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Hybrid MPPT - Simple boost control of Z source inverter integrated in standalone PV systems

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Abstract

This study gives a hybrid strategy control of standalone system based on Z source inverter and powered by photovoltaic generators and electrochemical batteries. In off grid application, the most challenge is obtain voltage stability with a higher power quality in all really conditions (meteorological conditions, load variations). The Z-source inverter (ZSI) provides an alternative solution for the conventional voltage source inverter (VSI) by eliminating de DC/DC converter, and replace it by LC network design, this solution reduce the switching power number, losses and cost. In this work, a combined P&O MPPT technique and simple boost control strategy will be integrated in the Z sourec inverter to elaborate the shoot through situations. Many simulation results expose clearly in different situations the reliability and the robustness of the proposed control.

Keywords: Photovoltaic; Maximum power point tracker (MPPT); Z source inverter; Simple boost control; Battery; Standalone system.

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1. Introduction

With the decrease of conventional energy sources and the growing problem of environmental pollution, the research and utilization of the renewable energy, such as solar energy, wind energy as so on, has been concerned with more and more attention [1], [2]. Photovoltaic power is becoming more prevalent as its cost is becoming more competitive with traditional power sources. However, the utilization of dedicated energy storage systems needs to be taken into account because of the intermittent nature of the PV generation. Energy storage systems can open the possibility to employ renewable energy sources able to operate in standalone mode, grid-connected mode, and mode transitions from stand-alone to grid, or vice versa in micro-grid systems [3], [4].

The power electronics converters have a very important role in integration, control and management of photovoltaic systems. The usually standalone system includes two converters: The first is DC/DC converters which ensure the adaptation of photovoltaic impedance (MMPT). The second is DC/AC converter (inverter) used for create the three phase system. Another structure can be studied using the Z source inverters [5], [6], [7], [8]. By this converter we can reduce the number of switches (losses, and price), also, the input voltage is increased to the necessary value requested.

This paper presents a combined strategy control between MPPT and simple boost control to generate the shoot through and non-shoot through states of the Z source inverter as shown in Figure 1. The batteries are connected directly in parallel with Quasi Z source inverter capacitor C_1, it makes it possible to regulate the DC bus of the inverter and ensure a free power flow between PV generator and electrical loads. Feasibility and reliability of this control are verified by many rigorous simulation tests in different realistic conditions.

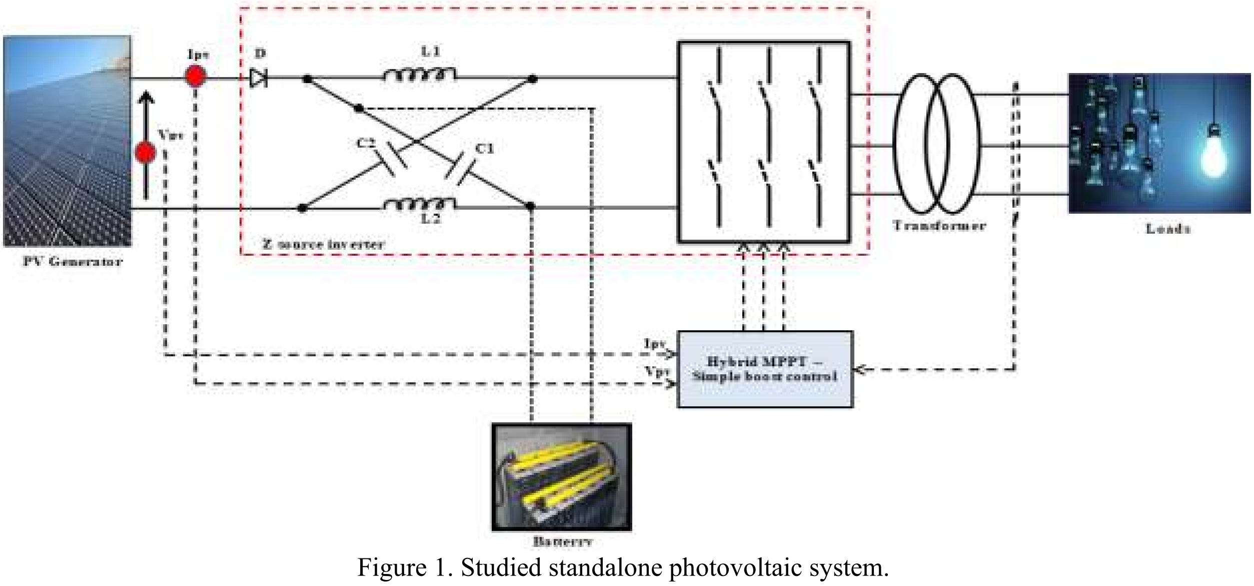

Figure 1. Studied standalone photovoltaic system.

2. Photovoltaic generator model

The photovoltaic cell is modeled like an ideal current source "Fig.2"; it current I_{ph} is proportional to the incident illumination, also, connected with diode which represent P-N junction, R_s and R_{sh} are used for modeling series connecting circuit and parallel current leakage [9], [10], [11].

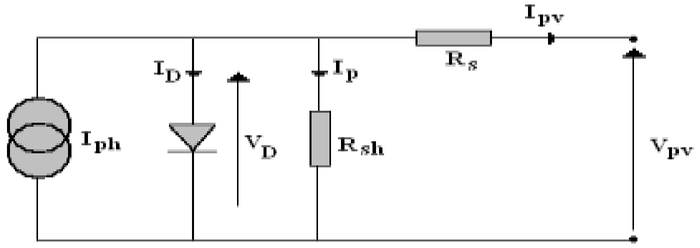

Figure 2. Simple model of the photovoltaic cells.

From this circuit, the PV cell current can be expressed such as:

$$I_{pv} = I_{ph} - I_D - I_p \qquad (1)$$

I_D expression being deduced from the semiconductor diode theory, the above relation may be detailed as:

$$I_{pv} = I_{ph} - I_o(\exp(\frac{V_{pv} + R_s I_{pv}}{nKT/q}) - 1) - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \qquad (2)$$

Where, I_{ph} is the light generated current (A), I_o the PV cell saturation current (A), q the electron charge ($q = 1, 6\ 10^{-19}$ C), K the Boltzmann constant ($K = 1, 38\ 10^{-23}$ J/K), n the cell ideality factor, T the cell temperature. R_{sh} and R_s are pure parasitic resistances characterizing respectively parallel current leakage and series connecting circuit.

In general, for a PVG involving an array of N_S cells connected in series and N_P in parallel, its output voltage current relation may be deduced from the basic cell equation (2) as follows [10], [11]:

$$I_{pv} = N_p I_{ph} - N_p I_o(\exp(\frac{q(V_{pv} + \frac{N_s}{N_p} R_s I_{pv})}{nKTN_s}) - 1) - \frac{V_{pv} + \frac{N_s}{N_p} R_s I_{pv}}{\frac{N_s}{N_p} R_{sh}} \qquad (3)$$

3. Z source inverter model

The structure of ZSI used in this study is shown in "Fig.3".

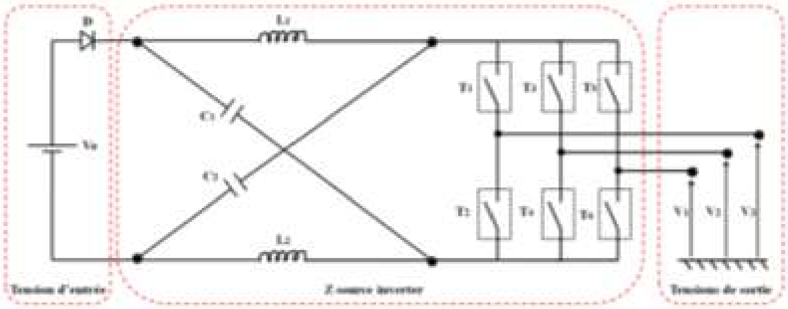

Figure 3. Structure of Z source inverter

From this circuit, we can define two operation modes: shoot through states and non shoot through states. The system equation can be expressed the following equations:
In steady state, the capacitor and inductor voltages are given by:

$$\begin{cases} V_{c1} = V_{c2} = V_c \\ V_{L1} = V_{L2} = V_L \end{cases} \quad (4)$$

The switching period T is divided into two intervals, the first is intended for the shoot states noted T_0 and the second noted T_1 for the traditional active states. Therefore the total switching period becomes:

$$T = T_0 + T_1$$

In shoot states period T_0:

$$\begin{cases} V_L = V_c \\ V_d = 2V_c \\ V_{dc} = 0 \end{cases}$$

In traditional states period T_1:

$$\begin{cases} V_L = V_e - V_c \\ V_d = V_e \\ V_{dc} = V_c - V_L = 2V_c - V_e \end{cases}$$

In the total switching period T:

$$V_L = \bar{v}_L = \frac{T_0 V_c + T_1 (V_e - V_c)}{T} = 0$$

So:

$$\frac{V_c}{V_e} = \frac{T_1}{T_1 - T_0}$$

By a similar analysis, the DC voltage can be expressed in steady state such as:

$$V_{dc} = \bar{v}_{dc} = \frac{T_0.0 + T_1 (2V_c - V_e)}{T}$$

So:

$$V_{dc} = \frac{T_1}{T_1 - T_0} V_e = V_c$$

The max DC voltage is defined by the following equation:

$$\hat{V}_{dc} = \frac{T}{T_1 - T_0} V_e$$

With:

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - 2\frac{T_0}{T}} = \frac{1}{1 - 2D} \geq 1$$

B : amplification factor

D : Shoot- throught duty ratio

The max AC output voltage delivered by the Z source inverter is given such as:

$$\hat{V}_{ac} = M.B\frac{V_e}{2}$$

With M is the modulation index expressed by this equation:

$$M = (1 - \frac{T_0}{T})$$

From the previous equations, the capacitor C_1 and C_2 voltages in steady state, can be expressed by the following equation:

$$V_{c1} = V_{c2} = V_c = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_e = \frac{1 - D}{1 - 2D} V_e$$

$$V_{C1} = \frac{1 - D}{1 - 2D} u_{pv} \quad , \quad V_{C2} = \frac{1 - D}{1 - 2D} u_{pv} \qquad (5)$$

The DC-link voltage average value is:

$$V_{dc} = u_{C1} = \frac{1 - D}{1 - 2D} u_{pv} \qquad (7)$$

The studied standalone system power flow consists of PV generator power which is controlled by MPPT algorithm and requirement load power, the batteries are used to compensate the nodded power occurred directly in any conditions, so its power is established such as:

$$P_{batt} = P_{pv} - P_{load} \qquad (8)$$

4. Principe of control

The Hybrid control diagram of the standalone PV system with batteries energy storage based on Z-source inverter is shown in "Fig.4".

4.1. MPPT control

When ignoring the voltage drop on the internal resistance, the voltage u_{C1} is approximate to the battery voltage V_{batt}, so from "equation (7)", we obtain [8], [12]:

$$V_{batt} = u_{C1} = \frac{1-D}{1-2D} u_{pv} \quad (9)$$

$$u_{pv} = \frac{1-2D}{1-D} V_{batt} \quad (10)$$

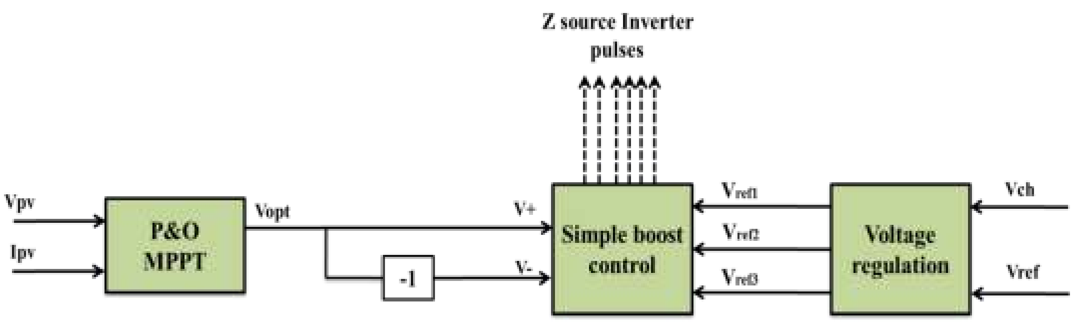

Figure 4. Hybrid control of Z source inverter

From "equation (9)" and "equation (10)" we find:

- By varying the shoot through time in one switching cycle, the input voltage can be boosted.
- The input voltage V_{pv} increases when the shoot-through time is decreased, and decreases when the shoot-through time is increased.

From this equation we can also remark that the maximum power point voltage (V_{opt}) can be tracked by adjusting the shoot-through duty ratio D. For that, the perturbation and observation (P&O) algorithm can be used to determinate the optimal voltage necessary for elaborate the straight positive and negative lines (V+, V-) commonly used for generate the shoot through states in simple boost control methods.

4.2. Simple boost control

From literature we can find three types of Z source inverter PWM control algorithm: simple boost control (SBC), maximum boost control (MBC), constant boost control (CBC) [13], [14], [15]. In this study, the first method was adopted, this control strategy inserts shoot through in all the PWM traditional zero states during one switching period. This maintains the six active states unchanged as in the traditional carrier based PWM. Two straight lines are employed to realize the shoot through duty ratio (D_o).

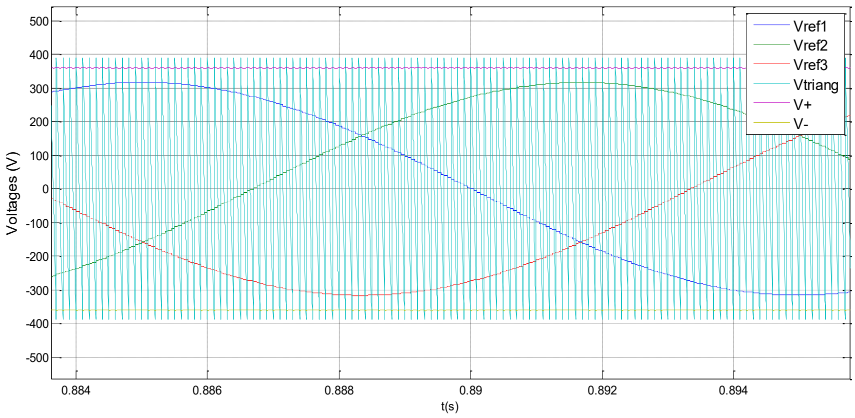

Figure.5. Simple boost control .

The PV voltage reference becomes the shoot-through reference signal (V_+, V_-). If V_+ is lower than the carrier signal, then all the switches in the three arms will be in the on position. Also if V_- is higher than the carrier signal, then all the switches will be in the on position.

5. Simulation results and discussions

Several numeric simulations are accomplished in MATLAB/SIMULINK for evaluate our system in different conditions (Weather, rapid load variation). The most important results obtained are presented in “Fig.6” to “Fig.12”.

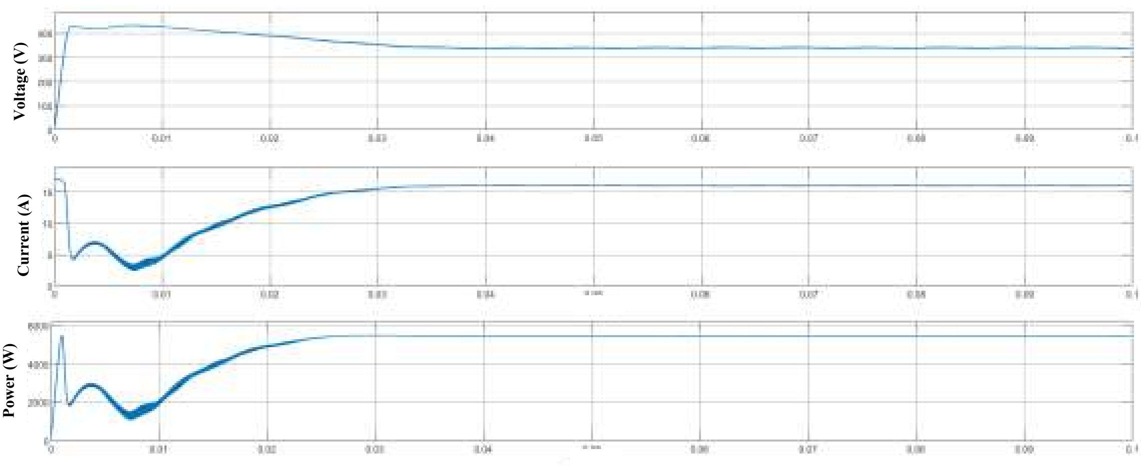

Figure.6. Electrical characteristics of the PV generator

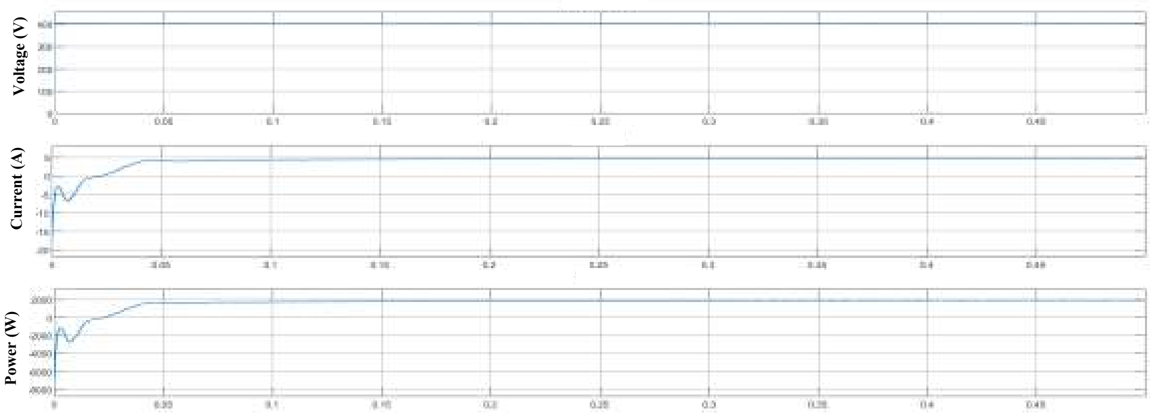

Figure.7. Electrical characteristics of the storage system

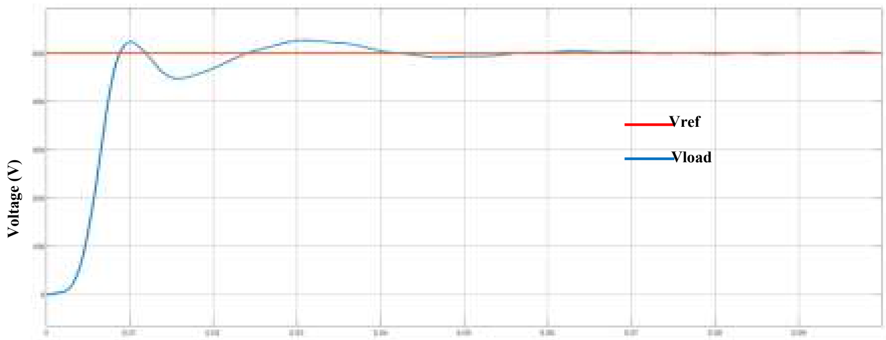

Figure.8. voltage regulation of the standalone PV system

If we have a variable loads fixed by the profile presented in Figure 9, the behavior of the system is expressed by the following results:

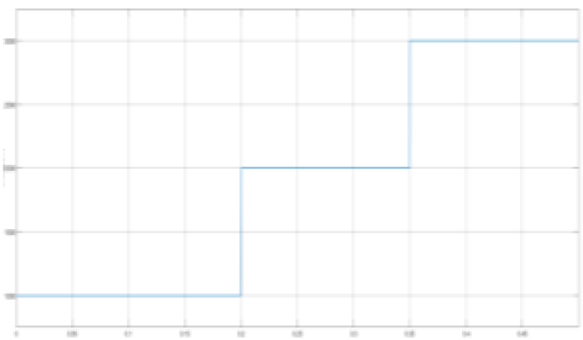

Figure 9. Load profile

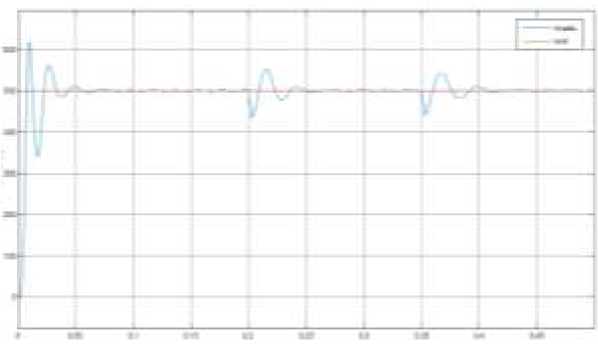

Figure 10. Voltage regulation of the standalone PV system

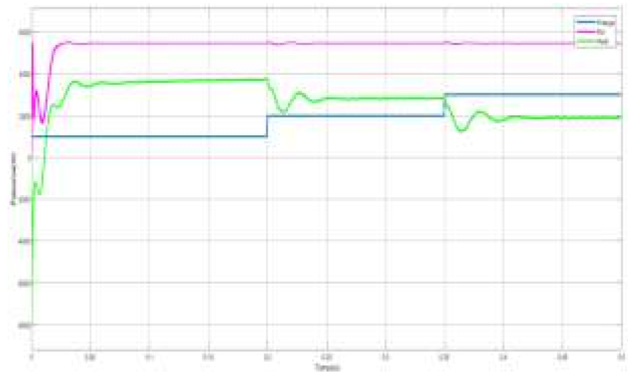
Figure 11. power exchange in the standalone PV system

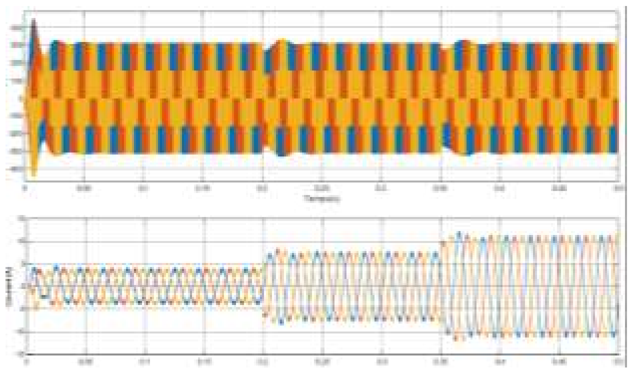
Figure 12. Variation of the load voltages and currents

The electrical characteristics of the PV generator are presented in Figure.6. In standards conditions, the adopted P&O MPPT algorithm follows the maximal point with very acceptable dynamic. In other hand, remarkable power oscillations can be observed in steady state due to the used technics. As presented in Figure.7. The storage system (batteries) absorbs the power surplus produced by PV generator (2kW), so the batteries are in charge mode. From Figure 8, it is clear to observe that, the real load voltage V_{load} follow the fixed values (V_{ref}=500V) with very high dynamic.

The voltage regulation exhibits a good performance to fast load variation, like presented in Figure 10, the real load voltage is correctly controlled to follow the reference despite the rigorous situations created at 0.2s and 0.35s. Also, the output simple voltage of the Z source inverter (Figure. 12) confirms the stability and the robustness of the control.

If the load power change from 1 kW to 2kW at 0.2s and from 2kW to 3kW at 0.35s as indicated in Figure 8. The load currents are similar to the classical inverter currents and change with the variation of the power (Figure. 12). In other hand, the P&O algorithm adopted follow exactly the maximum power point of the photovoltaic generator in various illumination conditions, so the totally power produced is transmitted to load and batteries. When the produced photovoltaic energy is higher than that demanded by electrical loads, more energy is stored in the batteries, in the contrary case; the battery intervenes (the batteries transmit energy to loads).

6. Conclusion

The paper presents a hybrid control of standalone PV system based on Z source inverter. The objective is to ensure a robust load voltage regulation and an efficient power management between source (PV), storage (batteries) and load. The MPPT technic and simple boost controls are simultaneously integrated to generate the shoot through states of the Z source inverter. Many simulation results obtained in several rigorous realistic conditions confirm the validity and reliability of the proposed control system.

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