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A Technical investigation of the Impacts of PV location and the Role of BESS on stability of the Grid: A case of a Cameroonian Network

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ABSTRACT

As solar photovoltaic (PV) technologies continue to evolve; their integration into electric grids demands precise modelling to preserve system stability. Currently, the Cameroonian Southern Interconnected Network (SIN) lacks solar PV interconnection. The main objective of this research was to evaluate the impacts of PV integration on the stability of the Cameroonian southern interconnected network (SIN), and to determine the impact of energy storage in seamless PV integration. The specific objectives were: to develop detailed models of both the SIN using collected data and a 30 MW grid-tied PV system for impacts analysis; to assess the influence of PV with battery storage location on grid stability. Data was obtained from energy of Cameroon records and interviews of energy professionals. Modelling and simulations were conducted using distribution system simulator (DSS for the SIN) and PVSyst (for the PV system). The 30 MW PV location scenarios were simulated. Locating three PV plants at three different places in the distribution network was found to be the best scenario, and achieved highest reductions in power losses, voltage deviation index (VDI), and voltage violation index (VVI) of 2.261 MW, 0.23% and 0.56% respectively. This paper gives insights of roadmap to PV integration into the SIN and recommends more of this type of studies for the country in order to accelerate the integration process.

Key Words: Energy storage systems, Power stability, Renewable energies, PV integration impacts.

1. INTRODUCTION

Global interest in green energy in general has registered an incredible increase. Solar energy in particular is getting more and more credit for its role in energy industry [1-3]. Cameroon is looking forward to implementing a solar PV electrification of some cities under a program named Cameroon 2020 Photovoltaic Power Project. Cameroon 2020 Photovoltaic Power Project targets standalone rural villages as well as grid-connected urban underserved populations. In the Cameroon 2020 Photovoltaic Power Project initiative the government targets to develop 500 MW of installed PV capacity throughout the country in future [4].

The intermittency characteristics of photovoltaic distributed generation PVDG give rise to impacts requiring different responses than those of conventional DG. Due to the variability caused by passing clouds, PVDG can significantly affect voltage control, power quality, and system operation [5][6]. A lot of studies were conducted on different approaches of PV systems integration which vary from rooftop, building integrated PV (BIPV), to large scale grid-tie PV systems. For instance simple rooftop and BIPV were designed and evaluated in [7], [8], [9]. In [9] a hybrid microgrid composed of PV and a wind turbine was designed for the Electrical, Electronic and Communication Engineering (EECE) department at Pabna University of Science and Technology (PUST), in Bangladesh. Both electrical parameters behaviour and financial analysis were performed with interaction with the grid, and the results showed that the parameters remained steady which makes the design practical. In [10] both rooftop and BIPV were considered and the use of both mathematical and evolutionary algorithms to combine them into an optimal system that achieved both grid reliability and reduction of energy fluctuations. The authors of [11] identified a BIPV with greenary (BIPVGREEN), and conducted a SWOT analysis for synergetic, performance, cost and CO2 emissions. The results proved the system to be effective regarding energy efficiency, decarbonisation, which makes it suitable for urban and informal settlements.

With proper planning PV renewable energies provide ancillary services that are crucial to electrical networks operation[10]. However the main issues coming with PV integration are; voltage variations and imbalances, current and voltage harmonics, grid islanding protection, and other power quality issues, such as flicker and stress on distribution transformer[5], [11],[12].

In this study PV integration impacts in the context of Cameroon were identified. A test case of the southern interconnected network of Cameroon was modelled together with a 30 MW PV system to verify some of the literature findings. This research will introduce new study tools and methodologies to help Cameroonian utility engineers to investigate the potential impact of these new types of generation on the grid.

2. LITERATURE REVIEW

2.1 Solar Energy status in Cameroon

Studies about solar energy potential in Cameroon[4], [13], group solar energy in the country into two categories. First, the highest solar energy intensity is in the Northern and Southern regions of the country with estimates of 5.8 and 4 kWh/day/m^2 respectively. It was found that it can go up to a quite encouraging values of 4.9 kWh/day/ m^2 possible in the southern regions (F. Abanda 2012). According to the study, the whole country possesses great solar energy potentials with some regions far above the required average to generate useful energy. Figure 2.1 maps the photovoltaic power potential in the country.

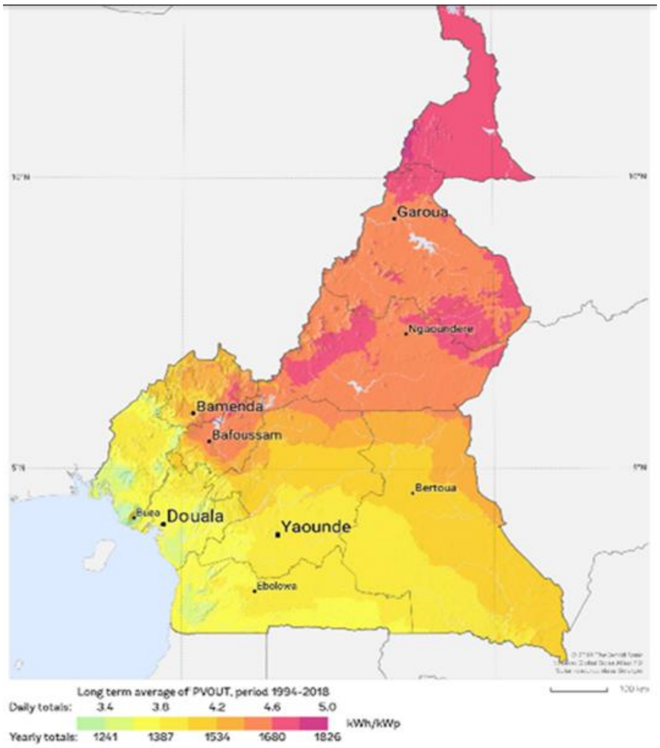

Figure 2.1: PV power potential for Cameroon (kWh/kWp).

The country is endowed with substantial RE potential, however, only a very limited percentage of this RE potential is exploited so far. In 2021 apart from hydropower other RE contributed less than 1% to the Cameroon's energy mix. Currently Cameroon has only two grid-connected solar PV plants; the Maroua and Guider solar power plants inaugurated in September 2023 with 36 MW installed capacity and a 20 MW/19MWh battery storage system between them. Both plants inject 80 GWh/year into the northern interconnected network, and contributes to carbon emissions reduction with approximately 60,000 tonnes of saved emissions per year[14]. In the southern zone, Sangmelima and Meyomessala are presently the only two localities, which are benefiting electricity from off-grid solar PV. The Southern interconnected network covers more than 93% of the total electricity supply but has no PV integration so far. One of the main reasons of this slow solar energy exploitation is deficit in technical studies, which assist in investigating the potential impacts of these new types of generation on the grid and eventually make proper plan for their integration.

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2.2 Overview of PV location and size influence on the stability

2.2.1 Voltage fluctuations

In researches [15]-[28] the authors illustrated the impact of PV systems on existing grid's voltage depending on the PV penetration level, and locations. In [15] I. El-Amin et al. conducted a PV integration study whereby the PV penetration levels were changed to analyse the possible changes in the grid parameters. The results from this particular study proved that if the penetration level of a renewable source of generation increases, the voltage at different buses of the micro-grid system also increases with a significant increase at the point of common coupling PCC. It was also observed that if the voltage at a particular bus is low due to an increased load at that bus, then a PV generation system can be connected to that bus in order to compensate for the decrease in the voltage. In a similar research intended to investigate the voltage fluctuation severity J. Wong et al. [26] connected a7.2kWp PV system to a laboratory distribution network in Malaysia. The voltage magnitude have been measured and recorded on a regular basis over a period of time. The results from this study showed that, as long as the single phase PV power output is greater than 4kW, the voltage at PCC is likely to violate its statutory limit. Higher flicker values were predicted for year 2050, due to the higher installed PV capacity in that year.

2.2.2 Overvoltage

In [17] S. Solanki et al. performed impact study simulations using the modified real-world test distribution feeder circuit, which was one of the test feeders published by the Electric Power Research Institute. The results illustrated that the traditional utility concern of under-voltage at remote locations on the feeder ('no PV' scenario) changes with the inclusion of PV to the extent where overvoltage becomes a new concern. In particular during times of PV peak productions over-voltages went higher than 10% above nominal values. Lowering the voltage set point of the regulator was proposed and studied under various penetration levels, as a solution to improve voltage profiles during lightly/heavily loaded hours along all the nodes of the feeder. J. Schoene et al. in[18], modelled a distribution network in distribution system simulator (OpenDSS) software for PV integration impact analysis, with different PV penetration levels (10%, 30%,50%). The results proved that unlike the other penetration levels as the penetration level increase to 50%, the voltage deviation in the downstream nodes of the Lovell circuit becomes considerable and cannot be mitigated with the existing regulator and capacitor controls. It was also noticed that without PV the voltage profile of the Highland circuit remained unaffected. The study aim was apparently to identify the PV integration voltage stability challenges.

2.2.3 Voltage Drops

The work in[19] conducted by G. Krishnamoorthy et al. proposed a transmission and distribution (T&D) co-simulation framework using both OpenDSS and MATLAB, to assess the impact of PV system penetration on the transmission network. Different PV deployment scenarios where considered using the Monte Carlo approach. The transmission test system model was comprised of IEEE 9-bus test system with three generators at buses 1 (slack), 2 and 3, three loads at buses 5, 6 and 8. A circuit named as EPRI Ckt-24 was used as the distribution test system. The study showed that the transmission voltages at the point of common coupling (PCC) decreases after 50% of PV penetration, which was justified by the slack generator acting as a load to balance the supply and demand. No mitigation approach was suggested by the authors. N. Tyutyundzhiev et al in [20]studied power fluctuations induced by rooftop PV generator on a building LV electrical grid. The study focus was to investigate the bilateral impact between decentralized generator and LV grid. Simulation results showed that 3 x 2 kW PV power injection in LV grid of a building can induce voltage drop of 0.7 V per phase. THD produced by inverters exhibits low level of distortion.

2.2.4 Power losses

R. Singh and P. Tripathi [21] studied and analysed the Impact of Solar Photovoltaic integration in Distribution Network. A modified IEEE bus test was considered in simulations that were intended to analyse the impact of PV integration on the system voltage profile, online load tap changer (OLTC), and system losses. The test system was taken for the analysis and PV was integrated to load buses with different penetration level. It was identified that with increase of PV penetration in the low voltage distribution system, the voltage of the system increases and after a certain level of penetration the voltage limits gets violated. It was also noticed that the integration of the PV in distribution system minimizes the overall power losses in the system by reducing the total power demand from the substation. But as the integration of the PV increases beyond of a certain limit the system losses start increasing.

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3. OBJECTIVES

The objectives of this research were to model the Southern Interconnected Network of Cameroon and a 30 MW PV system, and then identify the impacts of the PV system on the power stability and reliability when different locations are considered.

4. METHODOLOGY

3.1 Modelling the Southern Interconnected Network and a Grid-tie PV System

The SIN is the largest of the three interconnected network of the country. The production in the SIN consists mainly of three hydroelectric power plants with productions as follows; Songloulou (384 MW), Edéa (276MW) and, Menvele (90MW) out of its 211MW installed capacity. These three plants are complimented by the Kribi natural gas power plant and six main thermal plants with total installed capacity of 569 MW. The transmission is done at 225kV and 90kV approximately, using either aluminium cable steel reinforced (ACSR), all aluminium cable (AAC), or copper cables. The total transmission network consists of 1064 km 90kV lines and 480km 225kV lines supplying 20 substations [35]. The distribution is done at 30kV, 15kV and 5.5kV by either aluminium cable steel reinforced (ACSR), all aluminium cable (AAC) and it covers 11,450 km for the whole country [22]. The network counts a total of 23 three phase two winding step up transformers and 44 distribution transformers which are either two or three winding three phase transformers. A total load of 842.831 MW distributed at different substations was considered for the network modelling. Capacitor banks for reactive power compensation were also available for modelling and were taken into account. All the quantitative information used in the model was collected from the network operators, energy of Cameroon (ENEO) records, and other secondary source of data. The general modelling of the SIN was done using OpenDSS software with a Matlab software interface for simulations. In addition to the southern interconnected network model which actually doesn't have any integrated PV system, a 30 MW PV system was modelled in PVSyst software for impacts analysis purpose.

3.2 Scenarios definition

Different scenarios regarding impacts of PV location on the stability were considered as following:

1st case scenario: the 30MW PV system is placed at a single location in transmission network and power flow simulation run for impacts of location.

2nd case scenario: the 30MW PV system is subdivided into three equal systems of 10MW, and placed at three different locations in the transmission network and power flow simulation run for impacts of location.

3rd case scenario: the 30MW PV system is placed at a single location in the distribution network and power flow simulation run for location impacts.

4th case scenario: the 30MW PV system is subdivided into three equal systems of 10MW, and placed at three different locations in the distribution network and power flow simulation run for impacts of location.

The simulations consisted of steady state ones which are based on power flow formulas and snapshot of the state of the network at a given time. The best case scenario was determined in all the above scenarios based on the individual impacts on the stability of the network, and then the role of battery energy storage in seamless PV integration was determined.

5. RESULT AND DISCUSSION

Simulations results for voltage profile, currents through the lines, and power losses are presented and analysed in this section. Various PV locations scenarios were considered for the simulations as defined in the methodology.

5.1 Results for the 30 MW PV system at a single location in the transmission network

The 30 MW PV system was connected to the B90NGOUS bus which is one the transmission buses supplying power to substations with high load level and high voltage drops. Power flow simulation was carried out in OpenDSS to check for impacts of this PV interconnection.

Figure 4.1 shows voltage profiles for both the base case scenario (no PV) as reference and the first PV location case scenario, while Figure 4.2 provides currents comparisons.

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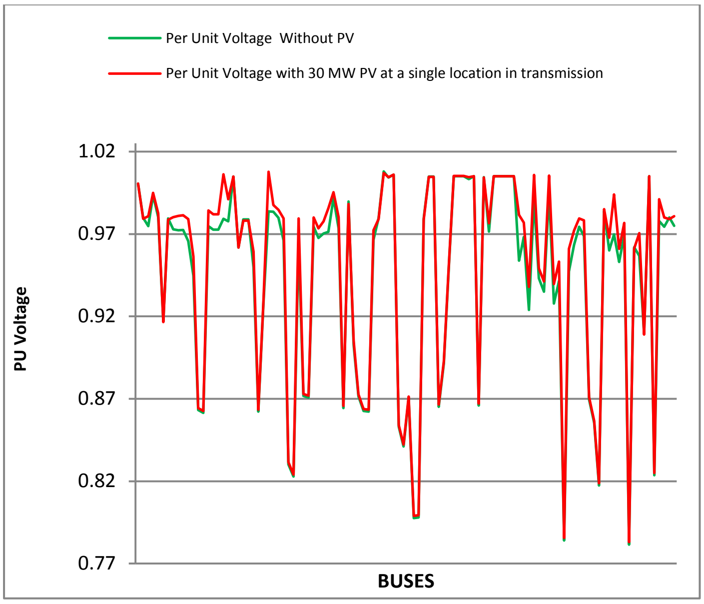

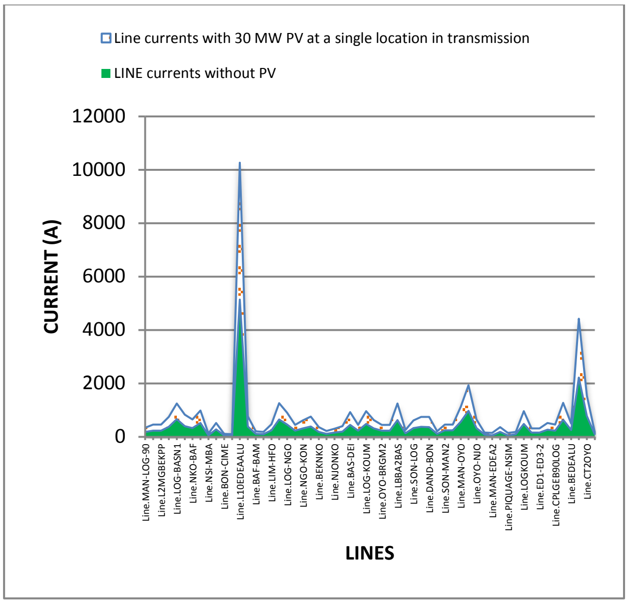

Figure 4.1 Figure 4.2

Figure 4.1: Voltage profile with PV at a single location in transmission network.

Figure 4.2: Line currents with PV at a single location in transmission network.

The voltage profile simulation results for both the base case and with 30MW PV at a single location in the transmission network scenarios as presented in Fig. 4.1 prove that the injection of 30 MW PV solar energy as in this case slightly improves the voltage profile as compared to the no PV case. Two voltage metrics namely; voltage deviation index which is a measure of how much the voltages deviate from the nominal value (1.0 pu), and voltage violation index which is a measure of how much the voltages violate the permissible boundaries (0.95 and 105 pu), were calculated from the detailed results using Eq. (1) and Eq. (2) to evaluate the impact of PV on the voltage profile improvement. The values of the above indices together with the lowest and highest per unit voltages in the two scenarios were tabulated in Table 4.1. For both indices the smaller the value the better voltage profile.

$$VDI = \frac{\sum |V_i - V_{nom}|}{n \times V_{nom}} \qquad (1)$$

With VDI: voltage deviation index, V_i: per unit bus voltage, V_{nom}: per unit nominal voltage, and n: number of buses in the network.

$$VVI = \frac{\sum |V_i - V_{bound}|}{n \times V_{bound}} \qquad (2)$$

With VVI: voltage violation index, V_i: per unit bus voltage with boundary violation, V_{bound}: per unit permissible voltage boundaries, and n: number of buses with voltage violation in the network.

Table 4-1: Voltage Improvement analysis with PV at a single location in transmission

	NO PV	**PV at a single location in transmission**
Min. Per unit voltage	0.78158	0.78221
Max. Per unit voltage	1.008	1.008
Voltage Deviation Index	5.68%	5.61%
Voltage Violation Index	8.26%	8.19%

The voltage improvement comparison in table 4.1 reveals that installing 30 MW PV system at a single location in SIN's transmission network may achieve a slight contribution in overall voltage profile improvement with reductions of 0.07% in both voltage deviation and voltage violation indices. The injection of the PV system also reduces the voltage drop by 0.00063 pu as shown by the comparison of lowest per unit voltages for the two scenarios.

Currents results comparison for the base case scenario and PV at a single location in transmission scenario as shown in Fig. 4.2; there are some slight increases in most of the line currents especially for the heavily loaded ones. For instance a current increase from 5132.63 A to 5132.65 A on the L10EDEAALU line is noticed but generally this no much

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impact of this PV integration scenario on the line currents, and this is explained by the fact that the injection of this amount of PV in the transmission network that already has a stiff slack generator doesn't change much on the conventional centralized power flow from source to loads.

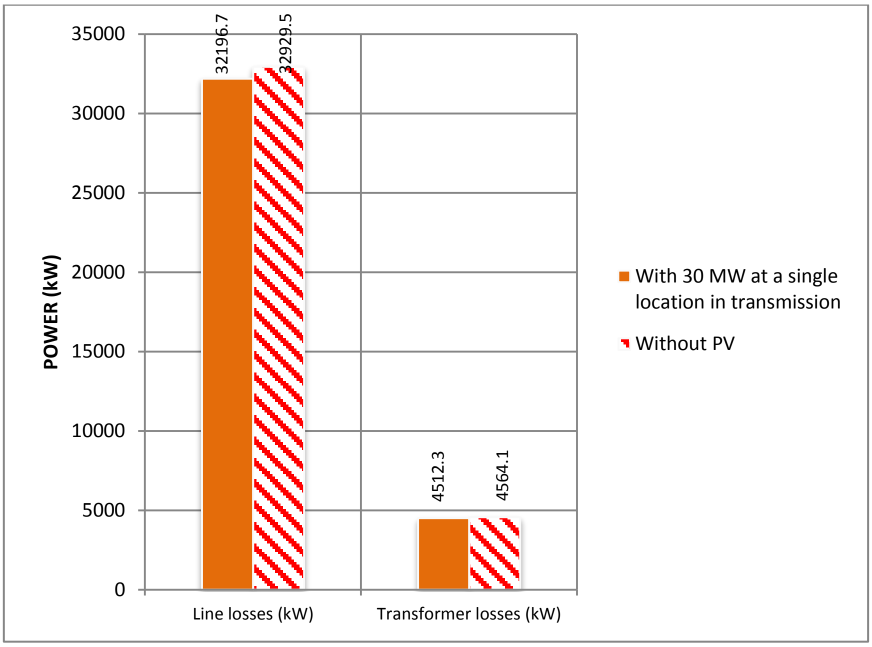


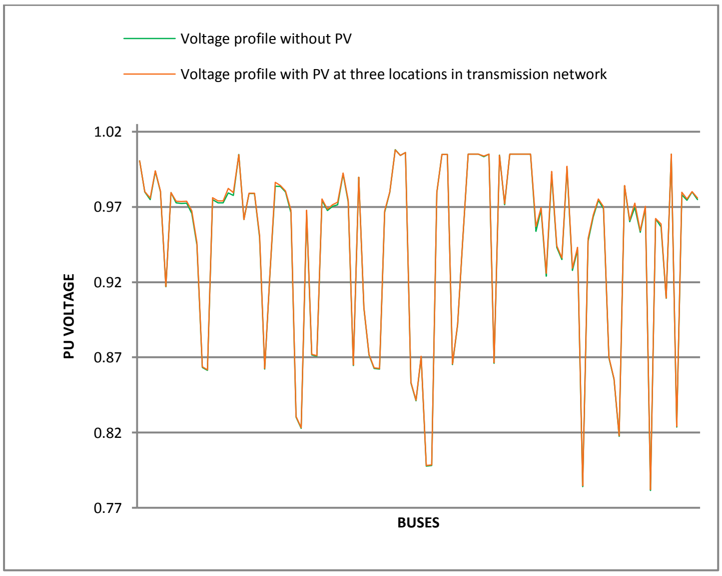
Figure 4.3: Power losses with PV at a single location in transmission network.

From the power losses results summarized in Fig. 4.11, there is a reduction of 784.6 kW in the cumulative power losses for the network due to PV integration according to this case scenario. The reduction is a result of some of power that is taken from the other existing generators to this PV point of common coupling which is replaced by the one from PV plant. Therefore some losses due to power transmission and transformers are cancelled by the PV injection.

5.2 Results for the 10 MW PV systems at three locations in the transmission network

For the simulation of the PV location scenario three locations namely; B90BASSA, B90BEKO, and B90LIMBE were selected to accommodate three equal PV systems of 10 MW each. The buses selection was done on the basis of their connection to high load and either their levels of voltage drop or the level at adjacent distribution buses. These buses supply their power to significant substations with high loads and therefore with important levels of voltage drops.

Both voltage profile results for the base case scenario and PV at three locations in the distribution network case scenario are graphically represented in Fig. 4.4. The per unit representations on the different voltage bases found in the southern interconnected network were used for better graphical distinction of the parameters.



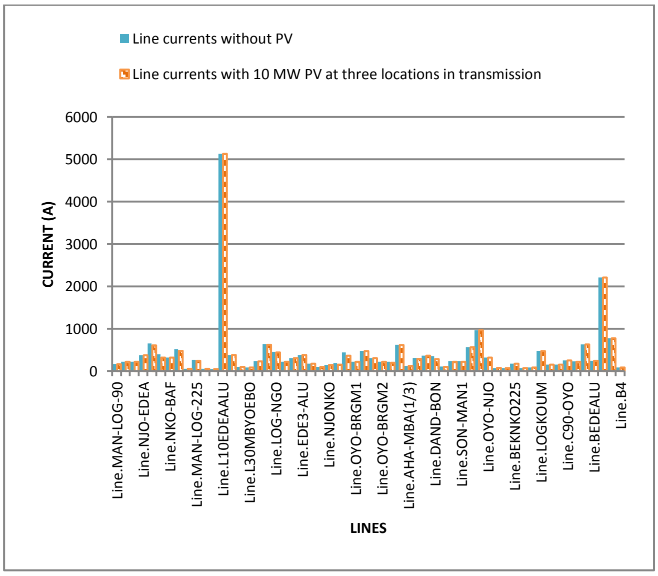


Figure 4.4 Figure 4.5

Figure 4.4: Voltage profile with PV at three locations in transmission network.

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Figure 4.5: Line currents with PV at three locations in transmission network.

Installing three PV systems of 10 MW each at three locations in the transmission network has a very slight impact on the voltage profile as it can be seen from Fig. 4.4. A slight voltage profile improvement is noticeable from the graphs, but for clear identification of PV integration impact on voltages in this case scenario again both voltage deviation and voltage violation indices were calculated using Eq. (1) and Eq. (2) respectively. A comparative voltage improvement analysis for this case is done through the results of table 4.2 that presents the values for the two indices and both the minimum and maximum per unit voltages.

Table 4-2: Voltage Improvement analysis with PV at three locations in transmission

	NO PV	PV at three locations in transmission
Min. Per unit voltage	0.78158	0.78212
Max. Per unit voltage	1.008	1.0079
Voltage Deviation Index	5.68%	5.6%
Voltage Violation Index	8.26%	8.19%

From table 4.2 comparison it is obvious that integrating three PV systems of 10 MW each at three different locations in the transmission network decreases both the lowest voltage drop and the highest overvoltage by 0.00054 pu and 0.0001 pu respectively. The voltage improvement measures in this case scenario show reductions in both voltage deviation and voltage violation indices of 0.08% and 0.07% respectively. The above mentioned results are calculated in comparison with the base case scenario.

The line currents results presented in Fig. 4.5 show that connecting three PV plants at three locations in the transmission network slightly increases most of the line currents, and this is because this PV location scenario doesn't change already existing power flow direction but emphasizes it. On the other side some few lines experienced slight decreases in currents depending on their locations with respect to the PV plants locations. In the above category we can see lines BAS-DEIDO and DANG-BON that saw their initial currents reduced by 45.228 A and 41.761 A respectively as well as some few others with slight changes. Current reductions in the above sample lines is due to that the first one is directly connected to the B90BASSA bus that accommodates one of the PV plants in this scenario and the second is another neighbouring line which has some far connection to the B90BEKO, another bus used to accommodate PV plant in this simulation.

The cumulative power losses simulation results for this scenario with three PV systems connected at three different locations in the transmission network are illustrated in Fig. 4.6 in comparison with those of the base case scenario.

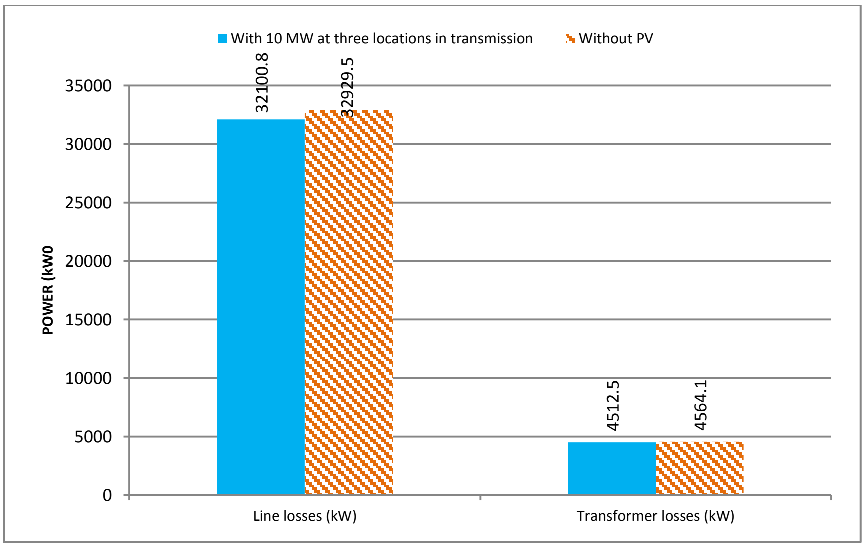

Figure 4.6: Power losses with PV at three locations in transmission network.

A power losses reduction of 880.3 kW was achieved through installing three PV plants at three different locations in the transmission network as illustrated by Fig. 4.6. It can be seen that more losses reduction were achieved as compared to the previous PV integration scenario and this is because the more you distribute the PV plants, the lesser power transported for long distances and therefore the losses are minimized.

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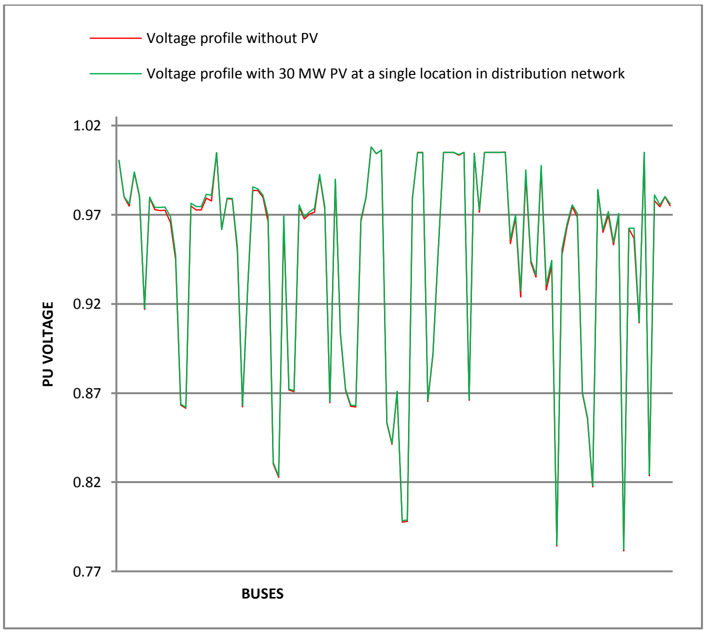
5.3 Results with the 30 MW PV system at a single location in the distribution network

For this PV location case scenario, a single location in the distribution network was selected to accommodate the 30 MW PV systems. The selected bus is the B30BEKOKO which due to being a power dispatching station is connected to a very high power demand. Again power flow simulation was carried out in OpenDSS software environment.

The voltage profile simulation results for this PV location case scenario with the 30 MW PV solar systems at a single location in the distribution network are graphically presented in Fig. 4.7. The voltage profile values at different buses are all in per unit representations and the base case scenario results are included for comparison. Figure 4.8 illustrates the currents results.



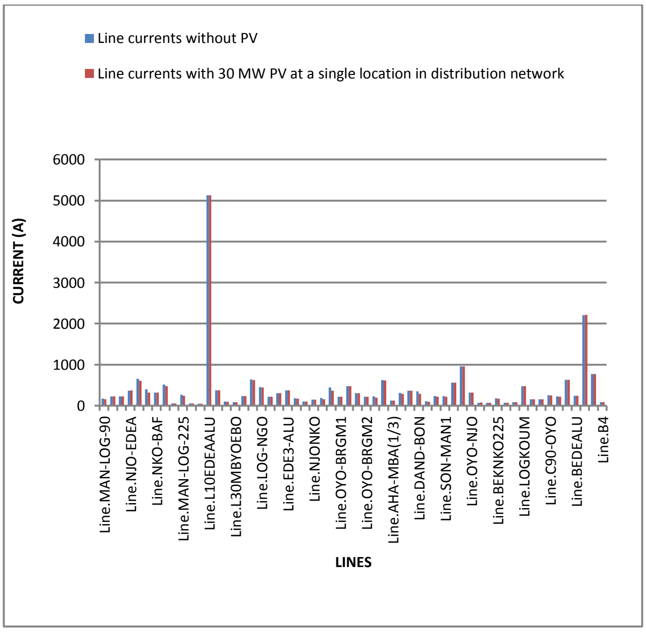


Figure 4.7 **Figure 4.8**

Figure 4.7: Voltage profile with PV at a single location in distribution network.

Figure 4.8: Line currents with PV at a single location in distribution network.

In this scenario whereby the 30 MW PV plant is installed at a single location in the distribution network, the voltage simulation results in Fig. 4.7 show some improvement in the voltage profile. Again Eq. (1) and Eq. (2) were used find out how much the PV plant has improved the voltages through the voltage deviation and voltage violation indices calculations. The analysis of the impact of this PV integration is based on comparing the voltage related quantities in table 4.3.

Table 4-3: Voltage Improvement analysis with PV at a single location in distribution

	NO PV	PV at three locations in transmission
Min. Per unit voltage	0.78158	0.78236
Max. Per unit voltage	1.008	1.008
Voltage Deviation Index	5.68%	5.57%
Voltage Violation Index	8.26%	8.15%

From table 4.3 comparison we can see the integration of a 30 MW PV system at a single location in the distribution network achieved a decrease in the lowest voltage drop of 0.00078 pu. This PV integration scenario also achieved voltage improvement by reducing both voltage deviation and voltage violation indices by 0.11%. The base case scenario voltage metrics were used in comparison in this analysis.

Results of Fig. 4.8 show that there are slight decreases in all line currents due to installation of the 30 MW PV plant at single location in the distribution network. The magnitude of the decreases depends on the positions of carrying lines with respect to PV plant. Currents are only decreased because most of the lines used in modelling are transmission ones, therefore installing a PV plant in the distribution network makes the currents flow in opposite directions to the initial ones which result in decreases.

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Cumulative network power losses with 30 MW PV integration at a single location in distribution network, together with the same type of results for the network without PV are summarized in Fig. 4.9.

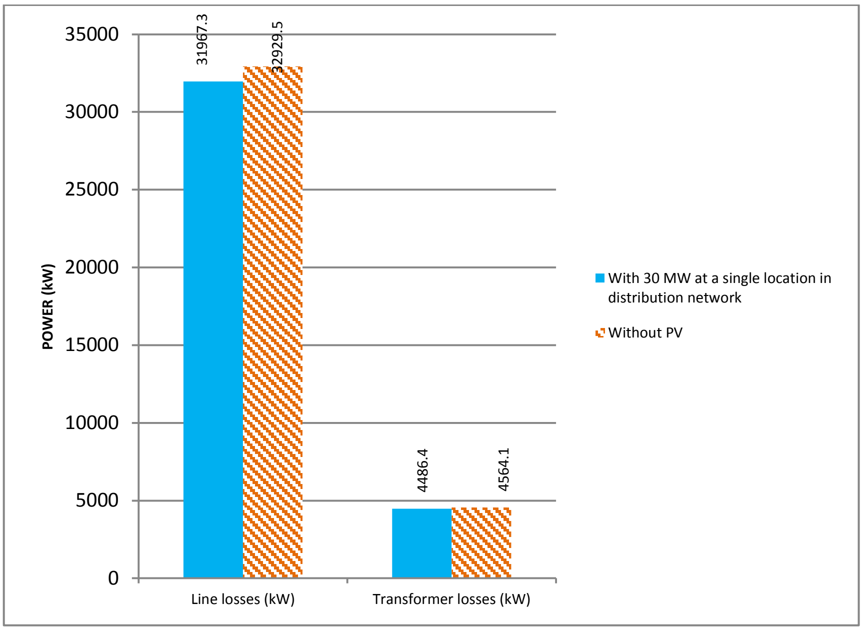

Figure 4.9: Power losses with PV at a single location in distribution network.

Installing PV systems in the distribution network means bringing power close to the end users and this affects positively the power losses. In this scenario with 30 MW PV plant at a single location in the distribution network, the power losses results presented in Fig. 4.9 show that a significant power losses reduction of 1039.9 kW (1.0399 MW) is achieved as compared to the no PV scenario. The reduction is a result of a portion of power required by the load which is taken from the PV plant without moving long distances.

5.4 Simulation Results with 10 MW PV Systems at three locations in distribution network

Simulation for this PV location case scenario were conducted considering the 30 MW PV equally subdivided into three systems and placed at three selected locations in the distribution network. The selected locations for the above purpose are the B10ALU, B15NGOUS1, and B15BASS21 buses. These are the buses that registered the most voltage drops during the simulation of the base case scenario and they have very high power demands connected to them.
Figure 4.10a and Figure 4.10b, show the impact of injection of 30 MW photovoltaic in three different systems on the voltage profile comparing the no PV case scenario.

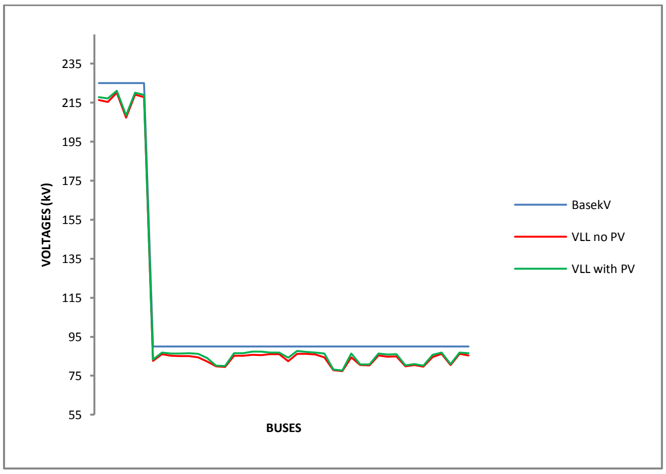

Figure 4.10a

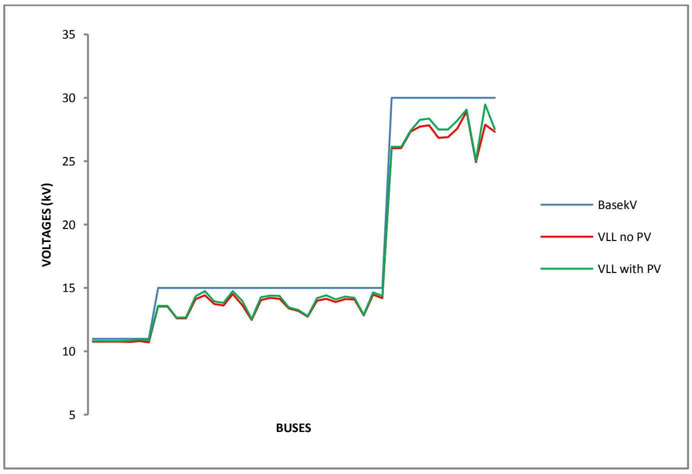

Figure 4.10b

Figure 4.10a: Transmission Voltage Profile with PV at three locations in distribution.

Figure 4.10b: Distribution Voltage Profile with PV at three locations in distribution network.

The voltage profile simulation results for the two scenarios; without PV and with 10 MW PV plants at three locations in the distribution network presented in figures 4.18a and 4.18b, show how this PV interconnection significantly improves the voltage profile as compared to the no PV case. Again the two voltage metrics, namely voltage deviation

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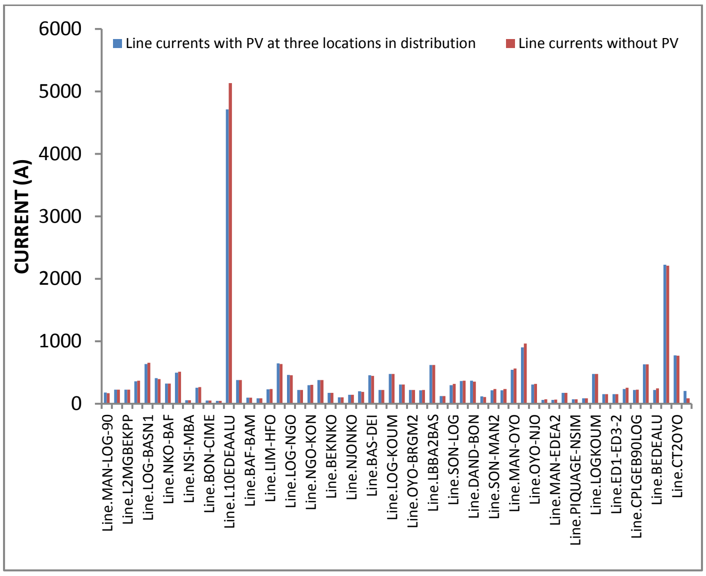
index and voltage violation index were calculated using Eq. (1) and Eq. (2) to evaluate the impact of the PV plant on the voltage profile improvement. All the outcomes of voltage improvement indicators are presented in table 4.4.

Table 4-4: Voltage Improvement Results with three PV Plants in Distribution network

	NO PV	Three locations
Min. Per unit voltage	0.78158	0.79102
Max. Per unit voltage	1.008	1.008
Voltage Deviation Index	5.68%	5.45%
Voltage Violation Index	8.26%	7.7%

The voltage indicators values of table 4.4 reveal that installing PV systems at three different locations in SIN's distribution network may achieve good contribution in voltage profile improvement with reductions of 0.23% and 0.56% in both voltage deviation and voltage violation indices respectively. The injection of the PV system also reduces the highest voltage drop by 0.00944 pu as shown by the comparison of lowest per unit voltages.

Figure 4.11 compares the currents passing through each of the network's lines before and after PV connection, while the network's power losses in the two cases are provided in Figure 4.12.



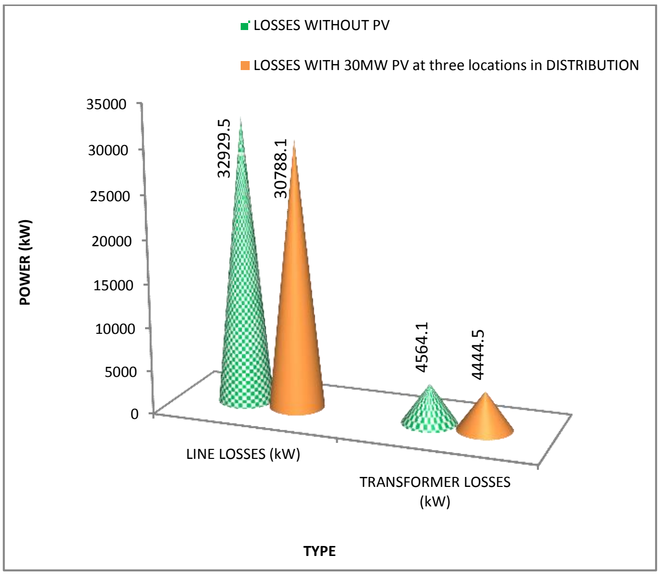


Figure 4.11 **Figure 4.12**

Figure 4.11: Line Currents with PV at three locations in distribution network.

Figure 4.12: Power losses with PV at three locations in distribution network.

Impacts of 10 MW PV integration at three distribution network locations on different line currents are shown in Fig. 4.11 and it is obvious that they depend on the positions of the individual lines with respect to the PV systems. Some currents register an increase after PV integration which means that the current injected by the PV is in same direction with the initial current. On the other side a decrease in line currents means that due to the bidirectional behaviour of the network with PV the injected currents are opposite to the initial ones. Impacts on currents can have an effect on the network protection. The highest decrease in line current of 423.28 A is obtained at L10EDEAALU line, and this is because there is one of the PV plants directly connected on the line, and therefore the very high load getting power from there takes a part of it from the PV plant.

A comparison of the power losses in the no PV case and the case of three equal PV plants at three different locations in the distribution network in Fig. 4.12 shows that there is a significant reduction of 2.261 MW in total active power losses thanks to the PV integration. This reduction is mainly due to reduction in copper losses in the lines as the PV distribution generations are brought close to end users, therefore decreasing some current to travel long distances.

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5.5 Impact of Battery Energy Storage System

A battery energy storage system (BESS) model with capacity to store full PV production in off peak case was considered together with the three PV systems at the various locations. Figure 4.13 illustrates the response of the BESS to the variations in PV power production and voltage at points of common coupling.

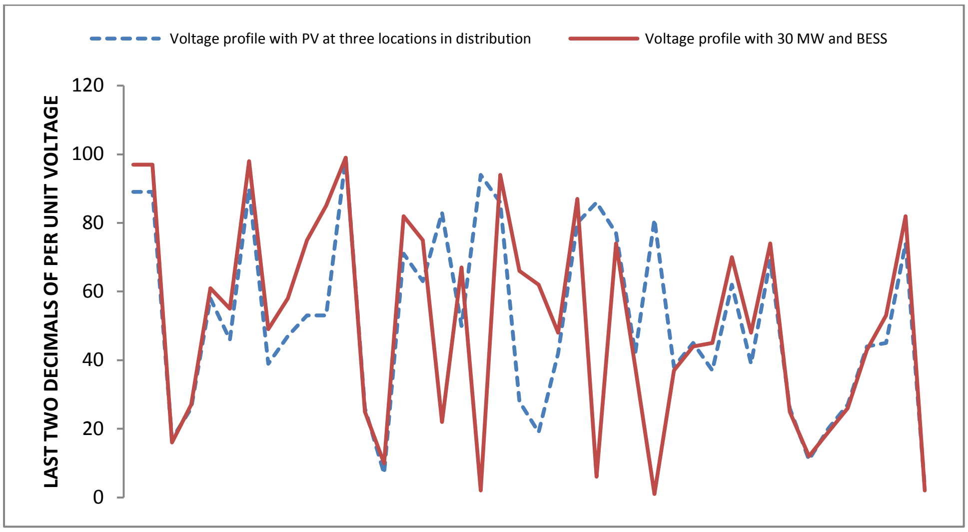

Figure 4.13: Reaction of BESS to changes in PV output voltages.

The BESS was used for seamless integration of PV into the network, and from Fig.4.13 the reaction of the storage system to oppose the changes in PV output voltage is highlighted. For visibility purpose only two last decimal digits of per unit voltages were compared in the two cases; without BESS and with BESS. The results prove that in addition to power supply role energy storage systems plays another key role of smoothing the PV output by opposing the voltage fluctuations.

6. CONCLUSION

This study gives important insights into the preliminary planning on PV energy integration into the southern interconnected network of Cameroon. The objective was to investigate the impacts this new energy generation type for the SIN may have on its stability in general, and particularly on the voltage, currents, and power losses. Through comprehensive simulations and analysis, different PV location, first considering the network without PV at a single location in the transmission network, then with three PV plants at different locations in transmission network, with a single PV plant in distribution network, and with three plants at different locations in distribution. A comparison of simulation results regarding power losses and voltage improvement put three PV plants at different locations in distribution on top with the highest reductions of 2.261 MW, 0.23% and 0.56% in power losses, voltage deviation index, and voltage violation index respectively. From findings of this research, it is recommended for the Cameroonian energy decision makers to consider PV integration in the Southern interconnected network; as the main country's electrical network this interconnection can help to improve the power stability and reliability, which are a concern for the country.

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