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Analysis of the Radial Distribution Lines of Federal University Otuoke with Increasing Level of Photovoltaic System Penetration

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ABSTRACT
The integration of photovoltaic (PV) systems into radial distribution lines presents both opportunities and challenges for enhancing the sustainability and reliability of power supply. This research focuses on analyzing the radial distribution lines of Federal University Otuoke to assess the impact of increasing levels of PV system penetration. Through detailed modeling and simulation, the study investigates the dynamic behavior of the distribution network under varying PV integration scenarios. Key performance metrics such as voltage regulation, power flow, and system stability are analyzed to evaluate the effectiveness of PV integration in meeting the campus's energy demands. Additionally, the research considers the technical and operational implications of higher PV penetration levels, including potential issues related to voltage fluctuations and reverse power flow. Economic analysis is also conducted to assess the financial viability of integrating PV systems into the existing distribution infrastructure. By providing a comprehensive evaluation of PV integration in the context of radial distribution lines, this research contributes to the advancement of sustainable energy solutions in academic institutions and provides valuable insights for optimizing future energy planning and management strategies.

KEYWORDS:: *Photovoltaic system, integration, Radial distribution lines, Renewable energy, Power system analysis, Voltage stability.*

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I. INTRODUCTION

The increasing utilization of renewable energy technology has become a prevalent trend in response to the depletion of fossil fuels over the past decade. The integration of renewable energy technology, such as photovoltaic systems, into sub-transmission and distribution networks is a prevalent practice. Despite occasional integration challenges on power system networks, the impact of photovoltaic systems on low voltage distribution networks is primarily attributed to the robustness of the power network.

The resilience of a power system is indicative of its ability to maintain stability across a range of feasible operating scenarios, thereby giving rise to two distinct classifications: robust grids and fragile grids. In the context of operational parameters, the voltage level within a robust power grid remains relatively stable. The negligible dV/dP and dV/dQ resulting from minor fluctuations in power flow within the system, specifically in relation to active or reactive power, can be attributed to the potential for reverse power flow resulting from increased penetration of photovoltaic systems. In the case of a weak grid, the opposite holds true. According to Mehdi et al. (2018), it is typically distinguished by discernible sensitivity in dV/dP and dV/dQ. In an electrical system with low grid strength, the voltage at the point of connection is highly responsive to fluctuations in the load. Conversely, in a high grid strength system, the voltage remains constant regardless of changes in the load. The term "system strength" refers to the ability of a power grid to maintain a consistent voltage level regardless of variations in load conditions.

The impedance of the lines and the short circuit current capability at the connecting point are directly correlated with the strength of the grid. In electrical engineering, a system with high impedance and low short circuit current is considered weak, while a system with low impedance and high short circuit current is considered strong. The presence of photovoltaic (PV) systems on a distribution network, regardless of the strength of the power grid, has the potential to cause voltage rise, reverse power flow, high feeder current, and increased loading on transformers.

The source cited is Ainah (2014). Weak grids are typically correlated with a significant level of losses. In order to enhance the characteristics of a high Renewable System, specifically a PV system, on the distribution network, it is necessary to implement compensation measures. Reactive power compensation refers to the act of supplying or consuming reactive power for the purpose of regulating the voltage of the system.

According to Liudvinavicius (2018), compensation serves to enhance the power factor of the system, regulate its voltage, furnish support for the actual power consumed from the system, and eliminate current harmonics. Consequently, it can be inferred that the voltage profile of the power system experiences a significant enhancement through the implementation of suitable compensation measures. As a result of the persistent power interruptions in Nigeria, both individuals and organizations are seeking solutions to address the escalating demand for electricity and concerns regarding its dependability.

The Federal University Otuoke is currently exploring the possibility of implementing a PV system as a means of addressing the challenges posed by rising demand, exorbitant diesel costs, and issues of reliability. This thesis examines the power distribution network of Federal University Otuoke with a focus on high PV penetration. The present study aims to identify potential threats associated with network integration and provide viable solutions to mitigate these issues. The integration of PV systems has led to voltage fluctuation, voltage unbalance, and voltage flickering, which can adversely affect loads. To address this issue, the Static Var Compensator (SVC) has been introduced as a means of improving the voltage profile.

II. MATERIALS AND METHODS

In this research the materials used to investigate the impact of high PV systems integration and mitigation of Otuoke power distribution network parameters are shown below in table 3.1 and ETAP software was used to model and investigate the research objectives.

Table 1 Parameters of Federal University Otuoke MV distribution network

S/N	PARAMETERS	VALUES	UNITS
1	Line voltage	33	KV
2	Line resistance	1.652	Omh/km
3	Line reactance	1.2	Omh/km
4	Length of line	2	Km
5	Frequency	50	Hz
6	Transformer	2.5	Mva

Methods

ETAP Work Environment

The abbreviation ETAP is representative of the Electrical Transient Analysis Program. The aforementioned software is founded upon Simulink, a platform akin to MATLAB. The software application ETAP is employed by professionals in the field of power systems engineering to facilitate electrical network modeling and simulation, as expounded upon in the erudite publication entitled "Electrical Network's Modeling & Simulation Tools: The State of the Art". The fundamental purpose of this system is to produce an "electrical digital replica" and assess the kinetics, momentary fluctuations, and safeguarding of electrical energy networks, as elaborated by Hase and Yoshihide's research (2019) and the "Electrical Transient Analyzer Program (ETAP)" resource. The software serves to expedite the establishment of a conventional power system and empowers the evaluation of load flow analysis in the face of any system alterations or anomalies. It is possible to configure the fault time, fault clearing time, and perform transient stability analysis. The ETAP software boasts a remarkable feature known as UDM, which empowers the user to create customized block diagrams for diverse components, including but not limited to the exciter, PSS, and Governor. ETAP is a highly advanced analytical engineering software that has been meticulously crafted to streamline the intricate processes of analyzing, simulating, monitoring, controlling, optimizing, and automating electrical power systems. The ETAP software offers a comprehensive and superior integrated solution for power systems, encompassing all stages from modeling to operation.

The application of this technology is predominantly observed in diverse domains encompassing power generation, transmission, distribution, industrial operations, transportation, and low voltage applications. The implementation of ETAP is advantageous in facilitating fundamental design and analysis functions for power generation systems, thereby fostering streamlined operational results. ETAP is a widely employed software solution among power generation facilities, spanning from sustainable to atomic sources, with the aim of furnishing reliable, environmentally conscious, and cost-effective energy to their respective clientele. The ETAP software is primarily employed in power transmission systems, with an emphasis on comprehensive transmission network planning, safeguarding, and energy administration.

The ETAP software amalgamates a multitude of features, including transmission network planning, substation models, network topology processing, transmission system analysis, and real-time transmission network energy management, to form a comprehensive grid transmission system software.

The ETAP grid provides a cutting-edge solution for distribution network analysis, which employs a geospatial platform to simulate and optimize the performance of both smart grids and microgrids. Furthermore, it exhibits prospective utility within the sphere of industrial conveyance and situations involving reduced electrical potential. The ETAP software facilitates power system engineers to perform investigations in both offline and online modalities.

Modeling of Otuoke Network Using ETAP

The Federal University Otuoke network is modeled in ETAP using the parameters of the networks depicts in Table 1., the network is 33KV feeders as shown in figure 1a and 1b below

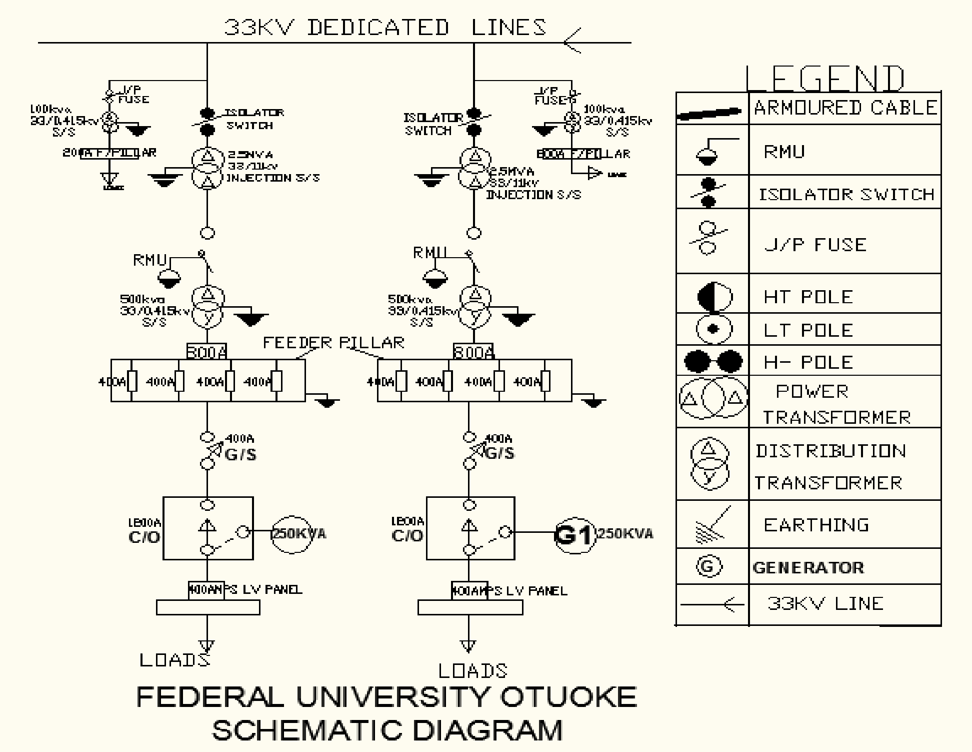

Fig. 1a: Schematic Diagram of Federal University Otuoke

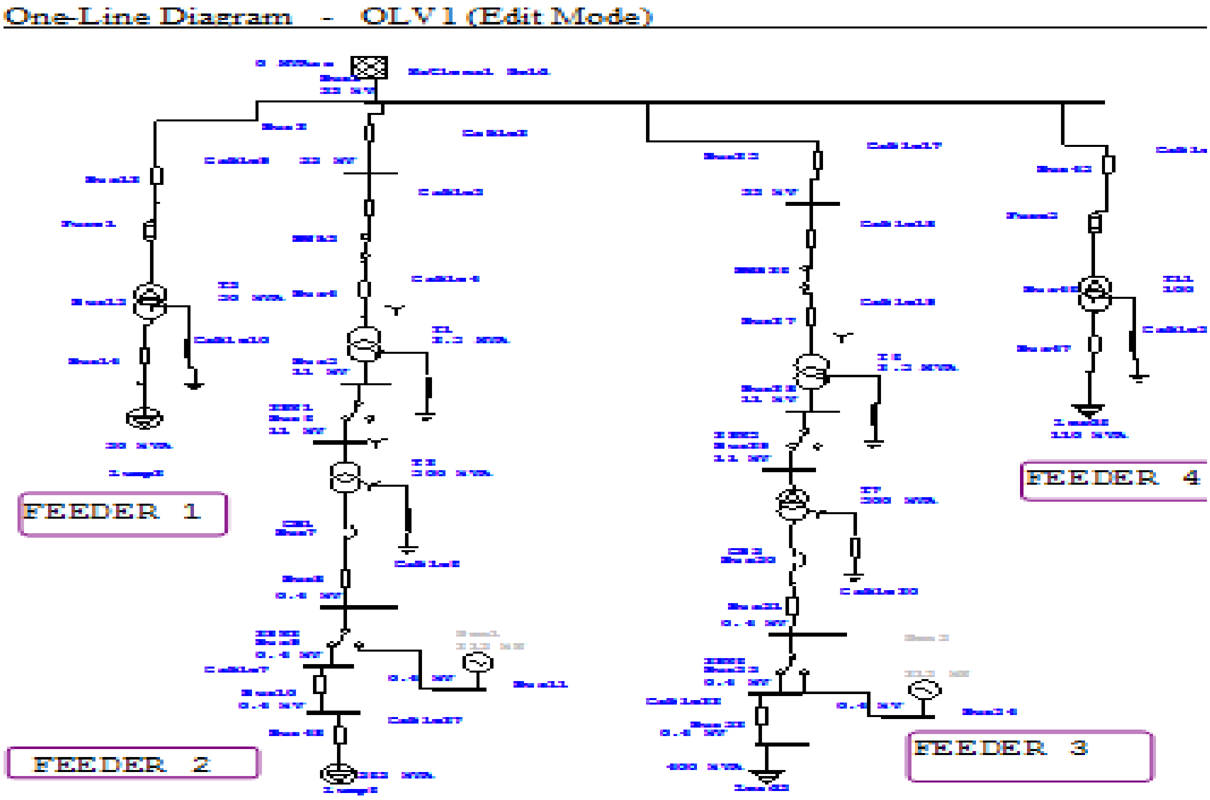

Figure 1b Modeling of power network using ETAP

The 33KV lines from PHEDC supply from Kolo transmission supply two numbers of 2.5MVA injection stations with line switches each for isolation. Each injection station consists of 2.5MVA, 33/11KVA transformer, line switch, 100KVA transformer with pillar, root mains unit (RMU), etc.
11KV lines are used to supply a distribution transformer (11/0.415KV) connected to a 800A feeder, from which the feeder pillar is connected directly to the loads.

Mathematical Analysis of Static Var Compensator (SVC) on System Voltage

Steady State Power Transfer Capacity

The deployment of a Static Var Compensator (SVC) holds promise in enhancing the power-transmission capacity of an electrical line, which is commonly known as steady state authority limit. Let us engage in contemplation of the single-machine infinite-bus (SMIB) system, as illustrated in figure 3.1, which is furnished with a connecting uncompressed tie line possessing reactance X. Assuming a generator with synchronous function and an infinite bus, let us denote the electrical voltages of the former and the latter as V1<–δ and V2<–δ, respectively. The quantity of power transmitted from the synchronous equipment to the infinite bus is symbolically represented by.

$$P = \frac{V_1 V_2}{X} \sin \delta \qquad 1$$

For simplicity, if V1 = V2 =V, then

$$P = \frac{V^2}{X} \sin \delta \qquad 2$$

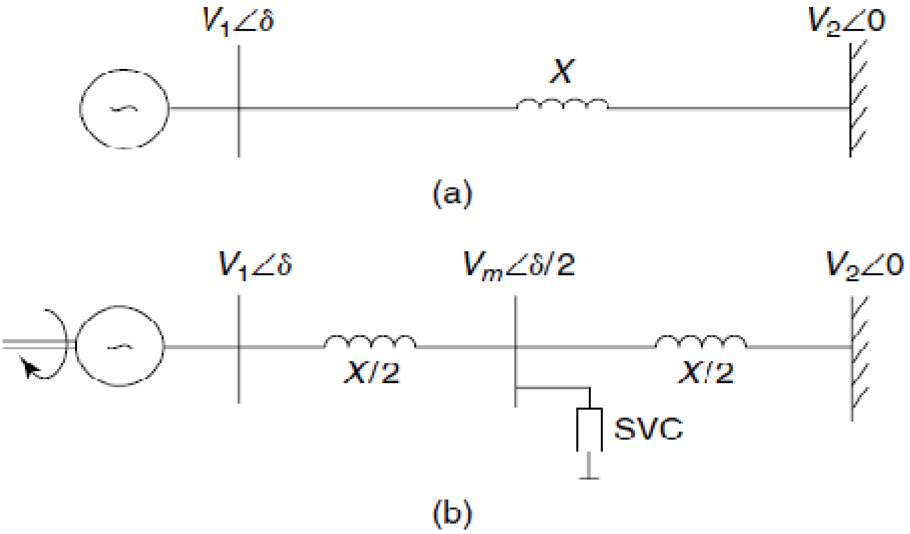

Fig. 2: The SMIB system: (a) an uncompensated system (b) an SVC-compensated system

The SMIB system is an uncompensated system. A system compensated by SVC. As per the depiction in Figure 2, the power's magnitude showcases sinusoidal characteristics concerning the angular difference between the synchronous machine's voltage and the infinite bus voltage. A δ value of 900 signifies the maximum level of constant power that can be conveyed through an uncompensated line without the presence of SVC. This value is conferred by the system.

$$P_{\max} = \frac{V^2}{X} \qquad 3$$

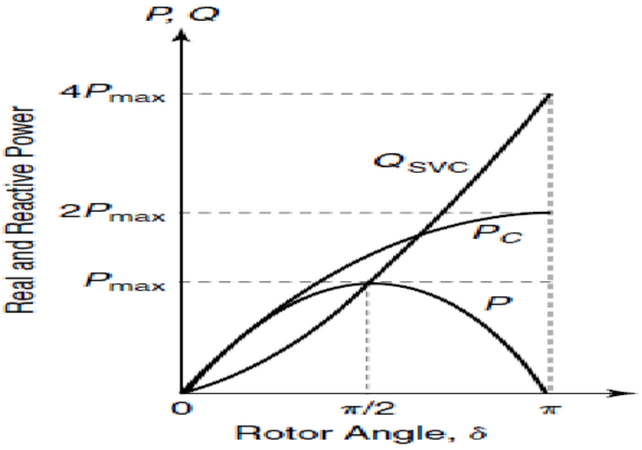

Fig.3: The variation of linear real-power flow and SVC reactive-power flow in a SMIB system

This study investigates the fluctuations in linear real-power flow and SVC reactive-power flow within a Single Mahine Infinite Bus (SMIB) system.as shown in figure.3.

Enable an optimal SVC to provide compensation for the transmission line located at its midpoint. The term "ideal" pertains to a Static Var Compensator (SVC) that possesses an unbounded reactive-power capacity and is capable of maintaining a constant magnitude of the midpoint voltage across the transmission line for all real power flows.

The expression for the SVC bus voltage is Vm<–δ/2.The expression for the electrical power flow through the half-line segment that connects the generator and the SVC is given as follows:

$$P_C = \frac{V_1 V_2}{X/2} \sin \frac{\delta}{2} \qquad 4$$

The maximum transmittable power across the line is then given by

$$P_{C\max} = \frac{2V^2}{X} \qquad 5$$

In the hypothetical scenario presented, the power conveyed is twice what could be transferred in the unadjusted setting. This phenomenon transpires at a juncture where δ/2 is equivalent to 900.

The transfer of energy (P'c) of a cable of electricity, partitioned into n identical sections, and equipped with an ideal Static Var Compensator (SVC) at each intersection to uphold a uniform voltage peak (V), can be theoretically expressed as follows:

$$P'_c = \frac{V^2}{X/n} \sin \frac{\delta}{n} \qquad 6$$

The expression denoting the upper limit of power transmission, P1cmax, through the given line is nV2/ X. Stated differently, when there are n sections, the power transfer has the potential to increase by a factor of n compared to the uncompensated line. It can be comprehended that the aforementioned limit is purely theoretical in nature, since the factual upper bound of power flow is constrained by the transmission line's thermal limit. The reactive power requirement, QSVC, for voltage stabilization of the midpoint SVC can be expressed as follows:

$$Q_{SVC} = \frac{4V^2}{X}\left(1 - \cos \frac{\delta}{2}\right) \qquad 7$$

SVC Operating Range within the Control Range

The defined range of control for the Static Var Compensator (SVC) is expressed as Imin<ISVC<Imax and Vmin<V<Vmax. Within this spectrum, SVC is denoted as a PV-node (generator node) located at an auxiliary bus, where P equals zero and V equals Vref. An additional reactance, commensurate with the gradient of the voltage-current characteristics, is introduced between the auxiliary node and the coupling node of the system. The PQ node situated at the point of common coupling is characterized by a P value of 0 and a Q value of 0, as visually depicted in figure 4.

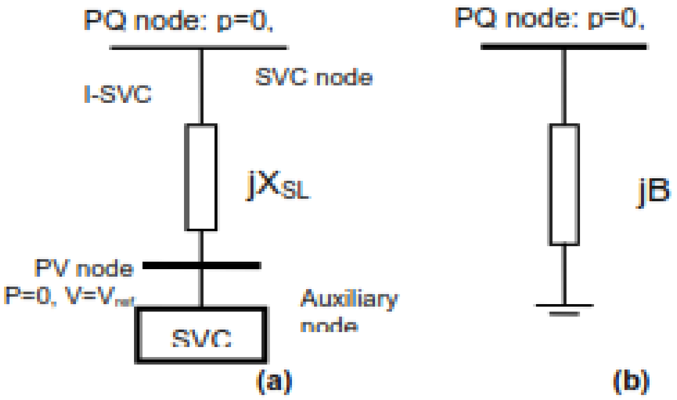

Fig.4: SVC model for operation within the control range (a) and operation outside the control range (b)

III. CONCLUSION

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.

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