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Regular paper

Study and Management of an Hybrid System Connected to The Network

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Renewable energy-based power generation systems are being developed to ensure an efficient energy transition and meet the ever-growing energy demand. The hybrid system is a promising solution when the expansion of the distribution network is impractical or not economical. The integration of renewable energy sources provides energy security, substantial savings and reduced greenhouse gas emissions, enabling the nation to meet emissions targets. Solar and wind renewable energies represent alternatives to fossil fuels thanks to their remarkable advantages. However, the intermittent nature of their availability requires the use of a storage system.

In this article, an optimal energy allocation strategy is established for a grid connected system integrated with photovoltaic systems, wind turbine and energy storage batteries. Simulation results are obtained for the optimum capacity of the photovoltaic system and the wind turbine system, state of charge / discharge of the battery and energy exchange with the grid.

Keywords: Renewable Energies, Hybrid, Solar, Wind, Network, Storage, Simulation.

1. Introduction

Renewable energies are a particular suitable response to the considerable energy needs of emerging countries, which today provide the bulk of global growth. They make it possible to develop their natural resources, hydraulic, sunshine, wind, biomass, hydrogen, etc., to bring production sites closer to centers of consumption and to reduce the dependence of these countries on fossil fuels. They also lend themselves to local equipment production which further adds to their interest [1, 2].

However, the energy transition model and the configurations of the conversion facilities must be in line with the specifics of the location of the country. In view of the report on the accelerated depletion of fossil resources due to the ever-increasing energy needs and the challenges of environmental preservation of carbon dioxide emissions, the use of renewable resources for the production of electricity is a promising alternative. However, there are many sources for renewable energy: Solar, Wind, Ocean, Hydro.... whose main resources are solar and wind energies [3, 4]. Due to the intermittent availability of these two last energy sources, a storage system is necessary for the continuity of the service [5- 7]. Indeed, a storage system is required to compensate the lack of the power under all conditions and to ensure a performing and a continuous power source for consumers using a bidirectional DC-DC converter which is controlled to satisfy the energy required by the load [8-10].

For that, it is a question of knowing the entry criteria which are the meteorological data of the site. Thus, the hybrid conversion system (HCS) proposed in this work contains essentially a photovoltaic generator (GPV), wind turbine (WT), (SB) and AC load connected to the electrical network via the static converters. This assembly is connected to

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the electrical network via static converters, as shown in Figure.1. In this case, the excess energy produced compared to that requested by the load would be stored (charging the battery) and when the energy requested by the load exceeds that supplied by the hybrid system, the energy stored would be used as a complement (discharge of the battery) to compensating the use of the energy produced by the electrical network to meet the needs of the load.

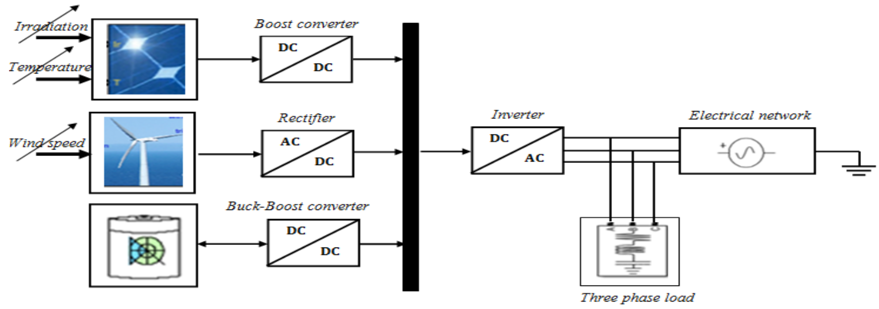

Figure 1. Hybrid conversion system

The aim of this work is to develop a mechanism for managing the energy of the different sources of the hybrid system. However, we started with the modeling and control of each component of the studied system. The first part of this work contains the principle of the operation of the hybrid sources (wind turbine, photovoltaic panel and battery) and the modeling of the various constituted parts. In the second part, the results of the simulation and the discussions are presented to initiate the analysis of the operation of a hybrid system: PV-Wind turbine-Battery-Grid and to validate its operation under irradiation, temperature and wind speed. Finally, conclusion is given in the last section. Each part of the proposed system is simulated using MatLab / Simulink software, thanks to which the behavior of the installation under different environmental conditions is analyzed in order to validate the study.

2. Modelization

This section considers the modeling of each component of the hybrid conversion system. For this purpose, it is a question of putting into equations each component for the modeling and the control of the whole system. At this level, the necessary condition is to know the entry criteria, i.e. the meteorological data of the site and the data relating to the equipment. Many papers published in the scientific literature relate to the development of models for each of the components of the system. In the rest of this section, we consider each component separately.

2.1 Photovoltaic system

The GPV is formed by a set of solar panels, which they consisted of photovoltaic cells connected on series and parallel in order to meet the power required by the installation [10, 11]. The photovoltaic cell equivalent electrical circuit model is shown in Figure.2.

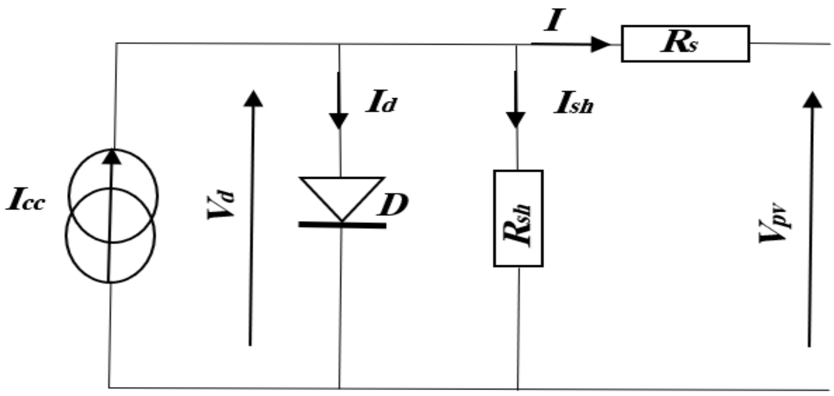

Figure 2. PV cell equivalent electrical circuit model

With, $I_{cc}(A)$: short-circuit current, I(A): cell current; V_{pv}(V): cell voltage; I_d(A): diode current; I_{Rsh}(A): current of shunt resistor; R_{sh}(Ω): shunt resistance which characterizes the junction currents; $R_s(\Omega)$: series resistance which characterizes the various resistances of the contacts and connection. The law of the nodes makes it possible to write the following relation [12, 13]:

$$I = I_{cc} - I_d - I_{Rsh} \tag{1}$$

The junction current I_d is given by:

$$I_d = I_0\left(e^{\frac{q}{nkT_c}(V+I.R_s)} - 1\right) \tag{2}$$

The current in the resistor R_{sh} is given by:

$$I_{R_p} = \frac{V + I.R_s}{R_{sh}} \tag{3}$$

We obtain,

$$I = I_{cc} - I_d - \frac{V + I.R_s}{R_{sh}} \tag{4}$$

In addition, considering a good quality photovoltaic cell, the R_{sh} will have a very high value and therefore the third term of the right part of the equation (4) can be neglected:

$$\left(\frac{V + I.R_s}{R_{sh}}\right) \tag{5}$$

Thus, we retain from (2) that:

$$e^{\frac{q}{nkT_c}(V + I * R_s)} >> 1 \tag{6}$$

So, the current-voltage equation of the cell is written:

$$I = I_{cc} - I_0 e^{\frac{q}{nkT_c}(V + I.R_s)} \tag{7}$$

I_0(A): saturation current of diode; q =1.602×10-19 (C): electron load; n: non-ideality factor of the diode junction; K =1.381.10-23 J/K: Boltzmann constant; T_c (K): effective cell temperature; T(K)=273+T (°C).

Despite the variation in weather conditions (Irradiation and Temperature), particular interest is reserved for the operation of the generator and its operation at the point of maximum power (MPPT).

2.2 Wind conversion system

The wind generator consists on a turbine directly coupled to a permanent magnet synchronous generator (PMSG). The blades are rotated by the energy of the wind.

- *Wind Turbine*

Wind turbine converts wind energy into mechanical power. The mechanical power is computed as follows [14, 15]:

$$P_m = C_p.P_e = \frac{1}{2}\rho\pi R^2 V_w^3 C_p(\lambda) \tag{8}$$

$$P_m = \frac{1}{2}\rho A V_w^3 C_p(\lambda,\beta) \tag{9}$$

The theoretical value is well-known as 'Betz limit' which determines the maximum power that can be extracted from a given wind speed and is defined by [16-18]:

$$C_p(\lambda,\beta) = 0.5176 \left((\frac{116}{\lambda_I} - 0.4\beta - 5)e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \right) \tag{10}$$

With:

$$\lambda = \frac{R.\omega_m}{V_w} \tag{11}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{12}$$

Where, ρ is the air density (kg/m^3), A is the blades swept area, V_w is the wind speed (m/sec), and C_p (λ, β) is the power coefficient, which is defined as the ratio of turbine power to wind power and it is a function of the pitch angle (β) and tip speed ratio (λ).

- *Permanent magnet synchronous generator*

The PMSG is an electromechanical converter, which produces an electric current whose frequency is determined by the rotation speed of this machine [19, 20]. The following differential equations of the stator voltages and dynamic equation, which are expressed by (13), and (14) define it, respectively:

$$\begin{cases} V_a = Ri_a + \dfrac{d\left(L_s i_a + \phi_{fa}\right)}{dt} \\ V_b = Ri_b + \dfrac{d\left(L_s i_b + \phi_{fb}\right)}{dt} \\ V_c = Ri_c + \dfrac{d\left(L_s i_c + \phi_{fc}\right)}{dt} \end{cases} \quad (13)$$

$$J\frac{d\omega_r}{dt} = T_m - T_{em} \quad (14)$$

With,

$$L_s = L.M \quad (15)$$

R: stator phase resistance; L_s: cyclic stator inductance or synchronous inductance; *L*: own stator inductor; *M*: mutual inductance between two stator phases; ϕ_{fa}, ϕ_{fb}, ϕ_{fc}: total fluxes sent by the inductor in the three phases.

2.3 Storage system

The excess energy produced with that required by the charge would be stored (battery charge) and used as a supplement (battery discharge) so that the charge receives the required energy under all conditions. The equation of the voltage across the battery (V_{bat}) is given by the following relation [21,22]:

$$V_{bat}(t) = V_c - R_v I_{bat}(t) \quad (16)$$

Where,

V_c: ideal input voltage source; R_v: variable internal battery resistance and I_{bat}: current developed by the battery.

The state of charge (SOC) of the battery is:

$$SOC = 1 - \frac{Q_d}{C_{bat}} \quad (17)$$

With, Q_d**:** battery charge; C_{bat}: nominal battery capacity.

The state of charge (SOC) provides information on the state of charge of the battery, expressed as a percentage, in order to avoid deep discharges or excessive charges which would damage the batteries [23-25].
As indicated in following equation:

$$SOC = \frac{AvailabC_{bat}(AH)}{No\min alC_{bat}(AH)}.100\% \quad (18)$$

2.4 Static converters

The analysis of the architectures of solar and wind conversion systems require the use of static power converters such as choppers, rectifiers and inverters. The three generators (03) listed above, in particular, GPV, WT and the SB supply the inputs, respectively, of the

Boost converter (DC/DC), an Inverter (AC/DC) and a bidirectional Buck/ Boost converter (DC/DC), whose mathematical models are developed in references [5, 11].

3. Simulation Results and Discussion

In view of the validation by numerical simulation under the MatLab/Simulink environment of the behavior of the installation without and with the storage system, the overall system was tested under the effect of four (4) levels of irradiation while keeping the temperature constant (T=25°C). Figure 3 shows the characteristics of the photovoltaic power Ppv=f(Vpv) and current Ipv=f(Vpv) as a function of the photovoltaic voltage. It should already be noted that each irradiation-temperature combination curve corresponds to a maximum power. Effect for irradiations E=1000W/m^2, E=900W/m^2, E=600W/m^2 and E=300W/m^2 with a constant temperature T=25°C. The obtained maximum powers are: 10855W, 9755W, 6450W and 3125W, respectively.

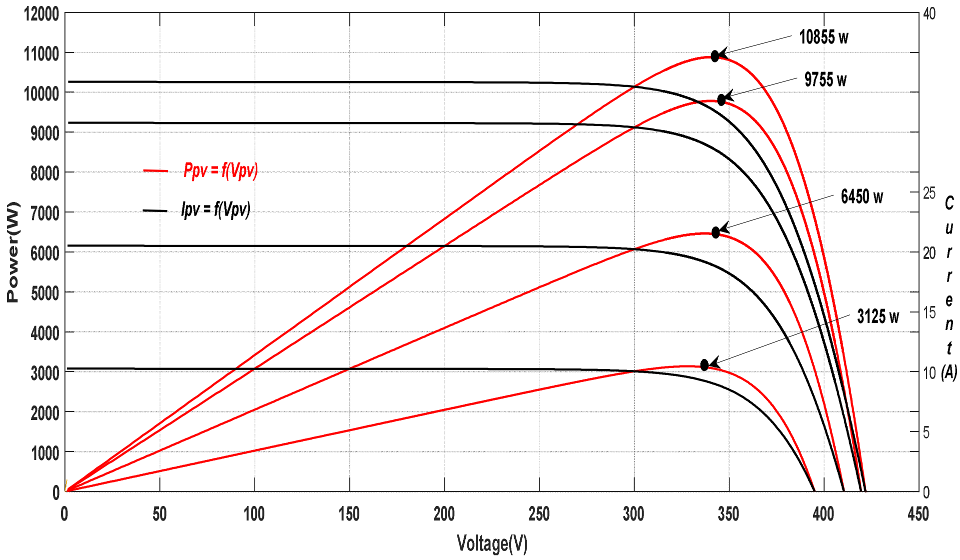

Figure 3. The PV panel characteristics

Figure 4 shows the behavior of the proposed hybrid system under the variable conditions of irradiation and wind speed with a constant temperature without the use of the storage system. We notice that when the irradiation is 1000W/m^2 and wind speed is 5m/s (between 0s and 1s), the total powers of the GPV and the WT satisfy the demand of the load with a surplus injected into the electrical network which is well shown with the negative power of the network and the call of alternating currents. From t=1s to 2s, the irradiation is 900W/m^2 the absorbed powers of the GPV and the wind turbine are always sufficient, so we notice that the network is at rest, which explains why the network currents equal 0(zero). On the other hand, when the irradiation decreases from 900W/m^2 to 600W/m^2 but the wind speed remains invariable and equal to 5m/s, the too powers supplied are insufficient, so the network helps with a part. Which explains the increase in network currents from t=2s to 3s. Finally, from t=3s to 4s the irradiation is still decreasing but there is an increase in wind speed, which explains the increase in wind power and consequently the increase in total power required by the load, which will influence the network which notices a decrease in its currents

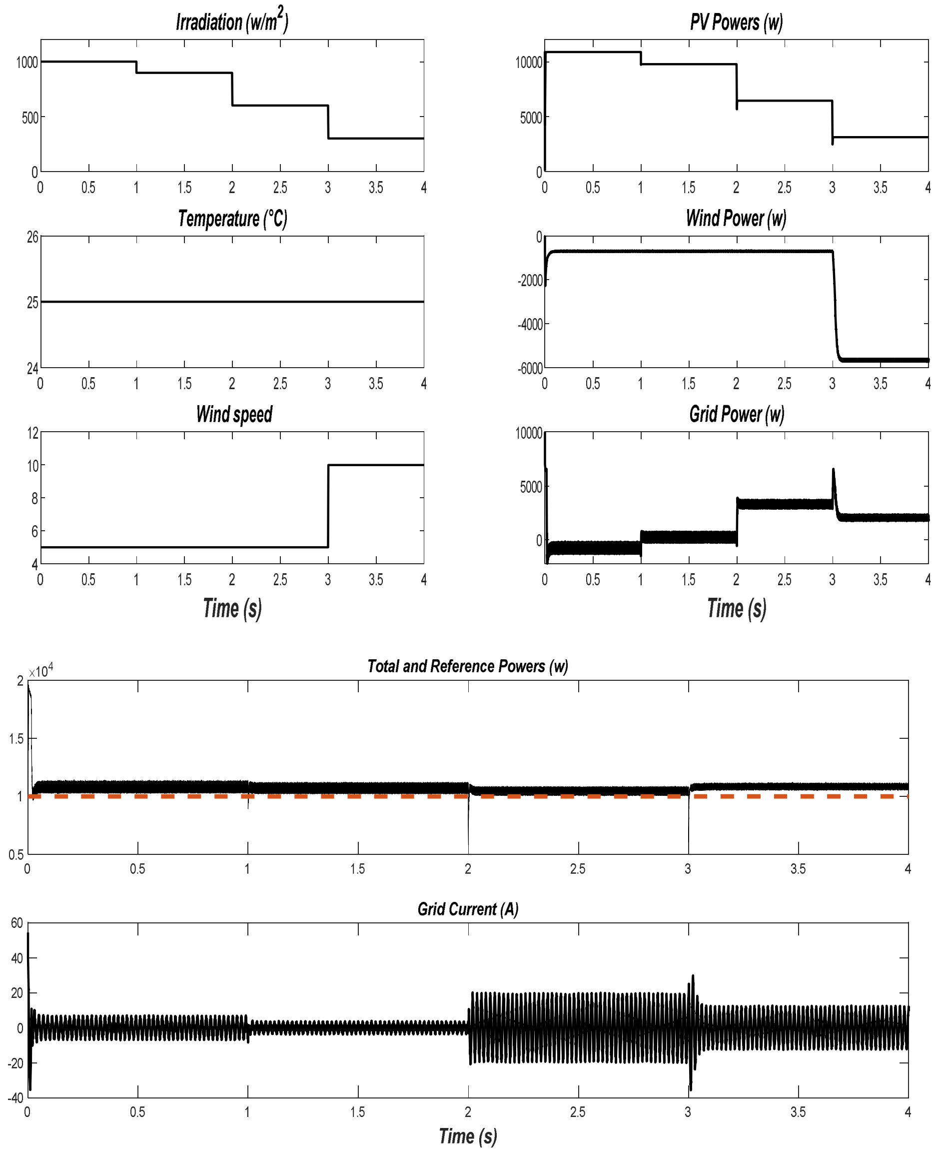

Figure 4. Behavior of HCS without storage system

However, for the rest of this work the figure 5 presents the simulation results where a storage battery is planned. For this, taking into count the interval from t=0s to 1s where the irradiation is 1000W/m^2 and a speed is 5m/s. The total power supplied exceeds that required by the load, so it is possible to store the excess energy produced in storage batteries. This explains the increased SOC of the battery state of charge. But, between 1s and 2s where the irradiation decreases from 1000 W/m^2 to 600W/m^2 which causes a decrease in the photovoltaic power and consequently a decrease in the total power supplied, in this case the battery takes over to supplement the lack of the requested power state of discharge. We also note that the currents of the electrical network are zero.

Finally, from t=2s to t= 3s with a decrease in irradiation from 600W/m^2 to 300W/m^2 and an increase in the wind speed from 5 m/s to 10m/s we notice an increase in the power supplied, which causes the decrease in the power of the battery that is used to fill the gap. We also notice that the network is still at rest.

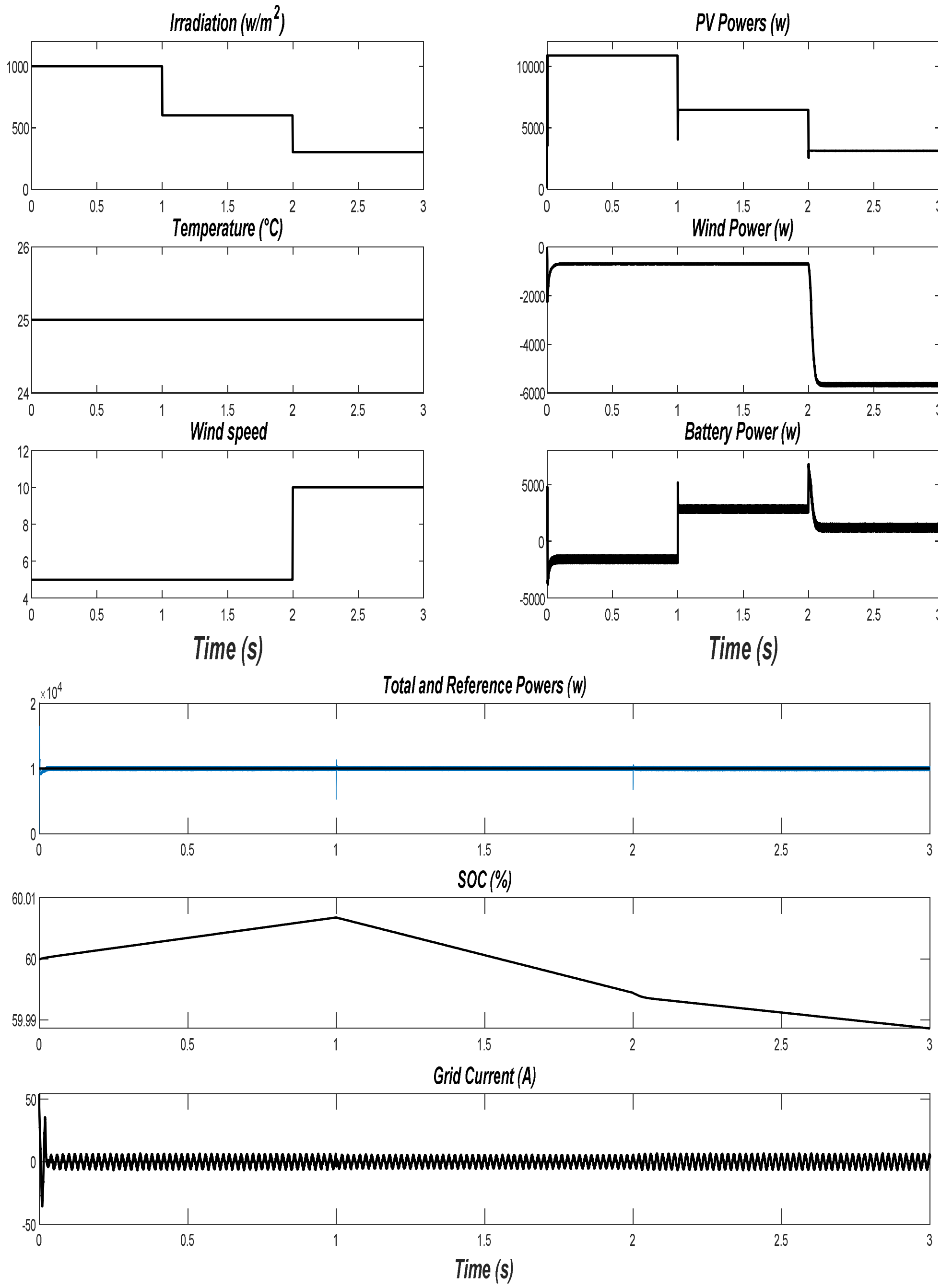

Figure 5. Behavior of HCS with storage system

4. Conclusion

The hybrid installation considered in this work contributes to the enrichment of the field of power management produced by the multisources. Mainly, it shows the importance of the storage device for the continuity of service even if the weather conditions, in particular, irradiation and temperature are unfavorable. All the more so, the availability of inexhaustible and clean sustainable energy sources, that is to say no discharge of waste into the atmosphere, is a major asset to encourage and promote the use of energy conversion systems renewable as a promising and indisputable alternative to the use of fossil fuels, thanks to the advantages they present, mainly, by their availability (durable and inexhaustible) and by their cleanliness. However, the intermittent nature of solar and wind energy, the option of hybridization with storage proves to be a configuration of great importance.

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