Demand side management applied to a stand-alone microgrid

Cedric Abbezzot, Johann Francou, Didier Calogine

To cite this version:

Cedric Abbezzot, Johann Francou, Didier Calogine. Demand side management applied to a stand-alone microgrid. International Journal of Smart Grid and Clean Energy, 2022, 11 (4), pp.127-134. 10.12720/sgce.11.4.127-134 . hal-04085196

HAL Id: hal-04085196
https://hal.univ-reunion.fr/hal-04085196

Submitted on 28 Apr 2023

International Journal of Smart Grid and Clean Energy

Demand side management applied to a stand-alone microgrid

Cedric Abbezzot[a], Johann Francou[a], Didier Calogine[a]

[a] *University of Reunion Island PIMENT laboratory, 120 rue Raymond Barre, Le Tampon 97430, France*

Abstract

“Mafate Micro Grid” is a research project funded by the European Regional Development Fund and held by a partnership between the PIMENT Laboratory of the Reunion Island University and the SIDELEC Reunion. The main purpose of the project is to develop and improve smart grid concept in Reunion Island. Mafate is a landlocked area non-connected to the main electrical grid. A major stake for local authorities is to electrify about 300 homes by means of solar microgrid installations. Our case study provides an actual Energy Management System application for 3 homes in Mafate, aiming to maximize the use of photovoltaic energy and to prolong battery life. The project is carried out closely with three Mafate homes, as a human-machine interface is installed in each house. This work is a preliminary approach to evaluate theoretically the effectiveness of a Demand Side Management process depending on the users’ acceptability. Results show the Energy Management System reduces energy wastes and increases the solar energy effectively used, provided users follow the given advice.

Keywords: stand-alone microgrids, photovoltaic, energy storage, demand side management, home energy management system

---

1. Introduction

Energy insecurity is a major issue, often caused by the area’s remoteness, or a difficult access to the said place. Electrifying isolated areas is very challenging because transportation of ordinary energy sources, mainly fossil fuels, is often laborious and grid extension is expensive. Mafate is a natural cirque, in Reunion Island, where about 700 inhabitants live (2019). Mafate is not connected to the main electrical grid, mainly because of the very difficult access to the cirque, as described in [1]. People in-situ, suffered for years from a major energy insecurity. Mafate is being massively electrified by means of solar panels and batteries incorporated into resilient distributed networks. This electrification project is carried out by the SIDELEC Reunion [2]. This work is focused on an experimental microgrid in Mafate feeding three residential buildings with a 7 kWp solar field and about 90 kWh lead acid battery pack. A novel Demand Side Management (DSM) device is being tested on this microgrid, where a Human-Machine Interface (HMI) has been installed into the considered residential buildings. The HMI displays optimal consumption advice obtained from a remote calculator. Main purposes of this paper, is to analyse the DSM strategy to prove its effectiveness on a simplified model of the microgrid. A comparison is done between three scenarios, a worst-case scenario, an ideal scenario, and a moderate scenario. Results show the DSM is a powerful to maximize the use of solar energy in order to reduce the energy and to longer the battery life. However even if the strategy is efficient, its real added value on the microgrid depends tightly on users’ acceptability and their willingness to contribute to their own energy management [3]. To address this acceptance issue, another objective of the paper is to present a user-friendly HMI installed in each home to encourage inhabitants to consider recommendations from the EMS.

---

* Manuscript received February 22, 2022; revised September 17, 2022.

Corresponding author. *E-mail address*: yvon.francou@univ-reunion.fr

doi: 10.12720/sgce.11.4.127-134

2. Microgrid Model

To evaluate DSM effectiveness, preliminary tests are required for deploying the proposed Energy Management System (EMS). The model used for the tests is validated beforehand with experimental measurements from the actual microgrid.

2.1. Structure

The model used is a very simple one since it is not the central topic of the present paper. The model is composed of 3 subsystems, solar panels, battery storage and consuming houses. The energy from the photovoltaic effect for one solar module is modelled as following, Duffie 2013 [4]:

$$E_{pv}(t) = P_c.\Delta t.\left(1-\eta_{pv}\right).\frac{G(t)}{1000}.[1+K_T.\left(T_{amb}(t)+G(t).\frac{NOCT-20}{800}-T_{base}\right)] \tag{1}$$

Where, P_c, t, Δt, η_{pv}, G, K_T, T_{amb}, $NOCT$ and T_{base} are respectively the peak power, the time, the sampling time, the solar yield, the solar radiation received by the solar panel, the temperature coefficient, the ambient temperature, the nominal operating cell temperature and the reference temperature. The evaluated battery feature is its State of Charge (SOC), as conducted in [5]. The SOC in discharging mode is calculated as:

$$SOC(t) = SOC(t-1) - \frac{E_{out}}{r_d.CAP} \tag{2}$$

The SOC in charging mode is estimated as following:

$$SOC(t) = SOC(t-1) + \frac{E_{in}.r_c}{CAP} \tag{3}$$

Where, E_{out}, E_{in}, r_d, r_c, and CAP are respectively the energy drawn from the battery, the energy added to the battery, the discharging efficiency, the charging efficiency and the nominal capacity expressed as an energy. When there is a solar production (P_{pv}), the energy flow is regulated to prioritize the use of photovoltaic (PV) production, the battery parc is discharged only when the PV production cannot meet the demand (P_{load}) and the SOC is superior to the minimal SOC value (SOC_{min}). If the PV energy is superior to the demand, the surplus energy is used to charge the batteries, provided that the SOC is inferior to the maximum SOC value (SOC_{max}). The regulation diagram on Fig. 1 represents the energy flows according to the solar resources and the consumption level at a given time.

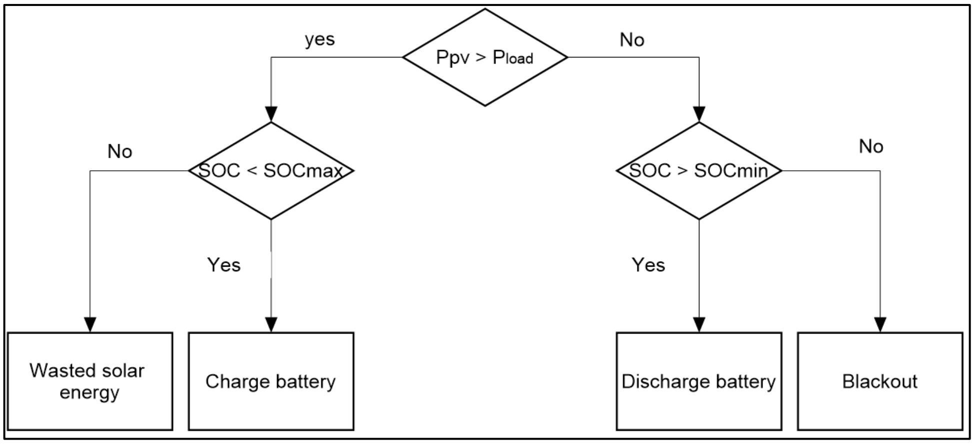
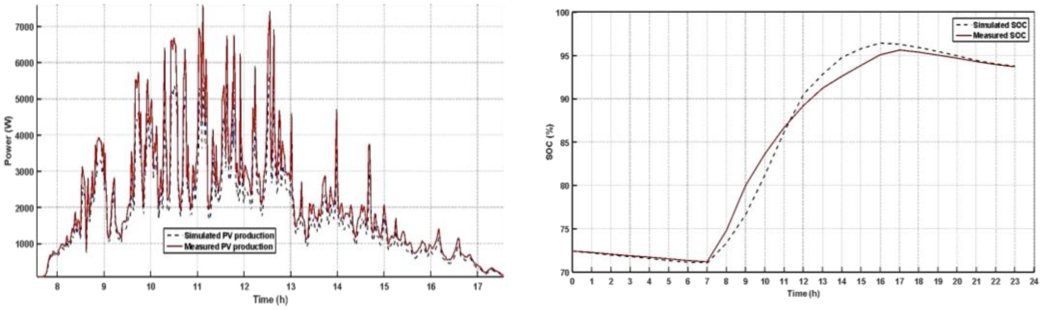


Fig. 1. Regulation diagram of the model



(a) (b)

Fig. 2. Real data measured on 28th August 2021 compared to simulated solar production (a) and SOC (b)

2.2. Model validation

The above model is compared to real measurements from the actual microgrid, under the same demand profile. Photovoltaic production is calculated from pyranometer and temperature sensor data measured on the microgrid in Mafate. The solar production simulated is very close to the actual photovoltaic profile in-situ as seen in Fig. 2-(a), the root mean squared error (RMSE) for the simulated day is about 304 W, which represents 4.28% of the solar field peak power. Errors on the solar model appear mainly when the solar production is substantial. Regarding the SOC in Fig. 2-(b), the estimated RMSE is about 2.00 % between simulated and real SOC.

3. Demand Side Management Application

3.1. Human machine interface

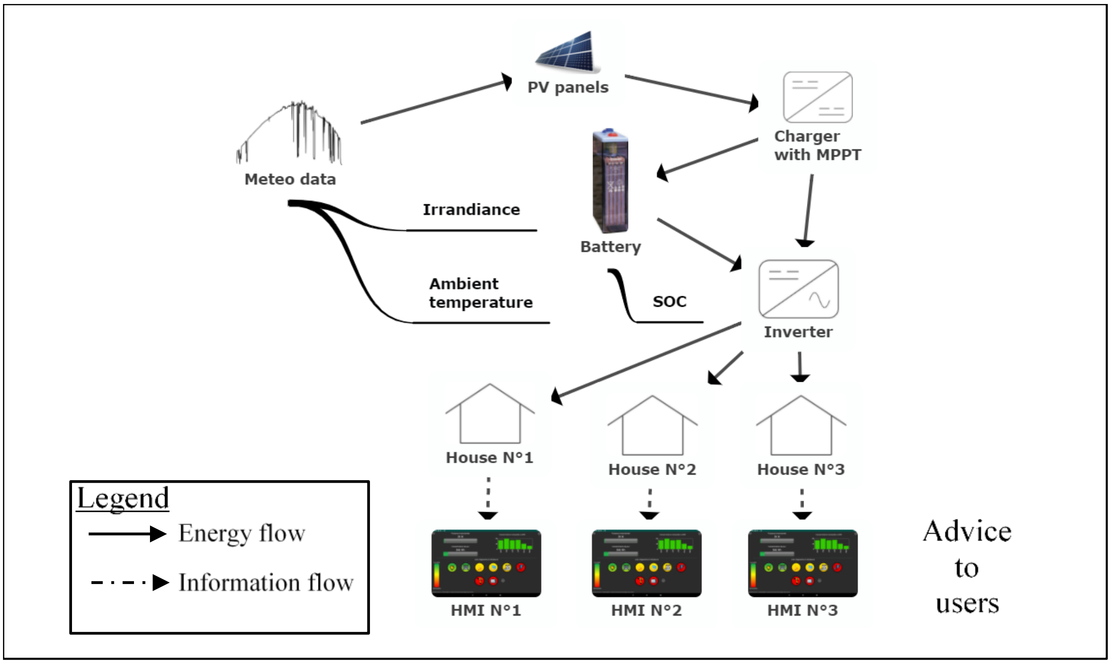
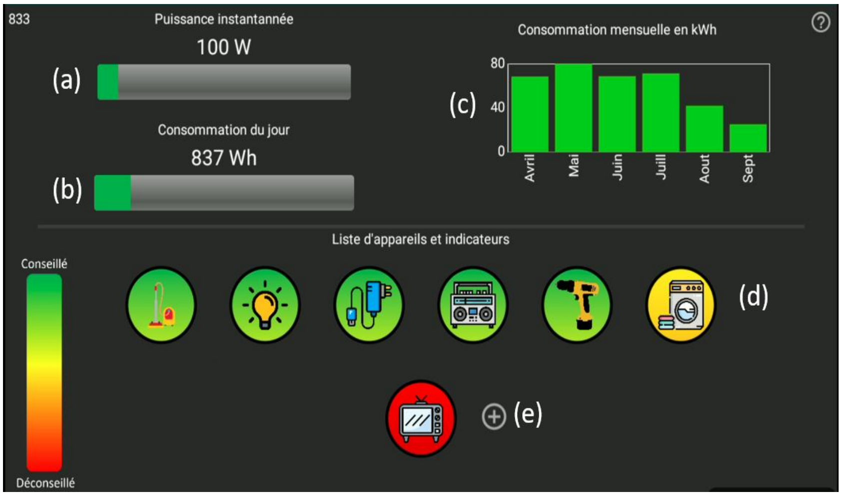


Fig. 3. Mafate Smart Grid architecture

Fig. 3 shows the smart grid architecture, with an HMI embedded in each house composing the microgrid. An HMI allows a simple visualization of the advice generated by the backend machine. The HMI is developed to be fluent, user-friendly and efficient. The HMI is developed on an Android 10 operating system, allowing the user to install the app on his Android smartphone, or any other Android device. The HMI is preferred to be installed on a dedicated tablet device hooked on a visible inside wall, to familiarize the users with the technology and to simplify the access to the displayed interface, as seen on the Fig. 4:

(a) This progress bar is the instantaneous total power consumed, it allows the user to see his power consumed, to ensure no device is forgotten in on mode, or to evaluate the power level of each device. The progress bar's maximum is the contracted power.
(b) The second progress bar represents the energy consumed for the current day. This information is useful to estimate the consumption within a day, if it is high, moderate, or low. The progress bar's maximum is the daily contracted energy.
(c) The bar diagram is the user's monthly consumed energy.
(d) The electrical devices pictures, on the coloured round tags, represents the device used by the consumer, if it is green it means the device is highly advised to be used at this moment, if it is yellow it means it is not advised, and if the background is coloured in red, the user is highly advised to not use this device. By clicking inside the round tags, it is possible to modify the information for the concerned device, such as rated power, use duration or preferred interval of use.
(e) The add button allows users to input new devices.



Puissance instantannée
100 W

Consommation du jour
837 Wh

Fig. 4. HMI main display, "conseillé" and "déconseillé" are the French words for respectively advised and not advised, "puissance instantannée" means instantaneous power, "consommation du jour" means demand for the current day, "consommation mensuelle en kWh" means monthly demand in kWh, "Liste d'appareils et indicateurs" means device list and advice indicators.

The EMS architecture is described in Fig. 5. User's device information is inputted on the HMI, i.e each device rated power, preferred consumption hour interval and the preferred device use duration. The HMI is constantly communicating with a remote real-time database storing appliances information and live consumption levels. The aforementioned user's information is inputted to the optimizer, described in L.D.Ha 2008 [6], to determine the best load schedule according to the available produced power and the users' preferences. Live measurement data are measured to update the progress bar and the bar chart values.

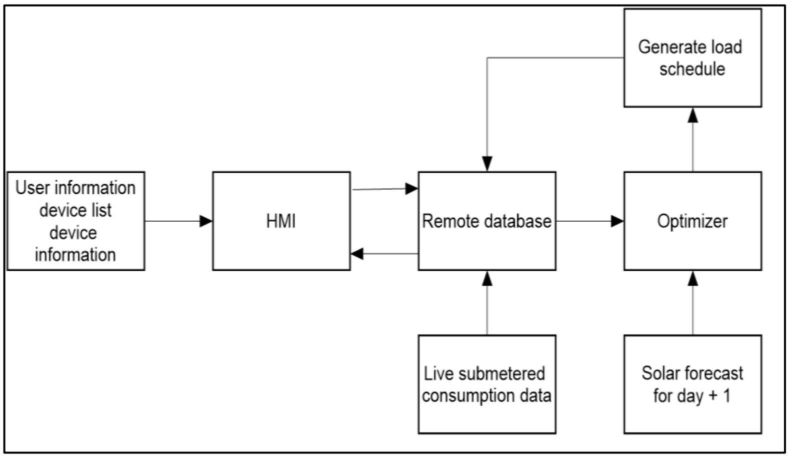


Fig. 5. Energy management system architecture

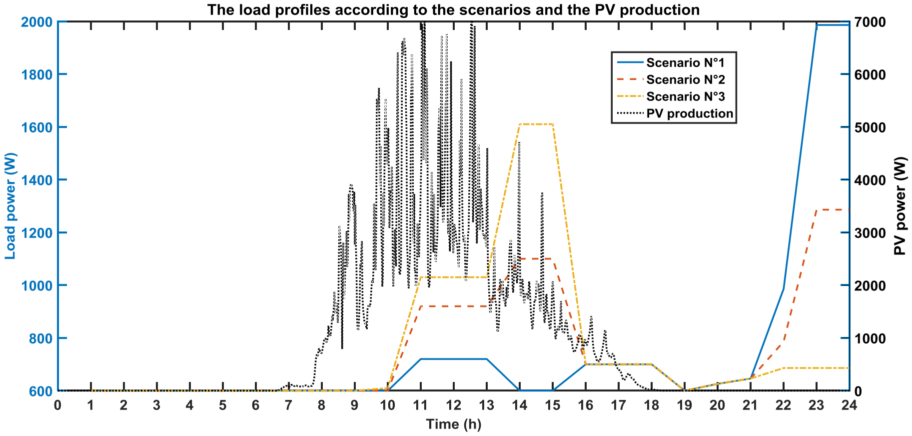


Fig. 6. Photovoltaic profile for the 28th August 2021 and fictive load profiles from the three scenarios

3.2. EMS experimentation

In a first step, the EMS is experimented on the microgrid model described above. This approach allows shifting loads as wanted. The inputted loads are presented in Fig. 6. The electrical appliances considered for the simulations are the actual appliances used. The appliances are listed below:

- Washing machine (2 out of 3 inhabitants hold a washing machine)
- TV set
- Lighting
- Phone chargers
- Fridge – Freezer

The microgrid users possess few equipment since Mafate is a lately electrified area, the inhabitants used to live without or with less electrical appliances. The main objective of the experiment is to evaluate the EMS performances as a function of user's acceptability. The acceptability is defined here as the inhabitant willingness to shift his own load following the HMI displayed advice. The EMS performances are evaluated energetically through the PV energy consumed directly noted E_{dir} and the energy lost due to the battery round trip efficiency, noted E_{loss}. Another criterion considered is the SOC value at the end of the day, i.e at 23:59. Different acceptability scenarios are considered, the first one is where nobody follows the advice. The second case is when one out of three follows the advice, and finally all three users accept to shift their loads in the third scenario. $E_{dir}(t)$ and $E_{loss}(t)$ are defined as,

$$E_{dir}(t) = \begin{cases} E_{load}(t) \ \ if \ E_{pv}(t) - \ E_{load}(t) > 0 \\ E_{pv}(t) \ \ if \ E_{pv}(t) - \ E_{load}(t) < 0 \\ 0 \ \text{else} \end{cases} \tag{4}$$

$$E_{loss}(t) = \begin{cases} E_{in}(t).(1 - r_c) \text{ in charging mode} \\ E_{out}(t).\left(\frac{1}{r_d} - 1\right) \text{ in discharging mode} \end{cases} \tag{5}$$

Where E_{load} and E_{pv} are respectively the energy demand and the photovoltaic energy that can be produced with E_{in}, E_{out}, r_c, and r_d are respectively the energy inputted in the battery, the discharged energy, the charge and discharge efficiencies.

3.3. Results

The PV consumed directly (PVDIR) is the photovoltaic energy consumed directly, irrespective of the storage. Scenario 1, has the lowest PVDIR, so it is the scenario where the battery is the most used. As energy flows in and out of the battery, an amount of energy is lost during successive chemical transformations. The less is the energy loss the better is the global efficiency of the microgrid. As seen on Fig. 7, the proposed EMS allows to reduce the energy loss by 20% with the retained hypothesis. Nobody follows the advice for the first scenario, main loads are consumed from the evening to the night, when solar production is low. Loads in scenario 1 are concentrated at the end of the day, that is why the slope is steeper between 10 pm and 11:59 pm. As loads tend to be shifted towards the forecasted high solar production moments, scenarios 2 and 3 are those for which the most energy is exchanged through the battery during daytime (8 am to 6 pm), explaining why the first scenario SOC profile is above the second and the third scenarios on Fig. 8. However, when users on scenario 1 turn the washing machine on after 10 pm, the SOC is highly decreasing. The final SOC at 11:59 PM for the scenarios 1, 2 and 3 are respectively 71.0 %, 71.7 % and 72.2 %. It demonstrates that the load shifting process proposed allows to limit the battery discharge.

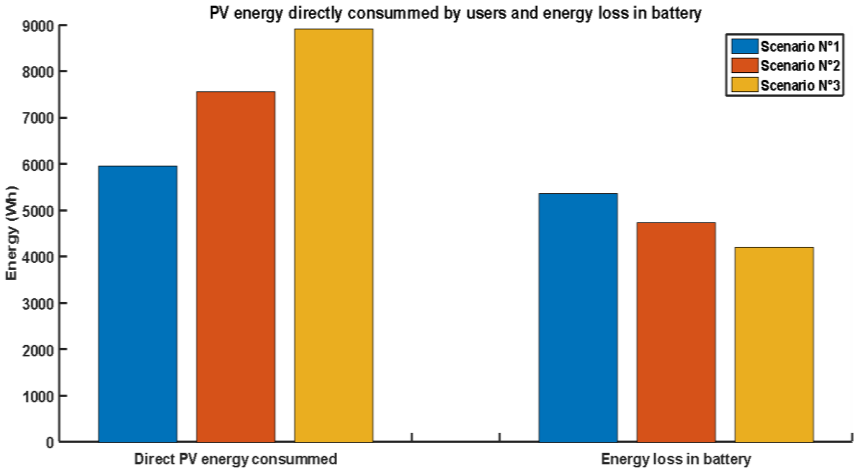


Fig. 7. Performance indicators and results

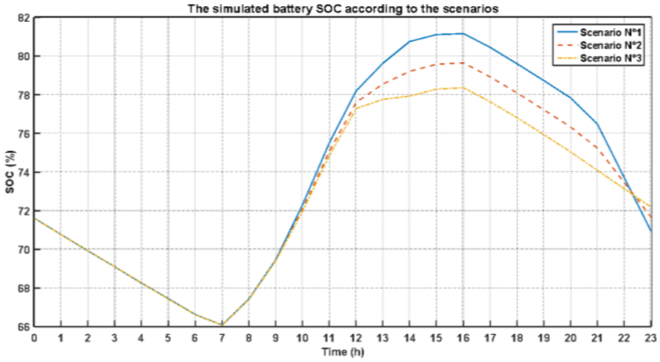


Fig. 8. Simulated SOC curves

4. Conclusion

In this work, a simplified microgrid model of the actual microgrid in Mafate is used as a test platform of the proposed EMS. First tests are done informatically to avoid invasive procedures. The energy demand for each commonly used appliance corresponds to the actual power rated from appliance datasheets. This work allows us to quantify the solar energy gain by using a load shifting EMS for a typical day, and as well quantify the potential gain on the battery usage. In fact, for the considered scenarios 1.2% of SOC could be saved at the end of the day by the DSM. Furthermore, load shifting allows to increase direct solar energy used for the scenario 2 and scenario 3, respectively up to 27 % and 50 % over a day, compared to the scenario 1. Regarding the energy loss due to the battery efficiencies, the scenario 3 allows to save about 22 % of energy compared to the energy lost in the first scenario. As mentioned by C.S Olsen 2014 [7], the efficiency of a DSM system depends tightly on users' acceptability. Thus the HMI has to be user-friendly, and has to be fluent and robust. Undoubtedly, the EMS performances are proportional to users' acceptability, and could be improved by means of a reward system, Nakano et al. 2020 [3]. Next step for the "Mafate Micro Grid" project members is to evaluate the actual gain since it requires a long experimentation time in order to familiarize the inhabitants with the EMS and to notice valuable improvements.

Conflict of Interest

All authors declare that they have no conflicts of interest.

Author Contributions

A,C contributed to the manuscript writing, he processed numerical simulations and contributed to the Energy Management System development. F,J contributed to the manuscript writing and to the Energy Management System development, he also carried out the data processing tasks. C,D supervised the conducted researches and contributed to the Energy Management System development.

Acknowledgements

Authors acknowledge European Union, Region of Reunion and French government for their financial support. We would also thank the SIDELEC Reunion for their valuable contribution.

References

[1] Calogine D, Chau O, Lauret P. A fractional derivative approach to modelling a smart grid-off cluster of houses in an isolated area. *Journal of Applied and Numerical Optimization,* December 2019, [Online]. Available: http://jano.biemdas.com/archives/965

[2] SIDELEC Reunion website. [Online]. Available: https://sidelec.re/?p=1634. 2020

[3] Nakano, Satoshi, and Ayu Washizu. On the acceptability of electricity demand side management by time of day. Energies, 2020; 13(14).

[4] Duffie JA, Beckman WA. Solar Engineering of Thermal Processes, 3. New York: Wiley, 2013.

[5] Bridier, Laurent. Modélisation et Optimisation d ’ Un Système de Stockage Couplé à Une Production Électrique Renouvelable Intermittente, 2017.

[6] Long HD. To Cite This Version : Institut Polytechnique de Grenoble, 2008.

[7] Olsen CS. Visualization of energy consumption: Motivating for a sustainable behaviour through social media. In: *Proc. of 2014 International Conference on Collaboration Technologies and Systems (CTS)*, 2014: 641-646.