Guaranteeing energy during peak period thanks to a grid connected PV system with Li-ion batteries: field tests results

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Abstract-- **Electricity storage has been identified as a key issue by European PV and the "Smart Grids" platform: it is a critical technology which will catalyze the large penetration of Renewable Energy Sources foreseen in Europe by 2020. In regions with a high solar potential, electrical storage combined with PV systems (converters, energy management systems) allows to address intermittency of generation. A producer is in a position to supply guaranteed power to the network operator in charge of the local balancing. The value of the shifted kWh of a grid connected PV + storage system has been modeled in an insular environment and confronted to experimental results carried out in the Guadeloupe island. Various operating scenarios and tariffs have been simulated taking into account the real electricity demand data and the manufacturer's industrial roadmap for a Li-ion battery technology. Orientations for further large scale experiments conclude the real life experiments conducted in 2008/09.**

Index Terms— **Electricity storage; Grid connected PV system; guaranteed power; Guadeloupe; Lithium-ion battery; PV + Storage**

I. Introduction

THE Distribution System Operator (EDF) in the French overseas department Guadeloupe is facing a growing electricity demand (25 to 50 % increase forecasted during the period 2005 - 2015) with two daily peaks in the morning and in the evening around 8 p.m. The current response is to use 20 MW sets of fossil fuel turbines with high running costs and environmental impact. The combination of electrical storage with Photovoltaic systems (including converters, energy management systems) is a promising solution to address intermittency of generation, especially in regions with high solar potential. It allows not only smoothing the PV production but moreover maximizing the value of PV energy through grid injection in periods of peak demand.

II. Method and Results

An impact analysis of guaranteed power supply to the system operator has been performed. The energy producer builds this offer upon a combination of a set of lithium-ion (Li-ion) batteries coupled with photovoltaic units. A simple model was built to simulate an hourly operation of the combined "PV + storage" system based on actual consumption data and solar irradiation in Guadeloupe island, as well as on technical parameters provided by manufacturers and on the marginal costs of electricity production in Guadeloupe. The model allowed an optimization of the system design according to boundaries conditions and the definition of operation strategies (day/night cycle; seasonal impact,…). The results obtained by simulations were compared to field experiments run in Guadeloupe during 18 months. The overall system architecture is depicted in Fig. 1 below.

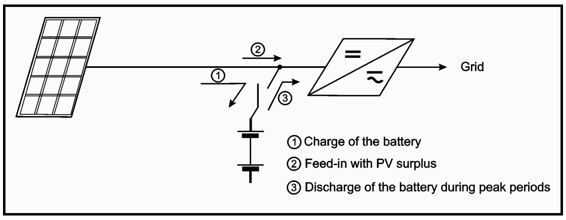

Fig. 1. System architecture and power flows

A. Work program and achievements

On the technical standpoint it included first the definition of operating profiles, then the development of inverter, battery storage and system management: the photovoltaic array was sized at 2 kWp, the inverter at a power range of 2 kW working at a voltage range of 150-400V. For the Li-ion battery the maximum energy storage capability was 10 kWh working at a voltage range 210/280 V.

In parallel, the techno-economic analysis was developed for the Guadeloupe configuration. The sensitivity analysis performed on a plausible cost evolution for storage and PV systems, conventional electricity, feed-in tariffs, led to a return of investment in the range of 6-10 years.

These tasks were devoted to prepare the field test campaigns. Fifteen systems were produced and installed in thirteen sites in Guadeloupe for field tests, two systems remaining in Saft and Tenesol premises for laboratory

This work was supported by ADEME, energy agency in France (convention number 0805C0061).

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B. Energy Management strategy and results

The guaranteed power supply requires: a) on the technical standpoint, a remote control by the system operator according to peak period, and b) a commercial agreement on a guaranteed tariff price (GT) that should be higher than the normal feed-in tariff (FT = 400 Euros/MWh). The producer should be in position to supply in this guaranteed mode, despite the intermittency of the solar generation, thanks to the electric storage. To achieve this, the producer should have deployed a fleet of PV + battery systems in a large number of end use locations (typically household or commercial end customers). The battery is used, if needed, between 10% and 100% of charge. In the guarantee contract, penalties are foreseen in case of failure.

The offer is then driven by the peak periods of the network operator. During programmable peak demand periods and upon network operator request, the guaranteed energy is then supplied by the PV array and/or the battery at this guaranteed tariff (GT). During normal period (outside guarantee) the PV production is fed into the grid at the FT tariff.

There is a possibility for households to self consume their energy production if the support scheme incentivizes self consumption as it is the case in the new German law on energy (German Renewable Energy Act 2009).

The operation of the three system components – converter, PV, storage - should be analyzed specifically during a 24 hour cycle. In Fig. 2 below, the operation of each of the system component is represented.

Grid injection during peak demand periods and PV surplus are described in the first graph of Fig. 2. From 4:30 to 5:30 there is no solar activity and the period is considered off-peak, but the converter allows the batteries to feed the grid at that time (this experimental duration can be changed or made available upon demand by software tools).

From about 6 am the PV arrays start their electricity generation toward the electricity storage. The generation curve follows the nominal solar irradiation until 8:30 am. From 8:30 am to 11 am some irregular phenomena, due to clouds preventing the solar production appear in parallel with production and electrical storage (2^{nd} and 3^{rd} graphs), until the battery is fully charged. The system is not allowed to charge the batteries with power from the grid.

From 11 am to 5 pm, a non linear effect due to battery saturation appears (on the 1^{st} and the 3^{rd} graphs): the battery is fully charged and the electricity surplus is injected to the grid at the normal FT tariff (since the period is considered as off-peak).

Finally, during the 6:30 pm to 8:30 pm peak period, the stored PV energy is sold back to the grid at the GT tariff. This period is also programmed due to the consumption peak but must be adapted according to techno-economic and contractual conditions agreed among the involved parties.

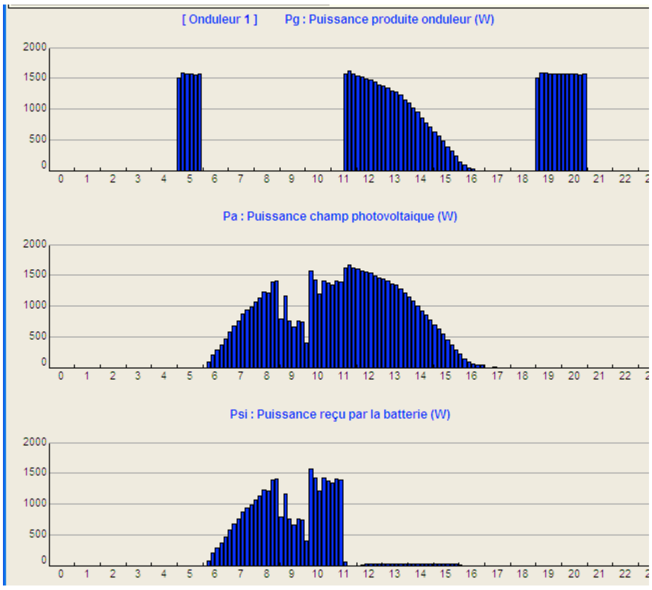

Fig. 2. Daily results from one Guadeloupe demonstration site

C. Conclusions and next steps

The follow-up and monitoring in Guadeloupe of the 15 demonstration sites from mid 2008 to end 2009 allowed producing a set of technical data on the operation of combined PV+ Li-ion storage systems: energy transfers, voltages, power,… The analysis of such data on a long period allows securing the definition of a guaranteed energy offer based on such technology.

More specifically, the study confirmed that the storage unit can effectively perform a daily cycle of the level of about 50% of depth of discharge with a yield of 97%. It should be mentioned that, on a global energy balance, about half of the produced energy by the PV is stored.

A final step in the project foresees the update of the techno-economic analysis with the actual monitored data and the conditions of the local Network Operator policy within the existing regulatory framework. This will validate the value of the business model, as well as its operation strategy and initial assumptions before further large scale demonstration projects needed to figure system industrialization.

Beyond the project horizon, further optimization of operation mode in term of production / storage / grid injection of PV energy is envisaged in close coordination with the Network Operator requirements. As the communication capabilities with the Network Operator evolve, the system will be able to adapt dynamically to the level of stress on the grid at a given moment of time.

The impact analysis has shown shared benefits for all of the involved parties from electricity generation to the distribution and end users. The challenge is a more secure and sustainable energy supply avoiding the use of fossil fuel turbines in islands with high solar potential

D. Orientations for further large scale experiments

Orientations for further large scale experiments concluded the real life experiments of 2008/09. The main objective of these experiments is to assess the impact on the non interconnected grid during peak demand.

E. Abbreviations and Acronyms

FT: feed-in tariff (for PV injected to the grid)
GT: guaranteed tariff price
kWh: kilowatt hour
kWp: kilowatt peak
Li-ion: lithium-ion
MWh: Megawatthour
PV: photovoltaic.

III. Acknowledgment

The authors gratefully acknowledge the contributions of ADEME (French Agency for Environment and Energy Management), the Guadeloupe region, the TENESOL subsidiary in Guadeloupe.

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V. Biographies

Jean-Christian Marcel works for energy systems application with more than 20 years of experience. He now belongs to Tenesol, a French company in the field photovoltaic (PV) systems.

Since 1983, TENESOL is involved in modules PV manufacturing, systems design, integration, supervision and even exploitation (roughly 1 million of square meters installed).

As an engineer, he is in charge of R&D programme co-ordination within the company in the fields of modules PV processing and performances; building integrated PV structures; balance of system (inverter, dataloggers, charger,...); rural electrification applications design (SHS - Solar Home systems, hybrid,...); grid connected PV for production and ancillary services.

Jean-François Cousseau holds a PhD in electrochemistry from the Pierre & Marie CURIE University of Paris. He joined Saft's Lithium Research Group in 1996 and the Lithium Development team, based in Poitiers, in 1998 as Electrochemical Manager. He took responsibility for the process team in 2000. From 2003 to 2008 he was the Technical Manager for the Li-ion medium prismatic (MP) product line. He has joined since 2008 the Systems Development Department in Saft Bordeaux as Programs Manager for Renewable Energy applications.

Athanase Vafeas, senior consultant, engineer graduated from Ecole Centrale Paris in 1989, joined Technofi in 1991. He has been in charge of management tool development and implementation in several projects, he has been in charge of project or work package coordination of projects dealing with energy resources, renewable with regards to business modeling and innovation management as well as on training and dissemination issues.

Serge Galant, CEO of Technofi, Aeronautical Engineer from ESMA (1971) and Ph. D. in Mechanical Engineering from the Massachusetts Institute of Technology, USA (1975) joined Bertin (France) in 1976. From 1992 to 1998 he was Director of new business development at Bertin. In 1998, he joined Technofi as a Vice President for Business Development in the private sector. Since 2001, he is CEO and main shareholder of Technofi.