

DigSALENT Model Base for the injection of Solar PV System with Grid Connected Network on 33/11kV Kubuwa network for Voltage Profile Improvement

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ABSTRACT

This research has initiated a comprehensive exploration of the potential for integrating photovoltaic (PV) energy sources into the power distribution system to enhance reliability. The study aims to provide a critical and systematic analysis of a PV grid-connected system modeled for the 33/11 kV Karu network, which consists of a 22-bus system. The model was developed to reduce active power losses and improve the voltage profile of the network. A forward and backward sweep power-flow technique was used to analyze the network and assess its actual operating conditions. Active power losses and voltage deviations were simulated using DigSILENT Power Factory, ensuring that all system conditions were satisfied. The total base-case power loss of the Karu 22-bus network prior to the integration of the PV system was 418.32 kW, with a minimum voltage of 0.8934 p.u. After the integration of the PV sources, the power loss was reduced to 315.48 kW, representing a 32.59% reduction in power loss while the minimum voltage improved to 0.9801 p.u. It can be concluded that the proposed method achieved a 32.59% reduction in power loss through the injection of PV at the Karu/Nyanya, Jikwoyi, and Karshi injection substations, compared to the initial base-case scenario without PV integration.

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1. INTRODUCTION

The power demand in Nigeria far exceeds the available supply. It is well known that global energy consumption has significantly increased, driven by the rising energy needs of industrial applications [3]. As a result, there is a growing focus on alternative energy sources that are both inexhaustible and clean, such as solar and wind energy, to reduce reliance on fossil fuels and other quickly depleting and environmentally harmful energy sources [5]. Among these, photovoltaic (PV) solar energy is recognized as one of the most widely used natural energy sources [4]. PV grid-connected systems have gained considerable attention due to the vast market potential for integrating solar power into distribution networks. This work aims to develop a multi-objective nonlinear control method to ensure the efficient operation of a PV grid-connected system. The control unit is designed to perform two primary functions. The first is to operate the PV generators at their maximum power by employing a maximum power point tracking (MPPT) algorithm. Various

algorithms are available for this purpose, including the perturb and observe (P&O) and incremental conductance methods. This focus has intensified due to the rapid advancements in solar cell technology in recent years, leading to improved efficiency and reliability [11]. The connection of PV arrays to the grid is typically achieved using a voltage source converter (VSC), which may include an intermediate DC-DC converter, a transformer, or both. It has been noted that high-bandwidth control of grid active and reactive power is achieved by directly controlling the currents of the VSC [13]. Today, PV applications are generally categorized into two main types: (i) standalone systems and (ii) grid-connected systems. [15]

2. Photo Voltaic cells

Electricity is directly generated from sunlight, when photons (light) are absorbed by semiconducting materials (e.g. silicon) in a solar cell [27]. The negatively charged electrons are knocked and loose from their atoms, and flow through the material thereby producing

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electricity. The complementary positive charges, holes, flow in the opposite direction. This process is known as *photovoltaic effect*

[18]. Figure 2.1 shows a Photovoltaic Phenomenon and depicts how sunlight is converted directly in to electricity.

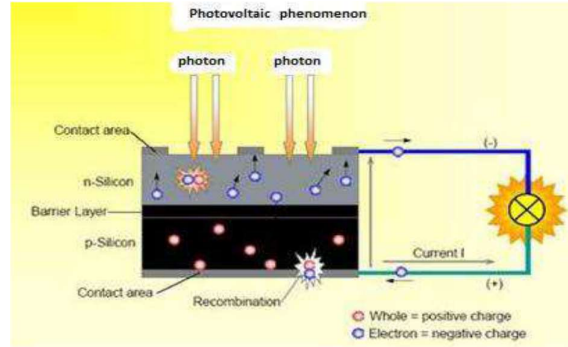


Figure 1: Photovoltaic Phenomenon [17]

A photovoltaic cell, also known as a photoelectric cell, is a semiconductor device that converts sunlight into electrical energy through the photovoltaic effect. When the energy of a light photon exceeds the band gap, it emits an electron, and the movement of these electrons generates an electric current. circuit [24]. The power converted into electricity is the square of the current multiplied by the resistance of the circuit. In PV system, each PV cell is connected together to form a module and several modules are connected together to form an array, while string is the combination of

several arrays. The PV generation system has two major problems; these are low efficiency and weather dependency. PV array has nonlinear current-voltage characteristics and output power depends upon atmospheric conditions [31].

The primary goal of mathematical modeling for a PV array is to represent its behavior and analyze the characteristics of the PV modules (Raina et al., 2013). To achieve this with fewer parameters and greater simplicity, a single diode model is utilized in this work, as illustrated in Fig. 2.6 [32]

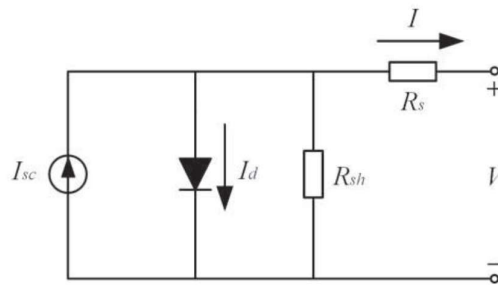


Figure 2: Single Diode model of a PV Cell [32]

By applying Kirchoff's law to the circuit above Figure 2.2, the output current of the PV Cell can be obtained as (Z. Yang et al., 2017):

$$I = I_{sc} - I_d - I_{sh} \quad (1)$$

$$I_{sh} = \frac{V + IR_s}{R_{sh}} \quad (2)$$

$$I_d = I_0 \left(e^{\frac{V + R_s I}{aV_T}} - 1 \right) \quad (3)$$

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DigSILENT The power factory software employs the Newton-Raphson (NR) method to solve nonlinear equations. In this software, the choice of method for formulating the nodal equations is determined by the user, depending on the type of network being analyzed. The NR method is utilized in this work due to its rapid convergence when dealing with power equations for large transmission systems. In the software, the nodal equations that represent the analyzed networks are implemented in two different ways.

1. NR current equations
2. NR (power equations, classical). In both ways, the resulting equations from the non-linear system must be solved by an iterative method. The calculation method in use is an AC load flow, balanced positive sequence

In the process of evaluating the operation and control of the network, the following Question were asked

1. Are the Busbar voltages in the network acceptable
2. What are the loading of the Transformers and Transmission lines in the network
3. How can optimal operation of the power system be achieved

The DigSILENT flowchart shows the sequential modelled and power flow of 33/11kV 22-bus network considering Real power loss and Voltage profile improvement used in this research is illustrated in Figure .

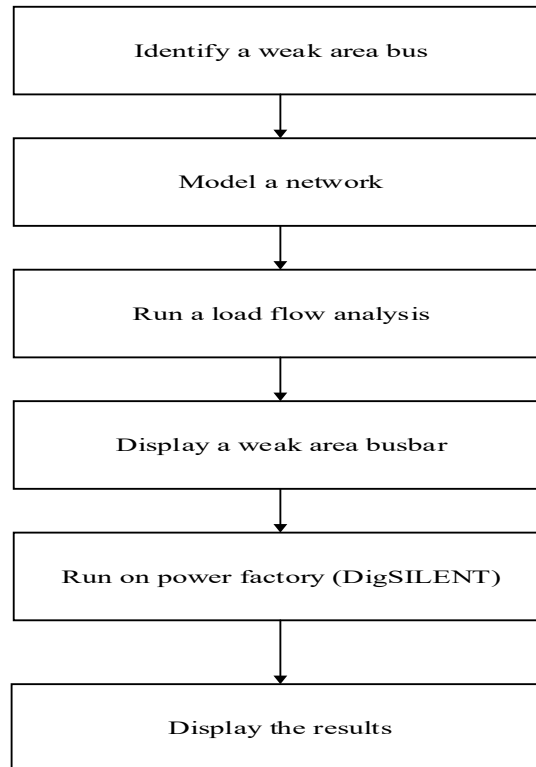


Figure 5: Power flow flowchart in Dig SILENT

The base case (without network PV connected to the grid and PV deployment), only network grid connected, only PV connected and simultaneous ran the power flow, PV placement, PV sizing are presented

in this chapter. The developed DigSILENT model is implemented on a grid Karu 22-bus network. The analytical comparison between the developed technique with the base case before injecting PV

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RESULTS AND DISCUSSION

The network is modelled on DigSILENT to depict the existing network conditions. A load flow analysis was conducted

to ascertain the state of the network conditions. The load flow result for the base case and the DigSILENT modelled is shown in Figure 6.

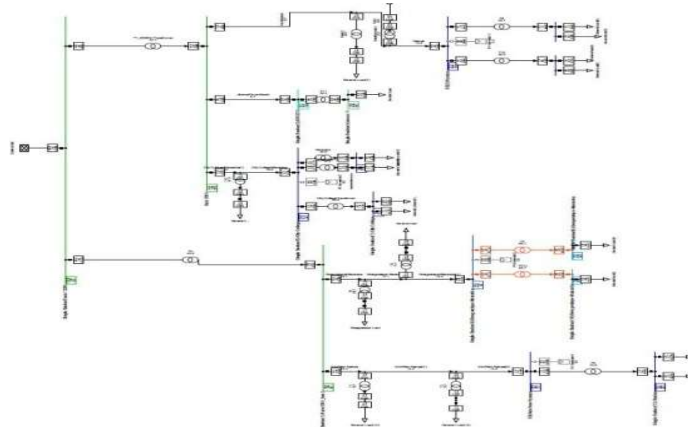


Figure 6: Base case modelled of Kuba 33/11kV DigSILENT load flow diagram

Scenario 1: Base Case for 22-bus Network of 33/11kV Kubwa Power Flow

Power flow analysis was carried out on 22-Bus network of 33/11kV Karu without PV using Newton Raphson. The active power loss and voltage magnitude of the Newton Raphson are presented in Figure 7. It is observed that the total power loss of the base case is 618.72kW, while the minimum voltage of

0.8934p.u occurred at bus 12. The higher voltage drop occurred at bus 12 as a result of the large distance between the substation and bus-12. The base case result (power loss and voltage magnitude) of 22-bus 33/11 bus network

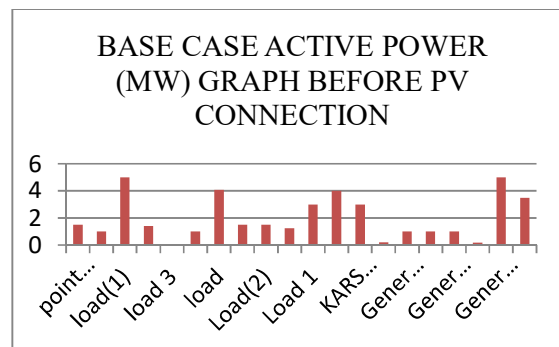


Figure 7: Base case active power (MW) graph before PV connection

Scenario II Karu 33/11kV Network with PV

In this scenario consists of the base case and connection of Karu 33kV of 22-buses with PV that are affected with low voltage. The

load flow diagram for this scenario on DigSILENT with the Newton-Raphson technique is shown in Figure 8

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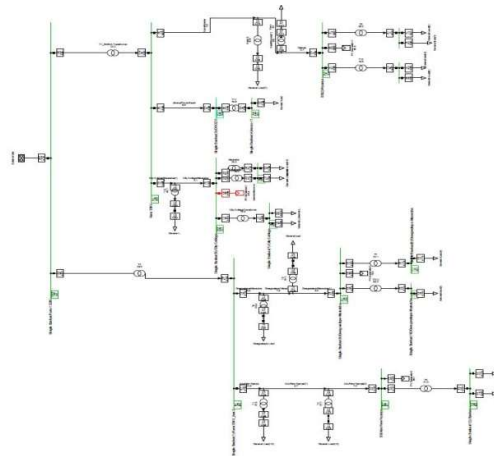


Figure 8: Base case modelled of Kubuwa 33kV DigSILENT load flow diagram with PV

Scenario II: With PV Grid Connected for Karu 22-Bus Network

Power flow analysis was carried out on 33/11 Karu 22-bus network using Newton Raphson technique to determine the state of the network; total base case power loss of 511.44kW is obtained. Figures 4.4 and 4.5 show the power flow and voltage profile results during PV connection only, the total power loss of 408.26kW is obtained. It is also observed from voltage profile result that the minimum voltage of 0.9801p.u occurred at bus-12. The PV system PV were installed using DigSILENT to improve the performance of the network, PV sizes and locations, Four PV were injected to four 33/11kV injection Substation under Kubwa 33/11kV Network. On the Kubwa feeder leading to the Karu 33/11kV injection Substation a 4MW PV was placed. On the associated injection substation on city college feeder a 4MW PV was

placed on the bus. On the 33/11kV Jikwoyi injection Substation 3.5MW PV was placed on the bus while for Karshi 33/11kV injection Substation 2.5MW PV was placed on the bus at buses 12, 8 and 13 respectively. After the PV installation, the power loss reduced from 618.72kW to 515.48kW representing 16.7% power loss reduction and the voltage magnitude improved from 0.8934p.u to 0.9801p.u. It can be deduced that the proposed technique recorded a percentage power loss reduction of 16.7% with injection of PV at Kubwa/Nyanya, Jikwoyi injection Substation and at Karshi injection Substation as against the initial base case of the network with PV injection to the grid network system 14, 15 and 16.

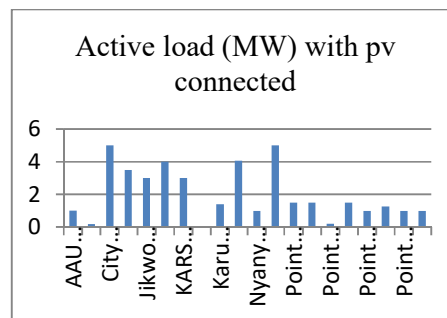


Figure 9 Active load (MW) with PV connected

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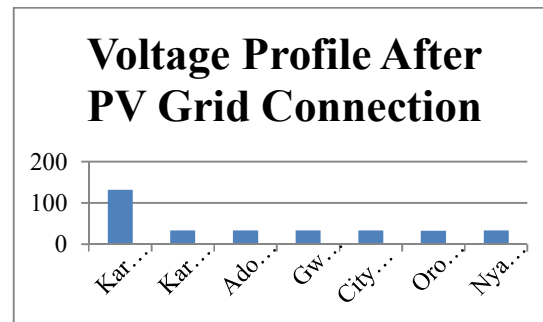


Figure 10 Voltage Profile with PV Connection

CONCLUSION

A DigSALENT for the injection of PV grid connected network was model on 33/11kV Kubuwa network with 22 bus network has been developed in order to reduce the network active power loss and improve voltage profile. Newton Raphson power-flow technique analysis was used to analyse the networks so as to examine the true state of the network. Active power loss and voltage deviation were formulated into DigSilent which satisfied all system condition. The total base case power loss of Karu 22-bus network prior to PV grid connected network. The total base case power loss of 33/11 Karu 22-bus network prior to PV connected network and PV placement is 618.72kW, while the minimum voltage of 0.8934p.u but after the power loss reduced from 618.72kW to 515.48kW representing 16.7% power loss reduction and the voltage magnitude improved from 0.8934p.u to 0.9801p.u. It can be deduced that the proposed technique recorded a percentage power loss reduction of 16.7% with injection of PV at Karu/Nyanya, Jikwoyi injection Substation and at Karshi injection Substation as against the initial base case of the network with PV injection to the grid.

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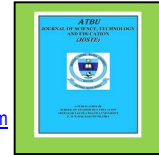


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