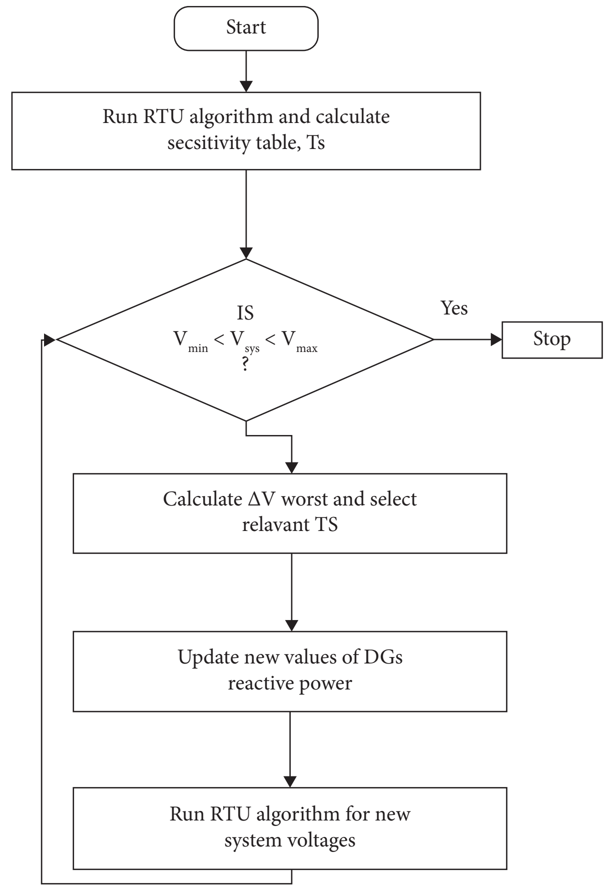

Figure 5: Flowchart of the RTU algorithm.

$$\begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} = J^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}. \quad (12)$$

There are several differences between MV and LV networks when it comes to the voltage sensitivity coefficients obtained from the inverse Jacobian matrix, which are not constant depending on the network production or loading conditions. The complexity of the calculations is exacerbated by the wide range of coefficients that can be used, and updating the data is a laborious process. Classical methods are difficult and time-consuming to implement in a large-scale distribution infrastructure. Phase angle values in radial distribution systems are not very crucial considering that our goal is to keep voltage magnitude within acceptable limits. A direct voltage sensitivity analysis is employed to solve this problem. A node voltage at any bus can be approximated by

$$V_i = V_1 - \frac{1}{V_{\mathrm{nom}}} \left(\sum_{j=1}^{N} R_{ij}.P_j + \sum_{j=1}^{N} X_{ij}.Q_j \right). \quad (13)$$

Power injected into node I and power injected into other nodes in the network affect the voltage at node I.

$$V_i = V_i\left(P_1, P_2, \ldots, P_n, Q_1, Q_2, \ldots, Q_n\right). \quad (14)$$

The total differential of function V_i is given by

$$dV_i = \sum_{j=1}^{N} \frac{\partial V_i}{\partial P_j} . dP_j + \sum_{j=1}^{N} \frac{\partial V_i}{\partial Q_j} . dQ_j. \tag{15}$$

From equation (15), voltage sensitivity coefficients are

$$\frac{dV_i}{dP_j} = -\frac{1}{V_{\text{nom}}} . R_{ij}, \tag{16}$$

$$\frac{dV_i}{dQ_j} = -\frac{1}{V_{\text{nom}}} . X_{ij}. \tag{17}$$

Voltage sensitivity coefficients for nodal active and reactive infusions are represented by derivates (16) and (17). Expression (15) can be expressed in matrix form by considering the n equations.

$$\begin{bmatrix} dV_1 \\ \vdots \\ dV_n \end{bmatrix} = \begin{bmatrix} \frac{\partial V_1}{\partial P_1} & \cdots & \frac{\partial V_1}{\partial P\, n} & \frac{\partial V_1}{\partial Q_1} & \cdots & \frac{\partial V_1}{\partial Q_n} \\ \vdots & \cdots & \vdots & \vdots & \cdots & \vdots \\ \frac{\partial V_n}{\partial P_1} & \cdots & \frac{\partial V_n}{\partial P_n} & \frac{\partial V_n}{\partial Q_1} & \cdots & \frac{\partial V_n}{\partial Q_n} \end{bmatrix} . \begin{bmatrix} dP_1 \\ \vdots \\ dP_n \\ dQ_1 \\ \vdots \\ dQ_n \end{bmatrix}. \tag{18}$$

Only reactive power variations are taken into account in this treatment to control the voltages at the nodes. Reactive power injections are given by equation (18).

$$\begin{bmatrix} dV_1 \\ \vdots \\ dV_n \end{bmatrix} = \begin{bmatrix} \frac{\partial V_1}{\partial Q_1} & \frac{\partial V_1}{\partial Q_2} & \cdots & \frac{\partial V_1}{\partial Q_n} \\ \vdots & \vdots & \cdots & \vdots \\ \frac{\partial V_n}{\partial Q_1} & \frac{\partial V_n}{\partial Q_2} & \cdots & \frac{\partial V_n}{\partial Q_n} \end{bmatrix} . \begin{bmatrix} dQ_1 \\ \vdots \\ dQ_n \end{bmatrix}. \tag{19}$$

The above equation can be written in simple form given by

$$[\Delta V] = [S_Q].[\Delta Q], \tag{20}$$

where $[\Delta V]$ is the nodal voltage vector, $[\Delta Q]$ is the reactive power variation vector, and $[S_Q]$ is the reactive sensitivity matrix.

6. Selection of a DG for Reactive Power

The selection of an individual DG system for reactive power support in multiple DG system environment depends on its influence on node i. In order to regulate voltage, the DG system which has the highest sensitivity value with respect to node i will be selected. Thus, analyzing (20), we choose the DG which has maximum "sensitivity product" given by

$$\frac{\partial V_i}{\partial Q_j} . \Delta Q_j. \tag{21}$$

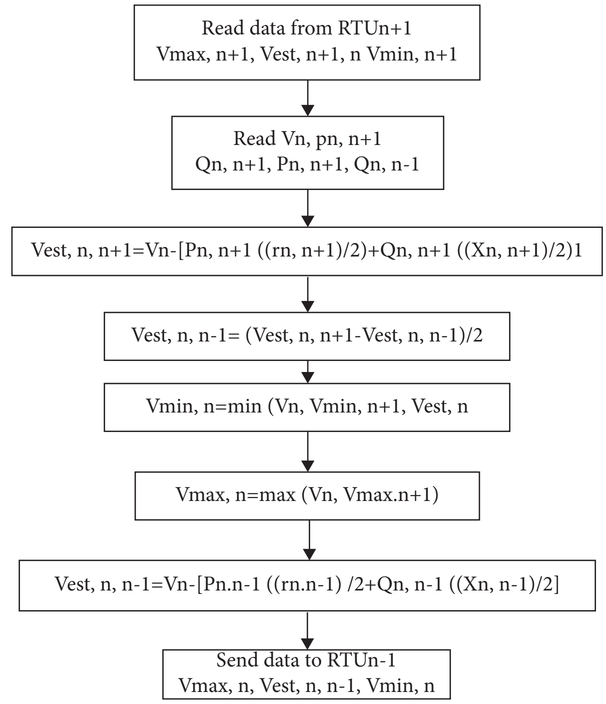

Figure 6: Flowchart of the developed algorithm.

According to equation (22),

$$[T_s] = [S_Q].[\Delta Q]. \tag{22}$$

Figure 6 shows the flowchart of the developed algorithm for DG system reactive power support.

Voltage sensitivity matrix and reactive power capability for each DG system are presumed to have been developed and are readily available in the controller. Lookup tables are used by the controller to select the most sensitive DG system. The on-load tap changing transformer will be utilized for voltage regulation process, if the reactive power contribution from the DGs is insufficient to bring voltage levels within acceptable limits. The voltage regulator will use the equation in [12] to determine the optimal tap position, where *Step* is the step-change value of voltage regulator. $V_{\text{max, feeder}}$ and $V_{\text{min, feeder}}$ are maximum and minimum voltages of the feeders. Tap_{old} and Tap_{new} represent initial tap and new tap positions, respectively.

$$\text{Tap}_{\text{new}} = \text{Tap}_{\text{old}} + \left[\frac{\left(1 + \left(V_{\text{max,feeders}} - V_{\text{min,feeders}}/2\right)\right) - V_{\text{max,feeders}}}{Step} \right]. \tag{23}$$

7. Simulation Results

In this section, several simulation results will be reported to validate the presented voltage regulation scheme. Figure 7 shows the IEEE 69-bus radial distribution system

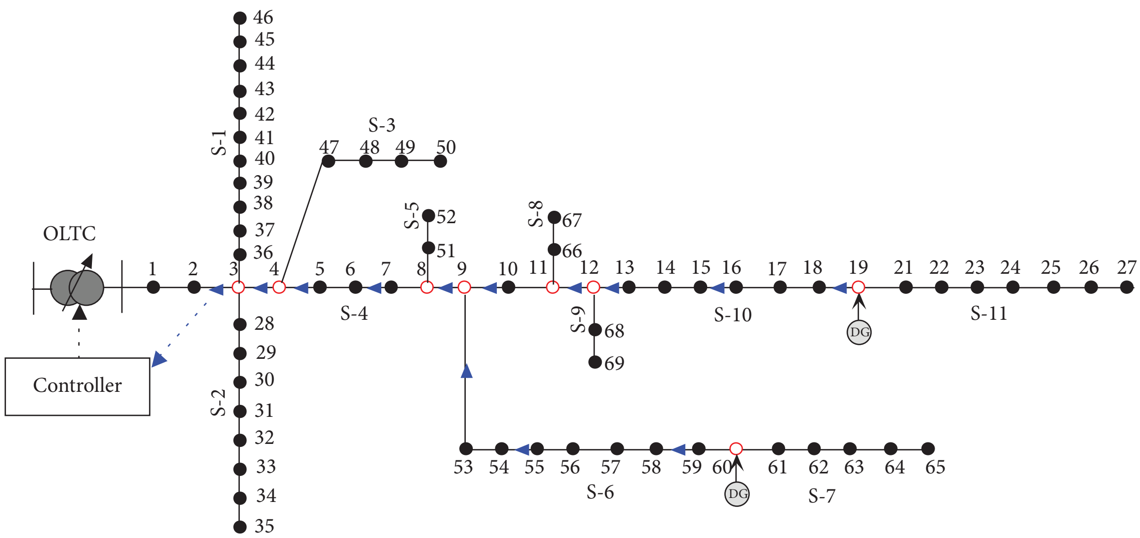

Figure 7: IEEE 69-bus radial distribution system with DG systems.

with 12.66 kV which is used to validate the presented method. Detailed line and load data for the system considered are provided in [27, 28]. In this research, active power control of DG is not taken into consideration. Two generators of capacity 2 MW and 1 MW both operating at 0.9 power factor are connected at nodes 19 and 60, respectively. For all the case studies, red colored circles indicate RTU connected buses and VP stands for voltage profile in figures. For comparison purpose, the system is divided into different sections ($S-1$, $S-2$, . . .) as shown in Figure 7. The transformer secondary voltage value is initially set at 1.04375 per unit. The following constraints are considered in the case study presented in this paper [29, 30].

Allowable maximum voltage = 1.05 p.u.

Allowable minimum voltage = 0.95 p.u.

The number of taps = 32.

Step change/tap ratio = 0.00625 p.u.

The IEEE 69-bus system has seven laterals originating at six different node points along with main feeders. Hence, in order to estimate voltage profile of the system, at least 6 six RTUs are connected at lateral originating node points (RTUs at nodes 3, 4, 8, 9, 11, and 12) along with two RTUs at DG connected nodes (RTUs at nodes 19 and 60). Table 1 gives the voltage profile of the system based on load flow solution and readings of RTUs. It is clear that voltage values estimated by RTUs are comparable with the forward/backward sweep load flow method. Figure 8 shows the voltage profile obtained from the load flow and RTU method.

It is clear from Figure 8 that voltage profile of the system is not acceptable because the maximum voltage value is 1.0871 p.u. at bus 19, against allowable maximum voltage of 1.05 p.u. in the system. Hence, voltage regulation has to be carried out to maintain voltage profile within the limits. Table 2 provides the case study

Table 1: Comparison of voltage profile based on load flow solution and RTU method.

Sections	Backward/forward load flow method [29–31]		RTU method	
	V_{max}	V_{min}	V_{max}	V_{min}
$S-1$	1.0436	1.0422	1.0436	1.0421
$S-2$	1.0436	1.0427	1.0436	1.0419
$S-3$	1.0436	1.0382	1.0436	1.0402
$S-4$	1.0436	1.0396	1.0436	1.0413
$S-5$	1.0392	1.0392	1.0392	1.0392
$S-6$	1.0390	1.0134	1.0390	1.0189
$S-7$	1.0112	1.0016	1.0112	0.9983
$S-8$	1.0450	1.0449	1.0450	1.0449
$S-9$	1.0502	1.0499	1.0502	1.0501
$S-10$	1.0837	1.0502	1.0502	1.0668
$S-11$	1.0871	1.0859	1.0871	1.0855
Global values	1.0871	1.0016	1.0871	0.9983

parameters. DG_1 and DG_2 are capable of supplying 968 kVAr and 484 kVAr of reactive power, respectively. Table 2 shows that DG_1 has the highest sensitivity factor for reactive power changes at bus 19 compared to DG_2, so it is chosen to regulate the voltages. As capacity of DG_1 alone is not sufficient to address the voltage regulation issue at bus 19, the next generator candidate, DG_2, is called upon to help. When both generators' reactive power contributions are insufficient to regulate the voltages, an on-load tap changing transformer is utilized in the voltage regulation process. Based on the presented voltage regulation technique, on-load tap changing transformer will change the tap setting from 7 to 3 and settle at new value 1.0187 per unit to correct the voltage profile of the system [31, 32].

Figure 9 shows the voltage regulation by DG systems and on-load tap changing transformer. It can be seen from the figure that coordinated operation of DGs and on-load tap

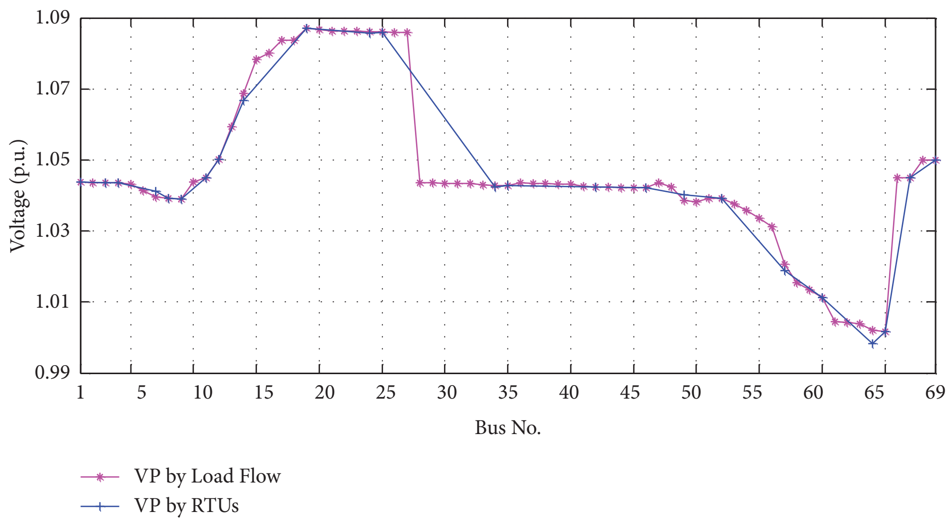

Figure 8: Voltage profile generated from load flow load flow versus RTU method.

Table 2: Parameters for case study.

V_{worst} (before) in p.u.	1.0871		1.072	
T_s (sensitivity table)	$T_{19,19}$ 182	$T_{19,60}$ 37	$T_{19,19}$ 0	$T_{19,60}$ 37
Q_{DG-1}	+968 kVAr		+968 kVAr	
Q_{DG-2}	0		+484 kVAr	
ΔV in p.u.	−0.0151		+0.0011	
T/F step	7		7	
V_{worst} (after) in p.u.	1.072		1.0709	
T/F step (after)	—		3	
ΔV in p.u.	—		+0.025	
V_{worst} (after T/F step) in p.u.	—		1.0459	

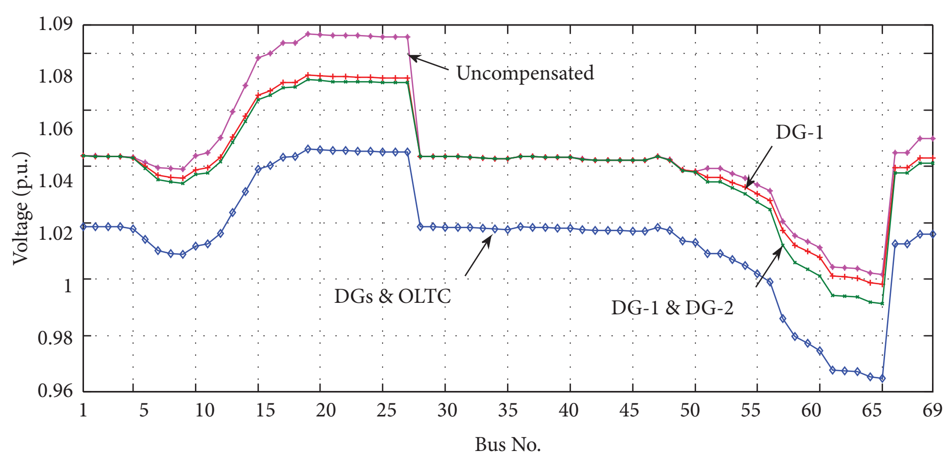

Figure 9: Regulation of voltage by DG reactive power support and on-load tap changing transformer.

changing transformer effectively regulate system voltages within the tolerance limit.

8. Conclusions

In this work, real-time sensor-based online voltage profile estimation and coordinated Volt/VAR control are developed to address voltage rise issue. An algorithm is developed using real-time sensor RTU to estimate voltage profile of the system. The estimated voltage values are comparable with load flow values. Coordinated Volt/VAR control using DG systems along with on-load tap changing transformer is presented. A direct sensitivity method is developed for selecting a generator in multiple DG environments. On-load tap changing transformer is utilized in control process when DG's reactive power support is not enough to solve voltage problems. The IEEE 69-bus radial system is considered for the case study. Simulation results show that coordinated operation of DGs and on-load tap changing transformer effectively regulate system voltages within the tolerance limit.

Data Availability

The data used to support the findings of this study are available from the corresponding authors upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] P. P. Barker and R. W. De Mello, "Determining the impact of distributed generation on power systems: Part 1 - radial distribution systems," *Power Engineering Society Summer Meeting*, vol. 3, pp. 1645–1656, 2000.

[2] T. Ackermann and V. Knyazkin, "Interaction between distributed generation and the distribution network: operation aspects," *IEEE/PES Transmission and Distribution Conference and Exhibition*, vol. 2, pp. 1357–1362, 2002.

[3] C. L. Masters, "Voltage rise: the big issue when connecting embedded generation to long 11 kV overhead lines," *Power Engineering Journal*, vol. 16, no. 1, pp. 5–12, Feb. 2002.

[4] R. F. Arritt and R. C. Dugan, "Distribution system Analysis and the future smart grid," *IEEE Transactions on Industry Applications*, vol. 47, no. 6, pp. 2343–2350, 2011.

[5] F. Shariatzadeh, S. Chanda, A. K. Srivastava, and A. Bose, "Real-time benefit analysis and industrial implementation for distribution system Automation and control," *IEEE Transactions on Industry Applications*, vol. 52, no. 1, pp. 444–454, 2016.

[6] C. J. Mozina, "Impact of smart grids and green power generation on distribution systems," *IEEE Transactions on Industry Applications*, vol. 49, no. 3, pp. 1079–1090, May 2013.

[7] D. T. Chessmore, W. E. Muston, W. Muston, T. Anthony, F. Daniel, and L. Kohrmann, "Voltage-profile estimation and control of a distribution feeder," *IEEE Transactions on Industry Applications*, vol. 45, no. 4, pp. 1467–1474, Jul, 2009.

[8] A. Shinypradeepa and C. Vaithilingam, "Voltage profile Assessment in power distribution system using generalized regression neutral networks," in *Proceedings of the International Conference on Power Engineering, Computing and Control (PECCON)*, pp. 209–215, Energy Procedia, United Kingdom UK, June 2017.

[9] P. Raghavendra and D. N. Gaonkar, "Online voltage estimation and control for smart distribution networks," *J. Mod. Power Syst. Clean Energy*, vol. 4, no. 1, pp. 40–46, Jan. 2016.

[10] P. Raghavendra and D. N. Gaonkar, "Voltage Estimation in Smart Distribution Networks with Multiple DG Systems," in *Proceedings of the Annual IEEE India Conference (INDICON)*, pp. 1–6, New Delhi, India, December 2015.

[11] M. E. Elkhatib, R. El-Shatshat, and M. M. A. Salama, "Novel coordinated voltage control for smart distribution networks with DG," *IEEE Transactions on Smart Grid*, vol. 2, no. 4, pp. 598–605, Dec. 2011.

[12] O. Homaee, A. Zakariazadeh, and S. Jadid, "Online voltage control approach in smart distribution system with renewable distributed generation," in *Proceedings of the 2nd Iranian Conference Smart Grids*, pp. 1–6, ICSG), Tehran, Iran, May 2012.

[13] F. A. Viawan and D. Karlsson, "Coordinated voltage and reactive power control in the presence of distributed generation," in *Proceedings of the IEEE Power and Energy Society General Meeting— Conversion and Delivery of Electrical Energy in the 21st Century*, pp. 1–6, Pittsburgh, PA, July 2008.

[14] T. Senjyu, Y. Miyazato, A. Yona, N. Urasaki, and T. Funabashi, "Optimal distribution voltage control and coordination with distributed generation," *IEEE Transactions on Power Delivery*, vol. 23, no. 2, pp. 1236–1242, 2008.

[15] S. Deshmukh, B. Natarajan, and A. Pahwa, "Voltage/VAR control in distribution networks via reactive power injection through distributed generators," *IEEE Transactions on Smart Grid*, vol. 3, no. 3, pp. 1226–1234, Sep, 2012.

[16] D. Ranamuka, A. P. Agalgaonkar, and K. M. Muttaqi, "Examining the interactions between DG units and voltage regulating devices for effective voltage control in distribution systems," *IEEE Transactions on Industry Applications*, no. 1–1, 2016.

[17] P. Raghavendra and D. N. Gaonkar, "Online Volt/VAR control in a smart grid with multiple DG systems," *7th IEEE Power India International Conference (PIICON)*, pp. 1–6, 2016.

[18] X. Hu, Z.-W. Liu, G. Wen, X. Yu, and C. Liu, "Voltage control for distribution networks via coordinated regulation of active and reactive power of DGs," *IEEE Transactions on Smart Grid*, vol. 11, no. 5, pp. 4017–4031, Sept. 2020.

[19] A. Newaz, J. Ospina, and M. O. Faruque, "Coordinated Voltage Control in Distribution Systems with Distributed Generations," *IEEE Power & Energy Society General Meeting (PESGM)*, pp. 1–5, 2019.

[20] Y. Guo, Q. Wu, H. Gao, X. Chen, J. Ostergaard, and H. Xin, "MPC-based coordinated voltage regulation for distribution networks with distributed generation and energy storage system," *IEEE Transactions on Sustainable Energy*, vol. 10, no. 4, pp. 1731–1739, Oct, 2019.

[21] S. Mahdavi and A. Dimitrovski, "Coordinated Voltage Regulator Control in Systems with High-Level Penetration of Distributed Energy Resources," in *Proceedings of the North American Power Symposium (NAPS)*, pp. 1–6, Wichita, KS, USA, October 2019.

[22] S. M. Mohiuddin and J. Qi, "Optimal distributed control of AC microgrids with coordinated voltage regulation and reactive power sharing," *IEEE Transactions on Smart Grid*, vol. 13, no. 3, pp. 1789–1800, May 2022.

[23] A. Newaz, J. Ospina, and M. O. Faruque, "Controller hardware-in-the-loop validation of coordinated voltage control scheme for distribution systems containing inverter-based distributed generation," *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*, vol. 3, no. 2, pp. 332–341, April 2022.

[24] M. Brenna, E. De Berardinis, L. Delli Carpini et al., "Automatic distributed voltage control algorithm in smart grids applications," *IEEE Transactions on Smart Grid*, vol. 4, no. 2, pp. 877–885, Jun. 2013.

[25] B. Bakhshideh Zad, H. Hasanvand, J. Lobry, and F. Vallée, "Optimal reactive power control of DGs for voltage regulation of MV distribution systems using sensitivity analysis method and PSO algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 68, pp. 52–60, 2015.

[26] M. Brenna, E. D. Berardinis, F. Foiadelli, G. Sapienza, and D. Zaninelli, "Voltage control in smart grids: an approach

based on sensitivity theory," *Journal of Electromagnetic Analysis and Applications*, vol. 02, no. 08, pp. 467–474, 2010.

[27] H. Abdellatif and Z. Khaled, "Efficient load flow method for radial distribution feeders," *Journal of Applied Sciences*, vol. 6, no. 13, pp. 2741–2748, 2006.

[28] C. Yammani, S. Maheswarapu, and S. Matam, "Enhancement of voltage profile and loss minimization in Distribution Systems using optimal placement and sizing of power system modeled DGs," *J. Electrical Systems*, vol. 7, no. 4, pp. 448–457, 2011.

[29] D. Shirmohammadi, H. W. Hong, A. Semlyen, and G. X. Luo, "A compensation-based power flow method for weakly meshed distribution and transmission networks," *IEEE Transactions on Power Systems*, vol. 3, no. 2, pp. 753–762, May 1988.

[30] G. W. Chang, S. Y. Chu, and H. L. Wang, "An improved backward/forward sweep load flow algorithm for radial distribution systems," *IEEE Transactions on Power Systems*, vol. 22, no. 2, pp. 882–884, May 2007.

[31] A. Augugliaro, L. Dusonchet, S. Favuzza, M. G. Ippolito, and E. Riva Sanseverino, "A new backward/forward method for solving radial distribution networks with PV nodes," *Electric Power Systems Research*, vol. 78, no. 3, pp. 330–336, Mar. 2008.

[32] Z. Tang, D. J. Hill, and T. Liu, "Distributed coordinated reactive power control for VoltageRegulation in distribution networks," *IEEE Transactions on Smart Grid*, vol. 12, no. 1, pp. 312–323, Jan. 2021.