Vol. 14(9), pp. 81-87, 16 June, 2019
DOI: 10.5897/IJPS2018.4762
Article Number: 8A379E561063
ISSN: 1992-1950

http://www.academicjournals.org/IJPS

International Journal of Physical Sciences

Review

Designing off-grid hybrid energy supply with photovoltaics in Senegal

T. Schneiders*, L. Alvarez and S. Fassbender

Cologne Institute for Renewable Energy (CIRE), Cologne University of Applied Sciences (TH Cologne), Germany.

Received 31 August, 2018; Accepted 10 December, 2018

In Africa, electrification of rural areas are low and off-grid power supply is needed. Often diesel generators are used to provide local electricity supply. However, the tremendous decrease in the costs of photovoltaics provides an attractive option to substitute existing diesel generation or to build up a new electricity supply in those locations, lowering power costs and environmental impact. Photovoltaics (PV) hybrid system combines photovoltaics with diesel generators and batteries. The design of PV hybrid systems requires an in-depth analysis of load, solar resources and the interaction between PV, diesel generator and storage for the appropriate sizing of components. The team at CIRE TH Cologne has undertaken several projects to examine the feasibility of such PV hybrid systems in different African locations, e.g. a generic Senegalese village in the Thies region. In addition, a modelling tool was developed to analyze the benefits and optimum setup of PV hybrid systems. Furthermore, hands-on experience was gained by installing a PV hybrid system in Ghana, proving the local benefits of this rather new energy source.

Key words: Photovoltaic hybrid system, load profiles, energy system modelling, photovoltaics project planning, installation.

INTRODUCTION

In Senegal, like in several other African countries, electrification rates of the rural areas are low and off-grid power supply is needed. In many cases, diesel generators are used to provide electricity supply, more than 1 million diesel generator systems are used worldwide for this purpose. The tremendous decrease in the costs for solar power makes photovoltaics an attractive option to substitute existing diesel generation or to build up a new electricity supply in those locations, lowering power costs and environmental impact. In combination with batteries, photovoltaics may even fully substitute existing diesel generator systems. However, the design of such a system requires an in-depth analysis of load, solar resources, and the interaction PV, diesel generator and storage for the appropriate sizing of the components. However, little is known about the right setup and design needs for such a system.

At CIRE at TH Cologne, a feasibility study for the design of an off-grid power system including photovoltaics, batteries and diesel generator was carried

*Corresponding author. E-mail: fojals@yahoo.fr.

out for a typical Senegalese village. This feasibility study is based on an extensive literature review of the state of the art of technology and research, the experience from developing numerical simulation tools, the communication with suppliers of components (especially diesel generators, photovoltaics and batteries) and the in planning and installation of comparable projects in Africa and South America. Firstly, the energy needs of a typical Senegalese village were investigated. This required the determination of the load curves with the dedicated free internet tool LoadProGen. Secondly, data on the solar resources was collected. Thirdly, the off-grid hybrid energy supply was modelled with the common software tools PV*Sol and HOMER to determine the size of the different components. Altogether, this project has yielded valuable insights into the methodological approach, tools, and data available for designing off-grid energy systems. Thus, it is providing results as the basis for real projects in Senegal.

In addition, the results from other projects at TH Cologne in this research field are presented. This includes the creation of a modelling tool to examine the possibilities and limits of integrating photovoltaics into existing diesel generator systems. It considers the setup and operating modes of the diesel generators (with aging and partial load effects), also taking into account the use of batteries (including different types of batteries and aging processes). As a result, the optimum setup of the re-designed hybrid PV-diesel-battery system can be calculated.

Furthermore, the hands-on experience from a recently finished installation of a 90 kW PV hybrid system at the St. Dominic’s Hospital in Akwatia/Ghana will be covered. It shows the lessons learned on how such a project could be implemented from the first evaluation of energy data to the final installation on the rooftops.

Altogether, the research hypothesis can be formulated as follows: Given the lack of information, scientific evidence and basic data (e.g. load, solar irradiation), how can a hybrid photovoltaics energy systems be setup properly for a generic village in Senegal and what steps are needed for this, both scientifically and practically?

GENERAL SETUP AND BENEFITS OF A PV HYBRID SYSTEM

Photovoltaics hybrid systems combine power generation from photovoltaics with diesel generators and batteries. They can be grid-connected to the public electricity grid or operate as island power supplies without a grid connection. As scalable solutions, they can supply a single house with a load below 1 kW up to a commercial premise or hospital with a load of several hundred kilowatts.

The tremendous decrease of the costs for solar power makes photovoltaics an attractive option to substitute existing diesel generation or to build up a new electricity supply in those locations, lowering power costs and environmental impact (e.g. soot and noise). In combination with batteries, photovoltaics may even fully substitute existing diesel generator systems.

In Senegal, PV hybrid systems can help to improve the rural electricity supply with currently less than 30% electrification rate, increase the share of local renewables (more than 90% of electricity is produced from fossil fuels) and decrease the dependency from energy imports (all fossil fuels are imported).

When setting up a PV hybrid system, the following aspects need to be analysed:

(1) Load patterns: how much electricity is needed by whom (private or commercial consumers) at what time for what purpose (e.g. lighting, cooking, manufacturing)
(2) Renewables resources: which renewables resources are available on the spot (e.g. solar, wind, hydro), in the following only solar resources will be considered
(3) Storage capacities: how much electricity can be stored
(4) Interaction of components: PV, diesel generator and storage interact and depend from each other and have technical boundary limits (e.g. minimum load of generator, ramps of PV with clouds and rain).

LOAD PATTERNS AND PROFILE

The load pattern is the basis for the design of the energy system. But how can you estimate the electricity needs of people who have not had any access to it before? To accomplish this, a generic rural village was created based on the findings on a study made on 30 unelectrified rural villages in Senegal. This generic village covers 350 inhabitants in 27 households. The load profile was then created on the basis of the freely accessible platform LoadGenPro as provided by the Politecnico di Milano (Italy) (accessible via Facebook). LoadGenPro has been developed on the basis of extensive research work on typical loads and energy consumption behaviour in Africa and so far provides the most suitable numerical tool for this purpose. The interface of this platform is as shown in Figure 1. It allows to include several electrical appliances and types of consumers.

As a result, the load profile of the generic Senegalese village is as shown in Figure 2. Starting from a rather low consumption at night, the load increases in the morning hours to reach the first peak of 6 kW at 9 h and an afternoon peak of around 7 to 8 kW from 14 h onwards till 22 h (resp. 2 to 10 pm).

However, the experience from commercial projects shows that electricity consumption is not only influenced by the need for light or other electrical appliances but also the willingness, respectively ability of the consumers to pay for power supply. So, load patterns are also

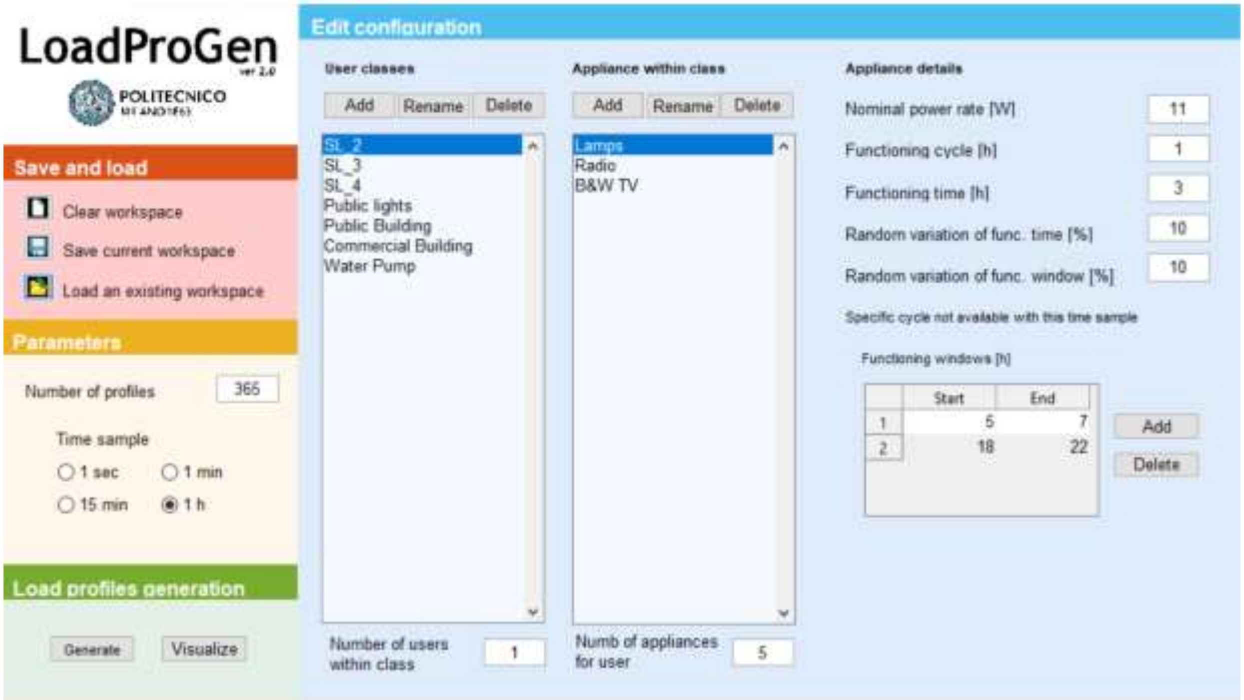

Figure 1. Interface of LoadProGen platform to create load profiles (source: LoadProGen by Politecnico di Milano).

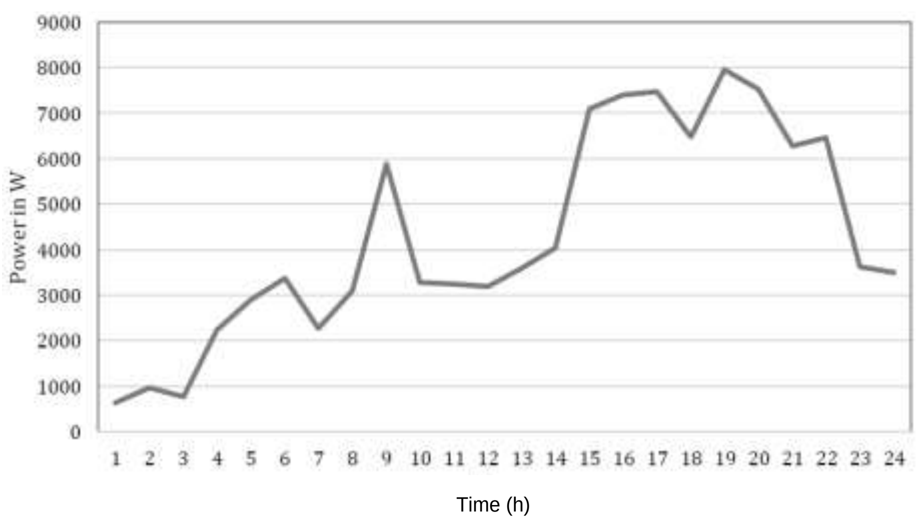

Figure 2. Load profile of generic Senegalese village.
Source: CIRE/TH Cologne.

influenced e.g. by the time when workers are paid. Furthermore, seasonal or temporal mobility of inhabitants may have influence the overall load.

SOLAR RESOURCES IN DIOURBEL REGION

In most locations, renewables resources are limited to solar irradiation and the space for installing photovoltaics on buildings or ground-mounted. The region of Thies provides a rich average global horizontal irradiation of 2,150 kWh/m² in a year (Source: SolarGIS). Figure 3 shows the annual distribution which provides a rather stable daily radiation (left axis) between 5 and 7 kWh/m²/day, depending on the clearness index (right axis). This data is usually derived from several years'

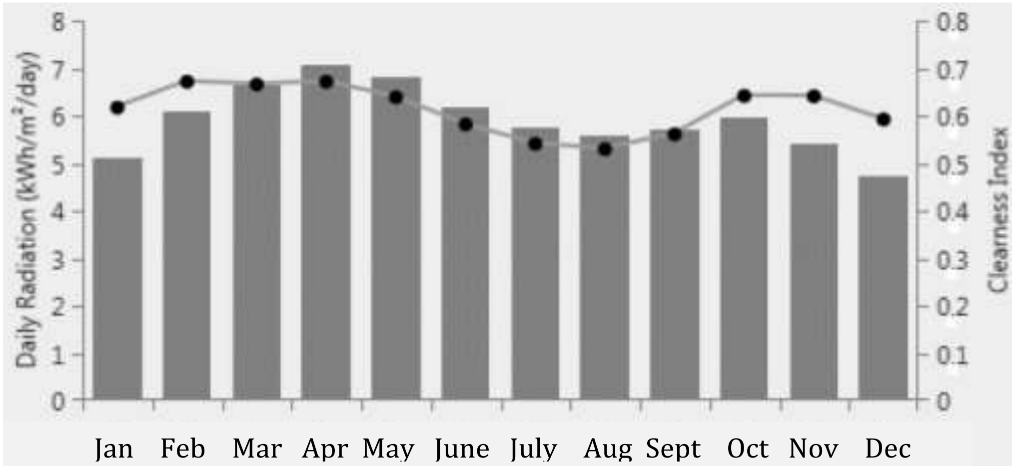

Figure 3. Load profile of generic Senegalese village.
Source: Meteonorm 7.

Table 1. Modelling results for the generic village in Thies region – sizing of components.

Software tool	Architecture					COE
	Batteries (kW)	Diesel-Gen. (kW)	PV (kW)	Converter (kW)	Type of dispatch	(€/kW)
Homer	5.94	9.20	38.9	9	LF	0.233
PV×Sol	10.65	8.33	19	20	CC	0.25

Source: PV×Sol/Homer applied at CIRE/TH Cologne.

average data, so deviations may occur in individual years. Furthermore, it needs to be mentioned that solar resource data may be hard to investigate or even not available at all for specific African locations.

This distribution of solar irradiation with a rather low spread is a reliable basis for photovoltaics power generation over the entire year, like in many African countries. In contrast, values in Germany have a seasonal spread between 5% (December) and 100% (June) over the year.

MODELLING THE PV HYBRID SYSTEM

To find the optimum setup of the PV hybrid system, two different software platforms were used: PV*Sol and HOMER (PV*Sol is commercial, while HOMER can be tested for free for a limited amount of time). In this simplified analysis, no care was taken of potential limitations for installing photovoltaics, e.g. limited roof or ground space and shading. Other effects, like efficiency losses due to the warming of the solar cells are taken into account. The modelling was carried out taking into account the load pattern and solar resources. The modelling tools automatically analyzed the setup to provide an optimum setup. However, as shown in Tables 1 and 2, results strongly deviate between the two tools, leading to two totally different setups. However, the costs of energy (COE) are similar, around 0.25 €/kWh.

These deviations are based on the very different setup of the tools, with different approaches on:

(1) The precision of solar irradiation data and calculation of electricity yield from solar irradiation
(2) Efficiencies of components,
(3) Dispatch, charging and discharging of batteries
(4) Economics underlying assumptions (e.g. price increases of diesel fuel)
(5) Mathematical logic in the tools and different blocks of it
(6) Costs of operations and maintenance

It needs to be considered that not all information on underlying logic and basic assumptions are made public by the providers.

SETUP OF MODELLING TOOL AT TH COLOGNE

Due to the limitations of available numerical modelling tools, the team at TH Cologne developed a MatLab/Simulink based tool for PV hybrid systems. MatLab/Simulink allows using different programming blocks for each technical component which then are

Table 2. Modelling results for the generic village in Thies region – energy flows.

Parameter			Homer	PV×Sol
Consumption	Total per year	[kWh]	35,495	35,495
	Load peak	[kW]	8.3	8.3
PV array	Production	[kWh/year]	64,821	32,176
Diesel Genset	Production	[kWh/year]	1,124	11,278
	Fuel consumption	[l/year]	393.4	3,591
Battery	Consumption coverage	[kWh/year]	18,456	19,537
Converter	Energy in	[kWh/year]	36,516	35,275
	Energy out	[kWh/year]	34,690	21,176
System	COE	[€/kWh]	0.233	0.25

Source: PV×Sol/Homer applied at TH Cologne.

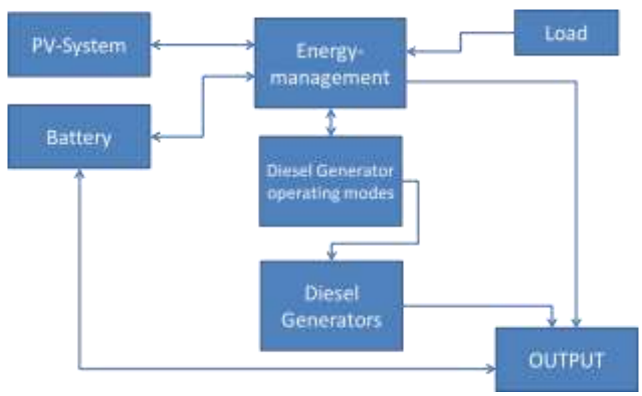

Figure 4. Setup of PV hybrid modelling tool .
Source: CIRE/TH Cologne.

connected via mathematical operations and routines. These "modelling blocks" are as shown in Figure 4. The technical elements PV, diesel generator and load are connected via the energy management which decides on how the electricity is flowing (e.g. from PV to load, but not from a diesel generator to battery). Furthermore, the diesel generator operating modes decide on which diesel generator is operated at which load (if more than one genset is available). The block "PV-system" converts the irradiation into electric power. The block "Battery" includes the parameters of the battery (e.g. state of charge) and the mathematical logics which describe the electrochemical behavior and aging of the battery. "Diesel Generators" cover fuel demand per kWh depending on load factor, a minimum load of the diesel generator and its aging. It is worth noting that partial load puts a greater stress on the diesel generators due to coking and incomplete lubrication. "Output" is a set of calculation results, e.g. costs of energy, charging cycles or optimum setup based on iterative calculations.

It is obvious that this kind of modelling tool is able to provide more detailed analysis and allows more individual settings (e.g. of interest rates or fuel prices) than the tools described earlier. In Figure 5, the input and output of the modelling tool is listed in more detail. It furthermore shows the results for a specific application case, where a maximum of savings could be found by an optimum combination of PV, batteries and diesel generator. Results also show that due to the spinning reserve of diesel generators (that is, the minimum load possible), it is better to split large diesel generators into smaller units (e.g. 3 × 70 kW instead of 1 × 210 kW, while optimum battery depends on the PV size.

In an ongoing research project at TH Cologne, this modeling tool has been refined to cover a wide range of different diesel generators and provide more flexible and precious modelling.

PRACTICAL EXPERIENCE ON-SITE

The CIRE team was also involved in the planning and

Input	Output
Load profile	Diesel fuel consumption
Standardized photovoltaics profile (or insolation values)	Lost photovoltaics generation due to feed-in restrictions
Generator data (size / fuel consumption /minimum load)	Aging of components
Battery data (type / technical properties)	Costs and savings of all combinations
Operating modes	Selection of optimum combination
Costs and lifetime (manufacturer data)	
Variation of input parameters for the model	

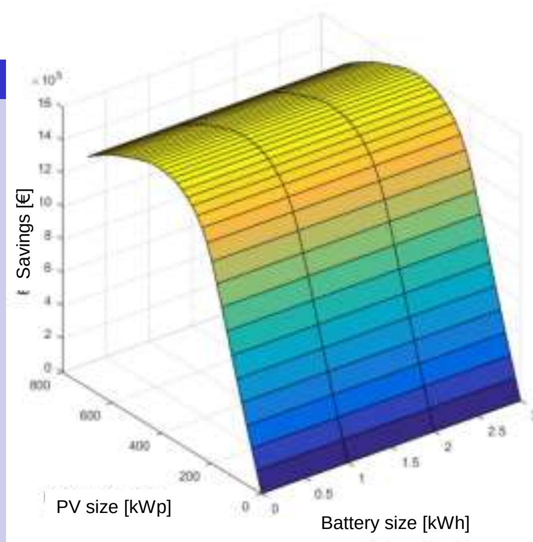

Figure 5. Input and output of modelling tool and results from specific analysis. Source: CIRE/TH Cologne.

Figure 6. Installation of a photovoltaics hybrid system in Ghana (source: CIRE/TH Cologne)

installation of the "Father Franz Kruse Solar Energy Project" at the St. Dominic's Hospital in Akwatia/Ghana in cooperation with the charity organization "Kindermissionswerk" and "Begeca". This project covered the installation of 90 kW of photovoltaics on different roofs of the Hospital's premises. Frequent power cuts at any time of the day require the use of large diesel generators. Before the project, the hospital had a load between 50 kW at night times and weekends, and up to 160 kW at working days. When grid connected, PV reduces the load taken from the public grid. At times of blackouts, PV reduces the load of the diesel generators. Due to the connection to the public grid, no batteries were included in the setup. In addition, more than 550 LED lights were installed to decrease the electricity demand of the hospital significantly (by more than 20%). It is worth noting that before setting up generating capacities, reducing the electrical demand should be prioritized in such a case.

The measurements after the installation show a significant reduction of electricity consumption form public grid and diesel generation. Besides the fuel and costs savings, the PV Ghana project was a first step for implementing PV in Ghana. Within a few days, local craftsmen were trained to safely and reliably install photovoltaics on the Hospital's premises (Figure 6) and to take care of its operations and maintenance. This proves that photovoltaics cannot only provide a suitable and sound energy source, but also the opportunity for local training, qualification of skilled workers and value creation.

Conclusion

Hybrid energy systems combing renewables (especially solar power from photovoltaics), diesel generators and batteries provide a new alternative source of energy supply in Africa. They can provide new power at off-grid locations and substitute diesel power, providing a with local value creation. The works of the CIRE at TH Cologne in this field proved the feasibility of this concept for a generic village in Senegal. However, modelling tools need to be used carefully due to their different underlying setups. Cheaper and more environmentally sound energy source It allows the optimum setup of PV hybrid systems. In addition, the experience from the “Father Franz Kruse Solar Energy Project”, a PV hybrid project planned and installed by the CIRE team yielded valuable practical experience, showed the technical feasibility and proved the local benefits for professional education and qualification. Therefore, PV hybrid systems should play a major role in the future African energy mix and the education of the required technical specialists.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

REFERENCES

Luis A (2017). Design of a Hybrid System for Rural Electrification in Senegal, Master Thesis, Cologne, 2017 http://www.remmaster.Info
Thorsten S, Nicolas S, Marcello S (2016).Sunshine instead of soot - How solar power can substitute diesel generators, IESC Conference, Cologne, 30th of June 2016h;ttps://www.th-koeln.de/anlagen-Load ProGen platform to create load profiles, Politecnico di Milano, 2016https://www.facebook.com/energy4growing2014/posts/loadprogen-10-first-release-of-the-software-tool-for-daily-load-profileformulat/1699296350321186/