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Predicting the Efficiency of Solar Photovoltaic Energy Injection in a Localized Subtropical Grid by Modelling Actual Generation Trend Curves: Case Study of Douala

Georgette FUMTCHUM*‡, Aloys Martial EKOE A AKATA**, Ruben MOUANGUE*, Brayima DAKYO ***

*Energy, Materials, Modelling, and Methods Research Laboratory (LE3M), Polytechnic Higher National School, University of Douala, 2701, Pk.17 Logbessou, Douala/Cameroon

** Energy Systems Technology Laboratory (ESTL), University of Douala

***Laboratoire Groupe de Recherche en Electrotechnique et Automatique du Havre, Université Le Havre Normandie, 25 rue Ph. Lebon, 76600 Le Havre, France

(fumgeorgia@yahoo.fr , ekoealoys@yahoo.fr , r_mouangue@yahoo.fr , dakyo@univ-lehavre.fr)

‡ Corresponding Author ; FUMTCHUM Georgette, Tel: +237 699298662*;* fumgeorgia@yahoo.fr

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Abstract- Electrified cities in Cameroon suffer untimely power outages for several reasons, among which a low production of electrical energy; a palliative solution of the consequences would be, as projected, to identify and supply priority loads through solar photovoltaic electrification. Producing solar photovoltaic (PV) energy and injecting it into the domestic conventional electricity network (CEN), to supply priority loads, has to face high investment costs and in the economic and technical context, the feasibility and also the long-term efficiency must be analyzed. Based on the regulation of a set of production units, the collection of actual production and consumption data from several sites in the city of Douala was used. An analysis of the data from the data acquisition systems of the reference installations allowed the development of production models of the PV systems injected into the targeted conventional electricity network (CEN). Consumption modelling of PV system output over a long lifetime will be developed. Based on the collected real data, simulations of long-term load supply scenarios will be performed in the MATLAB software package environment. The influence of operational parameters on the efficiency of solar energy injections will be evaluated in order to improve productivity until the end of the system's life. We will show through the simulation of previously and judiciously selected conditions, the modalities of a good prediction of the efficiency of the solar energy injection in the urban CEN.

Keywords: solar photovoltaic modelling; subtropical urban grid; storage-free power system; efficiency forecasting.

1. Introduction

Access to electricity is a key issue for the development of the African continent, as stated in Sustainable Development Goal (SDG) number 7 which guarantees "access to affordable, reliable, sustainable and modern energy for all" by 2030, as it is a prerequisite for human and socio-economic development.

According to recent reports on Cameroon, installed power generation capacity has increased to 1,402 MW, of which 56.15% is from hydroelectricity, 43.84% from fossil fuels (17.55% from natural gas and 26.29% from oil) and 0.01% from solar photovoltaic [1]. The promotion of renewable energy is an important part of Cameroon's development plan to increase energy production and security [2].

Due to its favourable geographical location, Cameroon receives a good amount of solar radiation per day, with irradiation ranging from 4.85 $kWh/m^2/day$ in the southern part to 5.62 $kWh/m^2/day$ in the northern regions [3]. Douala has a good potential for solar energy development [4]. The intensity of solar radiation in the city of Douala varies between 3.04 kWh/m^2/day and 5.41 kWh/m^2/day, with an average value of 4.31 kWh/m^2/day. Minimum values are recorded during the rainy season (July to September) and maximum values during the dry season (December to February). In Douala with 4 million inhabitants, as in large cities, the injection of solar electricity into the domestic grid could be a way to make electricity more available for the domestic and industrial sectors while reducing the share of fossil energy and saving energy [5] .

In general, the injection of electricity from generators (both renewable and non-renewable) contributes to grid stability when it ensures that supply and demand are balanced in real time. The services to be rendered for grid stability and decarbonization include peak demand shaving, voltage and frequency control, and reduction of the contribution of fossil-fired generators [6].

However, despite the considerable decrease in the cost of solar photovoltaic installations, the use of solar generators as an alternative solution for the electrification of urban areas faces limitations. In addition to the fact that cost is a limiting factor, the variation in time and space of the efficiency of the whole system works against profitability by lengthening the amortization period.

With accurate knowledge of the electricity consumption of the loads, anticipating an update of the system to limit the non-powering of the loads, it would be possible to improve the rate of coverage of the energy needs, which would result in an improvement of the efficiency of the whole system.

2. Context and Methodologies of the Study

There are ways to popularize the use of the photovoltaic system in the cities of Cameroon benefiting from an electrical network. Oubah Isman Okieh [7] presents a study on the application of solar energy and its contributions to socio-economic development in a context similar to that of Cameroon, where the injection of PV energy produced into the REC is presented as a good alternative.

Christophe Tatsinkou [8] through his article highlights the evolution of the installations of photovoltaic solar energy production units in the 10 regions of Cameroon, which have increased from 1304.16 kilowatts peak (kWp) in 2013 to over 50 megawatts peak (MWp) in 2021. Georges Olong [9] confirms by presenting a summary table of installed power since 2013.

TABLE 1: SOLAR PV INSTALLATION CAPACITY IDENTIFIED IN CAMEROON

Plants	Capacity (MW)	Observation*
Maroua	15	Scatec Solar
Garoua	30	Enerray Solar
Guide	10	Scatec Solar
Lagdo	20	
Bertoua	5	
Ngoundéré	20	GDS Orion Solar
Before 2013	1.3	10 regions
Djoum	0.372	
Lomié	0.125	
Ngoundal	//	
Yokadouma	//	
Project 1000	12	CSI
Total	**113.797**	

* The private structures that are partners of Eneo for the production are mentioned.

Tansi [4] from Figure 1 confirms the potential of Cameroonian cities by presenting information on production possibilities by region with the possibility of exporting energy to the interconnected grid.

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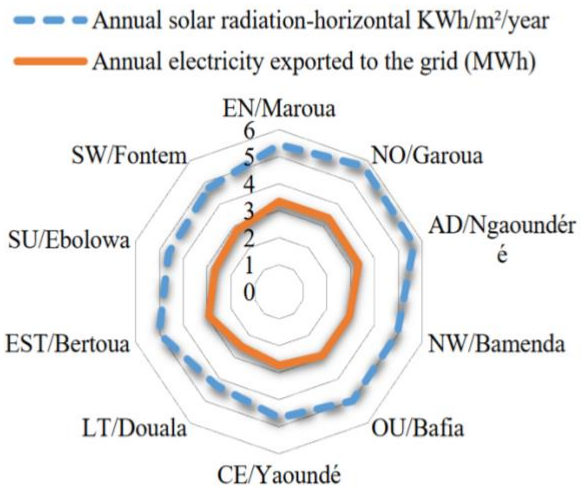


Figure 1: Minimum potential contribution of solar energy to grids by region.

Kouro, Vinnikov, Franquelo [10] in their paper where it appears that in grid-connected PV systems, batteries are not needed since all the energy produced by the PV system is transferred to the grid for direct transmission, distribution and consumption, supports the choice of the system configuration that is studied in this paper.

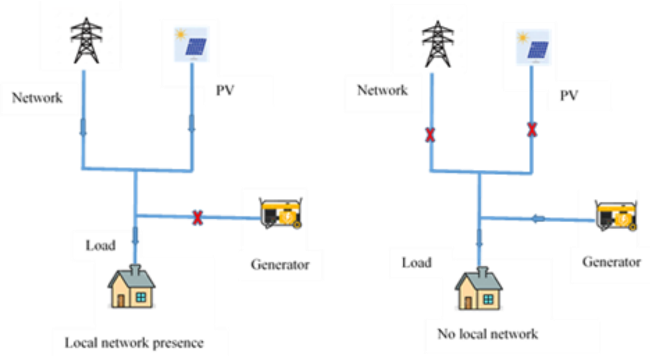


Figure 2: Architecture of a networked system without storage

According to the INS (Institut National de la Statistique), despite the progress made over the years, 46% of Cameroonian households (81% in rural areas and 12% in urban areas) still do not have electricity [8] . In urban areas of Cameroon, there are frequent power outages. This lack of constant supply of electricity in quantity and quality has negative consequences on sensitive economic activities. This leads us to wonder about the causes and reasons that could slow down the deployment of a new technology allowing, for example, the injection of renewable energy such as solar energy into the Cameroonian CEN. The injection of photovoltaic energy into the Low voltage power grid is considered a viable alternative to fossil fuel power plants, within a technical penetration ratio, and is gaining popularity worldwide [11].

The study of the PV energy production injected into the REC is carried out on 10 reference sites in the city of Douala, where the system has been implemented in a grid-connected architecture without storage. The choice of sites considers the fact that in some areas of the city, power outages are more frequent and the grid more polluted. The recording of the data was done in the presence of an Internet connection, the cut of this last one and of the CEN to often disturb the recording of the data on the studied sites.

All solar power plants studied are equipped with an intelligent device (Fronius Smart Meter) that provides monitoring (production monitoring, consumption overview, email reports), analysis (quick and easy troubleshooting, comparison of different plants) and proactive service (reports and email notifications in case of errors); the configuration diagram with the Smart Meter is as follows.

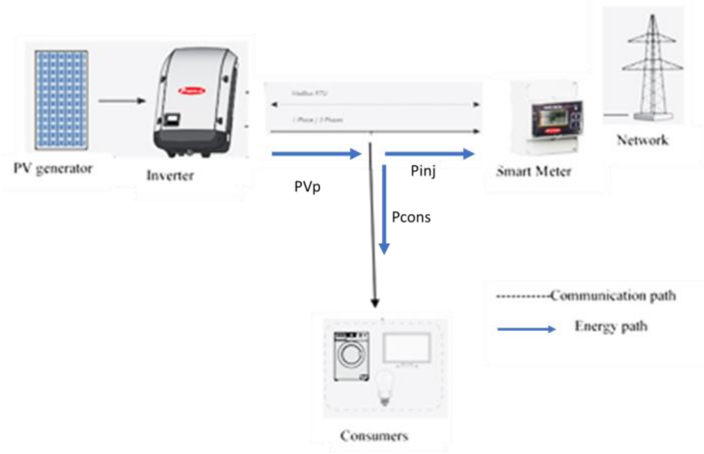


Figure 3: Diagram of Smart Meter implementation

The actual daily consumption data were collected for a whole year on the site of the inverter supplier; on an annual statistic of (18h-6h) × 30 days × 12 months; The trends where blurred enough. That leads to the choice of the 5 trends modelling check. In this study, the choice was to represent the results of monthly averages to make an estimate of the consumption of solar production over 25 years. Using Excel software, 5 models (exponential, polynomial, linear, logarithmic, power) of mathematical equations were generated using real data collected in the field. A MATLAB simulation of each mathematical model per site was done to present the load consumption trend curves, and the results are compared to the actual data collected in the field; see “Fig. 5”.

3. Discussions and Results

In order to obtain a well-fitted model, several forecasting models were chosen to be analysed that provided a better understanding of the evolution of the consumption of solar generation at different sites.

The basic assumptions are as follows:

- The load curve does not change during the life of the installed system.
- Replacing defective components does not affect the timely production of the solar power plant.
- The consumption forecast per site is made over a period of 25 years (300 months) corresponding to the life span adopted by the solar photovoltaic system engineering.

The current research framework is the study of the prediction of the efficiency of the injection of solar photovoltaic energy in a domestic CEN such as that of the urban areas of Cameroon. This paper focuses on the interest of investing a palliative solution to untimely power cuts in the cities of Cameroon. The first approach here is to identify a relevant model of energy production-consumption trends from a database of monthly average data.

Among numerous possibilities of approximation and modelling the five proposed by spreadsheet program from Microsoft (Excel) were used: logarithmic model (1), polynomial model (2), exponential model (3), linear model

(4), power model (5); The modelling procedure has allowed to highlight the resulting 5 trend curves obtained from the data of the studied reference sites. Only 4 sites results are represented in "Fig.3". The corresponding models are as follows, assuming that "y" represents the value of consumption of PV production by the loads (consumers), "x" the index of the month, "a" , "b" , "c" are coefficients obtained from the real data computation in Excel.

Mathematical models in general are written as follows:

$$y = a\log\ (x) + b \quad (1)$$

$$y = ax^2 + bx + c \quad (2)$$

$$y = ae^{b*x} \quad (3)$$

$$y = ax + b \quad (4)$$

$$y = ax^b \quad (5)$$

Let us represent the models of the site 1 and the site 2 by replacing "a", "b", "c" by the approximated values obtained from the real data computation.

Location1:

$$y = 8{,}197x^2 - 94{,}607x + 1284{,}2 \quad (6)$$

$$y = 11{,}962x + 1035{,}5 \quad (7)$$

$$y = 10{,}466\,log\ (x) + 1095{,}8 \quad (8)$$

Location 2:

$$y = 530{,}61e^{-0{,}072*x} \quad (9)$$

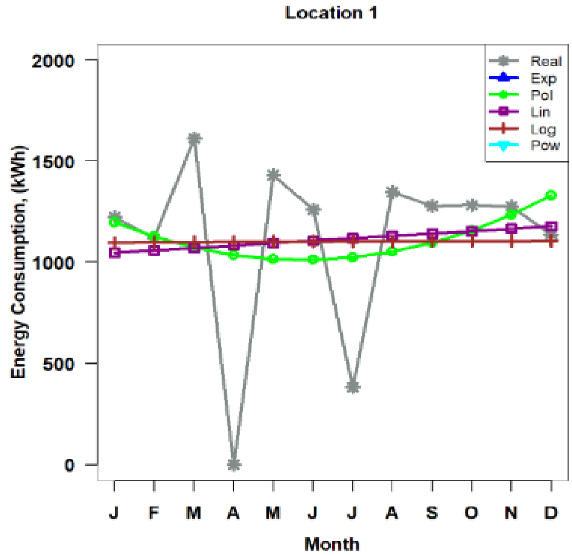
$$y = -23{,}648x^2 + 268{,}88x + 36{,}682 \quad (10)$$

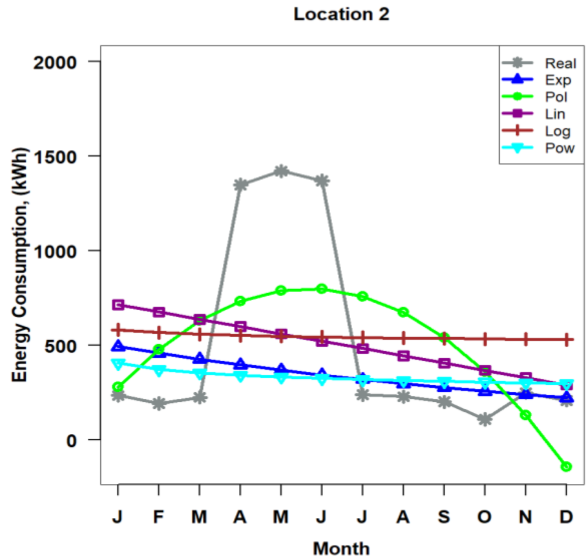
$$y = -38{,}538x + 754 \quad (11)$$

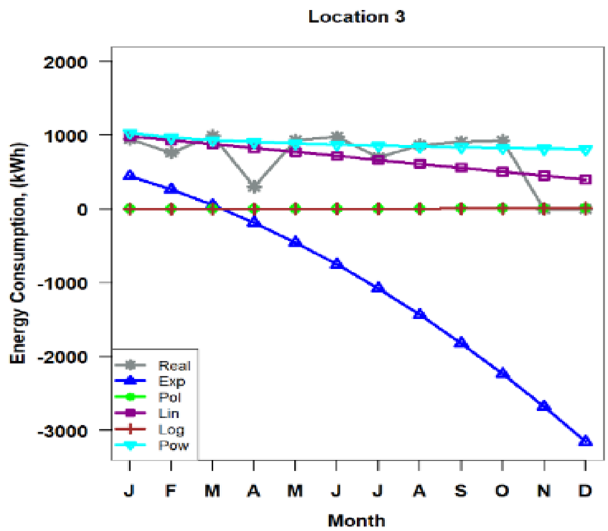
$$y = -47{,}3\,log\ (x) + 582{,}29 \quad (12)$$

$$y = 407{,}06x^{-0{,}123} \quad (13)$$

From the analysis of location “Loc.1”and “Loc.3”, “Loc.2” and “Loc.4”, it is possible to generalize the analysis on the other sites because “Loc.1” and “Loc.3” have respectively data which allowed to generate 3 mathematical models on the 5 initially chosen as on 2 other sites; and from the data of “Loc.2” and “Loc.4”, 5 models were generated just like on 6 other location. The curves in "Fig. 4" show an evolution that allows us to choose, among the 5 models studied, the appropriate model for each site. Thus, for "location 1" and "location 3", the logarithmic model is adapted for a simulation especially in the long term and for "location 2" and "location 4", two models, namely the logarithmic model and the power model allow to have satisfactory results with regard to the real data. When simulating models (6), (7), (8), (9), (10), (11), (12) and (13) over 300 months, the pattern of the polynomial and linear models leads to a negative "y", which is the same for all other sites studied.







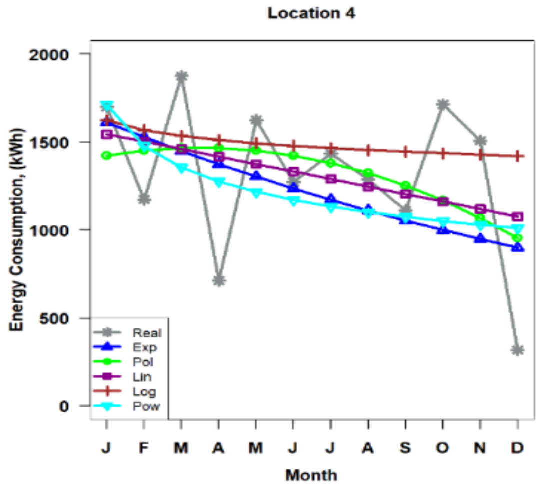


Figure 4: Evolution of trend lines by location for each model studied

Among the 5 models chosen, the computation with Excel, failed to generate the exponential model (3)and the power model (5) on 4 locations (”Loc1”, ”Loc3”, ”Loc9”, ”Loc10”). The real data of these sites were thus analysed and compared with the others. It appears that these sites have almost the same consumption profile with a pattern that does not allow for an exponential and power model, see “Fig.5” . Having the possibility, to have other interesting model for the study, we did not find necessary to dwell more on the reasons of the fact that the exponential and power models are not generated for the sites 1,3,9 and 10.

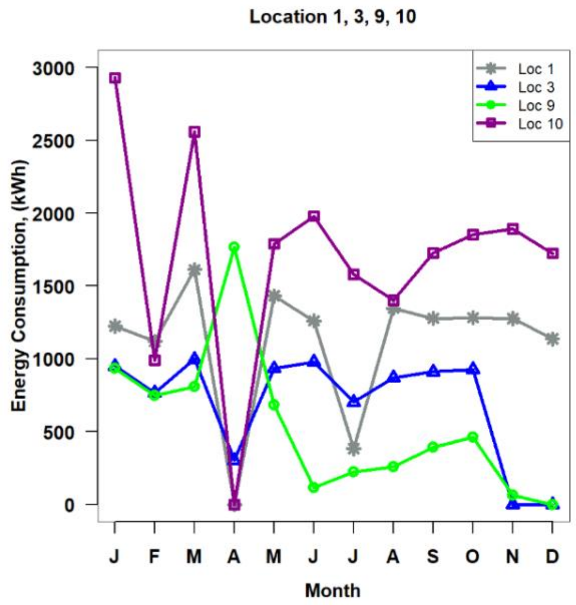


Figure 5: Actual consumption profile for sites 1, 3, 9, 10

From the analysis of the reference sites, it appears that the logarithmic model (1) would be appropriate for predicting the consumption of solar generation for the case of the city of Douala. To confirm this, a simulation with this model was done on all the reference sites over a period of 25 years (300) months, see “Fig.6”. At 25 years, the loads continue to consume a non-negligible amount of solar production compared to the initial consumption. While maintaining the same load profile, although consumption for most sites decreases over time, the level of consumption remains non-negligible with respect to the assumptions made for the simulation.

The amount of energy consumed by the loads in month "1" is greater than the amount of energy consumed in month "300", which leads us to question the causes of the decline in production over the months. The amount of available energy observed in month "300" gives reasons to dig deeper into the possibility of optimizing the installation costs.

As problem formulation, Sadik & all [12] have established in similar case, that the net present total cost (TB) of PV panels considering both cost and energy production can be used to optimize a PV system pay back by solving objective function:

$$max\{TB - IC - IR - OMC\} \quad (14)$$

Where, the installation cost (IC), inverter replacement cost (IRC) and operation and maintenance costs (OMC) are considered. The authors proposed in such case the TB calculation as follow:

$$\mathrm{TB} = \mathrm{ASH.dr.}\sum_{t=0}^{T}\frac{UR_t}{(1+r)^t}\sum_{\tau=0}^{t}\sum_{k=1}^{k}\sum_{m=1}^{M} n_{\tau km}\cdot e_{k,t-\tau}$$

(15)

ASH: annual sunny hours (h)

dr: PV panels derate factor

UR_t: utility rate in period t ($/kW h)

$n_{\tau km}$: number of panel type k installed in period t on building m

$e_{k,t}$: output power of panel type k with age t (kW)

r: discount factor

$(e_{k,t})$ is the power of PV panels as a function of their age. The prediction approach presented in this paper will help to better evaluate the optimum. A more accurate knowledge of TB over a long time would result from the actual generation trend curves modelling presented.

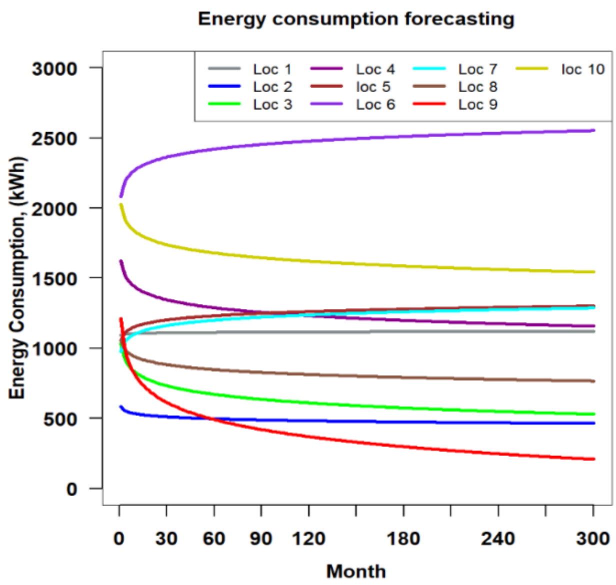


Figure 6: Consumption trend patterns of solar energy up to 25 years.

4. Conclusion

In this paper, the injection of solar PV production into CEN in urban area is found to be a sustainable solution to overcome the problem of untimely outages. The results of trends analysis presented here show a possible optimization of the consumption system of the solar production injected in the CEN. Further considerations on system ageing effect and losses reduction may help for global optimisation that considers the proposed efficiency prediction.

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