Optimization of the Managed Electrical Energy within a Hybrid Renewable Energy System

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Abstract— *Hybrid energy applications based on renewable energy sources are becoming more and more desirable every day. They have increased the economic attractiveness of renewable electric energy generation. Because of the sudden fluctuations of the load requirements, the main attribute of such Hybrid Systems is to be able to generate energy at any time by optimally using each source.*

In this article, we have proposed a combination between a sizing study and a control one for the aim of solving the complex optimization problem of finding the optimal combination of size and storage to make the best use of the renewable power generations and to become more independent of rising electricity costs.

Additionally, an improvement in the induced optimization algorithm is introduced in this paper so as to compute the optimal size and the operation control of the system with the aim of minimizing as much as possible the cost while responding to the load energy requirements taking into account the environmental factors.

Keywords—Optimization; Management; Sizing; Hybrid Renewable Energy System

I. INTRODUCTION

Energy is one of the main requirements of human life and, in the last decade, the continuous development of technology has raised this need of energy [1]. Furthermore, since the prices of petroleum products have been increasing, and due to advances in renewable energy technologies, it is widely acceptable today that renewables can play an important role in strengthening energy safekeeping. However, the availability of such a specific resource depends essentially on the specific changes in the weather variables; that is why hybrid renewable energy systems (HRES) are becoming a sufficiently promising energy generation application [2-3]. They are considered as a reasonable solution capable to cover the energy demand of residential, commercial, or institutional buildings. They can track load variations more closely, integrate a large range of technologies and avoid a centralized planning [4]. Nonetheless, systems based on renewable energies have major drawback such as the considerable unpredictability that results a disturbance in the generation if uncontrolled.

At each point in time, the load needs to be covered and for that reason the stability of generated, stored and used energy needs to be satisfied [5]. For this purpose, the HRES must act as a grid service provider and not as an unpredictable energy generator, and then a suitable energy management control that allows optimal energy controllability during the system functioning is requested [4].

In the literature, various papers in the field of sizing, management, control and optimization of an autonomous HRES have been proposed. Nevertheless, it is found that continued research and development efforts in this area are still needed for improving the systems' performance, establishing techniques for accurately predicting their output and reliably integrating them with other renewable or conventional power generation sources [6].

The appropriate selection of the hybrid system's components, its optimal sizing and operation control are essential and challenging steps to widely performed distributed generation systems based on renewable energy systems [7-8]. In this article, we have proposed a combination involving a sizing method and a control algorithm in order to resolve the complex optimization problem of finding the optimal combination of size and storage to make energy consumption affordable, manageable, reliable, and more independent in the use of energy, and to have the potential of changing the concerns that grid operators usually present [9].

The rest of the paper is ordered as follows: The hybrid system description and configuration are given in Section2; Section 3 presents the control strategy through unit sizing developed for the optimization of the hybrid system; the simulation results are discussed in Section 4; and finally, Section 5 provides the conclusions.

II. DESCRIPTIVE STUDY OF AN AUTONOMOUS HYBRID RENEWABLE ENERGY SYSTEM

Usually, hybrid generation systems are made up of different power sources that complement their other in order to allow improving the system efficiency and recovering the power reliability [6].

The objective of these hybrid installations is to find the suitable combination of the system components that reliably supply electric power to a given load profile at a specific location with the lowest cost [10].

Moreover, with the complementary characteristics between solar and wind energy, the hybrid solar–wind power generation systems have become the most reliable source of energy [11]. In order to ensure the sustainability of these hybrid systems, and to address the mismatch between the intermittency of wind and solar energy, a balance with the energy of a battery bank is required [2]. Indeed, choosing the suitable model for each source plays an important role in the evaluation of the energy output potential [11]. It is therefore very important for designers to find a feasible optimization technique to select the optimum system configuration.

In general, hybrid energy systems are integrated so as to fully cover the electrical load that could be an AC load, a DC one or both at the same time [12].

According to the size and the system configuration, the hybrid energy sources can be connected to the load via a current bus that could be a DC bus, an AC bus or DC - AC bus. This interconnection between the sources and the consumption load is achieved through the power electronics (the inverters that convert the direct current into a usable, suitable alternating current).

Overall, for residential or institutional usage of HES the AC bus configuration is the one that ensures high efficiency; therefore, the implementation of its control system is relatively simplified.

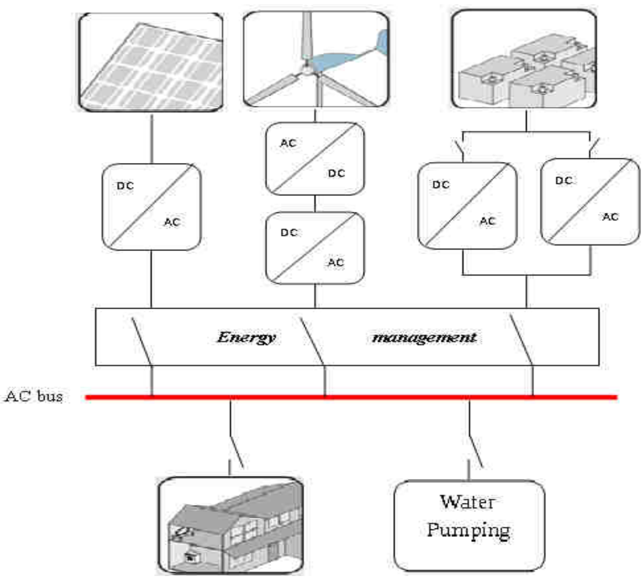

Fig.1: Configuration of the system proposed

III. SIZING AND OPTIMIZATION STUDY OF AN AUTONOMOUS HYBRID RENEWABLE ENERGY SYSTEM

With the purpose of guaranteeing an efficiently and economically usage of such hybrid systems in terms of cost and reliability requirements, one optimum sizing method is necessary.

Some researches use Typical Meteorological data for the hybrid system optimizations, many of them were developed based on the worst month scenario [13-14], and the yearly average monthly method. Also, there are various optimization techniques for hybrid solar–wind system that have been reported in the literature such as: graphic construction methods [15-16]; probabilistic approaches including the loss of power supply probability method[17] and artificial intelligence methods that are widely used to optimize a hybrid system in order to maximize its economic benefits such as Genetic Algorithms [18-19-20], Artificial Neural Networks [21] and Fuzzy Logic [22]; in addition to the multi-objective design as evolutionary algorithms [23].

In the present study, for the reason of fully satisfying the user demand, reducing the energy storage requirements for stand-alone applications, leading to an energy balance between the production, the load and the storage, and ensuring that the components are compatible to one another and that the storage system is optimally used, a grouping between a sizing approach and a control algorithm is the method that is consisted of, as shown in the flowchart below:

As a first step, we have calculated the renewable sizing based on the following equations [10]:

$$N_{PV} = f.\frac{\sum_{d=1}^{365} E_{Load}}{\sum_{d=1}^{365} E_{PV}} \quad (1)$$

$$N_W = (1-f).\frac{\sum_{d=1}^{365} E_{Load}}{\sum_{d=1}^{365} E_W} \quad (2)$$

With:

N_{PV}: Number of photovoltaic panels (PVP)

N_W: Number of winds

E_{Load}: Daily load profile

E_{PV}: Energy produced by the PVP

E_W: Energy generated by the wind turbine

f: is the fraction of each of the renewable sources; meaning that is the part of each source in the penetration rate with which these renewable sources contribute to the consumption $f_{PV} = 1 - f_W$.

And:

$$N_B = \frac{C_{bat}}{C_{bat,nominal}} \quad (3)$$

N_B: Number of batteries

$C_{bat,nominal}$: Nominal capacity of the battery

With:

$$C_{bat} = \frac{E_{Load} \times N_{ad}}{V_{bat} \times DOD_{max} \times \eta_{ch}}$$

With

C_{bat}: Battery capacity

N_{ad}: Number of days of autonomy

V_{bat}: Voltage of the battery

DOD: Depth of discharge

η_{ch}: Battery efficiency

Then, we have implemented a management strategy so as to manage the renewable production on the basis of the daily consumption, where the number of the batteries N_{Bat} required to cover the shortage of the energy produced by the renewable sources have been calculated based on the energy needed at the time of the lack of the energy production from the renewable resources. The energy excess is handled, in this case, in the form of water pumped, that allows the elimination of the very expensive electric storage in favor of a lower priced hydraulic storage.

This management strategy must insure the objective function proposed as:

$$f(x) = E_{PV}.x_{PV} + E_{w}.x_{W} + E_{Bat}.x_{Bat}$$

With respecting as condition:

$$E_{PV}.x_{PV} + E_{w}.x_{w} + E_{Bat,out}.x_{Bat} = E_{L} + E_{Bat,in}$$

Where:

x_s Signifies the penetration rate of each source (s: PV, W, Bat)

And self respect as constraints:

- Guarantee the continuous supply of the installation
- Request the maximum possible from the renewable sources.
- Reduce the energy storage requirements(for standalone applications)
- Prevent the profound battery discharge
- Avoid the overload of the battery
- Rise the battery lifetime (with an excellent regulation of its state of charge and discharge)
- Ensure the minimum price to the user

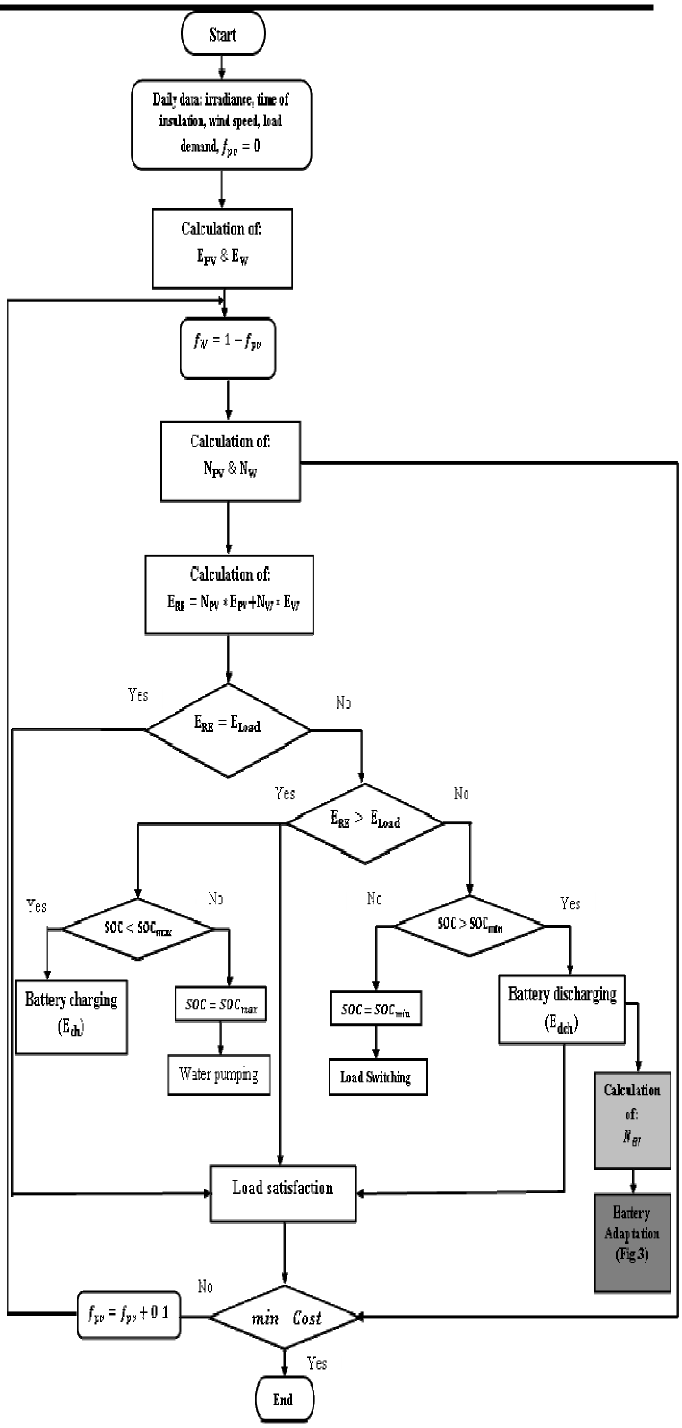

Fig.2: Flowchart of the algorithm proposed

As illustrated in the flowchart above, seeing that the energy excess is not stored in the battery bank, and so as to address the mismatch between the load and the production for the whole year without any interruption at all load consumptions and whatever is the type of the components used and wherever the system is installed, we have introduced an adaptation stage for the batteries for the aim of insuring a full coverage of the delivered energy to the load when the available renewable energy is not sufficient.

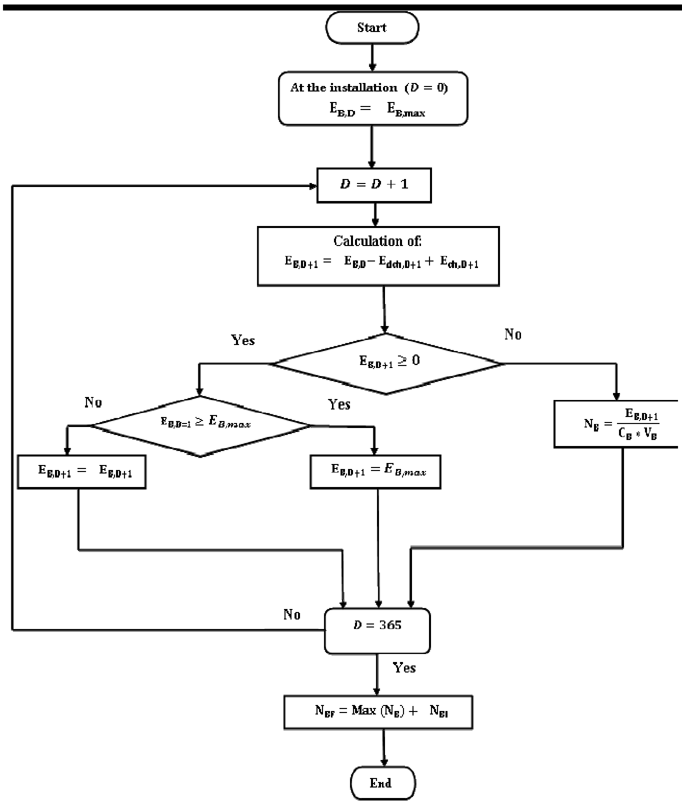

Fig.3: Flowchart illustrating the battery adaptation stage

With:

D: Number of days

$E_{ch,D}$: Energy charged in the storage system in day D

$E_{dch,D}$: Energy discharged from the storage system at day D

$N_{B,I}$: Initial number of batteries

$N_{B,F}$: Final number of batteries

However, due to the high capital cost required for investment and replacement cost of the batteries over the system life time, in the used optimization procedure we were able to further optimize the system by introducing an optimization coefficient C_{op}which allowed us to replace a number of batteries with a specific number of photovoltaic panels (or even another type of renewable sources, a matter that depends on the nature of the site where the system is installed) provided that the price is kept at the minimum to the user.

$$C_{op} = \frac{C_B}{C_{PV}} \qquad (4)$$

With:

C_{op}: Optimization coefficient

C_B: Cost of the battery

C_{PV}: Cost of the PVP

In this case:

$$N_{PV,op} = C_{op} * N_{PV} \qquad (5)$$

$N_{PV,op}$: Optimal number of photovoltaic panels (PVP)

By resizing the system through following the steps of the management algorithm proposed ("*fig.2*"), we will be able in this case to increase the number of PVP and reduce the number of the batteries to the extent that the price will be kept at the minimum to the user while reducing the energy storage requirements.

IV. SIMULATION RESULTS AND DISCUSSIONS

The aim of the conducted optimization study is to find the suitable hybrid system that meets simultaneously the technical constraints and the load demand in all conditions with the lowest cost possible.

The proposed case of study has been tested for Oujda/Angad Site, which is one of the sunniest regions in Morocco. The daily data taken into account in this study of the solar radiation and the wind speed are obtained from the meteorological weather station of the North-East [24]. Besides, the utilized load profile in this optimization process is taken to be of a typical home; it is renowned that the load demand varies from season to season. However, due to the lack of measurements for each season of a year, a repetition of the given load demand variation to obtain a yearly load profile is necessary; as shown in "Fig.4".

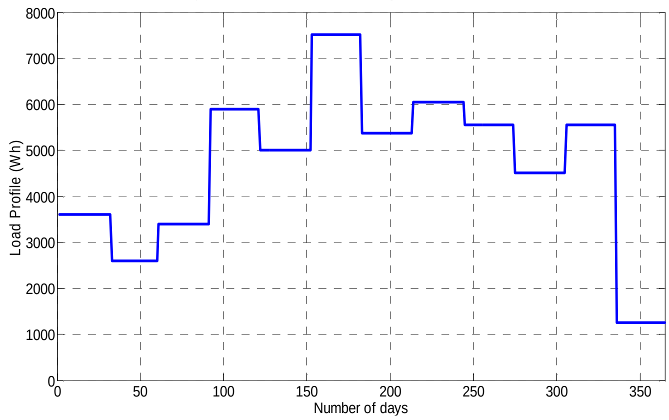

Fig. 4: The daily load profile

The hybrid system proposed in this paper includes the wind turbine of type WISHPER 200 of rated power 1kW and the PV module used is of 150 Wp as rated power.

The output energy for both solar panel and wind turbine, according to their pre-defined models [11] and to the meteorological data, are shown in *"Fig.5 and Fig.6":*

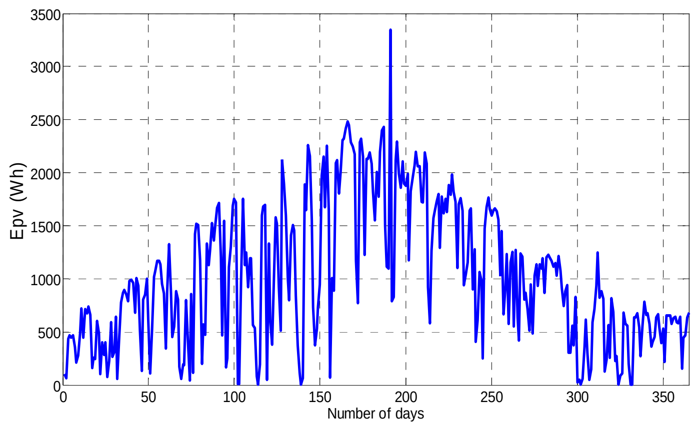

Fig.5: Energy produced by the PVP

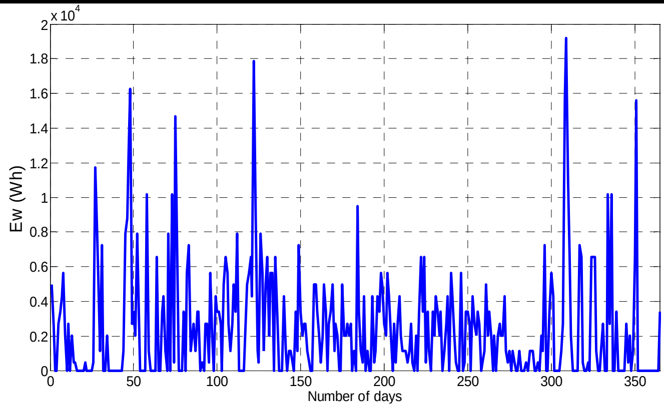

Fig. 6: Energy generated by the wind turbine

In this case study, the components size of the hybrid system is determined based on the sizing model and the optimization method proposed in Section 3.

For different fractions of the renewable sources, and based on the meteorological data and according to the load demand, *"Fig.7 and Fig.8"* illustrate the suitable sizing of the PVP and the wind for each fraction.

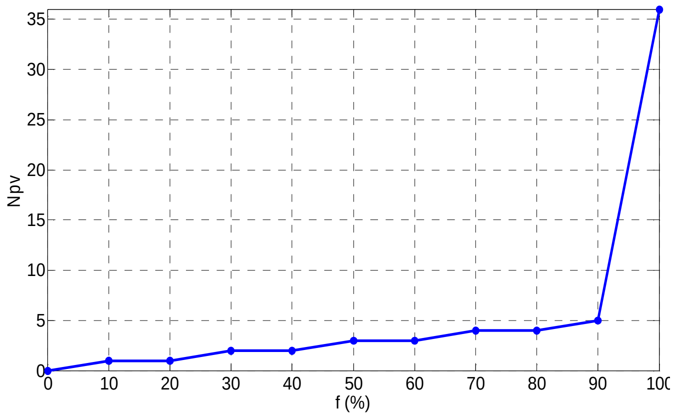

Fig. 7: Number of PVP needed for different fractions

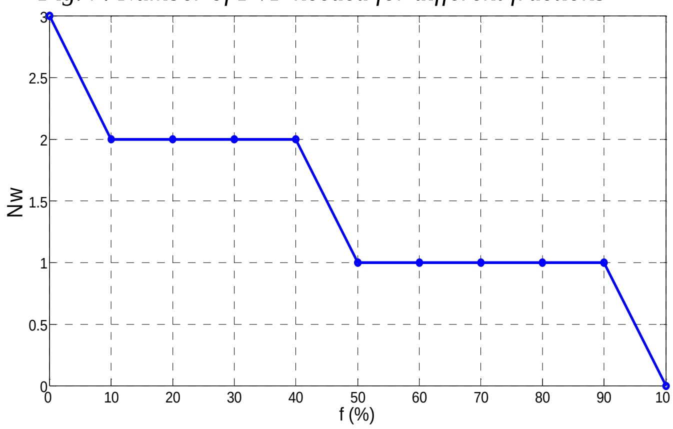

Fig. 8: Number of winds required for different fractions

Moreover, "Fig.9" gives a comparative result between a batteries size determined based on (3) which is a function of the load, and the one calculated by using the management strategy that has been implemented (*"Fig.2")* for the aim of managing the energy productions and concluding the energy needed on the time of the shortage of the renewable production. In relation to this latter, we have determined the number of the batteries needed to guarantee a total coverage of the load at each point of time.

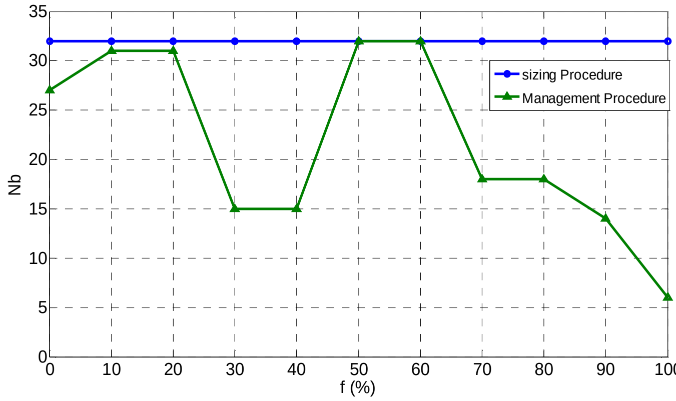

Fig. 9: Battery size by using both sizing and the management procedures

From the above figure, it is clear that the number of batteries needed could have been reduced to fulfill the production and meet the load consumption.

As has been mentioned before, due to the high investment cost referred to the use of the batteries during the system life time, the proposed optimization approach enables the system to reduce more and more the number of batteries by increasing the number of PVP to the extent that the price will be kept at the minimum to the user, as demonstrated in *"Fig.12"*.

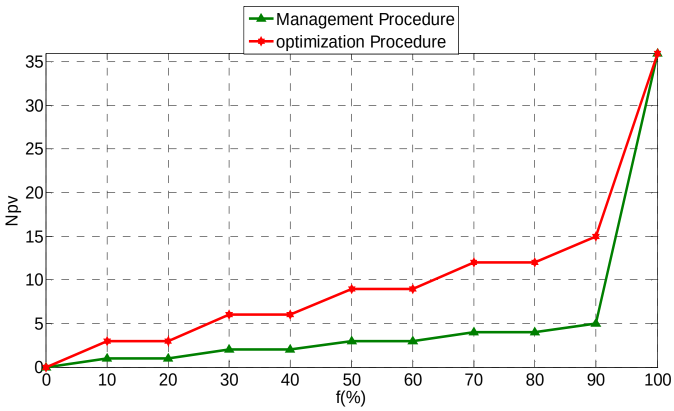

Fig.10: Optimal number of the PVP needed compared with the initial number of PVP

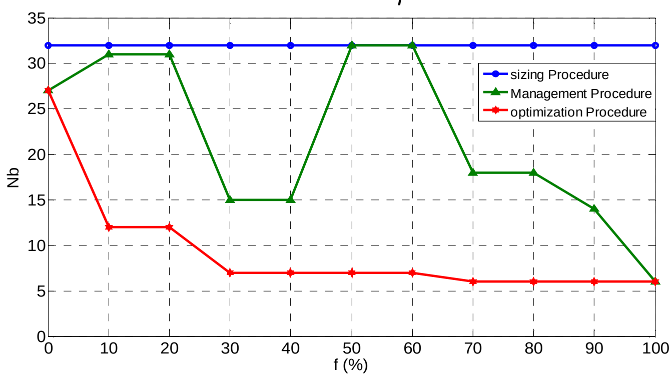

Fig.11: Battery sizing

This makes the proposed system more economical as well more sustainable to the clear green energy [10].

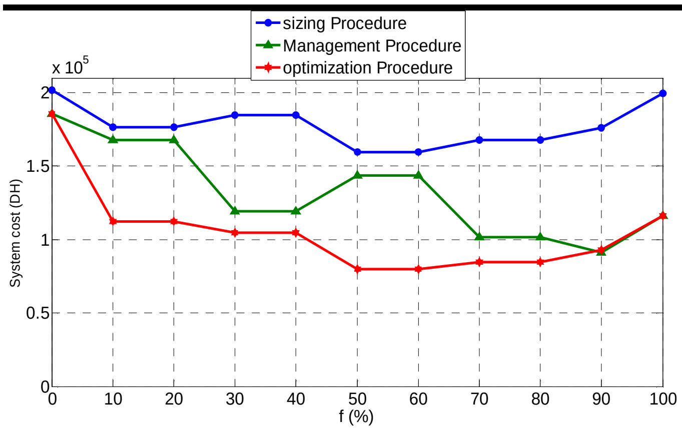

Fig. 12: System cost

In this case of study, the system with the lowest cost is found to be the one which is composed of 9 PVP and 1 Wind turbine and a storage system which is composed of 7 batteries.

Furthermore, in order to show the behavior of the optimized system, "*Fig.13*"demonstrates the complete covering of the load ("*fig.4*"), which is firstly met by the PV system that contributes with (73%) (Owing to the sunny character of the site), then by the wind generator which gives (21%), and lastly by the batteries as a backup system with a penetration rate of 6%.

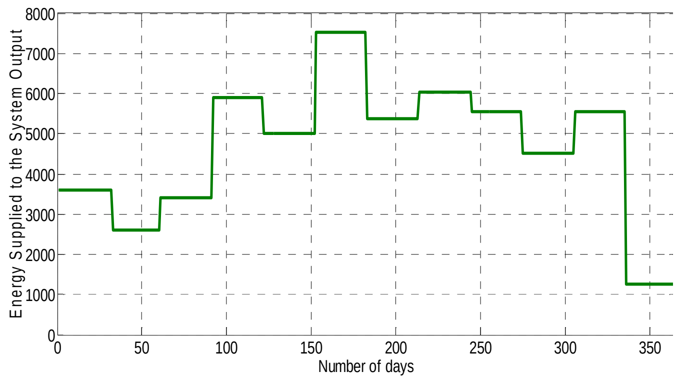

Fig. 13: Energy supplied to the system output

With respect to the main condition that: the batteries never reach their minimal state of charge ($DOD_{max} = 60\%$).

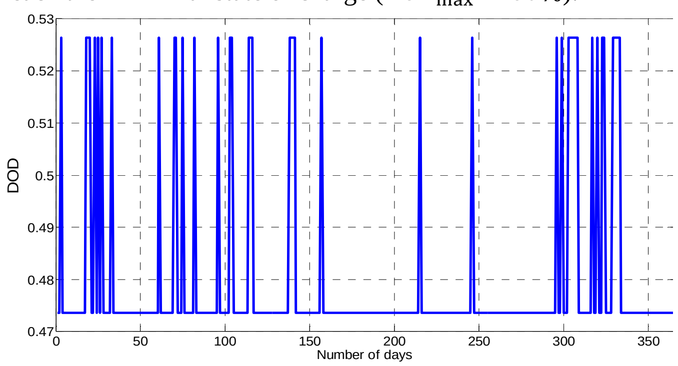

Fig. 14: Depth of discharge of the storage system

V. CONCLUSION

To increase the percentage of using renewable energies in the overall consumption, it is appropriate to raise the difficulties related to the use of this clean energy.

One of these challenges is then the optimization of the combination of several sources of energy while maintaining the minimization of ecological and economic cost which was the purpose of this article so that we have implemented a management and supervision system aiming at optimizing the sizing and aligning the production with the consumption.

A number of simulation scenarios validating the proposed optimization method were presented and discussed aiming at minimizing the system cost to the user.

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