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# Control of a solar PV/wind hybrid energy system

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**Abstract**

A serious disadvantage of coupling a solar PV and wind energies of a hybrid system into the main DC bus is the compatibility of the voltage. In fact the PV system response is faster than the wind system one. This can affect negatively on the whole hybrid system response especially in case of variable loads switching. In this paper a hybrid energy system consisting of two sources: wind turbine generator and photovoltaic solar, without energy storage is modeled and simulated using MATLAB/SIMULINK. Management of the obtained power is achieved through two adaptor switches in the DC output of both sources. Each subsystem switch is controlled in order to supply either a dump load or the consumers' loads via an inverter. The objective is to obtain an acceptable (compromise) system response and to make it more compatible. A control strategy of those two switches is proposed to adapt the inputs of the sources to the output of the DC bus. Satisfying results have been obtained in terms of voltage response stability, precision and global compatibility achievement.



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*Keywords:* hybrid energy system; wind turbine generator; photovoltaic array; DC bus coupling; dump load

## 1. Introduction

Renewable energy is actually being an up to date research in the world because of the complicated and increasing electrical energy demand. This is due to the decreasing potential of fossil energies and the environment issue.

Several renewable energy sources exist. The main ones are solar and wind energies. When they are mixed, a hybrid system is obtained. Currently, 90 % of current researches about hybrid systems are mainly oriented towards the design and economics aspects [1]. A hybrid energy system generally consists of two or more sources

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(photovoltaic or thermal solar, wind, biomass, wave and hydroelectric etc.), a storage device (battery, combustible cell, etc.). Conventional generators (gas turbine or diesel turbines) are sometimes added for efficiency and power system stability. The subsystems are connected (or coupled) into an AC or DC bus by a converter (e.g. DC/AC, AC/DC, DC/DC, AC/AC) in order to ensure adaptability of that energy to the electricity grid and the consumer [2, 3]. When the AC coupling method is used in the power supply frequency (PFA) and high frequency (HFAC), this method does not require synchronization between the energy sources. On the other hand, in the case of DC coupling, the main inconvenience is the compatibility of the voltage [4, 5]. In fact the PV system response is faster than the wind system one. This can affect negatively the whole hybrid system response especially in case of variable loads switching. In this paper, a hybrid energy system consisting of two sources: wind turbine generator and photovoltaic solar, without energy storage is modeled using MATLAB/SIMULINK. Management of the obtained power is achieved through two adaptor switches of the DC bus. Each subsystem switch is controlled in order to supply either a dump load or the consumers' loads via an inverter. The objective is to obtain an acceptable (compromise) system response and to make it more compatible.

## 2. Descriptions of the hybrid system components

Hybrid power systems integrate various renewable energy sources, storage and conventional sources. In this paper, the proposed system, as shown in Fig. 1, is composed of photovoltaic panels and a wind turbine generator. Coupling of the two sources to the DC bus is achieved through a DC/DC converter for the PV system and an AC/DC converter for the wind system. An inverter is used to supply the AC loads.

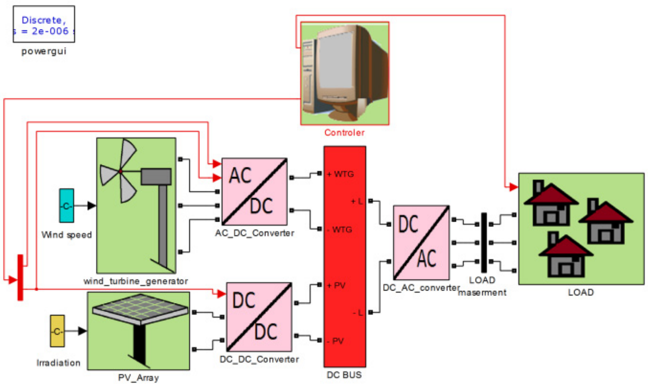


Fig. 1. Studied Hybrid energy system.

### *2.1. Photovoltaic solar energy system*

The solar photovoltaic panel is formed by a series-parallel combination of appropriate solar cell in order to provide the voltage and current necessary under normal conditions. A solar cell is essentially a P-N junction of semiconductors which converts solar energy directly into electricity [6]. The equivalent electrical circuit for a photovoltaic generator is represented in Figure 2. Its electrical characteristics under solar radiation are given by the current $I_{pv}$ and voltage $V_{pv}$ [7].

$$I_{pv} = I_L - I_0\left[\exp(\frac{V_{pv} + R_s I_{pv}}{V_T}) - 1\right] - \frac{V_{pv} + R_s I_{pv}}{R_p} \quad (1)$$

where

$I_L$ the current produced by the solar modules;

$I_0$ the reverse saturation current of the grid solar;

$V_T$ the thermal voltage;
$R_S$ the parasitic resistance of a solar panel in series;
$R_p$ solar panels shunt parasitic resistance.

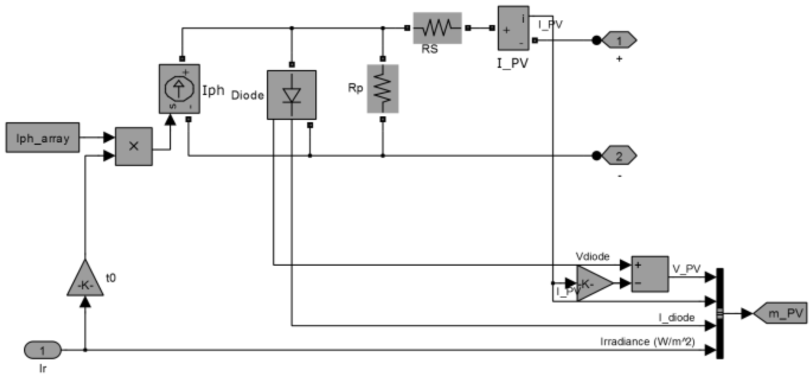


Fig. 2. Photovoltaic solar array.

### 2.2. Wind turbine generator

Wind energy systems exploit the kinetic energy of the wind and convert it into electrical energy or use it to do other work, such as water pumping, grain milling, etc. The kinetic power is expressed by the equation below [8]:

$$P = \frac{1}{2} C_p \rho A V_1^3 \tag{2}$$

where
Cp the power coefficient;
ρ the air density;
A the area swept by the wind;
V1 the speed of the wind.

The wind generator is composed of two main parts: the turbine and the electric generator. The used types of generators are [8]: the DC machine, the asynchronous machine and the induction machine. In this hybrid system the squirrel cage asynchronous machine type is used as shown in the MATLAB/SIMULINK model of Fig. 3.

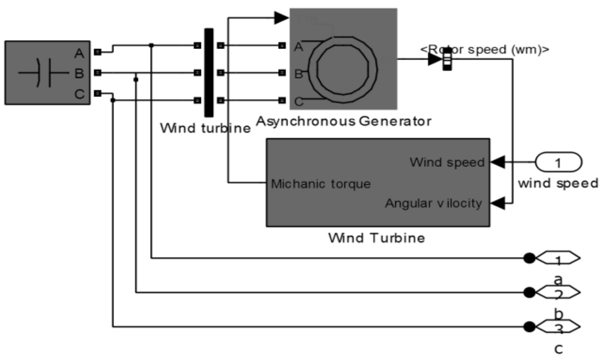


Fig. 3. Wind turbine generator.

*2.3. Rectifier ( AC/DC converter)*

Figure 5 illustrates a typical three-phase diode bridge rectifier. The average value of the DC output voltage $V_{dc}$ is given by equation (3) [4, 5]:

$$V_{dc} = \frac{3}{\pi} V_{LL} \sqrt{2} \tag{3}$$

where VLL is the AC source line-line RMS voltage.

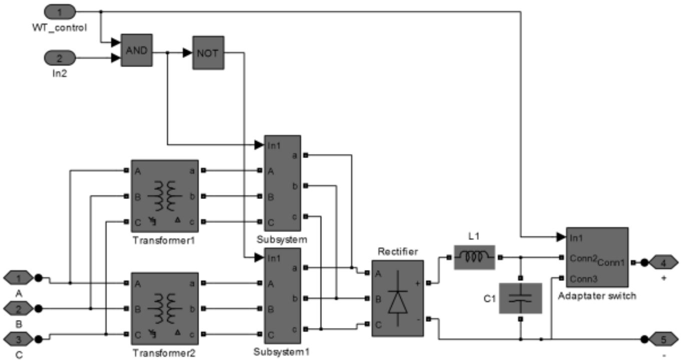


Fig. 4. Rectifier converter.

*2.4. Boost converter (DC/DC converter)*

To connect a PV generator to the DC bus, it is necessary to have a stable voltage of the photovoltaic generator and maximize power production cells. The DC/DC converter can provide this by using the MPPT strategy. Figure 5 details the composition of the converter. Equation (4) below shows the DC/DC converter voltage [9]:

$$V_{out} = \frac{V_{in}}{1-D} \tag{4}$$

where
$V_{in}$ the voltage of the photovoltaic generator;
$V_{out}$ the output voltage;
D duty cycle.

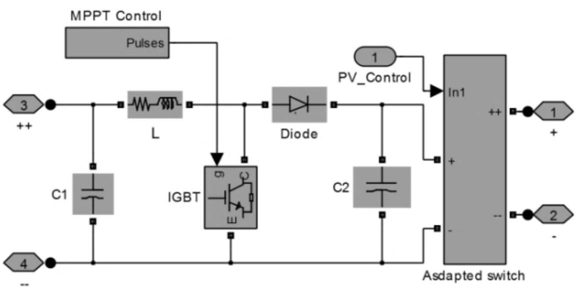


Fig. 5. Boost converter with MPPT controller.

### *2.5. Inverter (DC/AC converter)*

Figure 6 shows a DC converter to a three-phase alternating current with a voltage regulator. The DC current source is switched successively (PWM control) during a 20 ms period at 50 Hz frequency in three-phase so as to supply a three-phase load. The fundamental frequency (60 or 50Hz) phase to neutral voltage $V_{ph}$ is represented by equation (5) [9]:

$$V_{ph} = (\frac{2\sqrt{2}}{\pi}).\cos(\frac{\pi}{6}).V_{dc} \quad (5)$$

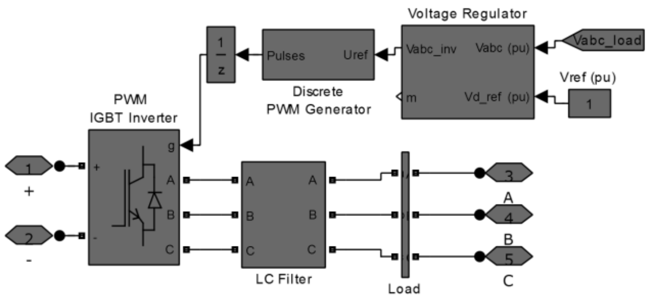


Fig. 6. Inverter (DC/AC converter).

### *2.6. Variable load*

The important goal of this hybrid system is to satisfy power demand of variable load consumption. Figure 7 shows the three-phase loads, where demand for loads 1, 2 and 3 is around 88 kW, 140 kW and 100 kW, respectively, for a constant frequency of 50 Hz and a voltage stabilized around 380 Vrms.

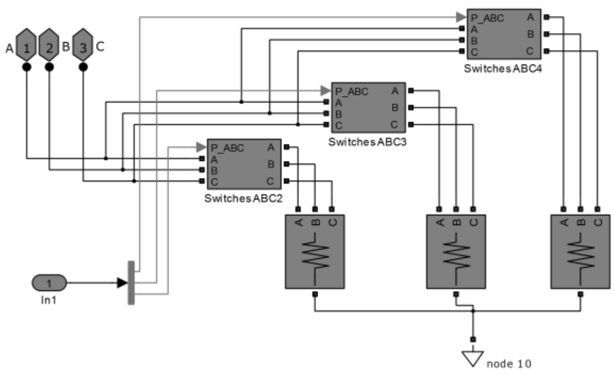


Fig. 7. Variable load.

## 3. DC coupling problem and control strategy

The main disadvantage of DC coupling is the voltage compatibility. On the one hand wind turbine generators are known for their slow time responses. On the other - PV arrays have fast transition responses. When both sources are coupled together, the hybrid DC bus voltage takes much time to be stable at a constant value around 610V. Figure 8 illustrates this phenomenon. One can notice that the corresponding PV system curve has a faster response of the DC voltage (blue curve) than that of the wind system (red curve) and the hybrid system response is clearly affected (green plot).

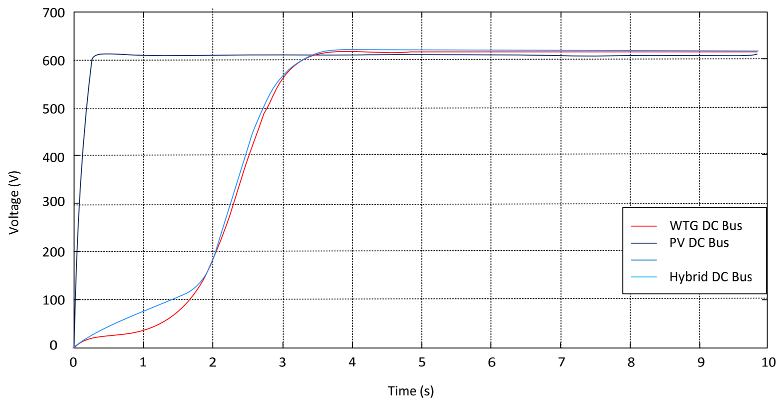


Fig. 8. DC bus voltage for PV, wind and hybrid systems.

A slow response of the hybrid system may negatively act on the load. For this reason, we must have an effective strategy to improve the DC bus voltage response time. This is proposed in the flowchart of Fig. 9.

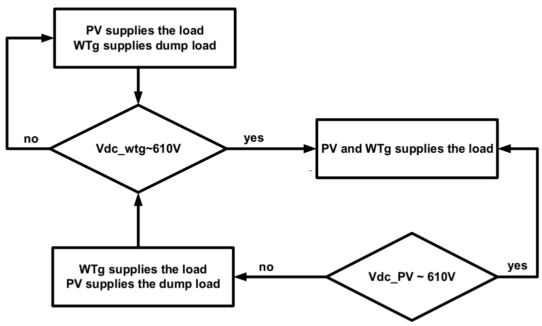


Fig. 9. Proposed control strategy.

The developed strategy is based on controlling two DC bus load adaptor switches: the PV circuit adaptor switch and the wind system one. In fact each adaptor switches the corresponding source between the dump DC load and the inverter independently. First the PV system delivers the full load power and in the same time the wind turbine generator supplies only a dump load. When the wind system reaches the steady state both systems supply the load. This is achieved through the DC bus controller. Then if for any reason (night, clouds, etc.) the PV system gives less power (consequently less DC voltage), it is directed to the dump load and the wind system supplies solely the load.

## 4. Results

Figures 10 (a) and 10 (b) represent the electric power versus time with and without the adaptor switch control, respectively. One can notice that the response of Figure 10 (a) is better. Figure 11 (a) represents the electric power versus time with constant load without applying control. The variation of loads are applied in Figure 11 (b).

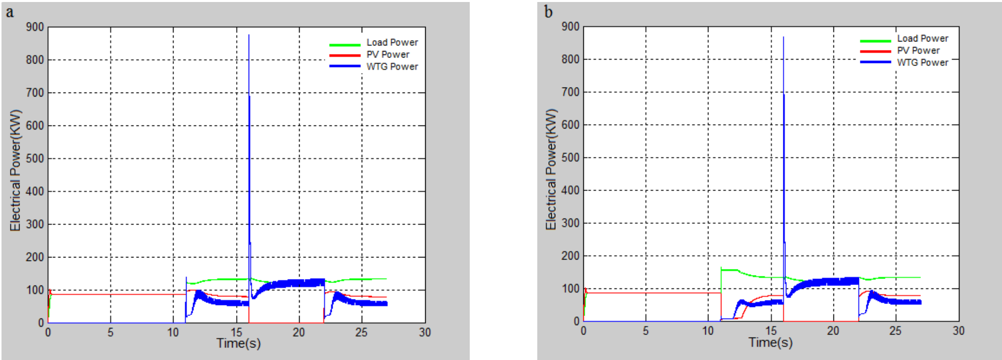


Fig. 10. (a) Hybrid power with adaptor switch control; (b) Hybrid power without adaptor switch control.

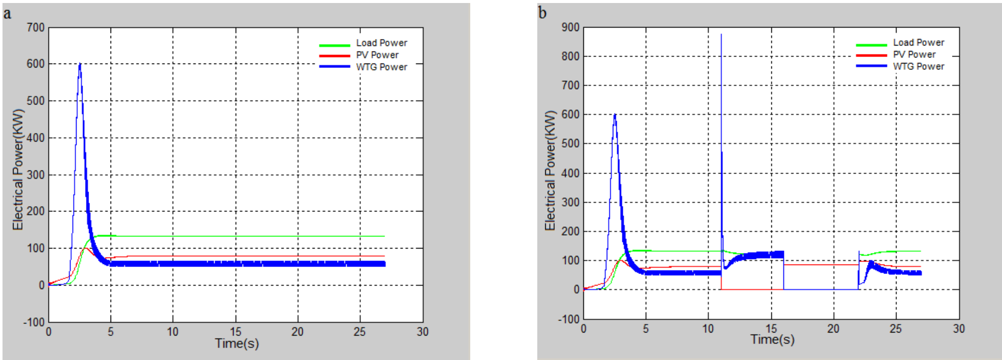


Fig. 11. (a) Hybrid power for constant load, without control; (b) Hybrid power for variable load with control.

In Fig. 12 the DC bus voltage is shown for different cases with and without the proposed control strategy. One can notice that the plot coloured in blue is the best situation where we have a variable AC load and the control is applied. Both DC load adaptors (wind and PV system DC buses) are used for the cases of AC load decrease (between 10-15 s) and increase (between 15 – 20s).

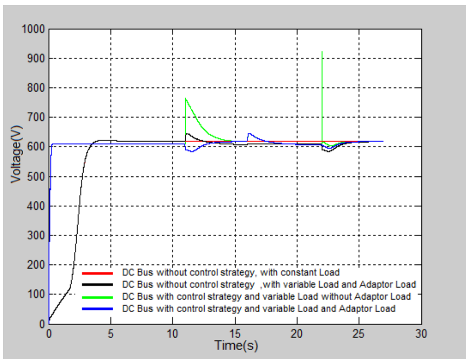


Fig. 12. DC bus in the different cases.

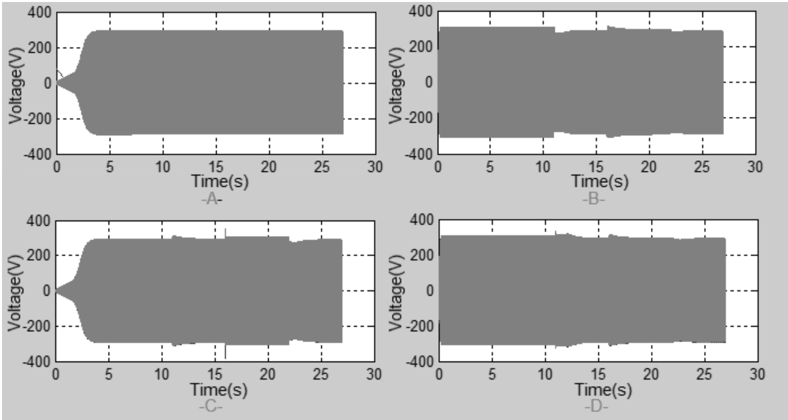


Fig. 13. AC output for a constant load.

The AC output voltage for the Hybrid power supplying a constant load and without the proposed control strategy is shown in Figure 13 (A). Of course the effect of the bad transients of the DC bus voltage is not seen in the plot. When using a load switch controller, the effect is clearly seen in the period 10 s to 15 s as indicated in Figure 13 (B) even though no DC bus control strategy is applied. The load adapter effect is seen in Figure 13 (C) and still no DC bus control (source control) is applied. Finally apply the proposed strategy i.e. source control and load adaptor control the affect is shown in the plot of Figure 13 (D). In all cases the AC output has generally excellent frequency with some tolerable harmonics as indicated in Fig. 14.

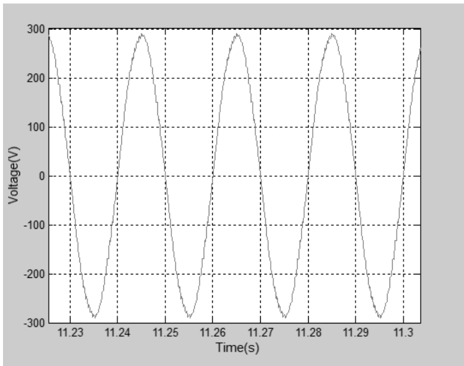


Fig. 14. Hybrid system AC output voltage in different cases.

## 5. Conclusion

A study on a hybrid system composed of a photovoltaic source and a wind generator was made, and a modeling through MATLAB/SIMULINK has been performed. We noticed an incompatibility of these two sources in DC coupling. In order to solve this problem, a control strategy of DC bus loads and sources by using adaptor switches is proposed. The behaviour of the hybrid system with that strategy has been studied and simulated. The satisfying results that have been obtained in terms of good transient response and stable DC bus voltage (at 610 V) demonstrated the effectiveness of the proposed strategy. A stable DC bus voltage is in fact essential for the inverter operation and consequently a normal AC loads connection. Our future goal is to test this method on a real experimental network and study its behaviour.

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