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Examining the voltage profiles of the 33kv power network lines with photovoltaic systems.

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ABSTRACT

The voltage profile of the 33 kV lines in the distribution networks is investigated in this research study with the incorporation of photovoltaic (PV) systems. With the introduction of renewable energy source, the study's main objective is to identify and analyze the elements that affect voltage stability and distribution efficiency. By employing sophisticated modeling methods and empirical data from operational distribution networks, the study seeks to offer a thorough comprehension of voltage fluctuations, possible problems, and optimization tactics for preserving a steady voltage profile. The results of this study are essential for improving distribution networks' performance and dependability, especially in areas where PV systems are not yet widely used or practical.

Key words: Voltage profile, Distribution, network, Photovoltaic systems, Voltage stability, static var compensator, network analysis,

INTRODUCTION

Electrical Transient Analysis program (ETAP) is a proficient software application that facilitates the planning and analysis of power network behavior. Thus, ETAP proves to be a valuable instrument for conducting power system analysis. During the network planning process, it is crucial to conduct compensation analysis to identify areas of the network that require compensation through the implementation of a Static Var Compensator (VAR). This compensation analysis is particularly important for improving voltage profiles and reducing losses along the line. The significance of minimizing system losses cannot be overstated due to its financial, economic, and socioeconomic benefits to the utility company, customers, and the host nation, as noted by Anumaka (2012). Technical losses comprise of two components, namely fixed technical losses and variable technical losses. The technical losses in a power system can be classified into fixed and variable losses. Fixed technical losses are independent of the current drawn in the system and typically account for approximately 25% to 30% of the total technical losses. On the other hand, variable technical losses are dependent on the current in the system, and their magnitude is directly proportional to the current flow. This article will examine the issue of high current and losses on the 33kv network lines, as well as other challenges arising from high PV penetration. The study will employ SVC and ETAP software to address these concerns.

The ETAP software would be employed to identify the network's most impacted lines. The findings could be valuable for the Campus in terms of appropriate network planning and expansion.

VOLTAGE CHALLENGES WITH HIGH SOLAR PV PENETRATION IN DISTRIBUTION SYSTEM

The utilization of solar PV technology has presented a number of logistical obstacles, including voltage rises in transportation feeder and abrupt voltage swings resulting from cloud transients, that have the potential to diminish power quality (Coster et al., 2011). The obstacles provided above can be ascribed to two fundamental factors. The existing techniques utilized for voltage control in distribution cables have been based on the assumption that power transfer will occur solely in a unidirectional manner.

The emergence of solar PV technology and other types of distributed energy resources (DER) has resulted in a phenomenon in which the pattern of the electricity flow is reversed, leading to an associated rise in voltage levels. The incorporation of solar PV access into a system results in significant unknowns and outside forces, including cloud intermittency and abrupt cloud cover. The aforementioned factors possess the capability to generate a range of voltage-related complications, encompassing swift voltage oscillations, apprehensions regarding power quality (such as voltage flicker), and abrupt voltage spikes and dips.

VOLTAGE VIOLATIONS

Power system operation, as it can lead to system instability and potential equipment damage. The integration of solar photovoltaic (PV) technology. The adherence to the ANSI C84 standard is observed in North America. Mandatory compliance is required by power utilities. This requirement mandates the upkeep of voltage levels for customers.

The levels are maintained within the prescribed upper and lower limits, which are conventionally established at 0.95pu and 1.05pu. The abbreviation "pu" denotes per unit. Below the desired range, which can negatively impact their performance and lifespan. However, the latter phenomenon is relatively less frequently observed owing to a rise in electrical potential. Accelerating the explication of a customary distribution feeder can be achieved by means of the examination of a single-line diagram, depicted in Figure 1, is necessary to determine the voltages at the point of connection for Distributed Energy Resources (DER).

The estimation of (node 2) can be achieved through the utilization of DistFlow equations.

$$V2 = V1 - (PL - PG)R1 + (QL - QG - QCF)X1 \qquad (1)$$

Let us denote the currents at node 1 and 2 as V1 and V2, accordingly The summation of PL and jQL denotes the weight of the load that is connected, while QCF represents the power that is reactive that is being injected by the capacitor at node 3. At node 2, DER is introducing power PG + jQG. It can be observed that if it is no DER i.e. PG = QG = 0,

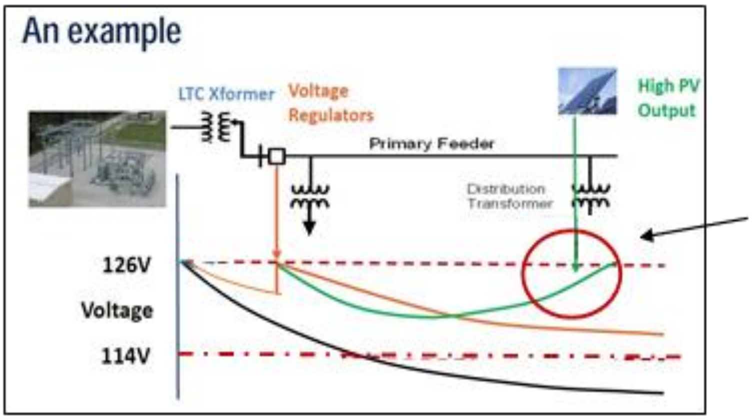

Figure 1: A conceptual representation of voltage rise caused by the solar PV Integration the voltage at node 2 is lower than the voltage at node 1.

Notwithstanding, the production of Distributed Energy Resources (DER) featuring non-negligible magnitudes yield a relatively heightened electrical potential at the second node. In scenarios where DER production is notably increased, there is a possibility for the amplitude of voltage at point 2 (V2) to exceed that of voltage at point 1 (V1) due to the occurrence of reverse power flow. Figure 1, as illustrated by Masters (2012), portrays the conceptual diagram. The voltage profiles under consideration are depicted by two discrete curves, one in the shade of black and the other in the hue of green. The former pertains to a circumstance wherein DER are absent, whereas the latter denotes a state in which DER is existent. The emergence of DER gives rise to a voltage profile that displays an upward trajectory, potentially causing over-voltage violations. The optimal conditions for voltage escalation during diurnal summer periods within residential vicinities transpire when the apex generation aligns with the nadir load.

It has been observed that the integration of solar photovoltaic systems into voltage regulation systems can result in both voltage drop and increases at the regulating point. The utilization of the traditional method of voltage regulation, specifically the approach of compensating for line drop, engenders a state of perplexity and consequent diminution in the ascertained voltage drop, culminating in a state of suboptimal voltage. Furthermore, a sudden decline in solar energy production during intervals of elevated demand or swift reduction in solar generation may lead to occurrences of low voltage infringements.

OLTAGE FLUCTUATIONS

One of the primary challenges in the assimilation of solar PV systems is the issue of unforeseeable fluctuations in cloud configurations, particularly cloud interruption and abrupt cloud protection. Figure 2 portrays the solar PV generation profile during a winter day with clear skies at the esteemed CSIRO Energy Center located in Newcastle. It is plausible that the actual photovoltaic examined may diverge from the conceptual photovoltaic curve and manifest notable intermittence. The presence of sporadic cloud formations and abrupt cloud coverage may lead to rapid oscillations in the consumer voltage, thus presenting a plausible hazard of voltage flicker infringements. As per the available data and information, according to Robbins et al. (2013), the presence of flicker possesses the capacity to elicit displeasure among consumers and impede the optimal operation of electronic devices. In a case study conducted by Farag and El-Saadany (2011), the Porterville network of distribution centers in California was examined, revealing the presence of voltage flicker phenomenon in response to the abrupt onset of cloud cover. As per the IEEE electrical quality requirements, voltage flicker refers to the voltage fluctuations in loads that elicit eye discomfort in consumers. The assessment of flicker degree is predicated upon the utilization of the GE flicker curve, which is visually represented in Figure 3.

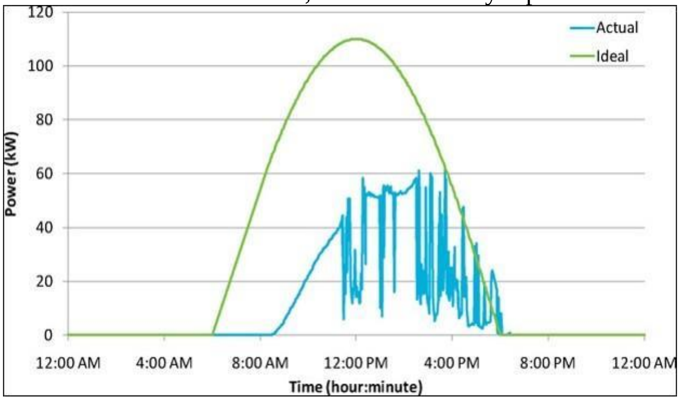

Figure 2: An ideal generation profile for solar PV, compared with a real profile from a cloudy day in winter.

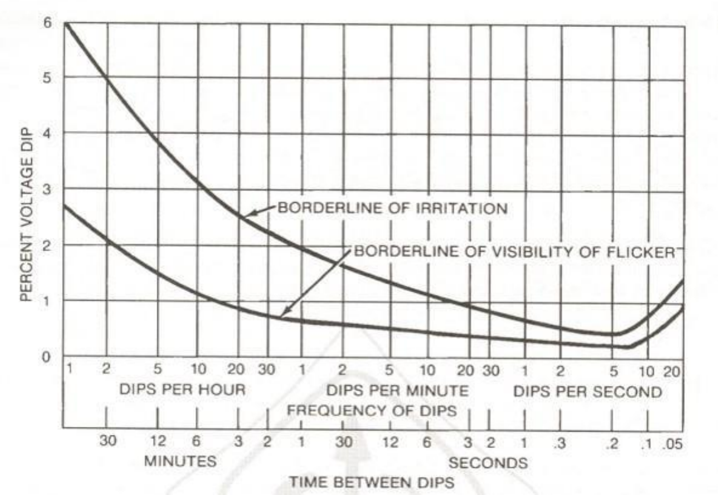

Figure 3: GE flicker curve from IEEE standard 141

VOLT/VAR CONTROL (VVC) IN DISTRIBUTION SYSTEMS

The management of voltage and reactive power, commonly referred to as volt/var control (VVC), is an essential operational necessity for all electrical distribution systems. The primary objective of Voltage Var Control (VVC) is to ensure a satisfactory voltage profile at all locations along the distribution feeder, irrespective of the magnitude of the load. The determination of the acceptable range of voltage is subject to the discretion of various regulatory bodies across diverse geographical locations. All utilities in the United States adhere to the ANSI standards. Typically, four distinct types of devices are employed for the purpose of managing voltage and reactive power flow in distribution systems. These include the on load tap changer (OLTC), step voltage regulator (SVR), substation capacitor, and feeder capacitor. The classification of these entities can be delineated into two distinct levels, namely the substation level, which encompasses OLTC and substation capacitors, and the feeder level, which includes step voltage regulators (SVR) and feeder capacitors. The voltage of the grid, denoted as V0, can be approximated as constant. However, the secondary voltage V1 is subject to variation with respect to the load due to losses incurred in the substation transformer. The OLTC is a device that is implemented at the substation transformer in order to regulate the voltage level V1, thereby ensuring that the voltage downstream remains within the prescribed limits. The installation of a capacitor Cs in a substation has been implemented.

The substation is responsible for regulating the flow of reactive power to ensure the maintenance of the system power factor (PF). Tap-changing transformers known as SVRs are strategically placed along the feeder to enhance voltage levels at low voltage nodes. The utilization of line drop compensator (LDC) in conjunction with single voltage regulator (SVR) is primarily aimed at voltage regulation at downstream nodes, as opposed to its point of connection. In this case, the SVR located at node 2 is responsible for regulating the voltage at node 3. The voltage drop between two points, specifically (V2 − V3), is simulated by LDC through the utilization of line impedance (R2 + jX2) and local current values. The Support Vector Regression (SVR) algorithm adjusts the tap in accordance with the input data. The methods of control have been expounded in detail in the publication by

Goergens et al. (2015). The Feeder Capacitor Cs is a capacitor that is either fixed or switched, and is strategically placed at various locations along the feeder in order to enhance voltage levels. Typically, the devices are subject to local control, such as the OLTC and SVR, which are regulated according to the voltage of the local bus. Capacitors can be regulated through either temporal or local bus voltage control.

Nonetheless, these devices do not adequately address voltage-related issues linked to solar PV systems due to their sluggish and discontinuous regulation. Barth (2013) has stated that the management of swift variations arising from solar generation, such as cloud transients, is beyond the capacity of the concerned parties. The volt/var control capacity is inherent in most inverter-based energy resources that are distributed (DERs), such as wind, solar PV, electric vehicle, and synchronous generator-based generation, which is a fortunate circumstance. The utilization of this capability has the potential to enhance the voltage profile of the network.

SOLAR PV SMART INVERTERS VOLT/VAR CONTROL CAPABILITY

Solar PV generation systems that are integrated with the grid are furnished with an inverter, which functions to convert the input direct current (DC) power into output AC power that is harmonious with the grid. It is of significance to note that the indistinguishable inverter possesses the capability to govern the voltage at the point of convergence by means of injecting and absorbing reactive power (var). PV inverters endowed with the capacity to execute multifarious tasks and govern voltage and reactive power are commonly denoted as 'smart inverters' and function in a state recognized as voltage control mode (VCM). The constant power factor (CPF) mode is a widely adopted operational approach for DERs. The operational modality in question pertains to the manipulation of DERs at a power factor of unity or a consistent power factor, commonly in a lagging fashion, with the aim of mitigating voltage escalation. The inverters' capacity rating serves as a limiting factor for their capacity to either inject or absorb reactive power. The inverter must satisfy the subsequent condition.

$$P\ 2 + Q2 \leq S \qquad (2)$$

The variables P, Q, and S denote the actual power output in watts, reactive power output in volt-amperes reactive, and rated capacity in a given inverter system. The maximum magnitude of reactive power that can be injected or absorbed by the inverter.

The PV inverters have become a viable option for volt/var control in modern distribution systems due to their ability to perform fast switching control actions at a time-scale of seconds and their dynamic control nature. This is in contrast to traditional VVC devices which have slower and discrete responses. The PV inverters provide continuous VVC capability and are effective in handling rapid variations in the distribution system.

VOLT/VAR CONTROL: REAL-TIME LOCAL CONTROL APPROACHES

As previously mentioned, the implementation of a local control layer is deemed essential for PV inverter VVC in the current context of rapid cloud transients and other external disturbances. In contemporary literature, there has been a growing emphasis on the utilization of local voltage and var control (VVC) techniques. This trend can be attributed to the heightened demand for practical and easily implementable local control methods. The local control framework known as droop VVC has gained significant popularity among utilities and in the existing literature.

NON-DROOP LOCAL VVC METHODS

It is noteworthy to mention some of the endeavors made towards the creation of non-sag regional VVC techniques (Zhu and Liu, 2016). DallAnese et al. (2014) proposed a scaled variable control that offers stability analysis of the control and exhibits enhanced local voltage and VAR control performance. According to Goergens et al., (2015), an integrated local voltage and var control (VVC) system with unrestricted var resources is suggested, despite the fact that in practical applications, var injection is restricted by the capacity of the inverter. Zhu and Liu (2016) have presented a straightforward methodology that relies on the compensation of impedance drop. The aforementioned methodology bears resemblance to the line drop compensation technique employed by traditional LTCs. The study conducted by Carvalho et al., (2018) proposes a two-stage architecture that utilizes a fully local VVC, akin to droop control, in the initial stage. Nevertheless, each of these approaches poses certain difficulties, as outlined subsequently.

Challenges with Non-Droop VVC Methods: Non-droop local VVC methods lead to the following challenges:

The localized nature of these methods belies the fact that their parameter selection necessitates access to centralized full topology information.

The lack of adaptability in adjusting parameters to accommodate varying operating conditions and disturbances poses a risk of control instability or diminished control efficacy.

The majority of these methodologies operate under the premise of linearized power flow and a consistent substation voltage during control design. Such an occurrence could potentially result in inaccuracies in the real-time tracking of voltage set-points.

Primarily, it is imperative to note that these devices lack compatibility with the local droop VVC framework established by the IEEE1547 standard, thereby posing a potential risk to their seamless real-time integration. The crux of our endeavor lies in the development of a droop-based adaptive control mechanism that adheres to established standards, with the ultimate goal of ensuring ease of implementation.

DROOP VVC

The droop VVC framework is widely recognized as the most commonly utilized local approach. Zhang (2013) initially introduced the concept in an EPRI technical report. Subsequently, the IEEE1547 integration standard has incorporated it due to its uncomplicated design and ease of implementation. Additionally, it has gained widespread usage in California's Rule 21 (Rylander et al., 2016) and Hawaii's Rule 14 (Safavizadeh et al., 2017). The framework utilized for volt/var control is the droop control, which is represented by a piecewise linear function as depicted in Figure 4. The axes in question pertain to the local node voltage and inverter VAR injection, with the horizontal axis representing the former and the vertical axis representing the latter.

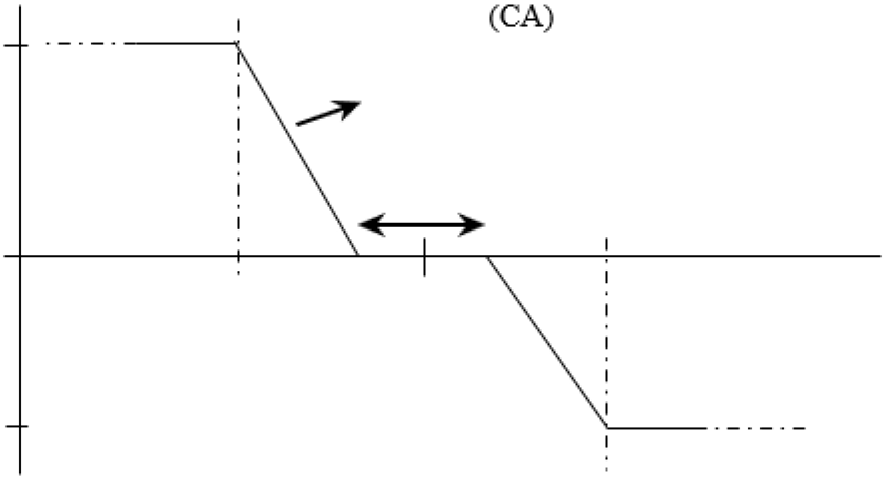

Figure 4: Conventional droop VVC framework recommended by IEEE 1547.8, Rule 21

The variables positive and negative represent the inverter's supply and absorption of reactive power, respectively. The present system involves the inverter detecting the nearby voltage and subsequently allocating the corresponding var on the droop curve. The control behavior is determined by a set of control parameters, namely vmin, vmax, qmin, qmax, and m. The Droop Voltage and Frequency Control (VVC) mechanism is intrinsically limited to a local scope and does not require any centralized data or feeder topology information. In addition, the compatibility of VVC with contemporary integration standards facilitates the production of a uniform VVC type across all smart inverters by manufacturers.

CHALLENGES WITH DROOP VVC

Notwithstanding the assessment of compatibility regulations, electric utility companies exhibit a lack of assurance in the deployment of solar PV systems in voltage control mode, owing to plausible hazards. The facilitation of local control can be achieved by leveraging close bus knowledge. However, ensuring the dependability and efficacy across the system control presents a formidable obstacle within the framework of local control design. Two principal obstacles that are commonly associated with the droop voltage vector control (VVC) method.

The main issue at hand relates to the identification of appropriate control parameters amidst a range of operational circumstances and external interferences. The optimal parameters for the standard droop control are subject to the feeder's arrangement and operational variables, encompassing the load profile, solar penetration level, preferred voltage set-point, and cloud cover, among other factors. Failure to do so may lead to subpar control efficacy.

The droop electricity vector control algorithm (VVC) has been found to possess a notable sensitivity to its droop parameter. Ineffectual selection of the slope value has been observed to lead to control unpredictability or voltage movements, as demonstrated by Rylander et al. (2016). As per the research conducted by Safavizadeh et al. (2017), it has been established through various studies that the identification of optimal smart inverter parameters is subject to a multitude of variables such as load status, PV penetration, and feeder arrangement. Slight modifications to these parameters have the potential to elicit significant fluctuations in the reactions of the system. The extant body of literature pertaining to droop command and analogous local management methodologies evinces a dearth of analytical analysis and neglects to attend to issues surrounding parameter selection, control stability, and convergence. Moreover, the existing norms exhibit a dearth of direction concerning the selection of parameters, thereby exacerbating the intricacy of executing traditional droop voltage and frequency regulation.

The secondary impediment of droop voltage and frequency control (VVC) concerns the delicate balance between achieving regulate security and guaranteeing optimal set-point following performance. The present quandary is inherently intertwined with the Voltage-Volume Curve (VVC) of droop, and its fundamental origin can be ascribed to the intrinsic blueprint of the droop mechanism. To ensure the preservation of control stability, it is imperative that the droop voltage VVC exhibits a diminished slope magnitude. Notwithstanding, the aforementioned slope value may exert an adverse influence on the control's stable state achievement, thereby giving rise to an augmented steady state error (SSE). Furthermore, our investigation in the ensuing section has ascertained that the implementation of the regional droop VVC with elevated steady-state error (SSE) is vulnerable to voltage infractions amid external perturbations. Furthermore, it is crucial to uphold a rigorous voltage regulation mechanism with negligible steady-state deviation not solely to circumvent violations but also to guarantee precise adherence to the designated voltage set-points. The implementation of localized control mechanisms is of utmost importance in achieving optimization goals at a macro level, such as the mitigation of energy use and the minimization of expenses.

Rylander and colleagues (2016) have posited a revised iteration of the customary droop regulation, denoted as the deferred droop control. The proposed alteration entails the incorporation of a deferred block antecedent to the customary droop VVC in order to curtail the control's operative gradient. The method that has been suggested demonstrates superior stability performance and operational efficiency when compared to the traditional droop technique under standard operating conditions. However, it is important to note that the system is vulnerable to instability and voltage violations when faced with external disturbances, owing to inadequate real-time parameter adaptation and significant steady-state error.

The present investigation introduces an innovative methodology to attain control stability and set-point tracking precision (with minimal steady-state error) by means of a completely localized and instantaneous adaptive voltage and VAR control (VVC) tactic. The method being proposed facilitates the self-adjustment of control parameters in response to outside influences that are commonly came across such as cloud intermittency, cloud cover, alterations in stress description, and fluctuations in a substation voltage. It is noteworthy that the suggested methodology does not require centrally controlled topology details.

RESULT PRESENTATION AND DISCUSSION

This section is basically centered on the result analysis and discussion of the effects of high photovoltaic (PV) penetration on the distribution network.

A. Impact of high PV Level on Feeder 2

Figure 5 This study examines the effects of a high photovoltaic (PV) penetration level of 1200W on the distribution of low voltage (LV) power. The research demonstrates that a high PV penetration level on the LV feeder has the potential to alter the voltage profile of the feeder, resulting in temporary high elevated voltage levels at the terminus of lengthy LV feeder lines. This phenomenon has an impact on the permissible voltage threshold and could potentially contravene the prescribed limits set by utility planning regulations and industrial norms. The standard voltage for low voltage networks is commonly accepted to be within a range of plus or minus 10%. When the voltage penetration level reaches 1.1 per unit (pu) or higher, as depicted in Figure 5 (1.18pu), it will affect the distribution network load because loads are sensitivity to voltage fluctuations.

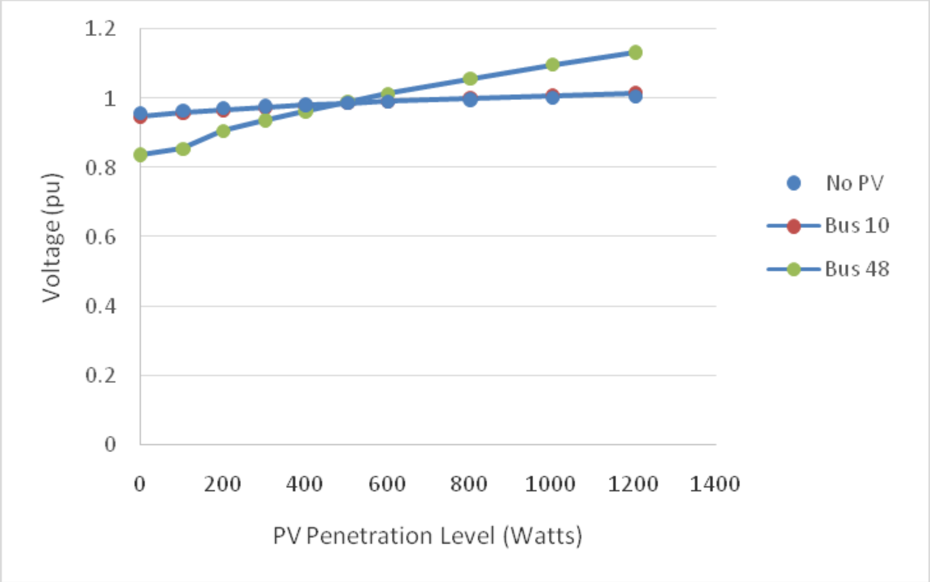

Figure 5: Voltage profile under Increasing PV penetration Level

B. Impact of high PV penetration on transformer loading on Feeder 2.

Reverse power flow, which refers to the phenomenon of power flowing from the load point to the transformer, is a significant concern associated with high photovoltaic (PV) penetration on the low voltage (LV) distribution feeder. This phenomenon has the potential to impact the loading capacity (rated power) of transformers and the ratings of conductors. When the loading exceeds 150%, it can have an impact on the coordination of over-current protection and the line voltage regulators. The impact of a high level of photovoltaic (PV) penetration on transformer loading is illustrated in Figure 6.

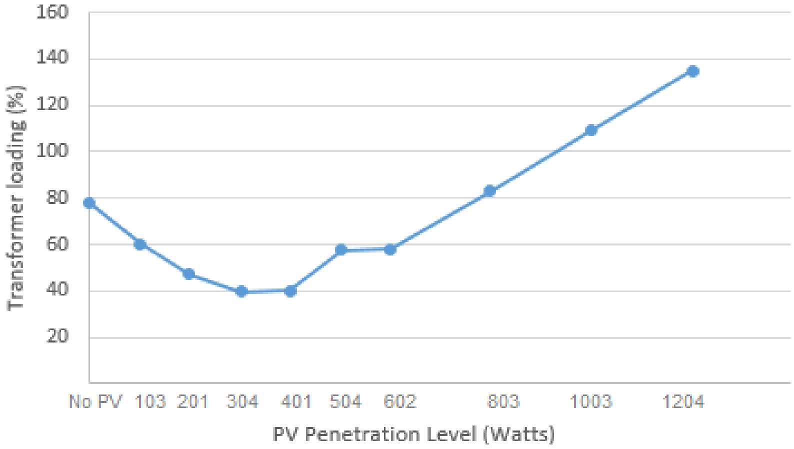

Figure 6: Transformer Loading due to increasing PV penetration

C. Impact of high PV penetration on feeder loses on the feeder 2.

Figure 7 demonstrates that a significant penetration of PV systems can alter the current of the feeder, potentially leading to elevated levels of losses. This phenomenon occurs due to the surplus photovoltaic (PV) injection surpassing the required load demand, resulting in the surplus power being redirected back to the grid. As depicted in Figure 7, the aforementioned condition has the potential to impact the loading of transformers in terms of their rated power, as well as the ratings of conductors.

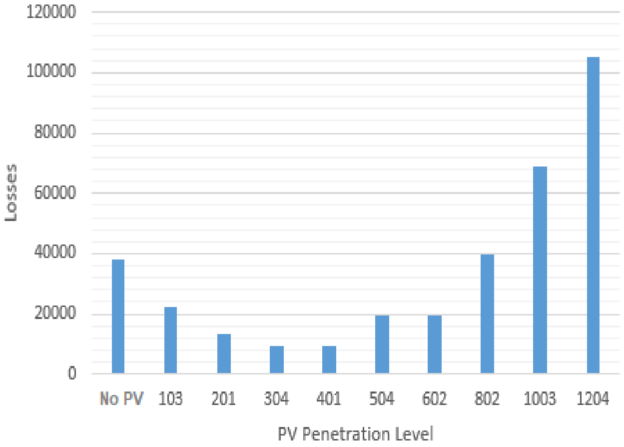

Figure 7: Feeder Losses under Increasing PV Penetration

D. Impact of high pv penetration of Feeder 2 current.

Figure 8 shows when PV penetration increases the current on the feeder is modified. It also shows that a high penetration will lead to a high feeder current.

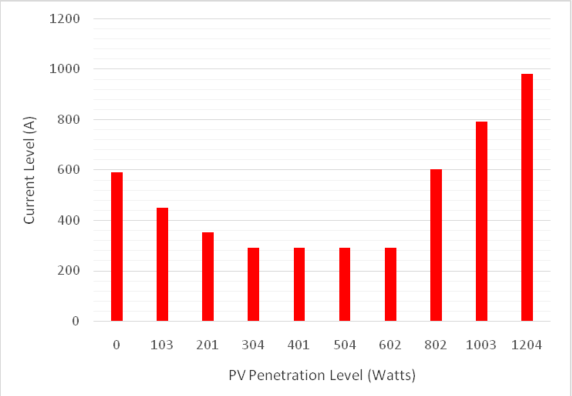

Figure 8: Feeder current under increasing PV Penetration

E. Impact of SVC on high PV penetration (1200w) on feeder 2

Figure 9 shows the impact of SVC on the distribution feeder voltage at 1200W PV penetration, when different range SVC reactive components were applied. From figure 9, it shows that when SVC reactive component value of 400KVAr was applied, it reduced the feeder voltage value from 1.18pu to 1.02pu which is below the acceptable voltage standard limit of ±10%.

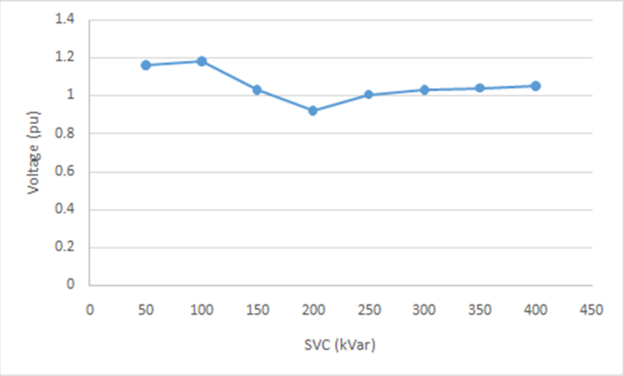

Figure 9: Voltage profile under SVC Application

F. Impact of high PV penetration with SVC on feeder 2 current

With the application of SVC on the LV network, the rapid increase in current was reduced and varies with the number of SVC injected in the network. So, undesirable increase in current due to increasing penetration of PV system is minimized with the help of SVC device as shown in Figure 10.

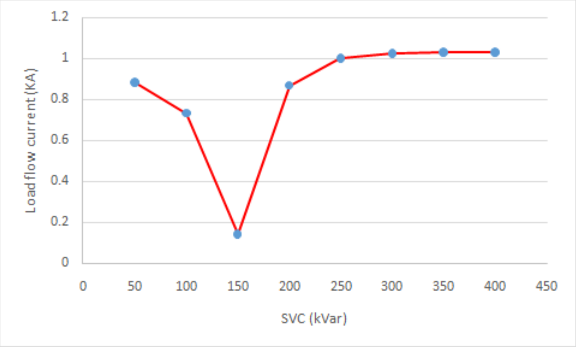

Figure 10: Feeder current under SVC Application

G. Impact of High PV penetration with SVC on the Feeder 2 transformer.

From figure 11, it can be seen that the transformer loading effect with SVC is approximately equal to that of the numerous applications of PV penetration on the feeder network since the injected SVC is less than the load demand avoiding excess generation being fed back to the grid. This condition can safeguard the transformer loading (rated power) and conductor ratings.

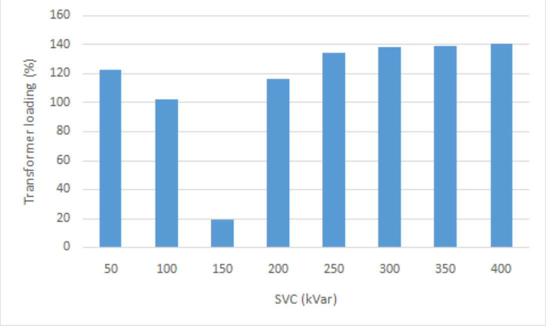

Figure 11: Transformer Loading due to Application of SVC device

H. Impact of high PV penetration with SVC on the Feeder 2 Current.

It is observed in figure 12, with less amount of SVC application on the LV network, the feeder current is adjusted and there is a considerable decrease in the level of losses. This is because the injected SVC is less than the load demand thereby preventing excess generation from being feed back to the grid.

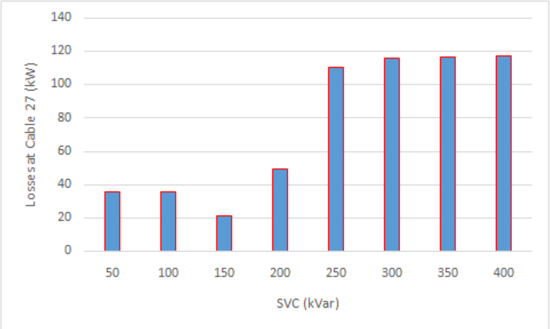

Figure 12: Feeder Losses under SVC Application

CONCLUSION

The global proliferation of energy from renewable sources technologies, including but not limited to photovoltaic systems and wind turbines, has engendered a pressing imperative to comprehend the ramifications of these systems on the power system network, particularly the voltage distribution network, and to devise strategies for ameliorating these effects.

The present study undertook a comprehensive analysis of the effects of high penetration on the voltage distribution network system in Bayelsa State. The outcome indicates alterations to the voltage profile, transformer loading, reversed power flow, and elevated feeder current on the feeder. Furthermore, the implementation of static var compensation (SVC) was simulated and incorporated into the feeder system in order to alleviate the potential consequences of high photovoltaic (PV) integration. The simulation outcomes indicate that the employment of SVC effectively mitigates the adverse effects on the distribution feeder.

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