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OPTIMAL ENRGY MANAGEMENT SYSTEM IN A GRID-CONNECTED RENEWABLE HYBRID SYSTEM WITH DIRECT POWER CONTROL

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Abstract

For grid-connected PWM converters, the Direct Power Control technique has gained popularity as an alternative to the traditional vector-oriented control strategy. In this paper, this method is applied to converts the nonlinear VSC model into a linear one, making it simple and operating point independent to design the controller. In the DPC framework, the issue is identified. Due to its constant switching frequency operation, the DPC with space vector modulation (DPC-SVM) is used. Also, we developed an algorithm to prioritize the storage system over the grid in supplying the load when the main system fails, taking into account the state of the battery during charging and discharging to extend the battery life. The obtained results confirmed the effectiveness of the technique in improving the generated power and load supply under different weather conditions. The dynamic behavior of the system was simulated and modeled using MATLAB/SIMULINK.

Keyword: PV Solar, Wind Turbine, Battery Storage, Grid Integration, DPC, PWM.

1. Introduction

Due to the increasing demand for electricity and the depletion of fossil fuel sources over time, there has been a shift towards harnessing new and renewable energy sources [1]. These sources are not only clean and environmentally friendly but also serve as a sustainable solution.

One of the weaknesses of renewable energy sources is their intermittent nature, which has prompted many researchers to propose effective and dynamic solutions [2-3-4]. Among these solutions is the hybridization of multiple sources, particularly solar and wind energy sources, which enhances production efficiency and meets consumer demand under various climatic conditions. Connecting renewable energy sources to the electrical grid as an integrated system for load supply is typically complex due to the diverse nature of these energy sources [5]. This complexity has led us to propose a comprehensive energy management scheme for the entire system, primarily relying on direct power control. This later is applied to converts the nonlinear VSC model into a linear one, making it simple and operating point independent to design the controller, Additionally, the method has worked on estimating the energy generated from the grid and seamlessly integrating it with the energy produced from the primary system (solar and wind energy system), prioritizing the latter for load supply.

On the other hand, to reduce the reliance on the grid for load supply, a storage system has been introduced, and its role has been activated through the implementation of an energy management algorithm, with a dedicated controller overseeing its operation, which will be explained in detail later, has been put in place to oversee this process.
The results obtained through the proposed method confirmed its effectiveness, accuracy, and instantaneous responsiveness in meeting load requirements under various weather conditions in the grid-connected hybrid system. The proposed system was simulated using MATLAB software.

2. Global schematic of a hybrid energy system proposed

Figure 1 present a grid-connected hybrid system's design. This hybrid system integrates solar and wind power as its primary energy sources, complemented by an energy storage system as a secondary resource. The purpose of the energy storage system is to support the primary system by managing battery charging and discharging operations. The diagram provides a comprehensive visual insight into the intricate control and energy management technologies employed in this hybrid setup.

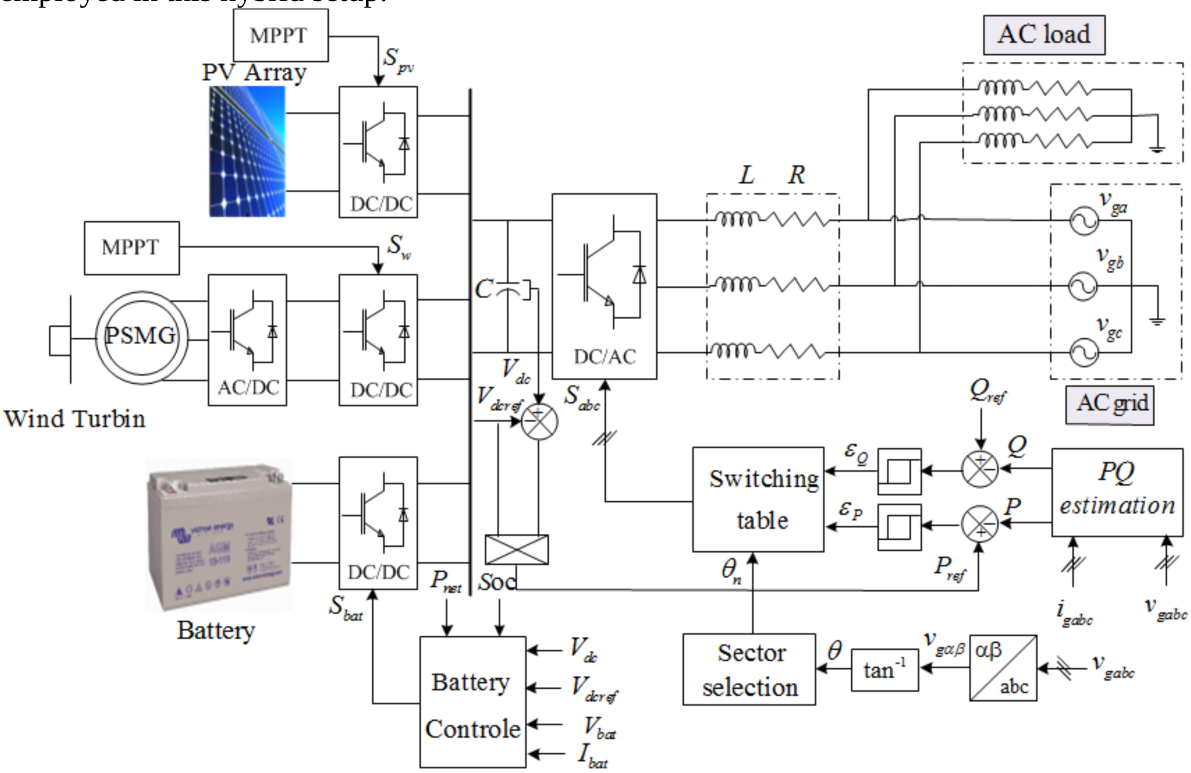


Figure1. Global schematic of a hybrid energy system proposed

The main control strategy used is a direct power control approach DPC, which proves highly effective in regulating the flow of energy to and from the grid. Depending on specific operational requirements, the system dynamically adapts. In some scenarios, it draws energy from the grid to supplement the load, while in others, it exports surplus energy generated by the primary sources back into the grid. The decision-making process hinges on the application of a predefined algorithm. Notably, there are instances where the energy storage system is bypassed, a topic that will be further elucidated in subsequent sections of this paper.

2.1. Implementing DPC for the control of the grid converter in the hybrid energy system.

DPC concept is based on the use of predefined "voltage vectors," which are specified in a "switching table" and applied to the 3-phase "PWM converter." These "voltage vectors"

correspond to sequences of "switching states" for the converter switches, namely "Sa, Sb, Sc" as presented in figure 2. The selection of these vectors is determined by evaluating the discrepancies (Sp, Sq) between the desired references (P*, Q*) and the actual measured values (P, Q) of both "active power" and "reactive power." Additionally, the selection process considers the "angular position θ" of the flux vector for the Rotor Side Converter (RSC) and the "grid voltage vector" for the Grid Side Converter (GSC) [6, 7].
The concept of DPC is visually presented in Figure 1. It relies on the comparison between the instantaneous reference values of "active" and "reactive" powers and their corresponding measurements. These comparisons are used as inputs for two "hysteresis" comparators. They, in conjunction with the "switching table" and the grid voltage magnitude, determine the switching states of the switches. Furthermore, a "PI controller" is employed to regulate the voltage of the "DC bus" [8-9].

To enhance precision and address issues that may arise at the boundaries of each "control vector," the vector space is subdivided into twelve sectors, each spanning 30°.

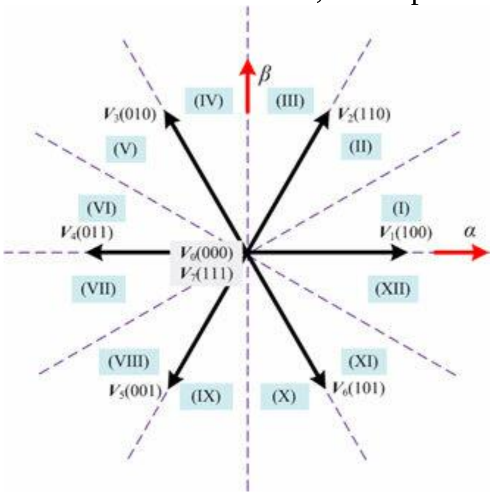


Figure 2. Eight voltage vectors and 12 sectors in the αβ reference frame.

2.1.1. Power grid estimation

It is a well-established fact that the calculation of "active" power "P" involves a "scalar" product between "voltages" and "currents," while the determination of "reactive" power "Q" can be achieved through a "vector" product between them [10-11].
Where:

$$P = v_a i_a + v_b i_b + v_c i_c \quad (1)$$

$$Q = \frac{1}{\sqrt{3}}[(v_b - v_c)i_a + (v_c - v_a)i_b + (v_a - v_b)i_c] \quad (2)$$

2.1.2. Creation of an Instantaneous Switching Table

The selection of "control vectors" is determined by the change in the sign of the "active" and "reactive" power variations. Depending on the logic outputs "Sp" and "Sq" from the "hysteresis comparators," the chosen vector should either increase or decrease both "active" and "reactive" powers.

This same rationale is applied when selecting the "control vectors" for the other sectors, resulting in the formation of Switching Table 1 [6].

Table1. Switching Table

Sp	Sq	θ 1	θ 2	θ 3	θ 4	θ 5	θ 6	θ 7	θ 8	θ 9	θ 10	θ 11	θ 12
1	0	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5
	1	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1	V_1	V_2	V_2	V_3
0	0	V_6	V_6	V_6	V_6	V_6	V_6	V_6	V_6	V_6	V_6	V_6	V_6
	1	V_1	V_2	V_2	V_3	V_3	V_4	V_4	V_5	V_5	V_6	V_6	V_1

2.2. The proposed algorithm for energy management system

For the optimal management of a hybrid energy system, given its complexity due to the diverse nature of energy sources [12-14], we have developed an algorithm. With no technical difficulties or blackouts, this algorithm is intended to efficiently and effectively manage energy to satisfy load demands. In the beginning, the suggested algorithm combine solar and wind energy systems to supply the load, reducing reliance on the grid and, as a result, lowering the environmental impact of fossil fuel usage. This algorithm has been applied to the energy storage system control unit, as illustrated in Figure 3, by inputting the following value: P_{pv}, P_{wind}, P_{batt}, P_{grid}, P_{load}, *SOC,* while maintaining the battery state within a limited range, all with the aim of extending the battery's lifespan.

Where: P_{load}: load power, P_{grid}: Grid power, P_{pv}: solar power, P_{wind}: wind power, P_{batt}: Battery power, SOC: state of the charge

$SOC_{max} \leq SOC \leq SOC_{min}$

Where: $SOC_{max} = 20\%; SOC_{min} = 80\%$

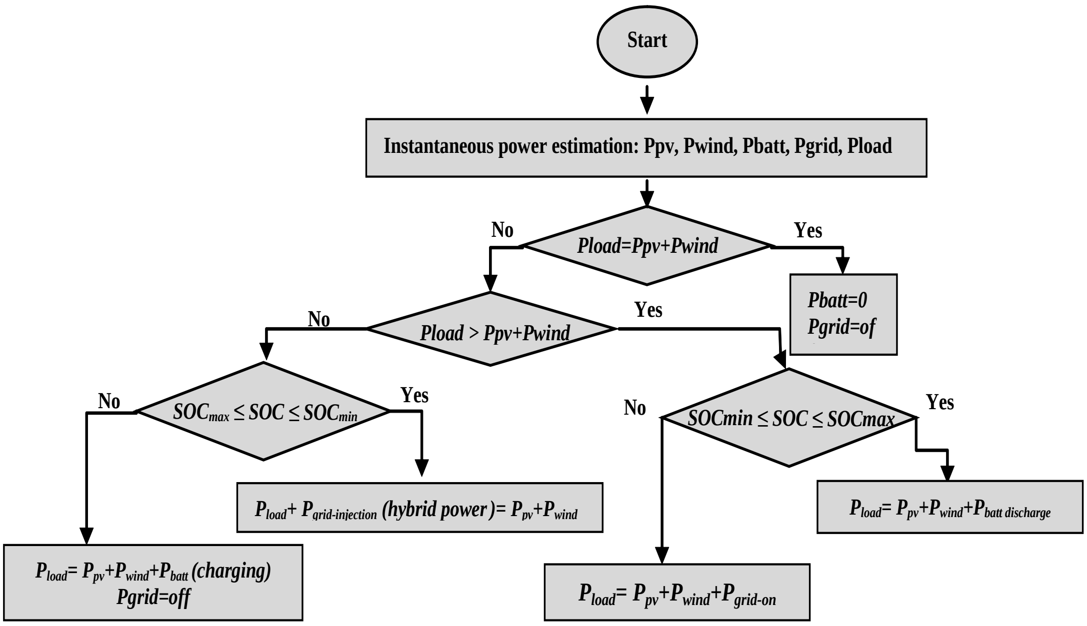


Figure 3. The proposed algorithm for energy management system

While:

$P_{grid\text{-}injection}$: The extra hybrid energy is injected into the grid when the load is saturated, and the battery is neither chargeable nor dischargeable.

$P_{grid\text{-}on}$: The electrical grid intervenes to supply the load with energy when the primary system fails to do so or when the battery is unable to discharge.

$P_{grid\text{-}off}$: The role of the grid is completely excluded when the system is capable of supplying the load with energy or when the storage system intervenes by discharging the battery.

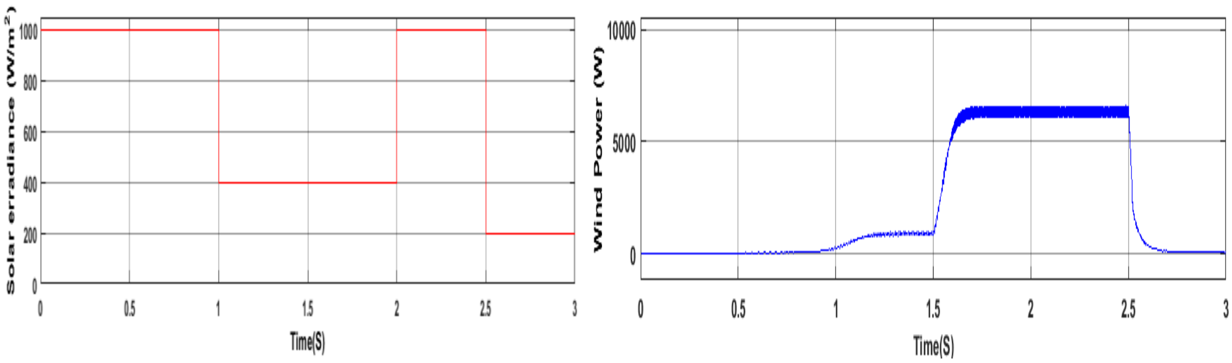
3. Results and Discussion

In the proposed hybrid system, we relied on both solar power generators and wind power generators as primary components for electricity production, in addition to a storage system as a secondary component to cover system deficiencies in certain situations. Each of the production elements was connected to a DC converter for later integration into the grid through an inverter. All the mentioned power generators share in supplying alternating loads. The system was simulated by MATLB/SIMULINK.

Considering the complexity of the proposed system, a method was previously outlined in this paper to efficiently manage various energy sources for load supply, as depicted in Figure 6. This figure illustrates a high degree of coverage for load requirements under various climatic conditions outlined in Figure 3. Several scenarios for energy production from primary sources and the involvement of the storage system can be observed, which can be divided into five scenarios:

- **Case01:** [0s-1s]: in the first scenario, it can be observed that the solar power generator is capable of meeting the load requirements without the need for the intervention of the storage system or th electrical grid.
- **Case 02:**[1s-1.5s]: in the second scenario, the primary system was unable to supply the load, necessitating the instantaneous intervention of the storage system to cover the shortfall. This was achieved by discharging the battery according to the proposed algorithm.
- **Case 03:** [1.5s-2s]: In the third scenario, the wind power generator intervened along with the solar power generator to meet the load requirements, leading to the elimination of the storage system's role.
- **Case 04:**[2s-2.5s]: In the fourth scenario, the energy load requirements doubled, necessitating the re-intervention of the storage system to assist the primary system in supplying the load.
- **Case 05:** [2.5s-3s]: In the final scenario, the electrical grid had to intervene in electricity production to assist the primary system, which exhibited a nearly complete shortfall in energy production. This was due to the failure of the storage system and the subsequent deactivation of the storage system's role after the battery was depleted in the fourth scenario.

The obtained results confirmed the effectiveness of the method in managing a grid-connected hybrid system.



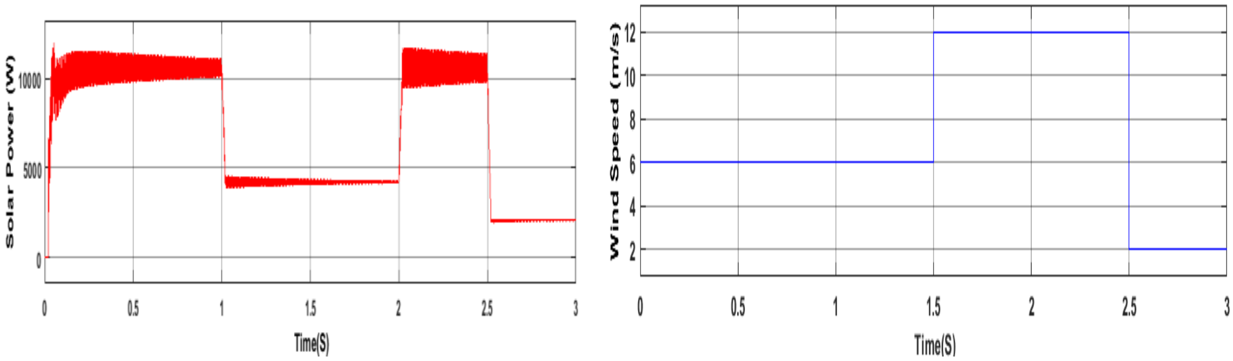


Figure 4. Impact of solar erradiance and wind speed change on generated power repectivally

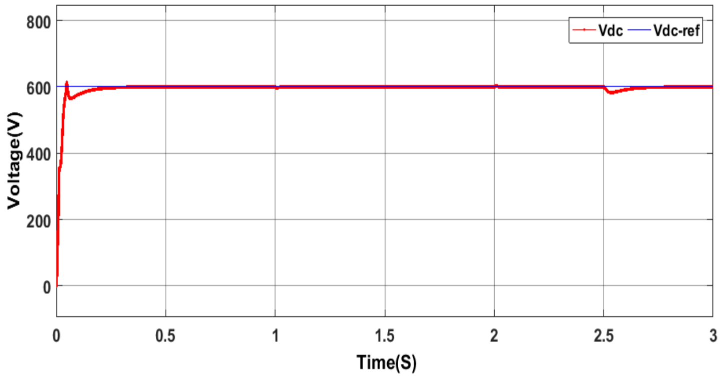


Figure 6. DC bus voltage

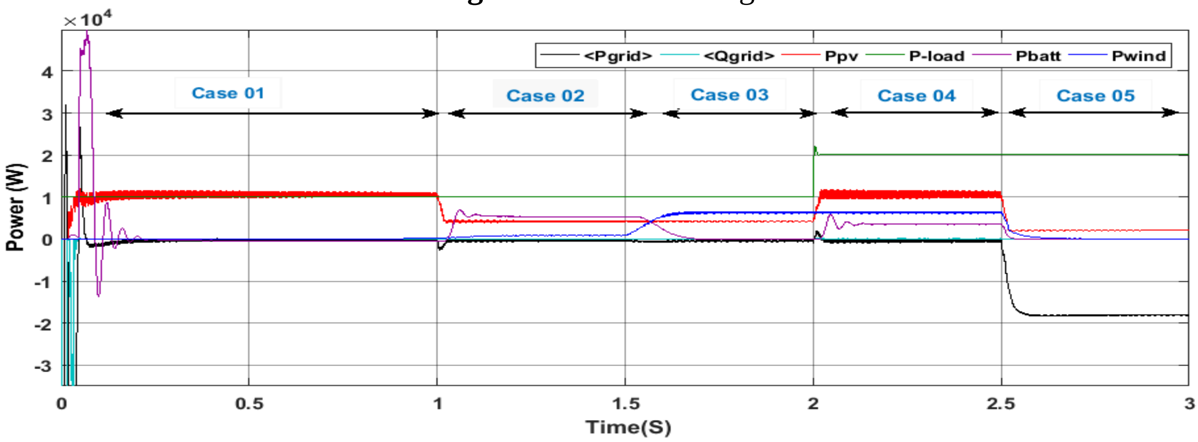


Figure 6. The various energy sources of the grid-connected hybrid system.

4. Conclusions

The management of an intricately interconnected hybrid renewable energy system is the main topic of this research article. In this research, a grid-connected inverter is controlled by a direct power control approach. Furthermore, a management algorithm is provided to effectively control various energy sources while preventing any technological disturbances. The results from the experimentation demonstrate the remarkable effectiveness of this technical strategy within the hybrid system, as it successfully satisfies the load needs without any interruptions. Through simulations carried out with the aid of the MATLAB Simulink software, the system's performance was carefully evaluated.

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