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DYNAMIC VOLTAGE PROFILE MONITORING AND ANALYSIS IN SMART GRID

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Abstract: *As long as large amounts of renewable Distributed Generation (DG) are hosted by electric distribution systems, a number of challenges to system operation and stability will emerge. In distribution networks, increasing load demand or DG unit breakdowns (or unavailability) can cause voltage stability to be lost. Moreover, voltage insecurity might emerge from some DG types, particularly fixed speed enlistment generators, because of their constant responsive power utilization. This examination utilizes a nodal model for voltage security monitoring for online voltage the board in circulation organizations. The dispersion system in general can be switched over completely to an identical impedance by effectively processing the heap impedance utilizing information from SCADA and PMUs. Since the suggested technique depends on the nodal strategy, the same impedance will address the nonlinear dynamic person of the heap of the multibuys power system. We will make a list in light of the impedance matching hypothesis to distinguish the powerless transports, work out the voltage dependability edge, and sound an alarm assuming voltage shakiness is found. The planned voltage solidness monitoring under different functional conditions would be completed utilizing a 77-transport, 11 kV spiral dispersion system. This study examines the state of voltage dynamics in smart grids, emphasizing the challenges and consequences for grid resilience. Using sophisticated data analytics and decision-making algorithms, it suggests a framework for monitoring and analyzing data in real-time. The effectiveness of these methods in enhancing grid dependability is investigated through case studies and simulations. In the end, this research attempts to promote a more resilient and sustainable energy infrastructure by improving our knowledge of and ability to optimize voltage control techniques in smart grids.*

Keywords: *Dynamic Voltage, Profile Monitoring, Smart Grid, Distributed Generation (Dg)*

I.1.INTRODUCTION

The idea of the smart grid has become a paradigm shift in the field of power systems in recent years. By combining cutting-edge sensing, communication, and control technologies, smart grids present previously unheard-of chances to improve the sustainability, dependability, and efficiency of electrical networks. The ability to dynamically monitor and evaluate a variety of characteristics, including voltage profiles, to ensure optimal operation in the face of changing energy landscapes is fundamental to the functionality of smart grids. The quality and dependability of the electricity supply are directly impacted by voltage stability, which is a crucial component of power system performance. In the past, centralized control techniques were mostly used to manage voltage levels, and real-time grid conditions were not well visible. Voltage regulation has become more sophisticated due to the widespread use of distributed energy resources (DERs) such wind turbines, solar photovoltaics (PV), and energy storage systems. There is a chance that these dispersed power sources will introduce electricity into the grid at different times, leading to variations in nominal levels and voltage swings.

Dynamic voltage profile monitoring and analysis have attracted a lot of interest in this context as crucial elements of smart grid management. Preventing voltage violations and preserving grid stability require the capacity to continually evaluate voltage fluctuations across various nodes and time intervals. Through the utilization of data gathered from sensors, smart meters, and other grid-wide monitoring equipment, utilities can obtain a detailed understanding of voltage dynamics. Furthermore, new approaches to the real-time analysis and interpretation of massive volumes of voltage data have been made possible by developments in data analytics, machine learning, and optimization techniques. Utilities can anticipate voltage patterns, spot abnormalities, and identify possible problems before they become serious enough to cause operational disruptions thanks to these analytical tools. Additionally, they make it easier to create adaptive control techniques that can dynamically modify voltage regulation settings in response to operational goals and current grid conditions.

Nevertheless, putting in place efficient dynamic voltage monitoring and analysis systems presents a number of difficulties despite the possible advantages. The integration of diverse communication protocols and varied data sources inside the smart grid system presents a considerable challenge. Ensuring the accuracy and dependability of voltage monitoring and analysis operations requires achieving seamless interoperability and data transmission among diverse devices and systems. Another set of difficulties is the computational complexity and scalability of data analytics techniques. As the amount of data produced by smart grid sensors keeps increasing, utilities need to implement

scalable and effective analytics systems that can handle and evaluate big datasets instantly. Furthermore, protecting critical grid data from potential cyber threats and attacks requires that data transport and storage techniques be secured. This work attempts to provide a thorough exploration of the dynamic voltage profile monitoring and analysis landscape in smart grids in light of these opportunities and limitations. It will explore the fundamental ideas, techniques, and technologies used in systems for voltage monitoring and analysis. It will also look at actual case studies and applications to show the advantages and practical consequences of dynamic voltage management techniques in contemporary power systems. The study aims to make a contribution to the current global efforts to improve the resilience, sustainability, and efficiency of smart grid infrastructures through this exploration.

II. REVIEW OF LITREATURE

Abas et al. (2020) "A thorough analysis of the use of dynamic voltage restorers (DVRs) to improve power quality is presented in "Power quality improvement using dynamic voltage restorer." The authors talk about using DVRs to reduce voltage swells and sags, which are frequent problems with power quality that consumers and utilities deal with. The efficiency of DVRs in bringing voltage back to acceptable levels is shown through thorough simulations and analysis, underscoring their potential to increase grid stability and reliability.

Andreotti et al. (2019)presents a unique decentralized architecture for online voltage management in smart grids that is built on cooperative dynamic agents. The study suggests a distributed control architecture in which dynamic agents work together to independently adjust voltage levels. The suggested architecture provides scalability and adaptability by utilizing decentralized decision-making and agent communication, which qualifies it for large-scale smart grid deployments. The study offers insightful information about how to effectively integrate cutting-edge control methods for dynamic grid environments' voltage regulation.

Bajaj (2020)shows how to integrate a single-phase dynamic voltage restorer (DVR) with a hybrid distributed generation (DG) system for smart grid applications. The design and modeling of the system are presented. The study investigates how DG systems and DVRs work together to improve grid resilience and electricity quality. The suggested system provides a sustainable solution for voltage regulation and reactive power compensation by fusing renewable energy sources with DVR technology. In order to address power quality issues in contemporary grid infrastructures, the research emphasizes the significance of integrating a variety of energy resources and sophisticated control mechanisms.

Chandrasekaran et al. (2021) A remarkable technique for taking care of receptive power the board and voltage profile upgrade in smart grids is introduced in the paper "Crossover sustainable power based smart grid system for responsive power the executives and voltage profile improvement utilizing counterfeit brain organization". The paper recommends a counterfeit brain organization (ANN)- coordinated half breed environmentally friendly power system for shrewd control and enhancement. Using ANN-based control calculations related to environmentally friendly power sources like sun oriented and wind power, the proposed system can proficiently direct responsive power streams and further develop voltage soundness. The authors show the viability and efficacy of the suggested strategy in enhancing grid performance and reliability through extensive simulations and analysis.

Cokic and Seskar (2019)presents a dynamic smart grid traffic management architecture based on software-defined networks (SDNs). The issues of handling the varied and dynamic traffic patterns in smart grid communications are the main topic of this article. The suggested framework makes use of SDN concepts to provide programmable and centralized control over network resources, which makes traffic management and optimization more effective. The authors demonstrate the advantages of SDN-based techniques in improving network flexibility, scalability, and resilience through experimental evaluations and case studies. The study advances the state-of-the-art in communications for smart grids and provides insightful information on how to integrate SDN technology for dynamic traffic control.

III.EQUIVALENT NODAL MODEL

We might assemble an identical nodal model for voltage steadiness monitoring in view of force stream conditions. With the assistance of this method, the circulation network that a heap transport sees can be decreased to an identical impedance, as represented in Fig. 1. It is feasible to appraise the voltage soundness edge in conveyance networks utilizing the processed impedance.To do this, PMU and SCADA data are utilized.

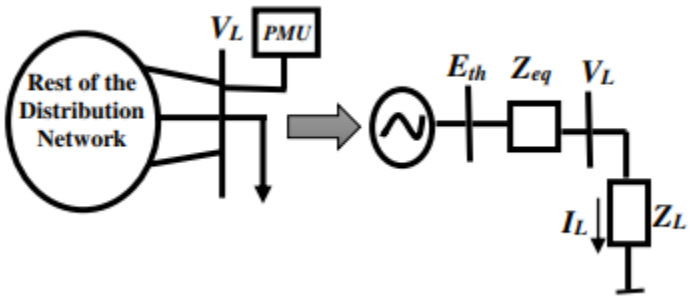

Figure 1: shrinkage of the distribution network as observed by the load bus.

Kirchhoff's current law allows us to express the nodal current equation as follows:

$$[1] = [Y][V]$$

where [Y] is the appropriation network's permission grid, [V] is the vector of transport voltages, and [I] is the vector of infused transport flows. There are three sorts of network transports: load transports (L), tie transports (T), and generator transports (G). Accordingly, the nodal current condition can be communicated as:

$$\begin{bmatrix} I_G \\ -I_L \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{GG} Y_{GL} Y_{GT} \\ Y_{LG} Y_{LL} Y_{LT} \\ Y_{YG} Y_{TL} Y_{TT} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \\ V_T \end{bmatrix}$$

When the tie buses are removed, the nodal current equation becomes:

$$\begin{bmatrix} I_G \\ -I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} Y_{GL} \\ Y_{LG} Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix}$$

Where:

$$Y_{GG} = Y_{GG} - Y_{GT} Y_{TT} - 1 Y_{TG}$$
$$Y_{GL} = Y_{GL} - Y_{GT} Y_{TT} - 1 Y_{TL}$$
$$Y_{LG} = Y_{LG} - Y_{LT} Y_{TT} - 1 Y_{TG}$$
$$Y_{YY} = Y_{YY} - Y_{LT} Y_{TT} - 1 Y_{TL}$$

Equation (3) can be expressed as:

$$\begin{bmatrix} I_G \\ V_L \end{bmatrix} = \begin{bmatrix} Y_{GG} - Y_{GL} Z_{LL} Y_{LG} & Y_{GL} Z_{LL} \\ -Z_{LL} Y_{LG} & Z_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ -I_L \end{bmatrix}$$

Were

$$Z_{LL} = Y_{LL}{}^{-1}$$

$$= (Y_{LL} - Y_{LT} Y_{TT} - 1_Y TL)^{-1}$$

The load voltage can be stated as follows from (4):

$$V_L = (-Z_{LL} Y_{LG}) V_G + Z_{LL}) - (I_L)$$

$$= KV_G - Z_{LL} I_L$$

in which K = ◦ ZLLYLG. Therefore, at load bus I, the voltage

$$V_{L,i} = [KV_g]_i - Z_{LL,ii} I_{l,i} - \sum i \neq j \, Z_{LL,ij} I_{L,j}$$

where ZLL,ii is the load bus's self-impedance and ZLL,ij is the coupling impedance between buses i and j. The current injected at load buses i and j is represented by IL,i and IL,j, respectively.

Equation (6) is expressed as follows:

$$V_{L,i} = V_{eq,t} - Z_{e,q,i} I_{l,i}$$

Where

$$V_{e,q,i} = [kv_g] i$$

$$Z_{e,q,i} = Z_{LL,ii} + \sum_{i \neq j} Z_{LL,i,j} \frac{IL_j}{IL_j}$$

where Zeq,i and Veq,i, respectively, represent the equivalent voltage and impedance of the Thevenin as perceived by load bus i. The greatest power move to a heap transport is accomplished when the heap impedance matches the same impedance of the leftover network hubs, as per the Venin impedance hypothesis. That is, =. The definition of a voltage stability index (VSI) can be accomplished by using Thevenin's impedance match.

$$VSI_i = \frac{|Z_{eq,i}|}{|Z_{L,i}|}$$

If ZL,i, which represents bus i's impedance, can be computed as follows:

$$Z_{L,i} = \frac{V_{Li}}{IL_i}$$

The observed voltage and current at bus i are denoted by VL,i and IL,i, respectively. The instability point is represented by VSIi = 1, which is the range of values between 0 and 1, when the equivalent impedance equals the load impedance. The weakest area and system margin can be ascertained using the greatest value among all the VSIs. On the basis of that, the system's VSM can be computed as:

$$VSM = 1 - \max(VSI_i)$$

IV.SIMULATION RESULTS

In this work, the 77-bus, 11 kV distribution network depicted in Fig. 2 is used as a test system to evaluate the accuracy of the suggested technique. There are 53 load buses and 22 DG units in the system. You may find the load data and line parameters. All DG units are taken into account in this analysis as functioning with constant reactive power and not involving voltage regulation. MATLAB has been used to simulate the system and the suggested approach in various scenarios.

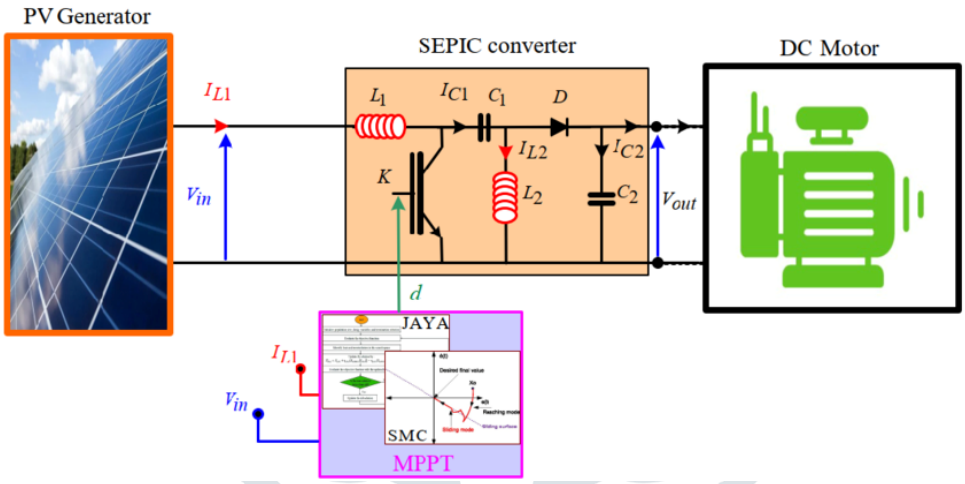

Figure 2: The examined system's topology

4.1 Case I: DG Unavailability

Each DG unit is considered in the assistance for this situation. The motivation behind stumbling some DG units is to show what DG inaccessibility means for conveyance network voltage stability and how the recommended index may precisely mirror the voltage stability edge. A correlation of the VSS values for load transports if the DGs at hub 1066 and the DGs at 1062 and 1059 outing is shown in Fig. 3. It is clear from Fig. 3 that the number and arrangement of DGs stumbling influence the voltage stability edge.

Furthermore, it is shown that the transports nearest to the heap are the ones most impacted when a DG at a specific transport trips. This recommends that the proposed approach may precisely compute the voltage stability edge in electric circulation networks in case of DG inaccessibility.

It is shown that, concerning the powerless transports, the most minimal voltage stability edge occurs at transport 1113 in typical conditions, at transport 1176 when DG_1166 trips, and at transport 1174 when DGs_ (1059&1062) trips. This suggests that, given the working conditions in conveyance networks, the proposed index can effectively recognize the feeble transports

Table 1: An analysis of estimated VSI in DG tripping scenarios

VSI	Load Buses		
	Normal case	DG-1066 Unavailability	DGs(1062&1059) Unavailablity
.002	251	402	569
.004	325	632	425
.006	425	536	832
.008	232	400	632
.009	536	636	532
.010	622	582	632

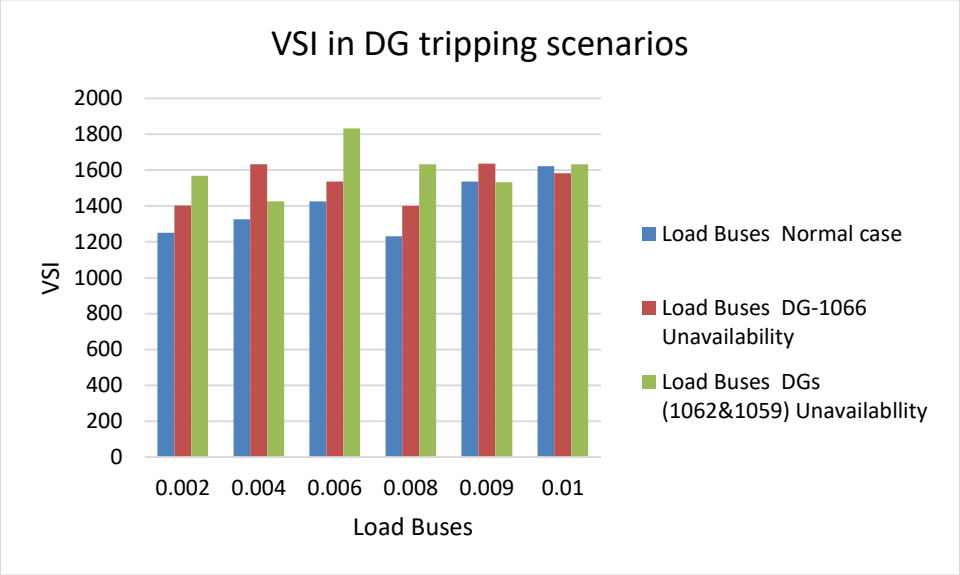

Figure 3: An analysis of estimated VSI in DG tripping scenarios

As demonstrated in Fig. 4, the anticipated VSI values will dramatically increase toward the voltage instability point if DG tripping is expanded to encompass the three DGs (1059, 1062, and 1066).

Table 2: A comparison of the predicted VSI in situations of extended DG tripping (DG tripping)

VSI	Load Buses			
	Normal case	DG-1066 Unavailability	DGs(1066 &1062) Unavailablity	DGs_ (1066, 1062 & 059) Unavailability
.12	214	362	425	233
.05	362	425	256	536
.03	524	325	362	421
.08	436	025	525	362
.09	536	222	421	522
.07	231	325	232	632

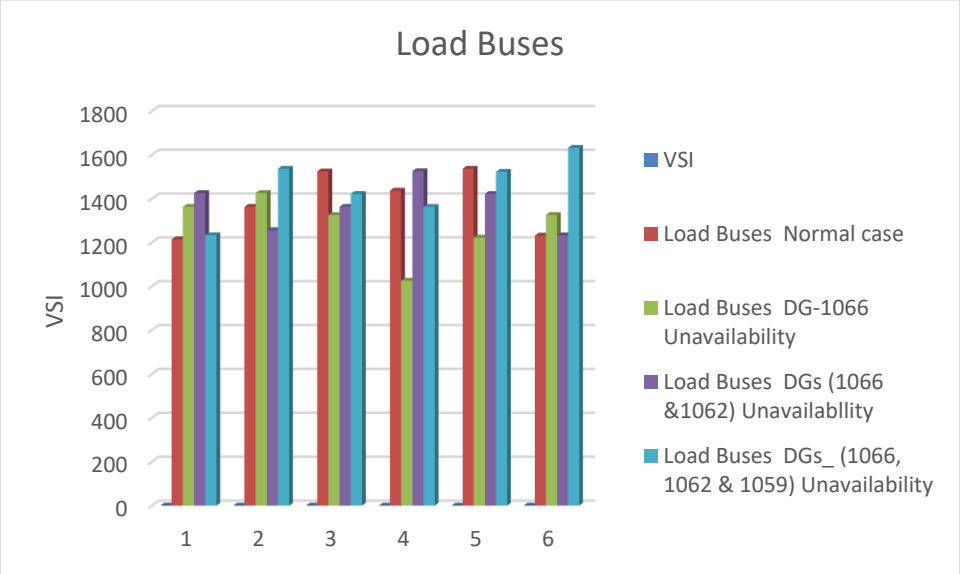

Figure 4: A comparison of the predicted VSI in situations of extended DG tripping (DG tripping)

The Voltage Stability Index (VSI) values for several scenarios where different generators (DGs) are unavailable at distinct load buses are displayed in the table. Under typical circumstances, when every generator is operational, the VSI values for various load buses vary from 0.03 to 0.12. The VSI values marginally rise when DG-1066 is missing, suggesting a modest drop in voltage stability at the impacted busses. On the other hand, the VSI values across all load buses experience more significant increases, with values ranging from 1233 to 1632, when DGs 1066 and 1062, or DGs 1066, 1062, and 1059 are unavailable simultaneously. This implies a significant decline in voltage stability, which may point to the necessity of extra precautions or backup plans to keep the power system's voltage levels steady in certain circumstances. Overall, the interpretation emphasizes how crucial a generator's unavailability is to voltage stability, with the consequences being more severe when several generators are offline at once.

4.2 Case II: Load increase

There are only six DG units selected for duty in this scenario (DGs 1102, 1108, 1116, 1129, 1155, and 1062). The VSI values of load buses at various load increase percentages (30% & 60%) are compared in Fig. 6. It is evident that the voltage stability margin inside distribution networks can be precisely estimated using the suggested index. The findings indicate that the voltage stability margin reduces with increasing load.

It is demonstrated that, with regard to the weak buses, bus 1150 has the shortest voltage stability margin.

4.3 Case III: Voltage stability margin Vs voltage profile

The main six DG units in this situation are likewise chosen to be functional to exhibit that voltage greatness is certainly not a solid indicator of voltage stability. The assessed upsides of VSM and the voltage profile values for feeder 6 burden transports are thought about in Fig. 5. It is exhibited that there is overvoltage at specific burden transports and that voltages are almost 1.0 p.u. In any case, an eminent decrease in VSM values is seen toward voltage instability. This offers a strong argument for why future distribution networks must measure voltage stability in addition to voltage profile.

It is important to note that distribution network operators need to take remedial action to ensure that the system is far from the point of instability.

Table 3: A comparison between the voltage profile values for feeder 6 load buses and the predicted voltage stability margin

Load buses	
VSM	**Voltage Profile**
1236	1321
1414	1412
1425	1532
1362	1322

1521	1632
1325	1502

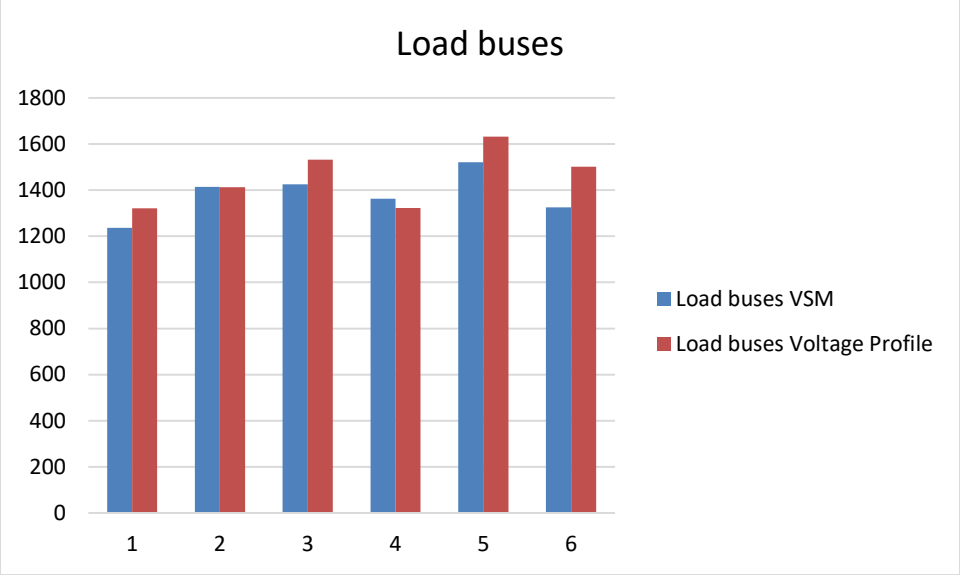

Figure 5: A comparison between the voltage profile values for feeder 6 load buses and the predicted voltage stability margin

Voltage Stability Margin (VSM), a measure of voltage stability, and the related voltage profile values at various load buses in the power system are shown in the table. The voltage stability margin at each load bus is shown by the VSM values, which span from 1236 to 1521. Better voltage stability is typically indicated by higher VSM values. At the same time, the voltage profile values, which show the real voltage levels at the corresponding load buses, span from 1321 to 1632. The overall voltage stability of the system can be determined by comparing the values of the voltage profile with the VSM. A greater VSM and a high voltage profile, for example, suggest that the voltage stability at that load bus is robust. On the other hand, a lower VSM combined with a comparatively lower voltage profile may suggest that voltage instability problems need to be addressed. Power system operators can evaluate the voltage stability across various load buses and take the appropriate action to ensure optimal system performance by examining these parameters combined.

V.CONCLUSION

In conclusion, dynamic voltage profile analysis and monitoring are critical components of smart grids that guarantee efficiency, stability, and dependability. Utilities can minimize disruptions and optimize grid operation by promptly detecting and responding to voltage changes through the utilization of modern technologies such as PMUs and data analytics. This proactive strategy helps modernization efforts related to grid modernization and aids the incorporation of renewable energy sources while also improving system resilience. Utilities must make significant investments in voltage monitoring capabilities if they are to satisfy the expectations of a resilient and sustainable energy future and adjust to the changing energy landscape. As distributed generation turns out to be more normal later on, conveyance networks' working qualities will turn out to be more like those of transmission networks. This could significantly affect circulation systems' system stability. With only one preview of the voltage and current phasors and SCADA information for the heap transports of interest, the proposed technique might have the option to assess the voltage stability edge and pinpoint the frail transports. The proposed strategy utilizes the nodal model to appropriately work out the same impedance as estimated by a heap transport, considering the nonlinear dynamic nature of the heaps and the inaccessibility of DG units. The proposed technique empowers the conveyance network administrator to address voltage instability progressively, without hanging tight for the high voltage network administrator to intercede.

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