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Simulation and Management Strategy of Energy Flow in Hybrid System

Zeïnabou Nouhou Bako*‡**, Mahamadou Abdou Tankari**, Amadou Seidou Maiga***, Gilles Lefebvre**

* University Dan Dicko Dankoulodo of Maradi, BP 465 Maradi – Niger

** University of Paris-Est Creteil, CERTES Laboratory, 61, Av. du Général De Gaulle, 94010, France

*** University Gaston, Berger EITER Laboratory, BP 234 Saint-Louis, Sénégal

(zeinabou.nouhou-bako@u-pec.fr, mahamadou-abdou-tankari@u-pec.fr, amadou-seidou.maiga@ugb.edu.sn)

‡ Zeïnabou Nouhou Bako, University of Paris-Est Creteil, CERTES Laboratory, 61, Av. du Général De Gaulle, 94010, France

Fax : +33 (0)1 45 17 65 61

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AbstractThis paper presents a control algorithm based on energy dispatch strategy in a remote area of Niger in the West Africa region. The system is a micro grid equipped with solar panels, conventional sources, and energy storage units. The hybrid energy management system presented is meant for rural and remote area power supply. The hybrid system configuration focuses on providing an uninterrupted power supply to the maximum load's energy demand. This approach can improve the living conditions through the increase of the economy and easiness of access to energy through a reasonable cost from an economic point of view to avoid over-sizing of production sources. The optimal configuration and model details of the proposed hybrid energy system have been described. The aim of this paper was to improve the design, operation and control requirement of a hybrid system in a specific area of Dakoro in Niger. The proposed control energy flow management strategy has been brought out by performing experimental studies on a laboratory prototype

Keywords Control strategy, microgrid, hybrid system, rural electrification, energy management.

1. Introduction

Energy is a central element of the development of the country[1]. It is directly related to the most critical social issues that affect sustainable development: poverty, employment, income levels, access to social services, urban-rural disparities, migratory flow, agricultural production, climate change, and environmental quality. Access to energy can help to solve economic and security issues.

One-third of the world's population amounting to about 2 billion of people around the world have not accessed to electricity, [2], [3]. Half of this population are in Africa , generally in rural area due to the high costs extending grids [4]–[8]. Lack of access to modern sources of energy aggravates poverty, particularly in the countryside where communities, basic activities such lighting, cooking, heating are dependent on traditionnal biomass such as fuelwood, charcoal, agricultural residue animal waste, largely on human and animal labor [6], [9]–[11].

Some habitable sites are not or cannot be connected to the public distribution network for two aspects: technical and financial. It is technically too complex to extend the electricity network to them because they are too far therefor long distance distribution and not easy to access. The financial profitability of an extension, the connection to the electricity grid is all less profitable as the users are dispersed therefore low density population and poor low energy demand. In this case, conventional electrification of urban areas dense population is favored.

Regardless of the geographical area, each site has exploitable natural resources like wind, sun, permanent watercourse…Indeed, depending on the natural resources available and need, it is possible to produce energy locally, using appropriate renewable technology to provide access such as PV, wind power, but also micro-hydro and biogas.

The potential of local renewable energy production can improve the quality of life in remote areas[12]–[14]. Several types of researches have focused on solving local issues, while satisfying local energy demands in some African countries, by performed to support energy development strategies carried out on the exploitation of renewable resources. Some of these works revealed and show the barriers , challenges, policies, plans to increase energy and benefits associated with renewable applications to access modern energy for some regions that have been limited in the word due to poor financing and low income levels of households [15]–[19].

The economic and environmental aspects of these renewable energy technologies promote access to energy and are one of the factors in the fight against climate change. These technologies are promising enough to include them in increasing electricity generation capacity in developing countries. One of the most promising applications of renewable energy technology is the installation of hybrid energy systems in remote areas that are poorly served or not served by the networks that supply large cities because grid expansion is costly and the cost of fuel goes up [20] . A renewable hybrid energy system consists of two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system or grid-connected, should be integrated to improve system stability and smooth out radiations fluctuations [20], [21]. The most common hybrid systems models usually used of photovoltaic, wind, diesel and batteries as components[22]–[25]. Renewable energy sources, such as photovoltaic, wind energy, or small scale hydro are a potential and realistic alternative solution for electricity generation in remote areas to supply energy demand. In various and recent research and development papers in renewable energy sources have shown excellent potential, as a form of a supplementary contribution to conventional power generation systems[20], [22], [26], [27]. In this system , the conventional system either diesel generator or grid are used as a back-up generator[20].

Hybrid (multi-source) energy systems have been shown to significantly reduce the total life-cycle cost of autonomous power supplies in many and various situations, and maximize energy efficiency while providing a more reliable supply of electricity through the combination sources of energy supply.

The potential micro- grid system installed taking into account, mainly, climatic conditions. The Photovoltaic–Diesel–Battery systems are ideal in areas with warm climates[22], [28].

The performance of the system is to evaluate its ability to distribute the energy produced while maintaining the equilibrium of the micro-grid.In the literature, much attention has been proposed to optimize the hybrid energy system by developed and applied energy management in isolated areas[29]–[34]. The authors in [35] present a comparative study of the techno-economic analysis of hybrid power systems (PV–diesel–battery and PV–wind–diesel–battery) intended to a remote telecommunication mobile base station in Nigeria. The considered the combination of PV–diesel–battery and PV approaches is the best feasible configuration for the site compared with the optimal solution given by HOMER. This configuration strategy is the best performing strategy due to the low wind speed regime at Doka-Sharia rural area of Kaduna State. The main objective in this paper[36] is to optimize the Distributed Energy Resources Customer Adoption Model (DER-CAM) to determine the optimal size and type of distributed energy resources (DERs) and their operating schedules for a sample utility distribution system. This technic shows that the microgrid application is able to improve the efficiency of a system. These papers focused on distributed energy management for an effective strategy to improve cost-effectiveness and reliability[37]–[39].

The main objective of this paper is to propose a system to supply the full energy demand of load, based on analysis simulations to better control the interactions and exchanges of flow between system entities (PV, diesel, batteries, loads). The algorithms have been subsequently implemented on the Programmable Logic Controller.

2. System Architecture

Fig.1 shows the production-consumption system, coupled with an energy storage system and diesel generator.

The solar insolation varies during seasons but also at times of the day. Therefore, the nature of generated by PVS is intermittent. So, under variable insolation conditions, the storage system and a diesel generator are added to ensure continuous energy supply. The hybrid system supplies the load demand. The energy surplus from the PV above the hourly demand is stored in the battery bank. When the energy demand is greater than the energy generated from the PV, the storage system is discharged to ensure the load demand.

A power electronic system consisting of a charge/ discharge controller device and inverter which converts the DC voltage output of PV into a load AC requirements.

The system becomes the seat of flow transfer through the power electronics system. And, all was managed by a steering and management system.

The approach adopted is summarized by the architecture below and as shown: in Fig.2, the input data available are technical and technological parameters for system various components, parameters related to the site, as well as energy and economic parameters. Optimization algorithms are used to determine the architecture and electrical cost. This paper approach to achieve a goal as followed:

- ➢ Data collection.
- ➢ Maximization solar energy collects on an inclined plane. - Optimization of energy system producible while mini-zing economic cost.
- ➢ Another element to optimize was the lifetime of the storage system by avoiding deep discharges of batteries.

- ➢ Data collect potential and produce energy.

A structure to the methodology approach to design the system production is presented in Fig.2. This approach taking into account the technical and technological parameters input data available of the system components, economic parameters the parameters related to the studied site, as well as the energy and economic parameters.

2.1. Data collection

A data collection focused on energy needs definition and services nature to be provided based on the socio-economic environment and factors such as family background, household income, number of persons per household home. Fig.3 and Fig.4 give respectively the flowchart of estimated and calculated the power and energy. Categorize different activity sectors; categorize the main devices types in each activity sector. The data; information is formatted in the form of a three-dimensional table, consisting of k-pages listing the number of devices, and m-columns listing the number of sectors, n-lines listing the number of sites.

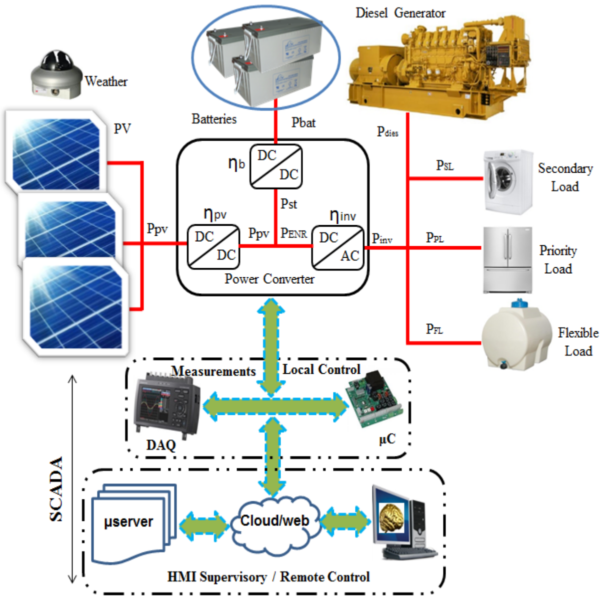

Fig. 1. Synoptic of the study microgrid.

Energy by type of appliance and sector $,E(i,j,z),$was calculated using Hadamard's product (1). Energy for a rural community $,E(i),$ and global energy demand for all rural communities E_T were estimated as:

$$\begin{cases} E(i,j,z) = N(i,j,z) \odot P(i,j,z) \odot D(i,j,z) \\ E(i) = \sum_{z=1}^{k}\sum_{j=1}^{m} E(i,j,z) \\ E_T = \sum_{i=1}^{n}\sum_{z=1}^{k}\sum_{j=1}^{m} E(i,j,z) \end{cases} \tag{1}$$

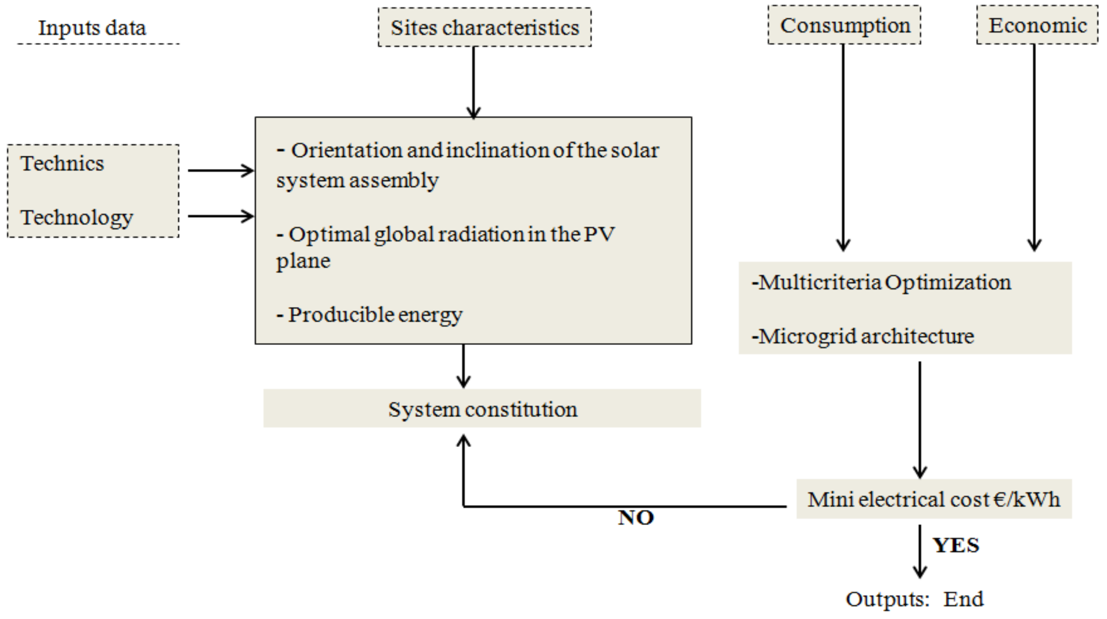

Fig. 2. Architecture approach.

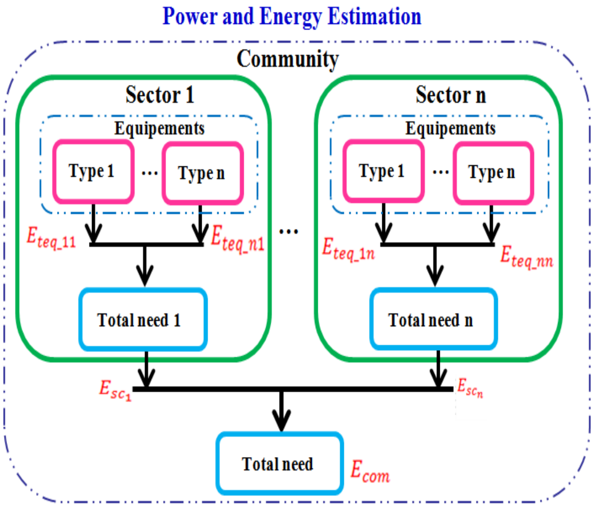

Fig. 3. Flowchart of estimated power and energy

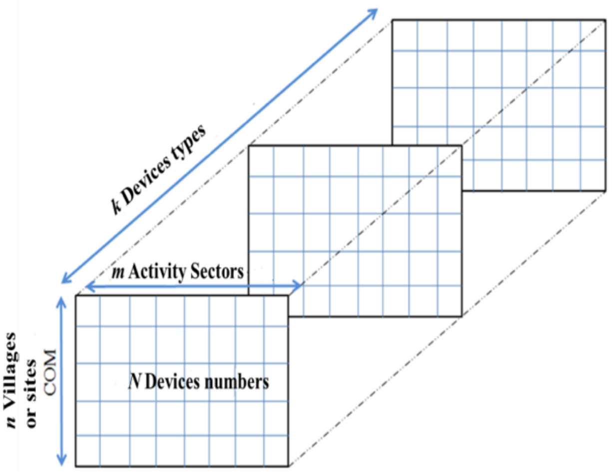

Fig. 4. Three-dimensional board.

For the solar potential estimation, the approach is presented in Fig.5. A model that has been established input variables such as the number of the day in the year and the meteorological parameters to allow calculations of parameters and functions associated with equations.

2.2. Producible energy

In addition to the consumption profile, it is necessary to estimate producible energy. It is summarized in Fig.6 and its expression is given by equation (2).

$$\begin{cases} E_A = \eta_p \eta_r (1-\lambda_p)(1-\lambda_c)\eta_r[1-\xi_p(\Delta T)]A_{pv}\bar{H}_t \\ \Delta T = (T_a - 25°) + C_f(219 + 832K_{Tm})\dfrac{NOCT-20}{800} \end{cases} \quad (2)$$

with,

$$C_f = \begin{cases} 1 & \text{if} \quad \beta = \beta_{opt} = \psi - \delta \\ 1 - 1{,}17.10^{-4}\,(s_M - s_r)^2 \end{cases}$$

The energy available from the solar PV array is characterized by its efficiency η_p, which is a function according to the ambient temperature and irradiance level , array losses, L_{pv} , and other power conditioning losses, L_C. Where the ambient, T_a ,and 25°C is the NOCT measurement conditions, the absorbed solar radiation at the optimal inclination $\bar{H}_t$, the temperature coefficient ξ_p (per k^{-1}) and η_r the reference efficiency of the module. ψ and δ are respectively the latitude and the declination. S_M and S_r the optimum inclination angle and the actual inclination respectively expressed in degrees [40].

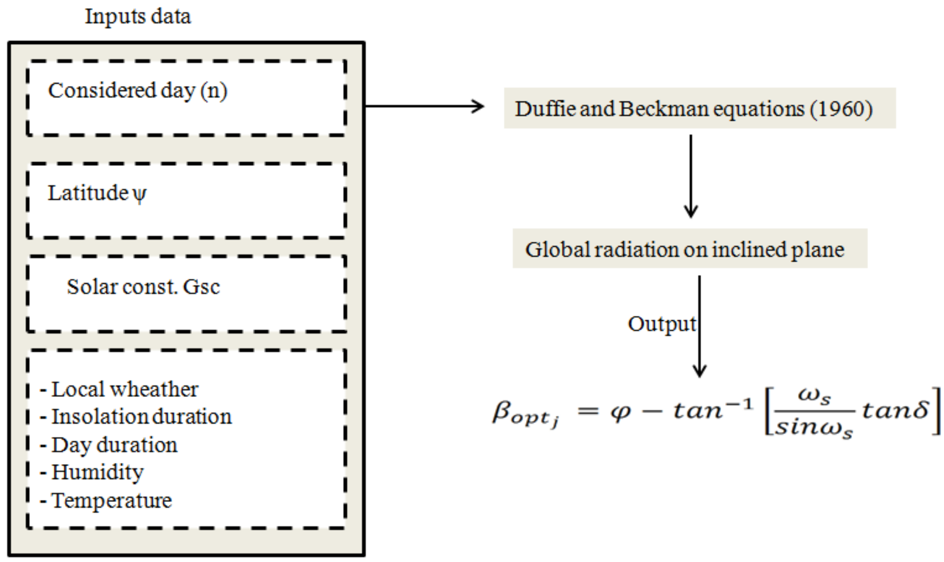

Fig. 5. Approach to solar energy estimation.

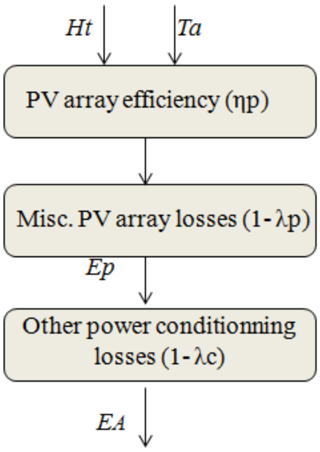

Fig.6. Model of PV generation

2.1. Storage system

Once estimated energy available, the question is about the storage system capacity[41]. The characterization battery approach is shown in Fig.7.

In the renewable energy system case, the batteries micro cycle amplitudes varied from the process of charging and discharging. Regarding the battery, the Kibam model presented in [42] has been chosen for this study. It takes into account the variations of the quantity of charge in the charge/discharge process and the voltage behavior over time. It also takes into consideration the *OVC* (Open Circuit Voltage), which is a function of the battery's *SOC* and the internal resistance.

The storage's maximum energy (E_{bmax}), which is in Wh, is defined by (3) for a constant current.

$$\begin{cases} Q_{max} = \dfrac{Q_{tc}(1-e^{-kt_c})(1-c)+ckt_c}{ckt_c} \\ E_{bmax} = V * Q_{max} \end{cases} \qquad (3)$$

c and *k* are parameters extracted from the KiBam model.

2.2. Diesel generator

The diesel generator supports the microgrid by supplying directly to the load and charges the storage energy system. The contribution of the diesel generator is defined par the expression (4)

$$0 \leq P_{dies} \leq P_{dies\_nom} \qquad (4)$$

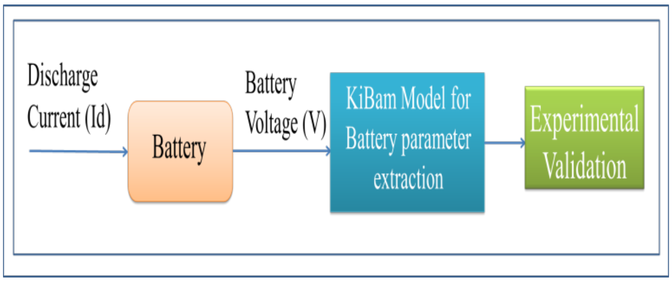

Fig.7. Characterizing battery approach

3. Energy Flow Management

We made the following assumptions about the energy consumption in our microgrid to provide the solution of deciding how energy source supplies the load energy demand:

1. Maximum output transfer from renewable resources (MPPT);

2. The diesel generator could operate in one of the following modes: continuous with (minimum and maximum) power limits or intermittently at constant or variable power;

3. The battery charge level is limited between two values (maximum and minimum);

4. Electrical charges are classified into two broad categories: main loads and flexible loads. The main charges consist mainly of priority loads (PPL), to supply priority in case of energy deficit as well as secondary loads (PSL) that can be relieved in case of energy deficiency. These charges are activated by the consumers according to their needs. Priority loads provide vital services such as product conservation or sanitary and medical facilities. Flexible loads (PFL) are powered by energy availability and activated by the overall plant supervisor. They consist of equipment whose use could adapt to availability. These include, for example, pumping and hydraulic storage or irrigation systems.

5. The batteries are primarily loaded by PV energy but can be recharged by the diesel generator in low deficit case to fill.

6. The size of the storage system is characterized by its maximum storage capacity [kWh] with a minimum bound capacity threshold (minimum SOC)

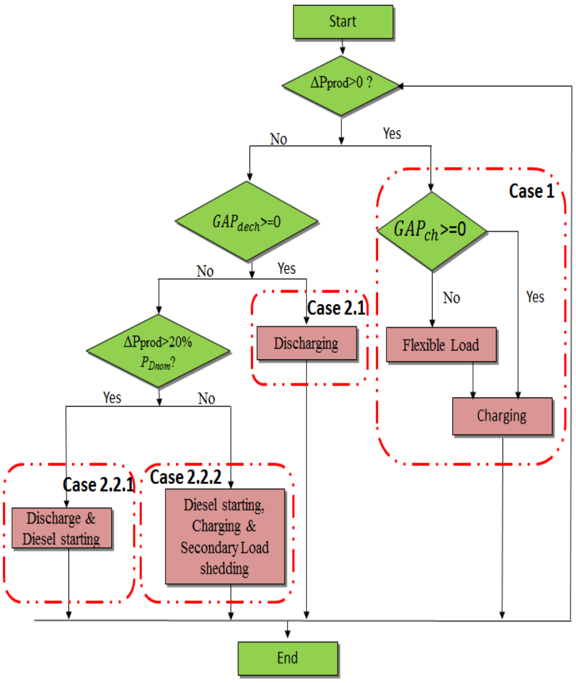

Fig.8: Energy flow under different cases

3.1. Mathematic formulation

All power flows in the microgrid can be expressed from the consumption $P_{Load}(t)$ and production $P_{pv}(t)$ and from the input data, η_{inv} , the efficiency related to the power converter .

The power flow diagram is shown in the figure 7, and each case corresponding with particular equations.

The flexible load is zero in normal operation. The nominal power of the load or main charges consists of two components. These are the priority and secondary loads, as expressed by (5):

$$P_{Load}(t) = P_{PL}(t) + P_{SL}(t) \tag{5}$$

The corresponding powers to the PV output and the discharge of the battery on the AC voltage bus are expressed by (6):

$$\begin{cases} P_{pv\_AC}(t) = \eta_{inv} * P_{pv}(t) \\ P_{stock\_AC}(t) = \eta_{inv} * P_{stock}(t) \end{cases} \tag{6}$$

The instantaneous contributions of renewable energy productions on DC and AC buses can be expressed according to (7).

$$\begin{cases} P_{enr\_AC}(t) = P_{pv\_AC}(t) - P_{stock\_AC(t)} \\ P_{enr\_DC}(t) = P_{pv}(t) - P_{stock}(t) \end{cases} \tag{7}$$

Energy flow management is based on sequential tests, the first level is defined by the difference (8) between photovoltaic production and load demand $\Delta P_{prod}(t)$:

$$\Delta P_{prod}(t) = P_{pv\_AC}(t) - P_{Load}(t) \tag{8}$$

The effective energy flow management process based on consumption and production is considered for study as four follows cases.

- *Case* 1: $\Delta P_{prod}(t) \geq 0$:

The PV panels contribution is equal to the load energy demand such as:

$$Contrib_{pv}(t) = P_{Load}(t) \tag{9}$$

The extra power $\Delta P_{prod}(t)$ in Eq. (10) could be stored according to the state of charge (SOC) of the batteries. The expression of power stored directly in the batteries has for:

$$Potentiel_{stock}(t) = \frac{\Delta P_{prod}(t)}{\eta_{inv} * \eta_{bat}} \tag{10}$$

SOC (State Of Charge) below its maximum value, the energy surplus could be stored totally or partially in the battery.if (Eqs. 11 and 12):

$$\begin{cases} \Delta E_{bat} \geq Potentiel_{stock}(t) \\ GAP_{ch} = \Delta E_{bat} - Potentiel_{stock}(t) \geq 0 \end{cases} \tag{11}$$

$$\begin{cases} P_{bat}(t) = Potentiel_{stock}(t) \\ E_{bat}(t) = Potentiel_{stock}(t) + E_{bat}(t-1) \end{cases} \tag{12}$$

So, otherwise, the battery charged and the dissipative charge activated, Eq.13

$$\begin{cases} P_{bat}(t) = \Delta E_{bat}(t) \\ P_{DL}(t) = \left(Potentiel_{stock}(t) - \Delta E_{bat}(t)\right) * \eta_{inv} \\ E_{bat}(t) = \Delta E_{bat}(t) + E_{bat}(t-1) = E_{bat\_max} \end{cases} \tag{13}$$

- *Case* 2 : $\Delta P_{prod}(t) < 0$

In this scenario, the photovoltaic production is lower than the demand of the load. Photovoltaic energy is insufficient to satisfy all the needs of electrical charges. The batteries can be used to compensate for the energy deficit at the level of their charge level. If necessary, the diesel group will be involved. The contribution of the PV corresponds to its total production is given by the expression (14).

$$Contrib_{pv}(t) = P_{pv\_AC}(t) \tag{14}$$

The energy deficit on DC bus: (Eq.15) :

$$Deficit_{dstock}(t) = \frac{\Delta P_{prod}(t)}{\eta_{inv} * \eta_{bat}} \tag{15}$$

The dischargeable capacity of the battery is estimated from the SOC:

$$\Delta E_{dbat} = E_{bat}(t-1) - E_{bat\_min}(t) \tag{16}$$

If the battery is enough to compensate for the energy deficit:

$$\begin{cases} \Delta E_{dbat} \geq |Deficit_{dstock}(t)| \\ Gap_{dech} = \Delta E_{dbat} - |Deficit_{dstock}(t)| \geq 0 \end{cases} \tag{17}$$

The battery new capacity, after discharge, becomes (Eq.18) :

$$\begin{cases} P_{bat}(t) = Deficit_{dstock}(t) < 0 \\ E_{bat}(t) = Deficit_{dstock}(t) + E_{bat}(t-1) \end{cases} \tag{18}$$

Otherwise, insufficient battery to compensate for the deficit, the diesel generator started .

The minimum power delivered by the diesel must be greater than or equal to 20% of its nominal power. It is considered that the diesel is able to satisfy all the possible deficits, in the absence of the batteries.

- *Case* 3: $|\Delta P_{prod}(t)| \geq 0.2 * P_{Dies\_nom}$

The energy deficit greater than batteries capacity and the diesel generator supports the load. The battery can be charged and the flexible charge activated if necessary.

either ,

$$P_{Dies\_min} = 0.2 * P_{Dies\_nom} \tag{19}$$

The compensated deficit by batteries has for expression (20) :

$$Deficit_{dst\_d}(t) = -\frac{|\Delta P_{prod}(t)| - P_{Dies\_min}}{\eta_{inv} * \eta_{bat}} \tag{20}$$

The dischargeable battery capacity is estimated from the SOC (21) :

$$\Delta E_{dbat} = E_{bat}(t-1) - E_{bat\_min}(t) \tag{21}$$

If battery enough to compensate the deficit, we have the below equation:

$$\begin{cases} \Delta E_{dbat} \geq \left|Deficit_{dst\_d}(t)\right| \\ Gap_{dech} = \Delta E_{dbat} - \left|Deficit_{dst\_d}(t)\right| \geq 0 \end{cases} \tag{22}$$

The battery capacity becomes (23) :

$$\begin{cases} P_{bat}(t) = Deficit_{dst\_d}(t) < 0 \\ E_{bat}(t) = Deficit_{dst\_d}(t) + E_{bat}(t-1) \end{cases} \tag{23}$$

And the diesel contribution is fixed at Eq. 24:

$$P_{Dies} = P_{Dies\_min} \tag{24}$$

Otherwise, the diesel compensates for the all deficit as:

$$P_{Dies} = \left|\Delta P_{prod}(t)\right| \tag{25}$$

Otherwise, the deficit is greater than the battery capacity and lower than the minimum power of the diesel generator started. The batteries can be charged and the flexible charge activated if necessary is given by the expression (25).

$$\left|Case\ 4{:}\ \Delta P_{prod}(t)\right| < 0.2 * P_{Dies\_nom}$$

In this case, the energy deficit greater than the battery's capacity, and the diesel generator supports PPL and charges the batteries.

Either the equation (26),

$$P_{Dies} = 0.2 * P_{Dies\_nom} \tag{26}$$

The power to be stored is given by the expression (27) :

$$Potentiel_{stock}(t) = \frac{P_{Dies} - \left|\Delta P_{prod}(t)\right|}{\eta_{inv} * \eta_{bat}} \tag{27}$$

SOC below its maximum value, the excess energy could be stored totally or partially in the battery.

İf ,

$$\begin{matrix} \Delta E_{bat} \geq Potentiel_{stock}(t) \\ GAP_{ch} = \Delta E_{bat} - Potentiel_{stock}(t) \geq 0 \end{matrix} \tag{28}$$

So

$$\begin{cases} P_{bat}(t) = Potentiel_{stock}(t) \\ E_{bat}(t) = Potentiel_{stock}(t) + E_{bat}(t-1) \end{cases} \tag{29}$$

Or else, charge the battery and activate the flexible load

$$\begin{cases} P_{bat}(t) = \Delta E_{bat}(t) \\ P_{DL}(t) = \left(Potentiel_{stock}(t) - \Delta E_{bat}(t)\right) * \eta_{ii} \\ E_{bat}(t) = \Delta E_{bat}(t) + E_{bat}(t-1) = E_{bat\_max} \end{cases} \tag{30}$$

The algorithm is programmed under Matlab and is a function called during multicriterion optimization calculations by the Particle Swarm Optimization (PSO) method developed also under Matlab. Multi-criteria optimization is used to dimension the main constituents (panels, diesel group, batteries) of the system taking into account the various constraints identified in order to minimize or maximize an objective function. In this case study, it is a question of minimizing the cost of the life cycle of the system. Aside from the PSO,a wide range of optimization methods using evolutionary programming exist that include,Genetic Algorithm, Ant Colony algorithm...[43]

The PSO technique is one of the potential techniques among various evolutionary algorithms [44]–[48]. It employs a swarm of particles that traverse a multidimensional search space to seek out optima, based stochastic methods .

PSO can be applied easily implemented due to its simple structure, fast computation ability.

The PSO algorithm is based on the speed $V_i^{(t+1)}$ (31) of the individual *i* at the iteration (*t+1*) related to the acceleration coefficients C_1 and C_2 which are random binary numbers [0, 1], on the position X_i^t of the individual *i* at the iteration *t*, on the best individual position P_{best} at the iteration *t*, and on the best global position G_{best} until the iteration *t*. The position of a particle (Xi) is adjusted by using the following relation:

$$\begin{cases} V_i^{t+1} = K[V_i^t + \gamma_i^t + \beta_i^t] \\ X_i^{t+1} = X_i^t + V_i^{t+1} \end{cases} \tag{31}$$

with,

$$\begin{cases} \gamma_i^t = c_1 r_1 (Pbest_i^t - X_i^t) \\ \beta_i^t = c_2 r_2 (Gbest_i^t - X_i^t) \end{cases} \tag{32}$$

Equation (33) defines the relationships between the constriction coefficients.

$$K = \frac{2}{\left|2 - \varphi - \sqrt{\varphi^2 - 4\varphi}\right|}\ , \varphi = c_1 + c_2, \varphi > 4 \tag{33}$$

For good convergence, the condition (φ> 4) on the constriction factor is verified by the choice of coefficients $C_1 = C_2 = 2.05$ [30].

4. Result

In Fig. 9 there is no priority loads and batteries are put in standby. In the absence of PV production, the diesel generator emulator provides a (negative) power of about 120W to power auxiliaries and provide power losses in the system. In the second phase of the curve, we observe the evolution of production, which is practically used, with power losses, for fluctuating loads, in the absence of an energy need expressed by main loads and batteries standby.

Fig. 10 illustrates four cases during system operation on a typical day. In case I, the PV production, and the main charges are null, the batteries and the diesel are not solicited.

In case II, a constant demand for power is made by the main loads when the PV starts to produce. The difference is compensated by the batteries. Both battery and PV contribute to supply the load. Then the batteries may charge. At the full charge of the batteries, the surplus energy PV supplies the flexible loads, the batteries are not any more charged and the diesel generator stills in standby, in case III. In case IV, the PV production is equal to zero, the supply of flexible loads deactivation the batteries remain in standby; the main charges are not active. The diesel generator nevertheless reacts to compensate power demands by the auxiliaries active.

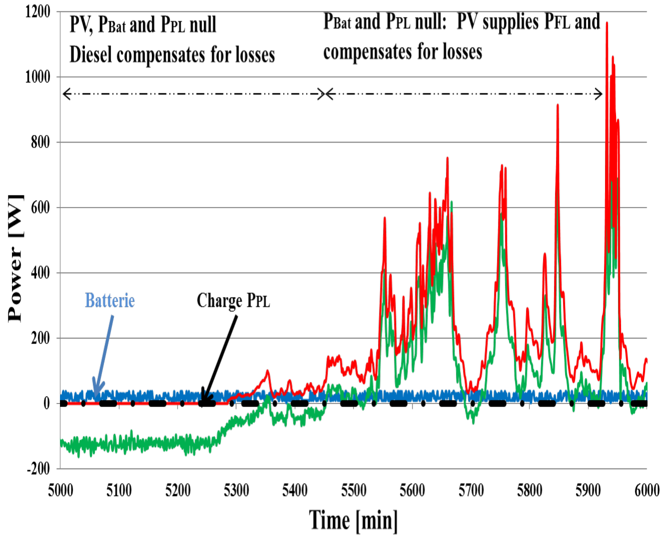

Fig.9. Interaction between the components of the system

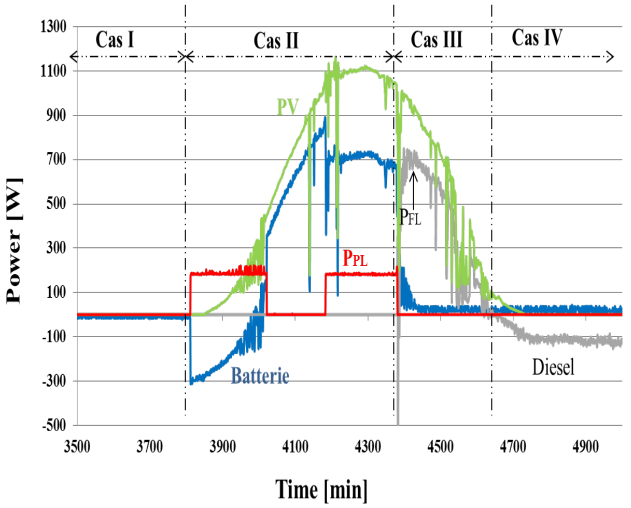

Fig.10. One day operation phases

In case I Figure 11, the Diesel generator compensates the priority loads demand in the unavailability of PV and batteries. Cases II and III illustrate the charging/ discharging processes of batteries according to the availability of PV production and load demand, the diesel being in standby. In case III, PV production is low then energy demand. For case IV, the system is stopped due to a lack of PV production and consumption.

In figure 12 a continuous operation of the diesel generator is imposed, with the constraint to provide at least an equal power to auxiliaries' need. In this situation, the diesel generator completes the deficit not covered by PV and batteries.

When the battery is at a low SOC, it goes into priority charge mode and can only be discharged when the SOC reaches a certain value, at least 50% (Fig. 13.).

In this case, the generator compensates for the entire energy deficit.

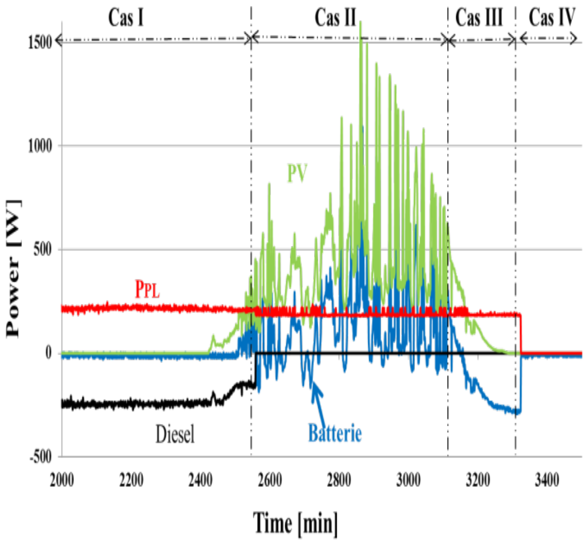

Fig.11: Another daily operation phases

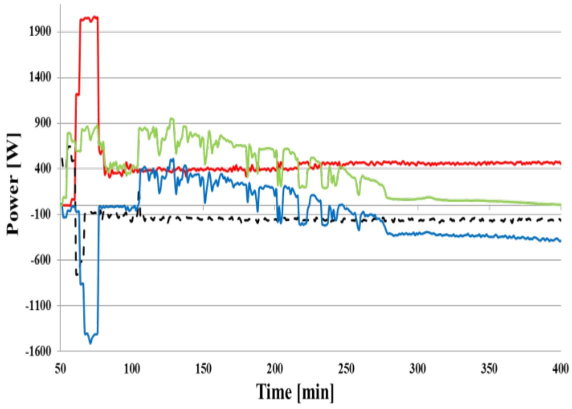

Fig.12. Diesel operation

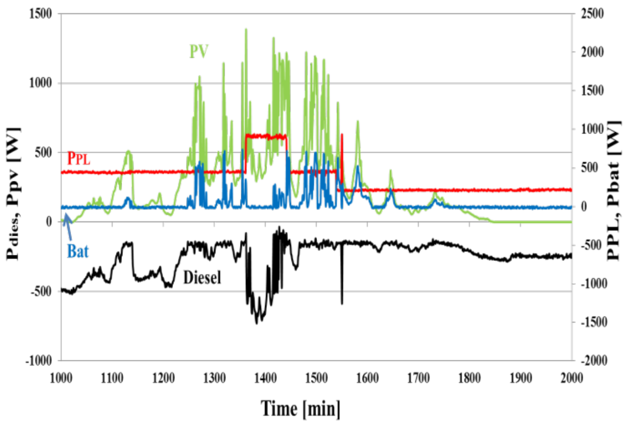

Fig.13. Operating phases with the lowest SOC batteries.

5. Conclusion

In this paper, an analysis was carried out through simulations to better control the interactions and exchanges of flows between the entities of the system (PV, diesel group, batteries, loads). Control strategies for energy flow management in a micro-grid system have been presented. The importance of design has been brought out by forming experimental studies on a laboratory prototype and a good correlation between the results of computer simulation and experiments has been established. The system behavior for four different operating modes has been observed on the availability of PV power; batteries charge level and load demand. The control strategy has been implemented on a PLC, and the algorithm was subsequently implemented has been verified for four modes of operation by varying the insolation closely matches the PV production.

The analysis of the results obtained shows a real maximization of the PV production as well as renewable energy penetration in the production system and the good performance of the control and the overall supervision.

This investigation could play a vital role in decision making for better management.

```
Pseudo Code PSO
Begin
For each particle
Initialize particule
Calculate the value of objective function
If the Vfo value is better than the best value obtained (pBest) in history define current value as new pBest
For each particule
Calculate particule velocity
Update particule position
End
```

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