Assessing PV systems performance in an unbalanced distribution network

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Abstract— The aim of this paper is to present a simulation of distribution systems adding PV generation using MATLAB and OpenDSS, the study was applied on a three-phased unbalanced distribution network, Using the IEEE 13 node distribution feeder as a test bed, The irradiance, and load values for each time step are managed on MATLAB and sent to OpenDSS for the calculation of three phase power flow. The simulation allows to analyze the power flows of the feeder without PV generation and further with the DGs, Results indicate that integrating DGs not only reduces the total power losses in the distributed system but improves the voltage profile as well.

Keywords— PV generation, time-series steady-state power flow, optimization, OpenDSS.

I. Introduction

The persistent rise in power demand is saturating the capacity of distribution networks in many regions; however, this situation can be alleviated by connecting distributed generators (DGs) in the form of firm generation or intermittent renewable energy sources such as wind and solar farms [1]. It is well known that DGs in a distribution network can compensate for transmission network energy demand, improve voltage profile in feeders, increase reliability, and reduce losses. the addition of DG systems causes changes in the distribution grid that create a number of technical challenges [2]. A true description of grid behaviour also requires advanced studies and trustworthy algorithms due to the complexity of these new systems' modelling, Due to complex methods with graphical interfaces that have developed from basic voltage drop calculators of balanced loads, grid characteristics can be determined and quantified [3].

In the first section, a time-series simulation will be run through MATLAB/OpenDSS co-simulation to visualize the active and reactive powers without integrating DGs, and in the second section, two PV systems were integrated to the network, as well as its performances were analysed. This paper assesses the impact of PV systems on power losses and voltages in three-phased unbalanced networks.

II. OPENDSS SIMULATION PLATFORM

A. OpenDSS software

The American Electric Power Research Institute created OpenDSS (The Open Distribution System Simulator), a modelling and simulating tool for distribution systems.

The OpenDSS is a simulator created particularly to simulate electrical power distribution systems. The majority of power distribution planning analyses related to the connecting of distributed generation (DG) to utility networks are supported by OpenDSS. Additionally, it enables a wide variety of additional frequency-domain circuit simulations that are frequently carried out on utility electric power distribution systems. Compared to many other tools, including commercial solutions, it depicts imbalanced circumstances, stochastic processes, and other features of electrical power distribution networks and equipment in far more detail. Other programs can use OpenDSS to drive highly customized simulations, Monte Carlo analysis, etc. through COM and scripting interfaces. Through automated processes, scripting, or dynamic linking, users can define their own models [4].
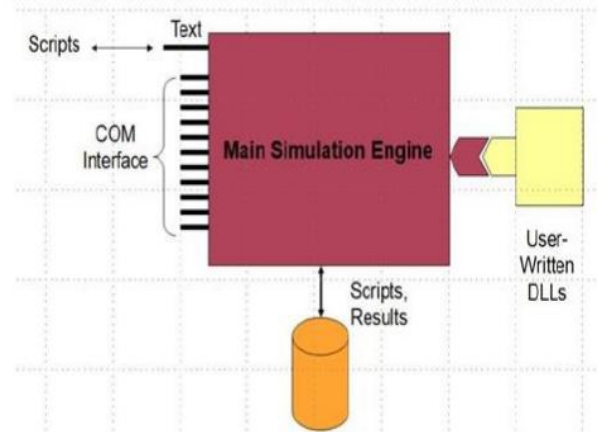

Fig. 1. OpenDSS structure[5].

B. PV System Element Model for OpenDSS

A schematic of the photovoltaic system model used by the OpenDSS program is shown in Figure 2. The present version of the model combines the generator photovoltaic and the inverter to perform simulations with a time interval greater than or equal to 1 second. Thus, it is assuming that the inverter can quickly determine the maximum power point (MP) of the panel, simplifying the individual, solar panel, and inverter component modelling. The majority of research involving connections with the distribution network ought to be compatible with this strategy [6].
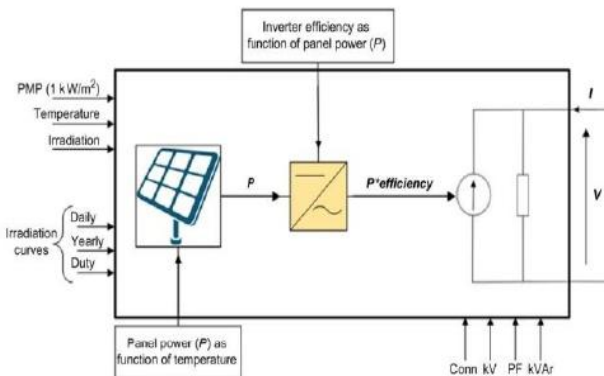

Fig. 2. The PVSystem Component Model Block Diagram [5].

The photovoltaic system is an energy conversion element. Basically, the model has an active power injected at the interconnection point P, which is a function of irradiation, temperature, converter efficiency, network voltage and the Panel's nominal power at the point of maximum power (Pmp). A Pmp applied at the required temperature (25°C), and an irradiation of $1, 0kW/m2$, the power value at the panel output in an instant $t0$, is calculated as follow [7]:

$$P(t0) = Pmp(1kW / m^2).irrad(pu)(t\,0).irrad(base).Pmp(pu,T(t\,0)) \quad (1)$$

P: Panel output power

Pmp(1KW/m^2): Maximum power at the rated power level

Irrad(pu)(t0): Irradiance value in pu at the moment $t0$

Irrad(base): Maximum irradiance value on the selected day

Pmp(pu,T(t0)) : Pmp correction factor as a function of temperature at the time $t0$

The active power supplied by the photovoltaic system is presented in Equation 2:

$$P_{active}(t) = P(t).eff(P_{active}(t)) \quad (2)$$

eff (P$_{active}$ (t)): Inverter efficiency for a given output power

Separately from the active power, reactive power is specified. It can be specified as fixed KVAR values or fixed power factor values. The model maintains a constant output power factor if the PF parameter is specified until the PF property is updated (default mode). Regardless of the current value of the panel power, if the Kvar attribute is given, it is assumed that the inverter will maintain that value. If the inverter's rated kVA is exceeded, the actual KVAR output is reduced [6].

C. Volt-VAR Control

Several articles have recently discussed the feasibility of integrating VAR control capability with PV inverters for network assistance. Due to the irregular behavior of PV output, high PV penetration results in a high level of unpredictability in the operation of distribution feeder every hour and day.

This is due to the PV output's reliance on solar energy that reaches the earth's surface and is captured by solar panels. This has a significant effect on the feeder's voltage profile and power flow. A low PV output on a foggy day combined with heavy grid usage results in a low voltage profile in the feeder.

oltage regulators and tap changers that maintain voltage levels during variations or switching capacitor banks that lower reactive power in the feeder when ON or enhance reactive power in the feeder when OFF are the classic methods for managing fluctuating feeder voltage. The issue of variable voltage is even more of a worry in micro-grids, which are radial in design [8].

Autonomous smart PV Unwanted oscillations brought on by interactions between the system's installed smart PVs may be produced through volt-var regulation. Such oscillations are depicted in Figure 3 by quasi-static time-series simulations carried out in OpenDSS for a secondary residential feeder in the actual world with a high penetration of smart PVs [5]. In response to an overvoltage condition that began after one cycle, the oscillation results for two distinct Volt-Var control settings (gentle and aggressive) are displayed. This PV, together with the other PVs, absorbs reactive power when there is an abrupt overvoltage in order to balance it. The voltage changes as a result of the new reactive power output, which changes the reactive power, and so forth [9].
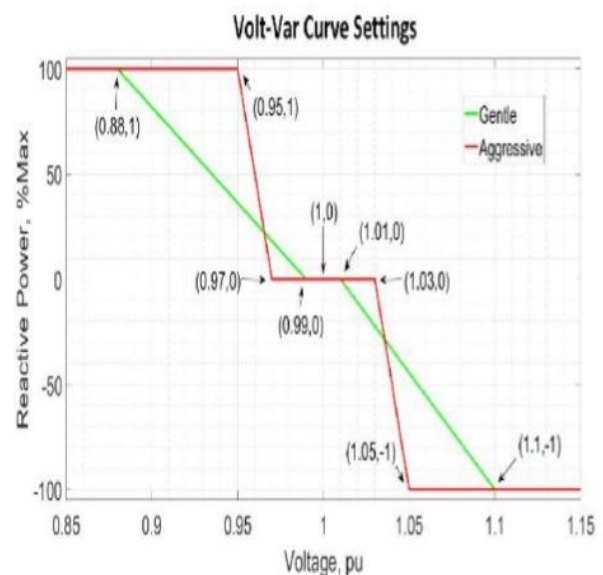

Fig. 3. Volt-Var curve.

D.   MODELING FRAMEWORK

As seen in Figure 1, MATLAB was used to set and maintain the data for irradiance, and load power. OpenDSS was then utilized to determine the three-phase power flow.

The result is a collection of solutions that can be analysed and used to determine additional performance and reliability indicators for samples of load demand and weather.
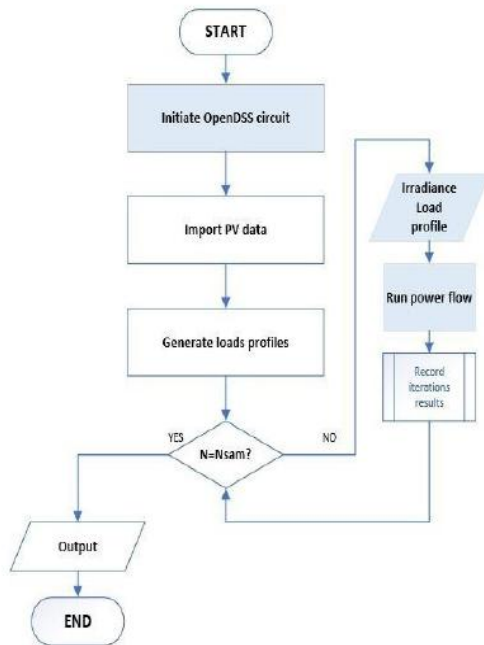

Fig.4 Process of iterative simulation into general diagram.

III. CASE STUDY

For analysis, an IEEE13 Bus Node Feeder is employed. A one-line diagram of the IEEE Node Test Feeder is shown in Figure 5. Despite being relatively little, this feeder has several fascinating qualities. In reality, it shows a rough representation of the small radial feeder for the most typical distribution system characteristic [10].

The testeIEEE13 bus network features unbalanced three-phase overhead and underground lines, single-phase, two-phase and three-phase branches, two three-phase distribution transformers, localized loads and one distributed load, two shunt capacitor banks and a regulator connected in star.

For this work, which will be simulated through OpenDSS derived trough MATLAB, the powers and voltages behaviours through the insertion of PV system will be discussed, for this, the system has been analysed before the insertion of distributed generation for comparison purposes.
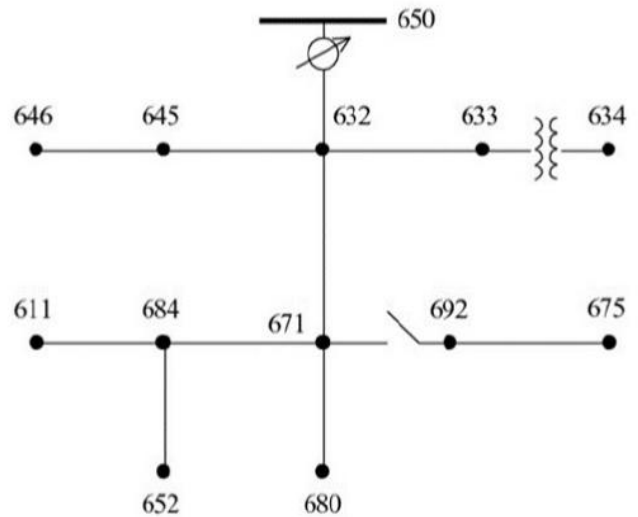

Fig.5. IEEE 13 Node Test Feeder Diagram.

IV. SIMULATION RESULTS

A. Daily simulation for IEEE13 node test feeder with no PV

In this simulation, only the substation supplies power to the loads. The electrical power supplied by the substation is shown in Figures.
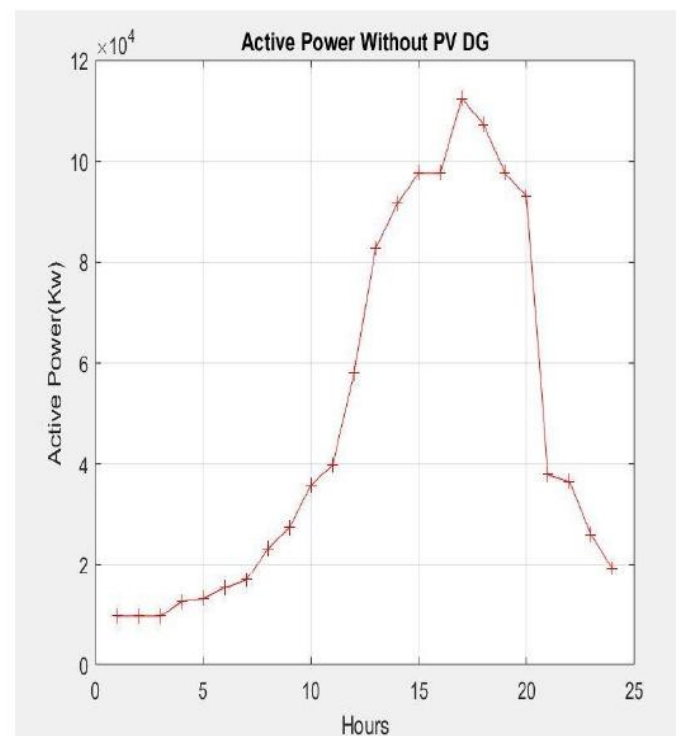

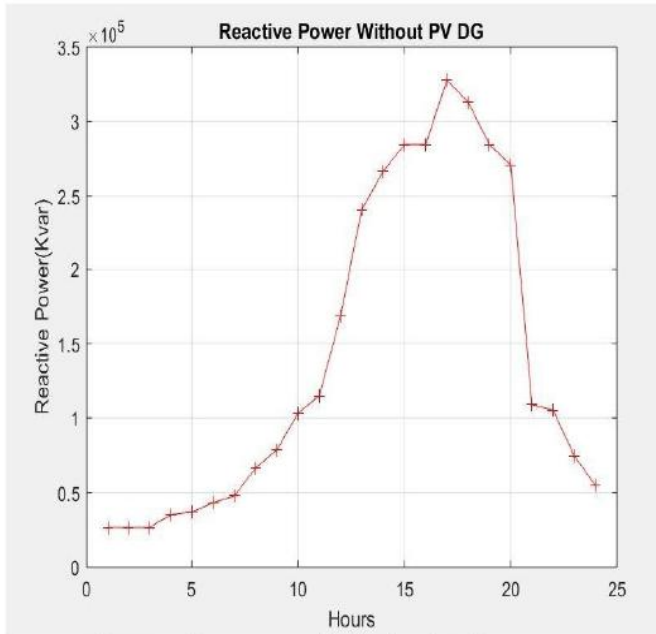Fig.6. active power provided by the substation.

Fig. 7. Reactive power provided by the substation.

- Voltages without PV generation

Fig.8. 24-hour voltage variation at bus 680
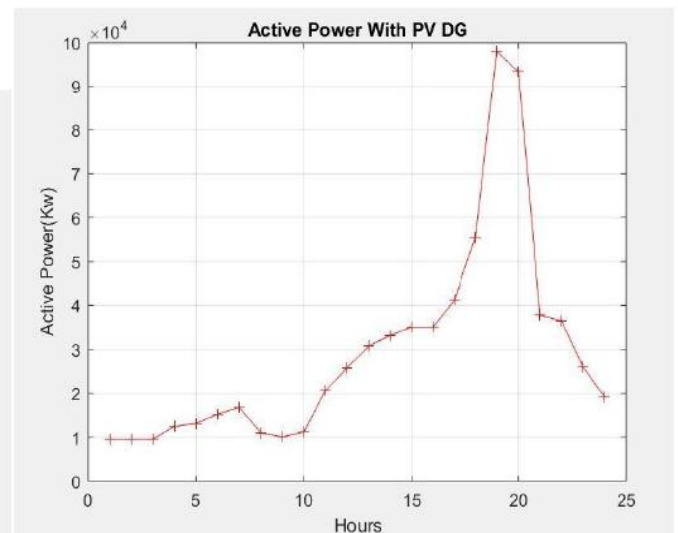
B. Daily simulation for IEEE13 node test feeder with PV insertion

In order to evaluate the performance of the network in the presence of GD, two PV systems are connected controlled through volt-var regulation to both buses number 680 and bus number 671. The IEEE 13 Node Test Feeder is short, somewhat densely loaded, and has a total of 9 unbalanced loads. The PV generators was given a power rating of 1500 KW. The irradiance and loads data for each time step

are controlled on MATLAB and transmitted to OpenDSS for the calculation of the power flow.

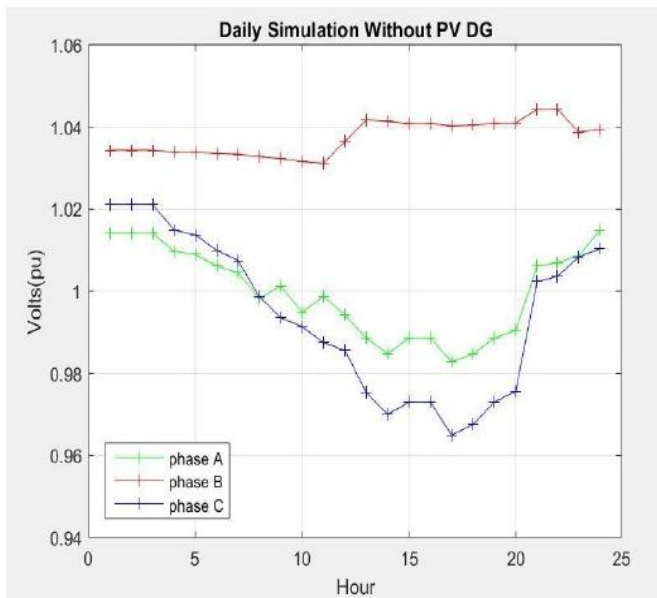Fig.9. the IEEE13 bus feeder diagram with the presence of the PV system

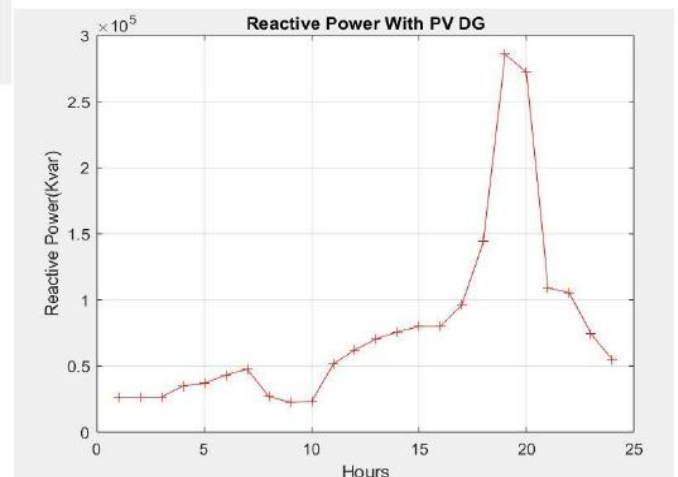Fig. 10. Active power supplied by the substation with the presence of the PV System

Fig.11.Reactive power provided by the substation with the presence of the PVsystem

On the periods when there is irradiation, it can be noted that the active power delivered by the substation after integrating the PV system is lower than the active power before PV system insertion. The reactive power has also changed, is it lower than the reactive power delivered by the substation.
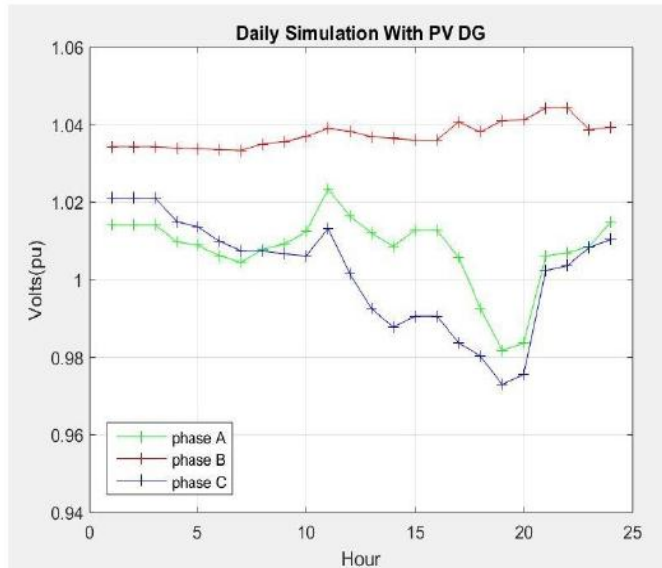
• **Voltages with PV generation:**

Fig.12. 24-hour voltage variance at bus 680's place of insertion.

• **Power losses comparison:**

	Without PV DG	With PV DG
Active power losses (MW)	1.1705	0.70747
Reactive power losses (MVAR)	3.3908	1.8773

when comparing the voltages in the presence of PV system with the voltages before the PV system insertion, presented in figure 8, it can be seen that the voltages remain unbalanced due to the fact that the PV systems provide balanced three-phase power, that is, identical in each phase. The voltages has been improved, as a PV system is connected.

V. CONCLUSION

This work's major objective is to examine the time-series behaviour of the distribution network. This study uses the OpenDSS simulation platform, which is driven by MATLAB, to discuss the effects of DG on the distribution network when low-renewable PV (photovoltaic) systems are incorporated. According to the outcomes of the time-series study of the IEEE13 feeder, grid-connected PV systems can significantly lower peak loads and enhance voltage profiles. However, incorporating wind generators and then performing time-series analysis could extend the proposed case study.

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