DESIGN AND ANALYSIS OF A HYBRID WIND-PHOTOVOLTAIC SYSTEM

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Abstract

Solar and wind energy systems are very important in our life, due to the fact that those systems poses the next characteristics: hybrid energy systems are omnipresent, freely available, environmental friendly, and maybe they represent the solution for power generating sources due to their availability and topological advantages for local power generations. In particular for remote areas, the hybrid wind turbine (WT) – photovoltaic (PV)– systems represent a green and reliable power system. Statistics from around the world prove that there is a steady increase in usage of hybrid energy system (HES) and indeed this system is the main issue for having a cost-effective system.

This study will review the stand-alone PV solar–wind turbine (WT) hybrid energy systems, using the current state of the design, operation, calculation process and control requirement for this system.

Keywords: *Hybrid energy systems, Photovoltaic, Wind, Renewable energy*

1. Introduction

The solution for a green and reliable power system for remote areas is the hybrid photovoltaic (PV)–wind turbine (WT) systems with battery storage. Statistics from around the world prove that there is a steady increase in usage of hybrid energy system (HES) and indeed this system is the main issue for having a cost-effective system.

The hybrid power systems (HPS) is the result of combining two or more sources of renewable energy as one or, the process of combining more conventional energy sources . The renewable energy sources such as photovoltaic and wind provides a more continuous electrical output, but they don't deliver a constant level of power.

Hybrid power systems are often used in remote areas and they are independent of large interconnected network. A hybrid power system needs to produce as much energy, as the load in the network is needed. The hybrid system has a lot of components, like: a DC or AC distribution system, a storage system, converters, filters and the possibility of loading management or

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supervision system, which can be connected in different architectures. The size of the system dictate the way that the energy sources are connected to the DC bus, because the power delivered in the network can vary from a few watts for domestic applications up to a few megawatts for electrification of small villages. DC loads are generally connected to hybrid systems with very low power (under 5 kW).

An AC bus is connected to a larger systems, with power greater than 100 kW, connected to an AC bus, which is characterized by several different sources, several different loads, several storage elements and several forms of energy (electrical, thermal) [1].

2. Hybrid Wind / Photovoltaic System

The optimization of wind and photovoltaic energy with electrochemical storage (batteries) depends on many economic models of each system separately (wind and photovoltaic). The advantage of a hybrid system depends on many important factors: the shape and type of load, wind, solar radiation, cost and availability of energy, the relative cost of the wind machine, solar array, electrochemical storage system and other efficiency factors. Photovoltaic systems are currently economical for low power installations. For autonomous systems the cost of energy storage is the biggest constraint. Minimizing the cost of storage and reducing its capacity are the main reasons for the combination of wind and photovoltaic systems. In Fig.1 , both energy sources are connected to a DC bus. A DC/DC converter can track the maximum power point of a photovoltaic subsystem. Similarly, a controlled rectifier is connected between the wind generator and the DC bus. Battery is included as part of back-up and storage system [2][3].

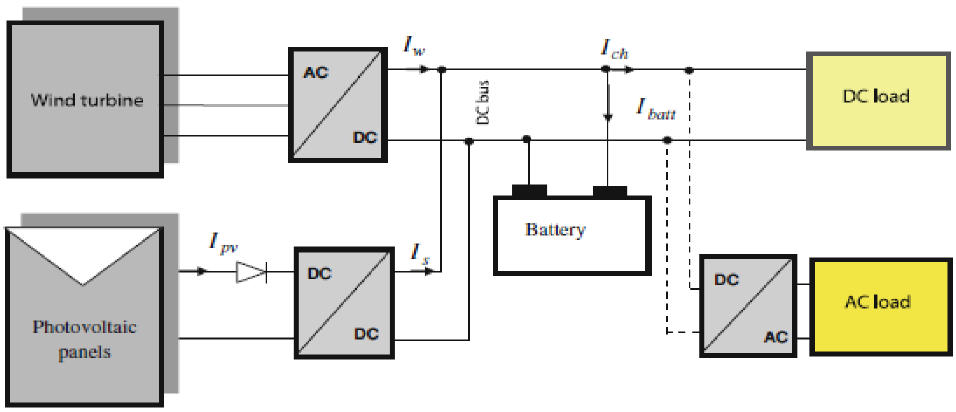

Figure 1. *Hybrid wind / photovoltaic system*

2.1. Sizing of Hybrid Wind/Photovoltaic System

The effectiveness of any electric system depends on its sizing and use. The sizing should be based on meteorological data, solar radiation and wind speed and the exact load profile of consumers over long periods.

• *Determination of the load profile of consumers*

The exact knowledge of the customers, load profile determines the size of the generators (Fig. 2)[4].

• *Analysis of solar and wind energy potential*

We make applications in Burgos (Spain) which is a coastal region. The curve in Fig.3 is the superposition of two characteristics (wind speed and radiation), and shows their complementarity; we can say that the coupling of a photovoltaic system and wind is very interesting for electricity production throughout the year.

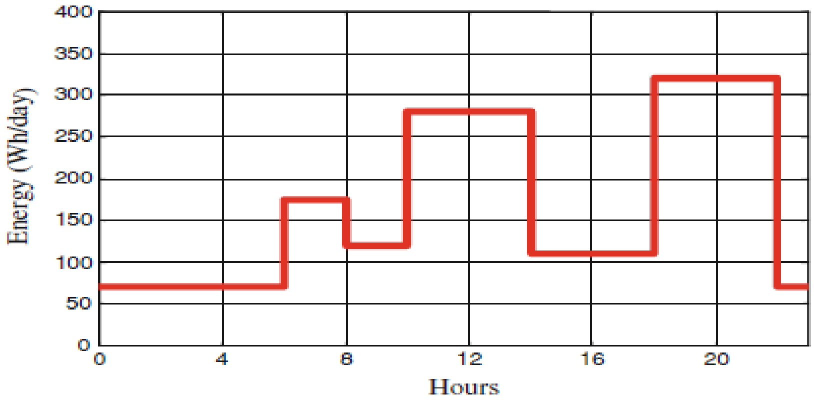

Figure 2. *Daily consumption profile of a house*

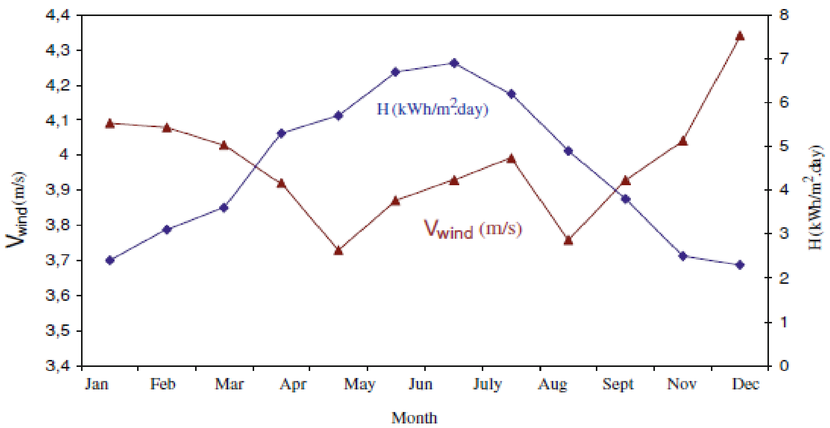

Figure 3. *Monthly average global radiation and wind speed monthly average of Burgos (Spania) site from 1998 to 2007*

• *Photovoltaic energy calculation:*

The energy produced by a photovoltaic generator per unit area is estimated using data from the global irradiance on an inclined plane, ambient temperature and the data sheet for the used photovoltaic panel.

The electrical energy produced per unit area by a photovoltaic generator is given by:

$$\Delta E_{pv} = \eta_{pv} \cdot G\Delta t \quad \textbf{(1)}$$

where G is a solar radiation on tilted plane module and η_{pv} the efficiency of the photovoltaic generator:

$$\eta_{pv} = \eta_{r-pv} \cdot \eta_{pc} \left[1 - \alpha_{sc}\left(T_j - T_{jref}\right)\right] \quad \textbf{(2)}$$

with η_{r-pv} the efficiency of the photovoltaic generator power electronic converter and η_{pc} the power conditioning efficiency which is equal to one if a perfect maximum power tracker (MPPT) is used. α_{sc} is the temperature coefficient of short-current $A/^{o}K$ as found on the data sheet, T_j the cell temperature and T_{jref} the reference cell temperature. We put the emphasis on the fact that η_{r-pv} is not a constant, but depends on the climatic conditions (temperature, irradiance…).

• *Wind energy calculation*

The power contained in the form of kinetic energy per unit area in the wind is expressed by:

$$P_{wind} = \frac{1}{2} \cdot \rho \cdot v^3{}_{wind} \eta_{wind} \quad \textbf{(3)}$$

with η_{wind} the efficiency of the photovoltaic generator (power electronic converter and power conditioning efficiency included).

The energy produced by wind generator is expressed by:

$$\Delta E_{wind} = P_{wind} \cdot \Delta t \quad \textbf{(4)}$$

• *Pre-sizing of photovoltaic and wind systems:*

The monthly energy produced by the system per unit of area is denoted $E_{pv,m}\left(kWh/m^2\right)$ for photovoltaic energy and $E_{wind,m}\left(kWh/m^2\right)$ for wind energy and $E_{\mathrm{L},m}$ represents the energy required by load every month (where m = 1, 2,…,12 represents the month of the year). One has:

$$E_{\mathrm{pv},m} = \sum_{monthm} \Delta E_{pv} \quad \textbf{(5)}$$

$$E_{\mathrm{wind},m} = \sum_{monthm} \Delta E_{wind} \quad \textbf{(6)}$$

$$E_{\mathrm{L},m} = \sum_{monthm} \Delta E_{L} \quad \textbf{(7)}$$

Pre-sizing is sometimes based on the worst month of the year. Then, the total area of the photovoltaic generator A_{pv} and the total area of the wind generator S_{wind} are chosen in such a way that

$$E_{L,\mathrm{worth}_m} = E_{pv,worth_m} \cdot A_{pv} + E_{wind,worst_m} \cdot S_{wind} \quad \textbf{(8)}$$

One can introduce the parameter f which is the fraction of load supplied by the photovoltaic energy, (1 - f) being the fraction of load supplied by the wind energy.

Then:

f=1 indicates that the entire load is supplied by the photovoltaic source.

f=0 indicates that the entire load is powered by the wind source. Using f, one has

$$A_{pv} = \frac{fE_{L,worst_m}}{E_{pv,\text{worst}_m}} \quad \textbf{(9)}$$

$$S_{wind} = \frac{(1-f)E_{L,worst_m}}{E_{wind,worst_m}} \quad \textbf{(10)}$$

The pre-sizing is also often based on a monthly annual average .The calculation of the size of wind generator and photovoltaic A_{pv} and S_{wind} is established from the annual average values of each monthly contribution ($\overline{E_{pv}}$ and $\overline{E_{wind}}$). The load is represented by the monthly annual average $\overline{E_L}$.

$$A_{pv} = f \cdot \frac{\overline{E_L}}{\overline{E_{pv}}} \quad \textbf{(11)}$$

$$S_{wind} = (1-f) \cdot \frac{\overline{E_L}}{\overline{E_{wind}}} \quad \textbf{(12)}$$

The number of photovoltaic and wind generators to consider, is calculated according to the area of the system unit taking the integer value of the ratio by excess.

$$N_{pv} = ENT\left[\frac{A_{pv}}{A_{pv,u}}\right] \quad \textbf{(13)}$$

$$N_{wind} = ENT\left[\frac{S_{wind}}{S_{wind,u}}\right] \quad \textbf{(14)}$$

Figures 4 and 5 show respectively photovoltaic panels and wind turbines area and the obtained number to install according to the fraction of the load (f).

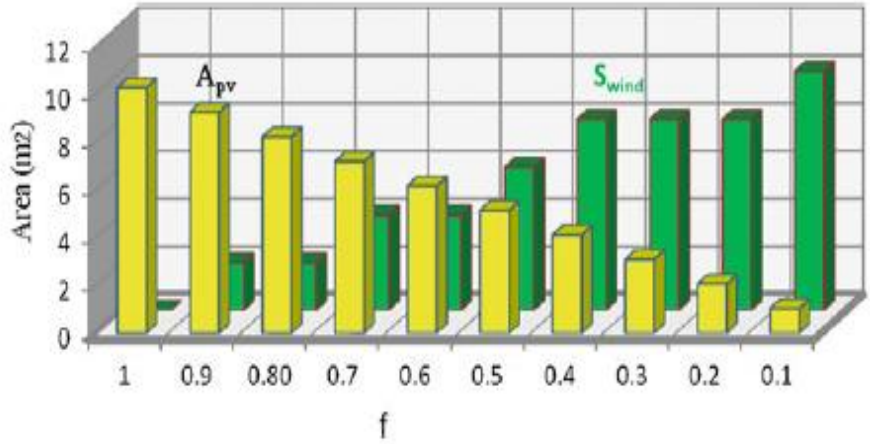

Figure 4. *Areas of photovoltaic panels and wind turbines*

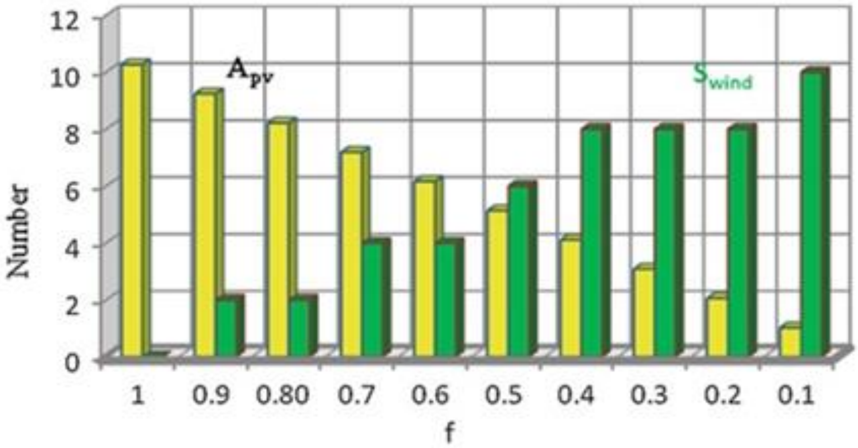

Figure 5. *Number of photovoltaic panels and wind turbines as a function of the fraction of the load*

2.2. Control of Hybrid Photovoltaic/Wind System

Managing energy sources (photovoltaic and wind) is provided by a supervisor. For the design of the supervisor, it was decided that the photovoltaic subsystem would be the main generator, while the wind generator subsystem would be complementary. This choice is motivated by the design already made based on the monthly averages annual site rating. However, the supervisor applications extend to considering the wind subsystem as the main generator and the photovoltaic subsystem would be complementary.

Three operating modes are possible to determine the ability of the hybrid system to supply the total power required (the power load and the power required to charge the batteries) on the basis of atmospheric conditions (irradiance, temperature and wind speed). This supervisor is essential to effectively control energy subsystems (photovoltaic, wind). We can have three cases [4][5]:

Case 1

This mode corresponds to the periods where photovoltaic power is sufficient for supplying the load demand. However, the PV generator must provide the total power while the wind subsystem is supposed stopped and the batteries are charging. This situation is maintained while the power required by the load does not exceed the maximum PV power. Beyond this limit, the supervisor switches in Case 2 and activates the wind generator. In this case, the objective of the photovoltaic system is under power control according to this reference:

$$P_{ref1\_s} = P_{required} = V_{batt} \cdot (I_{load} + I_{batt}) \quad \textbf{(15)}$$

with I_{load} the load current, I_{batt} the battery current, and $P_{required}$ the total required power.

Case 2

In this case, the photovoltaic system generates the maximum power (operating at maximum power point ($MPPT_w = 1$) and the wind system is controlled to produce a reference power. This one is the power required to complete the power produced by the photovoltaic generator at the same time supplying the total power load. It should be noted that in cases 1 and 2, batteries are not used to produce load power, instead they become a part of the power required. Once the maximum production limit of the hybrid system is reached or exceeded by any power demand, the system switches in the Case 3. In cases 2 and 3, the PV system produces maximum power at MPPT operation. Different algorithms can be used to extract the maximum power .The reference power is given by (Fig. 6, 7) [4]:

$$P_{ref2\_s} = P_{pv}^{opt} = P_{s}^{opt} = V_{pv}^{opt} \cdot I_{pv}^{opt} \quad \textbf{(16)}$$

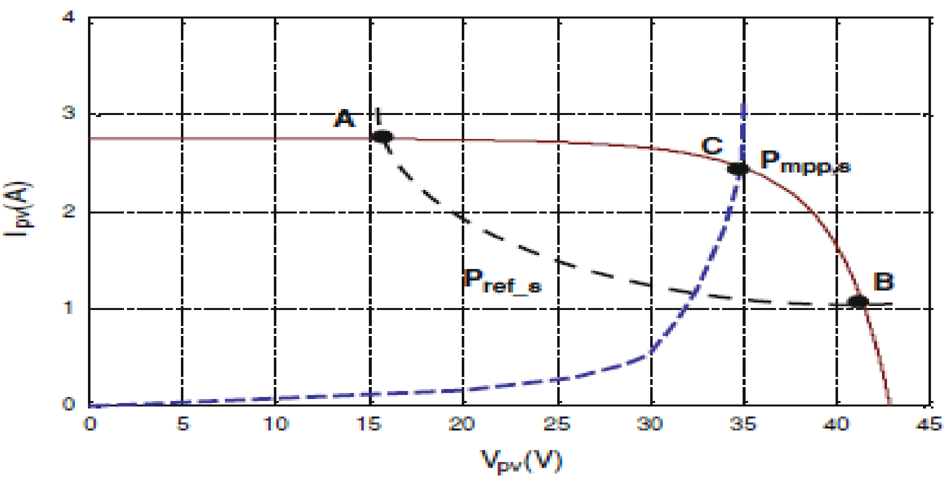

Figure 6. *Characteristic $I_{PV}(V_{PV})$ panel with photovoltaic power Reference P_{ref_s} produced*

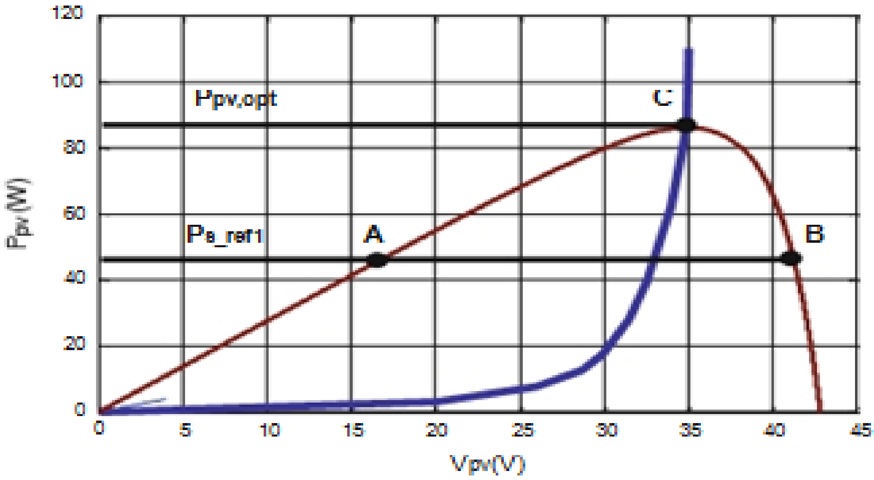

Figure 7. *Characteristic $P_{PV}(V_{PV})$ panel with photovoltaic power Reference P_{ref_S} produced*

The wind system starts its operation when the PV power is insufficient to supply the total power required. The supervisor controls the wind system by power control or by power operation. The objective in case 2 is to produce the additional power to supply the total power applied. The wind power reference is given by:

$$P_{ref1\_s} = P_{required} - P_s^{opt} = V_{batt} \cdot \left(I_{load} + I_{batt} + I_s\right) \qquad \textbf{(17)}$$

When the contribution of wind power subsystem is no longer sufficient to supply the total power required the supervisor switches in Case 3. The objective of this subsystem is the generation of maximum power extraction.

Case 3

In this case, the two photovoltaic and wind generator provide maximum power (operating at MPPT). In addition, to supply the load demand, the batteries are charged or discharged. At discharge, Case 3 is maintained as long as the available energy levels of the batteries is sufficient to complete the load demand, after that, the load must be disconnected to charge the batteries. The wind system produces maximum power MPPT, the reference power is given by:

$$P_{ref2\_w} = P_w^{opt} = K_{opt} \cdot \Omega_{opt}^3 \qquad \textbf{(18)}$$

with K_{opt} a coefficient which depends on the ratio of tip speed and optimal power coefficient.

We note in Fig. 8 the intersection of $P_w(\Omega)$ characteristic with reference $P_{ref2\_w}(\Omega)$ (point C^0) which corresponds to the maximum power point for a particular value of wind speed. As for the operation of photovoltaic system, we remark that two operating points can develop the same reference power (point A^0 and B^0). Operation on the right side of the point of maximum power requires a system of power control [6][7]. The operating point (A^0) would be the most appropriate. The reference angular velocity which corresponds to the operating MPPT is given by:

$$\Omega_{ref} = \Omega_{opt} = \sqrt[3]{\frac{P_{ref2\_w}}{K_{opt}}} \qquad (19)$$

Then the supervisor decides the case (1 or 2/3) by comparing the measured mechanical speed with the reference speed.

A description of operating cases is shown in Fig. 9.

$$P_{ref1\_s} = P_{required} = V_{batt} \cdot (I_{load} + I_{batt})$$

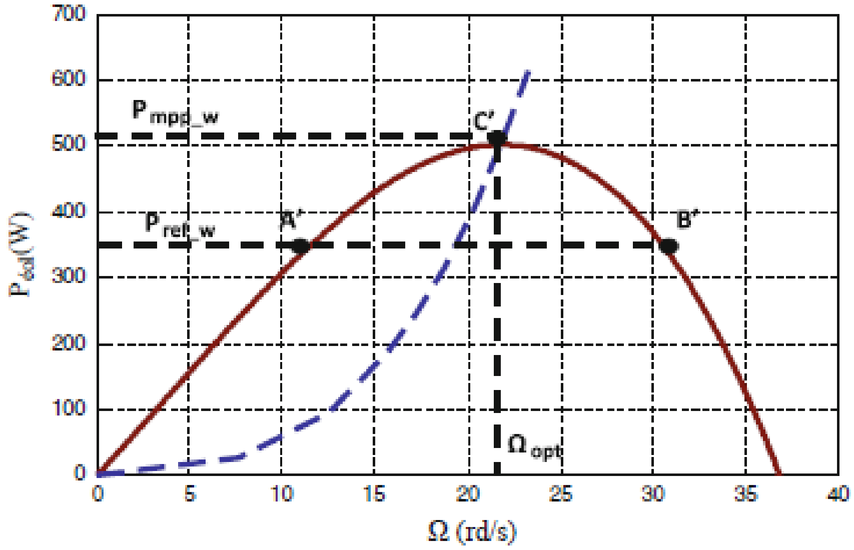

Figure 8. *Characteristic $P_W(X)$ with photovoltaic power Reference P_{ref_pv} produced*

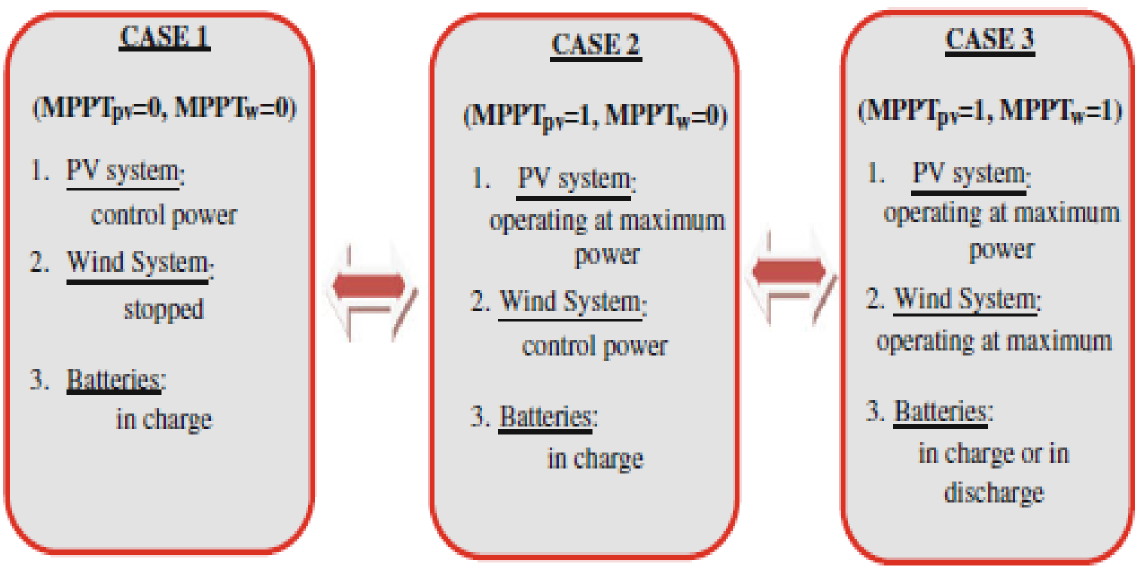

Figure 9. *Description of operating cases*

3. Conclusions

This study is based on the fact that the wind and solar energy are omnipresent, freely available, and environmental friendly. Some disadvantages occurred because of low wind speeds the unpredictability of solar energy, the wind energy systems may not be technically viable at all sites.

The solution of combining of these renewable energy sources is becoming more and more attractive and is used in present on a large scale as alternative of oil-produced energy. From the economic perspective, the renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. A renewable hybrid energy system consists of two or more energy sources, a power conditioning equipment, a controller and an optional energy storage system. The popularity of those hybrid energy systems is in a continuous growth in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products.

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