A 100% renewable isolated µ-grid in Mafate

Davide BERETTA
EIFER – Germany
davide.beretta@eifer.org

Philippe MOÇOTÉGUY
EIFER – Germany
philippe.mocoteguy@eifer.org

Matthieu LIMAGNE
EDF SEI – France
matthieu.limagne@edf.fr

Jean-Emmanuel BOUCHER
POWIDIAN - France
jean-emmanuel.boucher@powidian.com

ABSTRACT

Due to its very specific geographical characteristics (no road access and no connection to any electric grid), the cirque of MAFATE is powered with diesel generators. EDF, funded by the ADEME and in partnership with the local public authority for electrification and POWIDIAN, completed the existing µ-grid with an installation that provides a 100% renewable electricity. Called SAGES, the installation provides electricity to a school, a dispensary and the building of the "Office National des Forêts". The daily evolutions of their consumption and of the PV production were estimated, via a preliminary on-field study.On this basis, the installation is made of:PV panels (8 kWc), four Li-ion batteries (16 kWh), a water electrolyser associated with an hydrogen storage tank (1.1 m^3 @33bars) and a 2,5 kWe fuel cell. Energy balance studies showed that, except in June and July, the batteries were always able to provide the needed power and the fuel cell was not operating.

In parallel, in order to estimate the performance evolution of the installation and to prognose its future behavior, the daily energy profiles of all the devices have been modelled. More specifically, the daily evolutions of the end-user power consumption were classified into 14 classes, on the basis of the maximal consumed power level and the cumulated daily energy. Then, for each category, a representative average profile was built. Finally, a cost analysis will be performed to compare the LCOE of the installation with the case in which all the end-user electricity demand is provided by a diesel generator.

INTRODUCTION

The cirque of Mafate located in the Reunion island, (Indian Ocean) is an UNESCO site that is not connected to any electric grid and that is accessible only by foot or by helicopters. It hosts 800 inhabitants and is visited by 80000 tourists per year. The first PV pannels (few kWs) were installed at the end of the 80s and an electrification program was carried on between 1997 and 2006 (340 kW). Nowadays, due to the PV panels aging, Mafate is mainly powered with diesel generators, which fuel is supplied via helicopters. In addition, the geographical characteristics makes the maintenance a very tough task.

Fig.1: Mafate, installation site: Ilet de la Nouvelle

EDF, funded by ADEME (Agence De l'Environnement et de la Maîtrise de l'Energie), with the cooperation of SIDELEC (Syndicat Intercommunal d'Électricité de La Réunion) and POWIDIAN (a French SME who supplies the technical solution), completed the existing µ-grid with a pilot installation that provides an electricity produced by 100% renewable sources. It is servicing a school, a medical office and an office of the "Office National des Forêts"..

Called SAGES (Smart Autonomous Green Energy System), this installation is made of (Fig. 2):

- PV panels (8 kWc)
- Four Li-ion batteries (16 kWh) assuring a short term energy storage (1-2 days)
- Water electrolyser + Hydrogen storage system for long term energy storage (1100 l@33bar, 3 kg of H2, 80kWh corresponding to almost 5 days)
- Fuel Cell (2,5 kWe) consuming the H2-produced by the electrolyser
- Connections, inverters, sensors/measurement devices

SAGES is remotely monitored and controlled via a web interface that provides a real time visualization of the grid status (power produced, end-user consumption,...) and allows the operational management of the different devices. The aim of the pilot is to :

- Evaluate the reliability and the quality of the different devices (FC, electrolyser)
- Perform an economic analysis (LCOE, maintenance cost, …)
- Evaluate the replicability of the concept in other sites

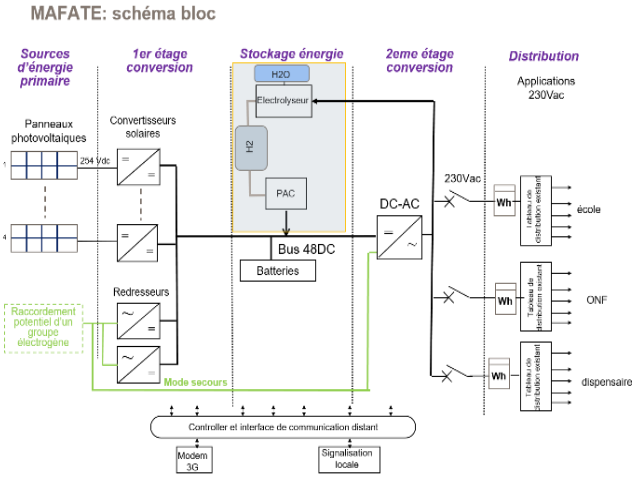

Fig.2: SAGES electrical scheme

PRELIMINARY STUDY

A preliminary study was done in order to quantify the energy needed by the three buildings and the meteorological characteristics of the site (weather conditions, solar irradiance,…). On this basis, the energy consumption and production were simulated in order to size the system, The total annual consumption of electricity was estimated

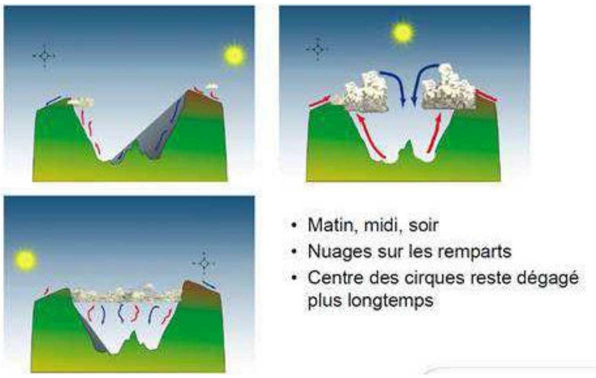

Fig.3: climate features in Ilet de La Nouvelle

In order to satisfy the user power demand, first, the power produced by the PV is used. When this power is not sufficient, the complementary part is supplied by the batteries. When their state of charge decreases below 30%, the remaining needed power is produced by the fuel cell, using the stored hydrogen. On the contrary, if the PV produces an excess of power, this excess is used to charge the batteries (if they are not fully charged) or is used to produce hydrogen by the electrolysers.
A simple scheme is shown in Fig. 4

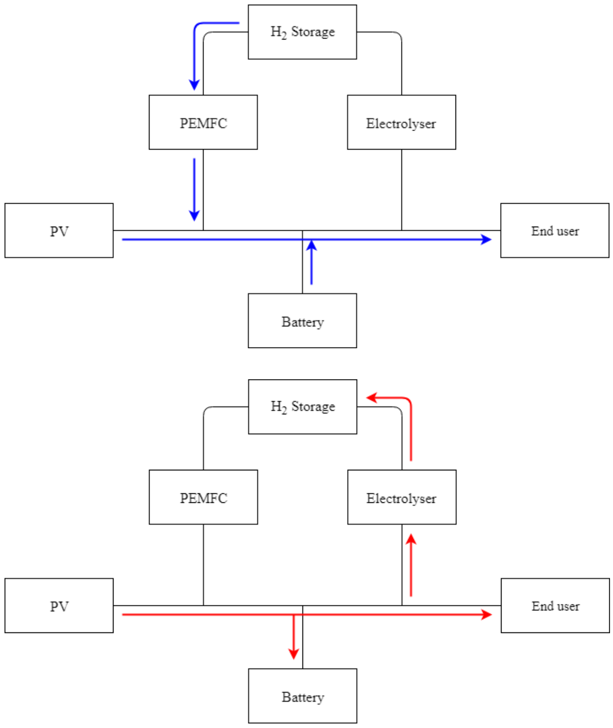

Fig.4: Principle of system operation in case of too low (top) or too high (bottom) PV production

ENERGY BALANCE

This section presents an overview about the energy and power data collected from May 2017 to January 2018, in order to understand how much energy is produced and consumed by the system and which are the different sources of power production.

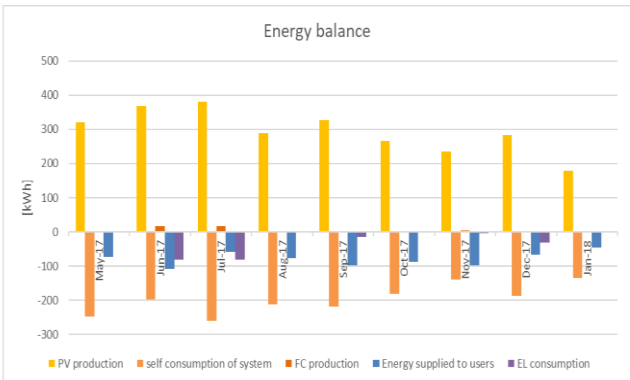

Fig.5: system's energy balance

As shown in Fig.5, the energy produced by the photovoltaic panels is significantly higher than the consumed energy. The evolutions of monthly minimal and average state of charge (SOC) of the batteries are shown, in Fig6.

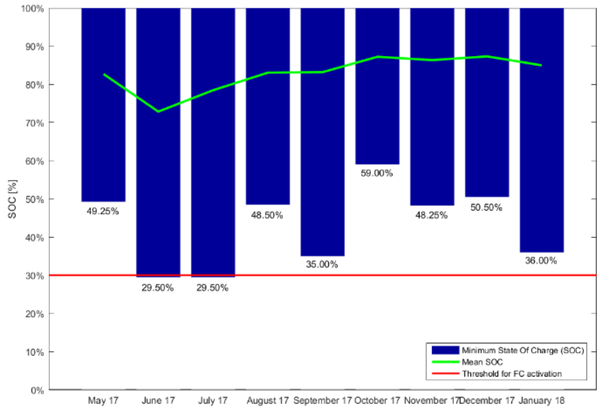

Fig.6: Monthly minimal and average state of charge (SOC) of the batteries

As shown in Fig.6, except in June and in July, the batteries are always able to supply the needed power and, as shown in Fig.10, the fuel cell is not operating. (N.B.: the visible production peaks in the figure are related to periodical tests). On the other hand, in June and July, the minimal battery SOC decreases below the threshold of 30% and the fuel cell produces additional power. Based on the observed low operating time of the fuel cell and in order to better valorise the amount of available renewable energy, a new building will be connected soon to the µ-grid. .

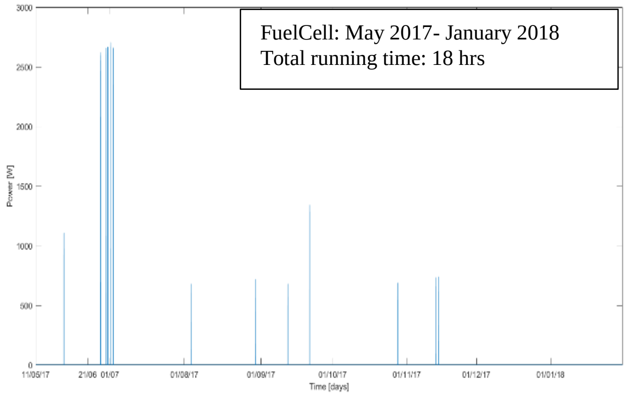

Fig.7: Fuel cell power production

Finally, the daily evolutions of the different sources and sinks of power were analysed. The **Error! Reference source not found.** allows understanding how the different devices are used to supply power to the user. In the plot, the positive area (corresponding to the power produced) is higher than the negative area (which represents the power consumed). This means that only a small part of the power produced by the PV is used to cover the end user demand, while the remaining part is used

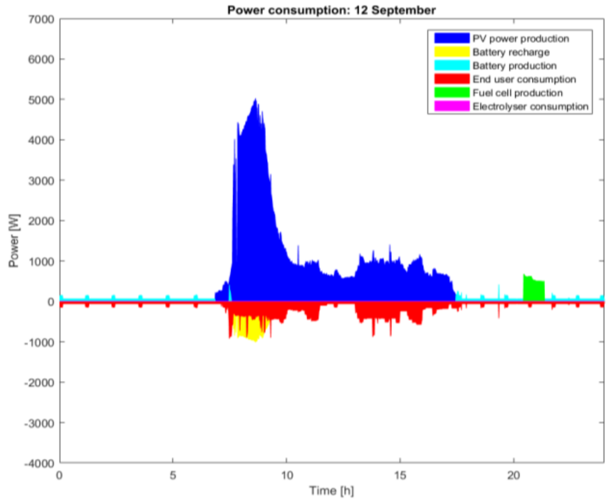

Fig.8: Sources of power consumption over a sunny day.

PROFILING

In order to perform a predictive maintenance (decrease maintenance cost), it is necessary to evaluate the power profiles of the different loads and generators. Indeed, a basic hypothesis of any prognosis is that the future behaviour of a device is known (future operations similar to past operations). That's why the daily energy profiles of all the devices of the installation have been modelled. In this section, we focus our attention on the end user's consumption profile. To describe the different operating conditions, a profiling of the experimental data was made by analysing the daily power required by the end user. According to their specific features, the measured daily power profiles were classified in some categories (or classes), following two criteria: the value of the highest peaks and the cumulated daily energy (in order to take into account the shape of the profiles). Then, for each category, an average profile was built, that approximates the real ones and that is assumed to represent the future load conditions of the system.

Class	**N° of sub-classes**	**Daily Energy [Wh]**	**Max Power [W]**
"Low" (55.9%)	3	< 2100	< 2000
"Medium" (40.3%)	9	> 2100	< 2000
"High" (3.8%)	2	-	> 2000

Table1: end user's profile classification

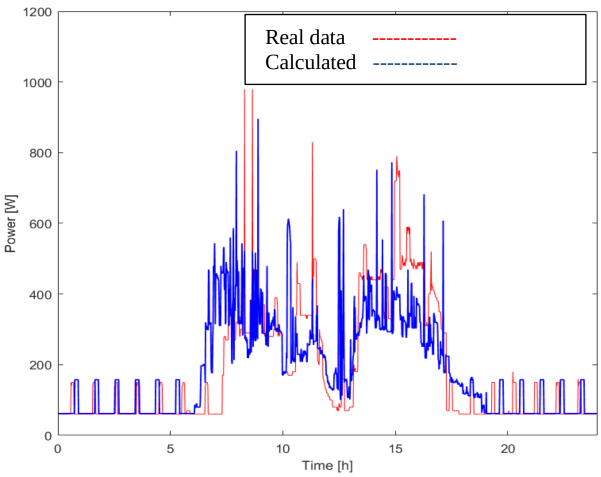

Fig.9: example of experimental and modelled end-user consumption profiles

The different average profiles have been evaluated considering different indicators:

- Percentage Relative Standard Deviation (PRSD):

$$PRSD(t)\ [\%] = \frac{\sigma(t)}{AP\ Power(t)} * 100$$

(Overall value evaluated on the whole day and on the running time)

- Difference on Energy [%] $= \frac{\int_0^\infty \sigma(t)\,dt}{\int_0^\infty AP\ Power(t)\,dt} * 100$

Giving, in comparison with real data, the following results:

Class	Energy Difference on analytic profiles	PRSD on analytic profiles
"Low 1"	12.7 %	29.2 %
"Medium 7"	22.0 %	24.1 %
"High 2"	33.1 %	70.1 %

Table2: classification results

This activity is the basis for a predictive maintenance (prognosis), which will be performed in the near future on the electrochemical devices such as electrolyser, fuel cell and batteries.

CONCLUSIONS

A complete remote site in La Reunion Island, previously supplied with energy produced via diesel gensets has been retrofitted with a complete 100% renewable energy chain. This solution avoids the very high operational cost of the "diesel" scenario assuring, in the meanwhile, a resilient and reliable µgrid (serving public buildings). The operation showed that the batteries provide and consumes all the power variations, minimizing the operating durations of the fuel cell and the electrolyzer. Based on this and in order to better valorise the amount of available renewable energy, a new building will be connected soon to the µ-grid.

The feasibility of this completely renewable µgrid and the technology solution provided have been demonstrated, continuous electricity supply is guaranteed thanks to the slightly oversized solution, which assure the possibility to increase the number of final users.