



# Simulation of the Injection of 25 MW Photovoltaic Energy Production: Analysis of the Impacts on the Grid of the Société Béninoise d'Energie Electrique (SBEE)

FANNOU Jean-Louis Comlan<sup>1, 2#</sup>, SEMASSOU Guy Clarence<sup>2</sup>, DANGNON Emmanuel<sup>2</sup>, ADJALLA Dieudonné K<sup>3</sup>, GEGAN Gérard<sup>1</sup>

<sup>1</sup>Laboratory of Applied Energy and Mechanics (LEMA), Polytechnic School of Abomey-Calavi, 01 BP 2009 Cotonou, Benin.

<sup>2</sup>National Higher School of Energy and Processes Engineering (ENSGEP)/UNSTIM BP 2282 GOHO Abomey, Benin.

<sup>3</sup>Société Béninoise d'Energie Electrique (SBEE), Department of Development of Renewable Energies (SDER / SBEE), 92, Av. Jean Paul II 01 BP 123.

#corresponding author

**Type of Work:** Peer Reviewed.

DOI: 10.21013/jas.v16.n2.p1

DOI URL: <https://dx.doi.org/10.21013/jas.v16.n2.p1>

## How to cite this paper:

FANNOU, J.C. et al. (2021). Simulation of the Injection of 25 MW Photovoltaic Energy Production: Analysis of the Impacts on the Grid of the Société Béninoise d'Energie Electrique (SBEE).

*IRA-International Journal of Applied Sciences* (ISSN 2455-4499), 16(2), 16-24. DOI:

<https://dx.doi.org/10.21013/jas.v16.n2.p1>

© IRA Academico Research.

 This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License subject to a proper citation to the publication source of the work.

**Disclaimer:** The scholarly papers as reviewed and published by IRA Academico Research are the views and opinions of their respective authors and are not the views or opinions of IRA Academico Research. IRA Academico Research disclaims of any harm or loss caused due to the published content to any party.

IRA Academico Research is an institutional publisher member of *Publishers International Linking Association Inc. (PILA-CrossRef)*, USA. IRA Academico Research is an institutional signatory to the *Budapest Open Access Initiative*, Hungary advocating the open-access of scientific and scholarly knowledge. IRA Academico Research is a registered content provider under *Open Access Initiative Protocol for Metadata Harvesting (OAI-PMH)*.

The journal is indexed & included in *WorldCat Discovery Service (USA)*, *CrossRef Metadata Search (USA)*, *WorldCat (USA)*, *OCLC (USA)*, *Open J-Gate (India)*, *EZB (Germany)* *Scilit (Switzerland)*, *Airiti (China)*, *Bielefeld Academic Search Engine (BASE) of Bielefeld University, Germany*, *PKP Index of Simon Fraser University, Canada*.

**ABSTRACT**

*In order to make up its energy deficit and reduce its energy imports from neighbouring countries, Benin is opting for the construction of photovoltaic solar micro-power plants in the sunniest regions and to consider injecting it into the existing electricity grid if this locally produced energy is not entirely consumed. With this in mind, a decentralised electricity production project has been initiated. In particular, the project, which is the subject of this presentation, aims to simulate and analyse the impacts of injecting 25 MW of photovoltaic energy production into the existing national electricity grid of the Société Béninoise d'Energie Electrique (SBEE). For this purpose, the dimensioning of the 25MW power plant has been carried out and injected at a specific point of the 20kVA line of the existing electricity network in the NEPLAN software environment, while respecting the requirements for injecting photovoltaic energy into an existing electricity network. Only extreme operating configurations have been studied: the synchronous hollow and synchronous point configuration. Simulation results showed overloads on certain transformer stations in the network, which indicates that adjustments must be made before the actual injection of the electricity produced. Besides, the power grid did not experience any disturbance in the voltage plan and power flows. Finally, the simulations carried out led to the conclusion that the integration of solar PV plants will make it possible to limit the import of energy from Ghana and Nigeria.*

**Keywords:** photovoltaic solar energy, power grid, energy reduction, dimensioning, decentralised application, renewable energies

**Nomenclature**

LV: Low Voltage

ECB: Electric Community of Benin

HVA: High Voltage category A

HVB: High Voltage category B

Hz: Hertz

KV: Kilovolt

KW : Kilowatt

MV: Medium Voltage

MVA: Mega Volt Ampere

MVAR: Mega Volt Ampere Reactive

MW : Mega Watt

PV : Photovoltaic

SBEE: Société Béninoise d'Energie Electrique (Benin Electric Energy Company)

Wp : Watt-peak

**Introduction****1. Introduction**

The permanent concern of developing countries in general, and Benin in particular, is to meet the basic needs of their population, including energy, which is constantly increasing, on the one hand, because of population growth and on the other hand because of the willingness of governments to transform their economies. In Benin, household energy consumption increased by 14.4% per year between 1996 and 2005, with an average population growth of 3.25% per year [1]. This energy demand is, unfortunately, growing faster than supply, which is dominated by imports. Given its dependence on external supplies of petroleum products and its very low national electrification rate, which rose from 25.5% in 2010 to 33.2% in 2015 [2], Benin is obliged to opt for the rental of generators for the production of thermal energy to meet the energy needs of the population despite imports from Nigeria and Ghana. Moreover, the use of conventional resources (oil, natural gas, coal) has a negative impact on the environment through the emission of greenhouse gases that contribute to the warming observed on the earth's surface and the drying up of streams. For all these reasons, the world is moving towards renewable sources to replace conventional energy. These renewable energy sources include solar, wind, biomass, hydropower and geothermal energy.

Given its current energy situation and above all its significant amount of sunshine, Benin offers a privileged setting for the development of photovoltaic technology. For a long time, it has based its energy development policy on energy imports and on the predominant supply of fossil fuel-based energy services. This development policy is neither viable in the long run nor even in the medium one. The interest in photovoltaics from an energy point of view is therefore strongly felt in Benin, particularly for the grid operator (SBEE). Photovoltaic technology makes it possible to diversify the production of electricity and to promote a favourable ecological record. A lot of work has been done in this direction. In 2012, Rubens Compere [3] carried out a feasibility study for a 30 MW photovoltaic power plant in Sirarou, in the Commune of N'Dali, Borgou Department, to reduce the energy deficit of the Benin Electric Community (CEB). Similarly, Idrissou Thalès Comlan [4] studied and sized a 100 MW photovoltaic power plant to reduce the energy deficit of the SBEE. In 2013, Gilmore Cherif Soude [5] contributed to the reduction of the energy deficit in Benin through his work on injecting photovoltaic energy into the SBEE's Abomey-Calavi

electricity grid. In 2014, Denis Luc Akognitche worked on the production of 60 MVA to be injected into the electricity grid of the town of Natitingou, once again to fill Benin's energy deficit with a photovoltaic plant [6]. Despite these numerous studies that argue in favour of the development of solar systems in Benin, it has been found that very few of them are truly oriented towards the impact of energy on the transport network following the injection of solar energy. The injection of the electrical production of photovoltaic (PV) systems, which is intermittent and sometimes uncertain, into a public electricity grid, affects its stability and protection [7]. It can lead to local voltage variation, voltage unbalance, rapid power variation (intermittency), harmonic injection, DC injection and protective blindness [8]. It is to overcome all this that we have decided to make our contribution with this work entitled "Simulation of injection of 25 MW photovoltaic power generation: Analysis of impacts on the SBEE grid". The choice of the village of Onigbolo (latitude: 7°11'7"North, longitude: 2°39'6"East) as the location for the future power plant is justified by the high rate of sunshine in this locality, which is estimated at 1788 kWh/m<sup>2</sup>/year with an annual production of more than 1430 kWh/kWp/year [9], a real asset for the PV system to be installed. The sizing of the plant only took into account the estimated energy deficit in Benin by 2026 and the HVA voltage level of the village of Onigbolo, without carrying out an in-depth study of the electricity grid through which the village is supplied. In 2017, Toussaint Tilado Guingane [10] carried out a study about the impacts of PV injection on the Burkina Faso grid. This study revealed that the PV system generally influences the power of the source substation, the grid voltage and the power factors of electrical installations without reactive power compensators. A study carried out by Thi Minh Chau Le [11] revealed that the connection of PV systems to the grid can have significant impacts on its operation, particularly in terms of voltage, protection, power quality and losses in the distribution networks.

This work aims to size the 25MW solar PV power plant, inject it into the existing SBEE electricity grid and study the impacts on the grid. More specifically, the aim is to assess the impact of changes on the state of the existing network such as increasing voltage levels, increasing power levels of transformer substations and to analyse the possibilities of installing new transmission lines and interconnecting one network with others.

## 2. Equipment and methods

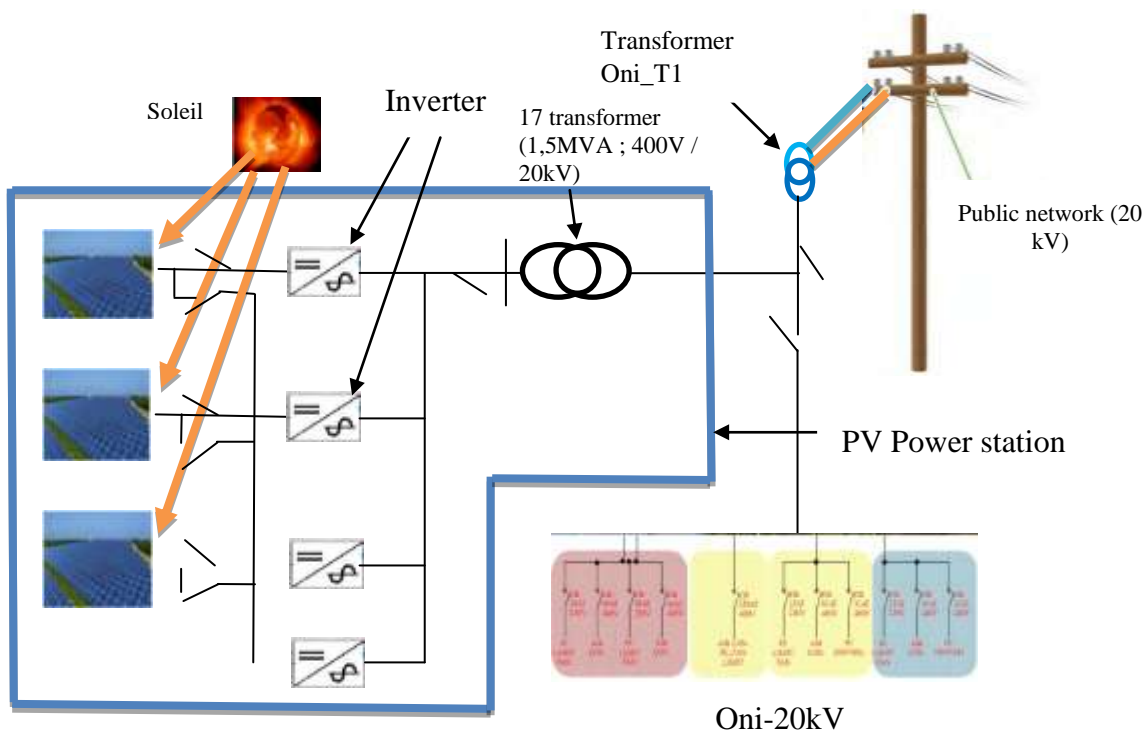


Figure 1: Block diagram of the 25 MWp PV solar power plant and the injection point (20kV)

**2.1 Equipment**

**2.1.1 Description of the system studied**

The system studied is mainly composed of the 25 MW PV solar power plant. Its main components are the photovoltaic modules, inverters, transformers and cable networks. This solar power plant is coupled to the national electricity grid managed by SBEE (figure 1).

**2.1.2 Presentation of the simulation tool**

Many software packages have been developed to solve power flow problems. These include Powerworld and Neplan. These softwares help to carry out graphic modelling of the network elements under study, to simulate the network and to output the desired results. The NEPLAN software was used in this work. NEPLAN (Network Planning and Optimization Tool) [12] is a very user-friendly tool for users of planning and information systems for electricity, gas, water and heating networks.

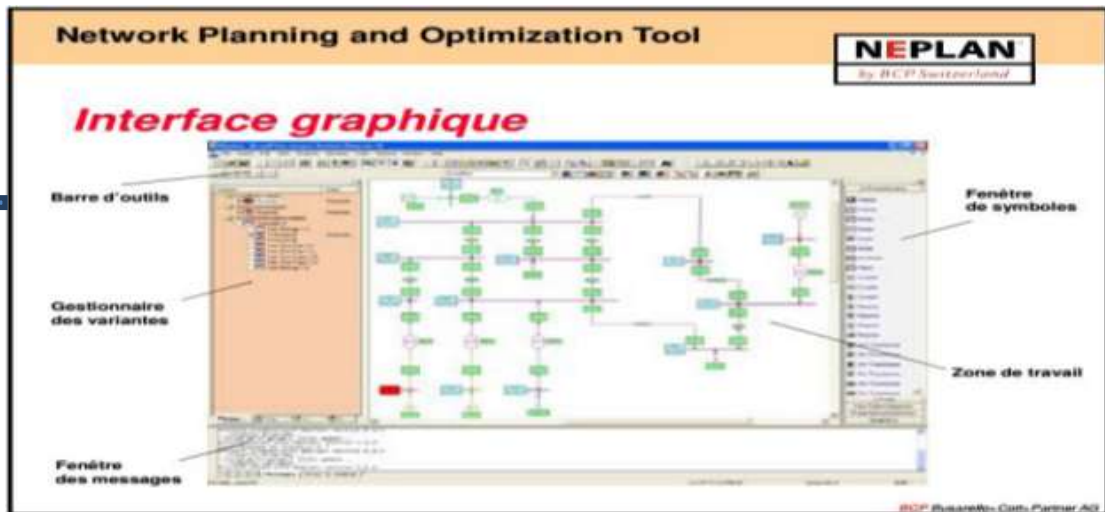


Figure 2: Operational windows of the User Interface [13]

It receives as input data the consumed (produced) powers and the network topology and provides as results the vectors with the electric voltages in the nodes, the electric currents on the lines and the global joule losses. To study the different cases, NEPLAN can create different root variants and combine them with the topology and load data files.

Figure 3 shows the principle:

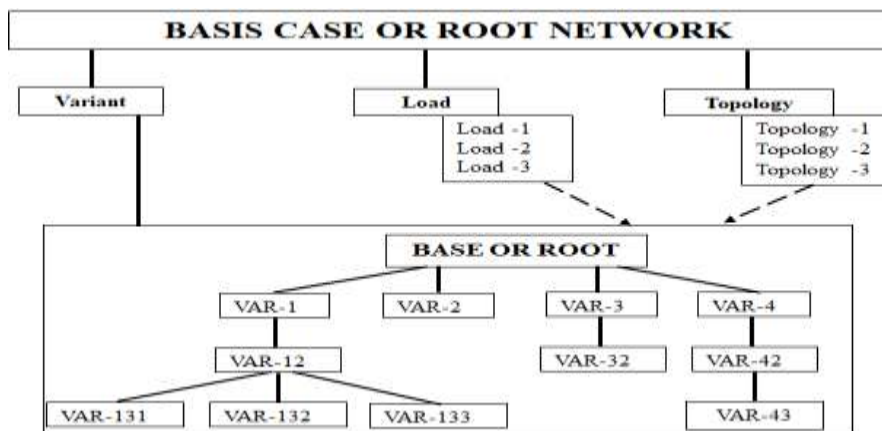


Figure 3: Variant Management System with NEPLAN [14].

The variants are saved together with the root in the project file (.nepprj). As far as topology and load data are concerned, separated files will be defined. By activating a variant, the topology and the assigned load files are opened automatically.

In a nutshell, NEPLAN helps to graphically build power networks, modify them, to perform simulations, analyses and output the results. However, as in theory, the software requires the definition of a balance node that will provide the active and reactive power needed to balance the exchanges and provide network losses. This means that the voltage module and its argument must be fixed in this node. This node is chosen arbitrarily but as the voltage is fixed at this point, a generator with sufficient power must be connected to it.

## 2.2 Methodology

### 2.2.1 Sizing of the photovoltaic power plant

Basing on the existing design models [4], [15], [16,17] and taking into account the recommendations proposed by David et al [18] and Shabaniverki [19], the PV power plant is composed of 17 sub-fields of 1.52MWp each. Each subfield is composed of 66 module tables. The tables consist of 4 rows of 18 landscape modules, i.e. 72 modules.

In general, it is recommended for the selection of the inverter that the maximum input power should be greater than or equal to 1.25 times the maximum power generated by the PV field in order not to exceed the limit set by the manufacturer [5]. Thus, the realization of the 25MW PV power plant at the entrance of the transformer station requires 748 inverters of 400 V and 30 kW nominal power connected in parallel.

Each sub-field will have a solar controller with a total of 17 solar controllers for the PV power plant.

### 2.2.2 Description of SBEE's electrical network

The study network is made up of forty-one (41) nodes of which two (02) are 330kV, nine (09) are 161kV, seven (07) are 63kV, three (03) are 33kV, nine (09) are 20kV, nine (09) are 15kV and two (02) are 11kV. Table 1 shows the voltage of the various nodes with the cities where they are linked to in the SBEE national grid.

**Table 1: Node on the SBEE Power Grid and Cities of Installation**

Node	Cities
330 kV	Sakété, Ikeja-West
161 kV	Parakou, Djougou, Bohicon, Cotonou-Vedoko, Maria-Gléta, Avakpa, Onigbolo, Tanzoun, Sakete
63 kV	Bohicon, Cotonou-Vedoko, Gbégamey, Ouando, Seme, Onigbolo, Akpakpa
33 kV	Natitingou, Bembereke_1, Bembereke_2
20 kV	Parakou, Djougou, Bohicon, Avakpa, Sakété, Onigbolo_1, Onigbolo_2, Tanzoun_1, Tanzoun_2
15 kV	Cotonou-Vedoko_1, Cotonou-Vedoko_2, Cotonou-Vedoko_3, Gbégamey_1, Gbégamey_2, Maria-Gléta, Ouando, Akpakpa_1, Akpakpa_2
11 kV	Wartsila, Cotonou-Vedoko

### 2.2.3 Simulation method

The power station was connected to the 20kV SBEE busbar located in Onigbolo's CEB transformer station (20kV voltage level). The following electrical specifications and requirements were imposed on the solar power plant in order to meet the requirements for power injection into an existing electrical grid [20]:

- Normal voltage level variation: +/- 5% of 20kV
- Normal frequency variation: 49.5Hz to 50.5Hz
- The connection of the control unit to the SBEE network must not, in a fault situation, cause the short-circuit current to exceed the limit that the 20kV equipment on the SBEE network can withstand.
- Constructive reactive power capacities: the power plant must be able to supply or absorb, at the connection point, the following minimum reactive powers:
- When the voltage at the connection point is within +/-5% of 20kV, the power plant must be able, without time limitation, to supply reactive power at least equal to 0.4\* Pmax, and to absorb reactive power at least equal to 0.35\* Pmax.

- When the voltage is between 90% and 95% of 20kV and between 105% and 110% of 20kV, the installation must be able to produce a reactive power at least equal to  $0.31 \cdot P_{max}$ , and absorb a reactive power at least equal to  $0.31 \cdot P_{max}$ .

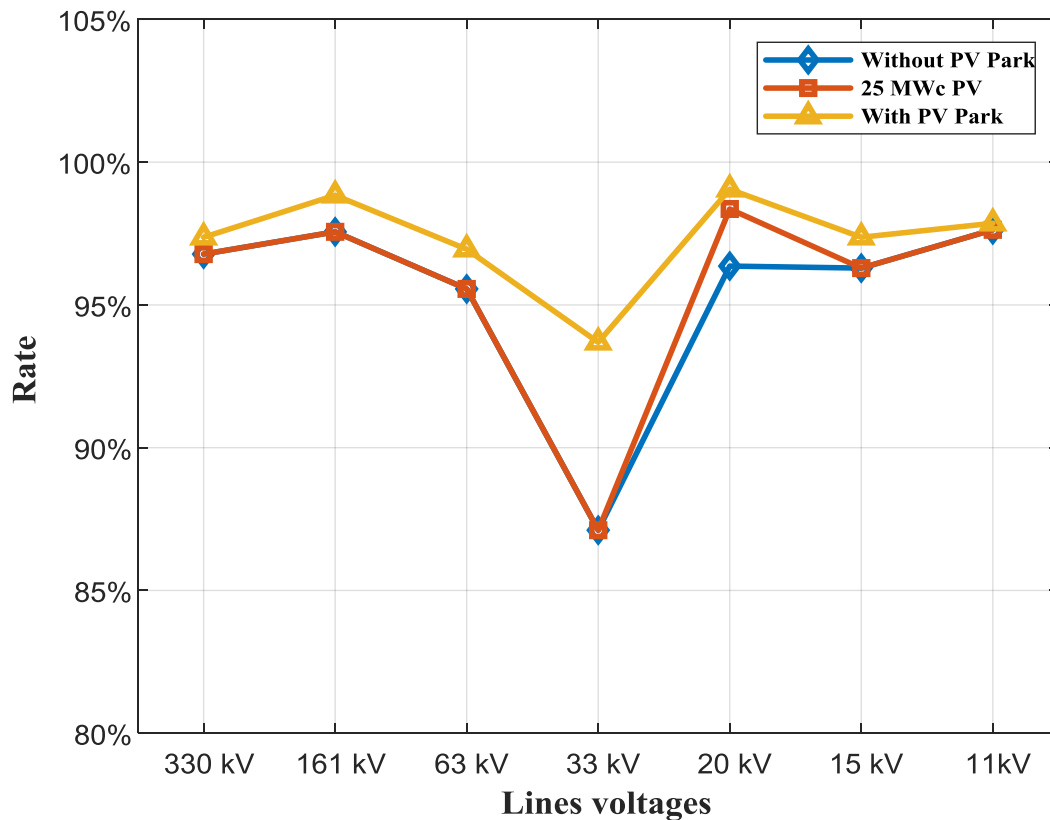
The network can be operated in several configurations that define its different possible states. Here, only the extreme operating configurations have been studied. These are the synchronous off-peak configuration (off-peak hours with the lowest consumption) and the synchronous peak configuration (peak hours with the highest consumption).

In this study, a first simulation is made of the SBEE's electrical network modelled in the NEPLAN software in order to have reference data. Subsequently, the coupling of the initial grid with the PV power plant was performed and the simulation results are compared with those without the PV power plant.

### 3. Results and discussion

#### 3.1 Network simulation in off-peak configuration

Figure 4 summarizes the main voltage results on the electrical network:

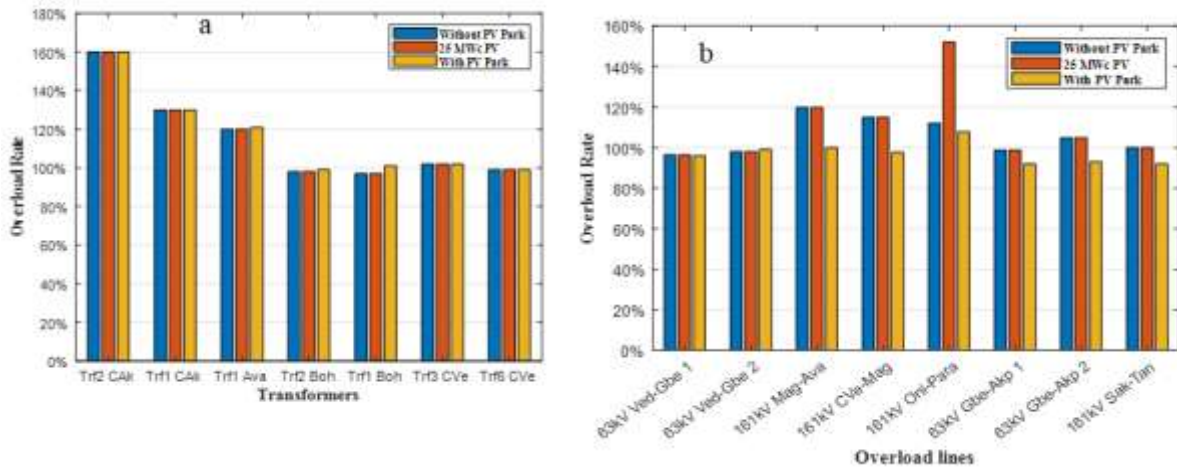


**Figure 4: Voltage overload on the electrical network**

It can be seen that the Bembérékè table (table 33kV) is well beyond the limits of  $\pm 5\%$ . Indeed, there is no generator at Bembérékè and the 108 km 161kV line between Parakou and Bembérékè is operated at 33kV. Not knowing when the 161kV line will be crossed, it was considered that it is still operated at 33kV in the configuration. The calculated Undervoltage is therefore logical since transporting energy over such a long distance in MV generates significant voltage drops. It should also be pointed out that without PV 25 MW<sub>p</sub>, we have 95.05% of the 20 kV busbars of Onigbolo (connection point) and 100% with PV 25 MW<sub>p</sub>. This has improved the voltage plan of the 20kV switchgear.

Figure (5a) shows the results in overload synchronous point transformers. These overload findings are related to the evolution of consumption which will require transformer reinforcements. It can be noticed that the only overloaded transformer associated with a PV power plant project is the one of Bohicon T1: PV power plant realized within the framework of the MCA ( Millennium Challenge Account) project.

Figure (5b) shows the results in synchronous line-to-point overload. These overload findings are related to the evolution of consumption which will require line reinforcements.

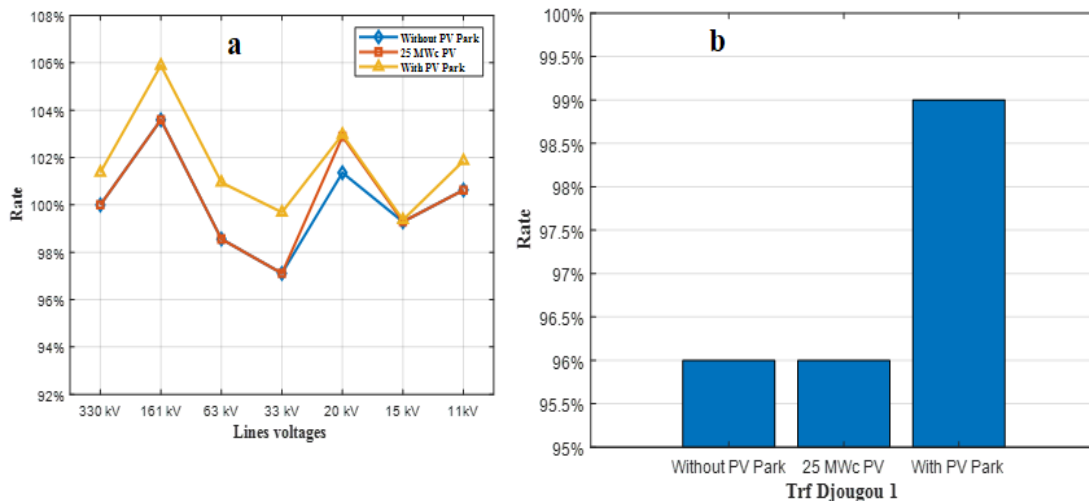


**Figure 5:** a) Overloading of transformers in the electrical network, b) The electric lines' overload

**3.2 Network simulation in peak configuration**

Figure (6a) shows the overloading of transformers in peak configuration simulation. By observing, it can be noticed that the 161kV table of Djougou is slightly overvoltage when the PV power plants are producing. Indeed, 4 future power plants are connected to this node (2 in Natitingou and 2 in Djougou), i.e. 22.5MW. This power is higher than the power consumed in Djougou and therefore transits over long distances hence the voltage rise.

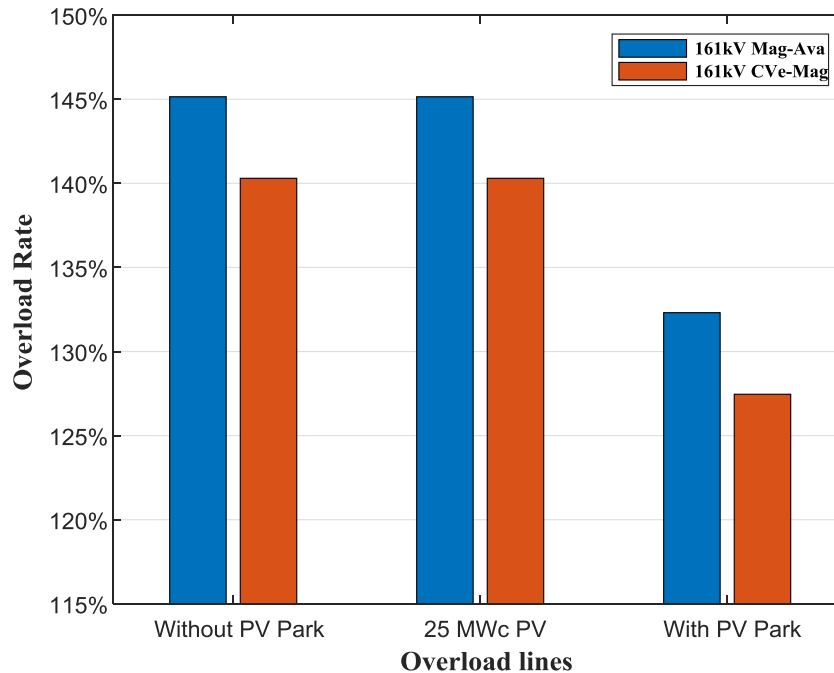
Figure (6b) shows the results for transformers' overload. At Djougou (Table 161 kV), the transformer is very overloaded at maximum PV output. However, when the Djougou Bembéréké line is operated at 161kV, the power produced by the future Djougou PV power plants will be transmitted to the 161kV grid via another transformer. Then the integration of the plants will reduce the power imported from Ghana and Nigeria.



**Figure 6:** a) Voltage overload b) Djougou transformer's overload

Figure 7 shows the results of an overload of two lines of the network depending on the injection of the power plants on the network. As it can be seen, the total injection of the whole of the PV production will reduce the overload of the lines when the demand is at the maximum.

These overload findings are linked to the evolution of consumption which will require line reinforcements.



**Figure 7: Observed overload of the two electrical lines**

#### 4. Conclusion

In this paper, we simulated the decentralized production of electrical energy via a photovoltaic power plant coupled to the grid of the Société Béninoise d'Énergie Électrique (SBEE). The complete SBEE network was taken into account, with the Onigbolo source station as the location. The main objective of this study is to contribute to the reduction of the energy deficit in Benin. To this end, we were particularly interested in the study and dimensioning of a 25 MWp PV system, the choice of components and then its connection to the grid with the ongoing projects. The simulations carried out have led to the conclusion that the integration of solar PV power plants will make it possible to limit the import of energy from Ghana and Nigeria. Moreover, the integration of solar PV plants does not disturb the voltage plan and power flows as long as the permissible threshold is respected. Finally, the existence of a cement manufacturing plant in Onigbolo will allow local consumption of the power produced.

#### References

- [1]. SBEE, I.E., SBEE's 2010 Rural Grid Electrification Program.
- [2]. ARE-BENIN, A.d.R.d.l.E. Electricity production at the national level. Cited 2020 17 December 2020; Available from <https://are.bj/laproduction/>.
- [3]. Compere, R., Etude de faisabilité d'une centrale photovoltaïque de 30 MW à Sirarou, commune de N'Dali, département de Borgou, pour réduire le déficit énergétique de la Communauté Électrique du Bénin (CEB). 2012, Ecole Polytechnique d'Abomey-Calavi (EPAC). In French
- [4]. Comlan, I.T., Reduction of SBEE's energy deficit by the installation of a 100 MW photovoltaic power plant: Study and Sizing. 2012, Ecole Polytechnique d'Abomey-Calavi (EPAC).
- [5]. Babatoundé, S.G.C., Contribution to the reduction of the energy deficit in Benin by injecting photovoltaic energy into SBEE's Abomey-Calavi power grid 2013.
- [6]. Luc, A.D., Production of 60 MVA to be injected on the electricity grid of the city of Natitingou to fill the energy deficit in Benin by means of a photovoltaic plant. Ecole Polytechnique d'Abomey-Calavi (EPAC) 2015.
- [7]. Bachtiri, E. Integration of photovoltaics into the electricity grid.



Available from: <http://www.est-usmba.ac.ma/coursenligne/TEREE-S6-M34.2-Int%C3%A9gration%20du%20PV%20au%20r%C3%A9seau-El%20Bachtiri.pdf>

- [8]. H. Colin (CEA-INES), et al. Connexion des installations photovoltaïques au réseau public de distribution électrique à basse tension: Cadre réglementaire, impacts et préconisations. 2010. p. 64. In French
  - [9]. DEFISSOL, Feasibility study for the construction of photovoltaic solar power plants.
  - [10]. Toussaint Tilado Guingane, Zacharie Koalaga, Cedric Beogo, Eric Simonguy, Nogma Ouyi, Dominique Bonkougou et François Zougmore. Impact De La Penetration Du Photovoltaïque Sur Le Réseau Electrique. *Am. J. innov. res. appl. sci.* 2017; 5(6): 397-404. In French
  - [11]. Le, T.M.C., Coupling photovoltaic inverters to the grid, control/command aspects and disturbance rejection. 2012, University of Grenoble. p. 195.
  - [12]. Baetscher, F., Application du logiciel Neplan pour le calcul des réseaux électriques. 2001: Freiburg. In French
  - [13]. NEPLAN, Modules for research. 2015.
  - [14]. Erwin, F., NEPLAN User Manual V5. 2014.
  - [15]. Fomouo, D., Conception, dimensioning of an autonomous photovoltaic system 2018.
  - [16]. Sharma, D.K. and S.R. Shakya, Training Manual For Engineers on Solar PV System 2011. p. 259.
  - [17]. Skunponga, R. and B. Plangklang, A Practical Method for Quickly PV Sizing. *Procedia Engineering*, 2011. 8 p. 120-127. Doi:10.1016/j.proeng.2011.03.022
  - [18]. David, T. and A.K. Seng, Handbook for Solar Photovoltaic (PV) Systems. 2009. P. 64. [https://www.bca.gov.sg/publications/others/handbook\\_for\\_solar\\_pv\\_systems.pdf](https://www.bca.gov.sg/publications/others/handbook_for_solar_pv_systems.pdf)
  - [19]. Shabaniverki, M., Design and Analyze of 20 MW Photovoltaic Solar Power Plant in Iran, in 2nd International Conference and Exhibition on Solar Energy (ICESE) 2015. August 2015: Tehran, Iran.
  - [20]. Ministry of Energy, R.A.D.e.P., Technical Rules of Connection and Rul, 2009
-