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Voltage Control of Standalone Photovoltaic System

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Abstract- This paper presents a simple control of a standalone photovoltaic system with lead-acid batteries storage. The objective of this system is to supply prescribed active power to stand-alone loads with correctly wave signals (current and voltage) in different atmospheric conditions. This presented work focuses on the strategy, which makes it possible to ensure the necessary power for the loads. Simulation and experimental results illustrate the performances obtained.

Keywords- Photovoltaic panels, PVG, MPPT, battery, voltage control, stand-alone photovoltaic system

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, has been concerned with more and more attention [1,2].

PV 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 stand-alone mode, grid-connected mode, and mode transitions from stand-alone to grid, or vice versa in micro-grid systems [2,3].

By comparison with the already exist work on stand-alone photovoltaic system [4, 5, 6]. In this work we proposed a basic stand-alone photovoltaic station with two electronics converters and batteries storage system, this structure is controlled to tracking the maximum power point and to guarantee the necessary standards voltage of the load for all conditions; so the active and reactive power demanded by the load is transmitted in any operation time.

The system performance is evaluated (simulation and experimentation) in rigorous situation to prove the feasibility and the simplicity of this control. In this way, we can increase the power generation of photovoltaic system and reduce the power cost.

2. PVG Model and External Characteristic Simulation Results

Starting from the widely known photovoltaic cell electrical equivalent circuit [7] (Fig. 1), an equivalent model for a more powerful PVG made of an (N_s x N_p) array of PV cells, is established [8, 9]:

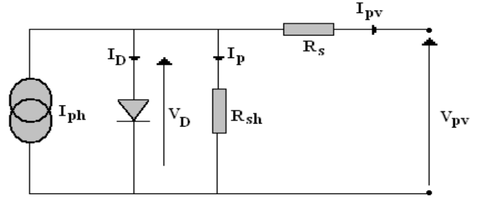

Fig. 1. Simple model of the photovoltaic cells

$$I_{pv} = I_{ph} - I_D - I_p \tag{1}$$

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

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

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 [8] [9]:

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

From equation 2, an already temperature dependence of the cell external characteristic is established. Furthermore, all the cell parameters (I_o, n, R_s and R_{sh}), are equally temperature related. However, semiconductor diode theory, suggests that the most significant temperature effect comes from the reverse saturation current I_o. Variation of its value I_o (T) with working temperature T, is usually evaluated relatively to its evaluated value I_o (T_r) at a reference temperature T_r [7].

$$\frac{I_o(T)}{I_o(T_r)} = (\frac{T}{T_r})^3 \exp[\frac{qE_g}{nK}(\frac{1}{T_r} - \frac{1}{T})] \qquad (4)$$

Where: Eg is the cell material band gap, supposed here no temperature dependant, and K is the Boltzmann constant. The value of saturation current Io (T_r), may be evaluated through the open circuit voltage V_{oc} (T_r) and the short circuit current I_{SC} (T_r) deduced from (2).

$$I_o(T_r) = \frac{I_{sc}(T_r)}{(e^{\frac{qV_{oc}(T_r)}{nkT}} - 1)} \qquad (5)$$

The equation of the illumination current brought back to the reference conditions (G_r = 1000W/m², T_r =25C°) is given as follows:

$$I_{ph} = [I_{cc}\frac{G}{G_r} + I_t(T - T_r)] \qquad (6)$$

I_t: Temperature coefficient of short-circuit current.
G_r: The reference illumination.
G: The actually illumination.

The precedents PVG model is implemented in environment Matlab/Simulink as indicated in the (Fig. 2).

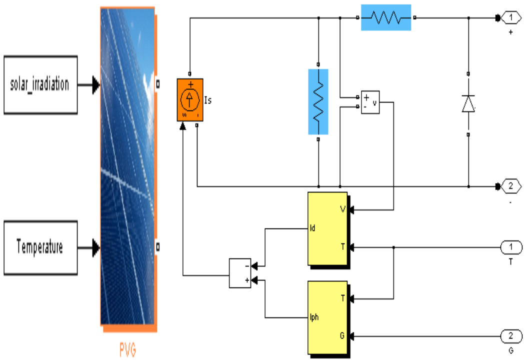

Fig. 2. Structure of the PVG Simulink model

The main external reference characteristics of the PVG are established using the identified perturbation inputs (solar illumination, temperature) as parameters (Fig. 4, 5).

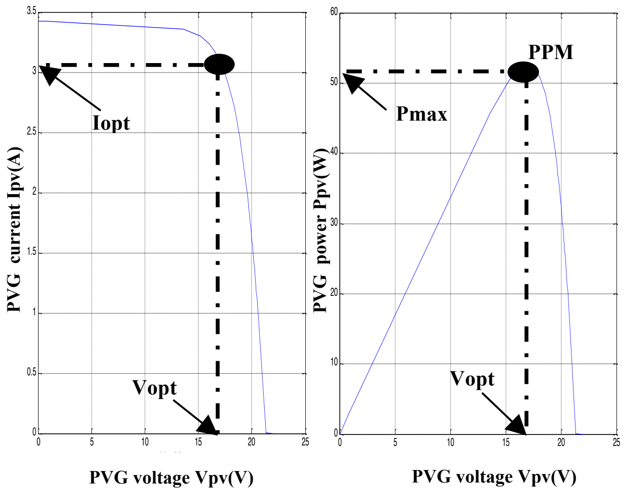

Fig. 3. PVG (current – voltage) and (power – voltage) characteristic for standards conditions

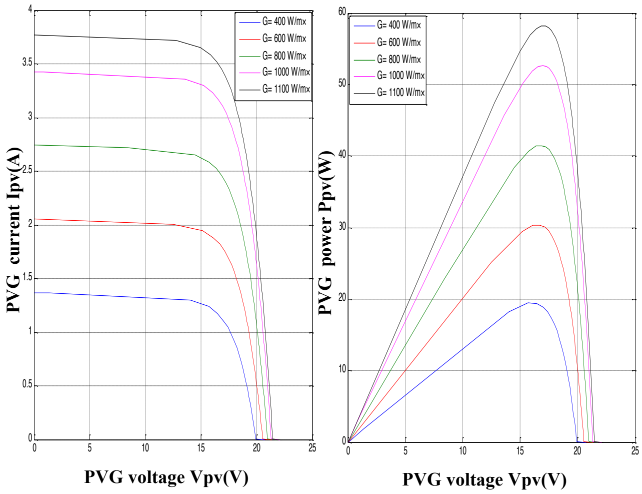

Fig. 4. PVG (current – voltage) and (power – voltage) characteristic for different solar illumination, T=25C°

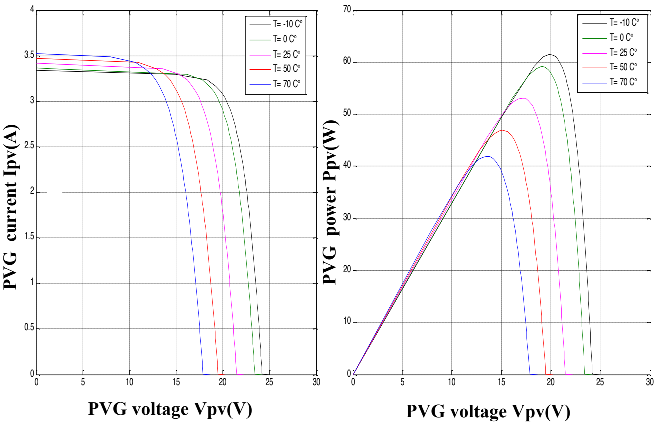

Fig. 5. PVG (current – voltage) and (power – voltage) characteristic for different temperature, G=1000W/m²

3. Storage System

One of the principal disadvantages of solar energy is its intermittent character. For a permanent use, it is thus necessary to store part of produced energy. There are several methods of storage: in water form, hydrogen, a supercondensator, or electrochemical battery [10], [11], [12]. The battery block (Fig.6) implements a generic dynamic model parameterized to represent most popular types of rechargeable batteries (Lead-Acid, Lithium-Ion, Nickel-Cadmium, and Nickel-Metal-Hydride) [13].

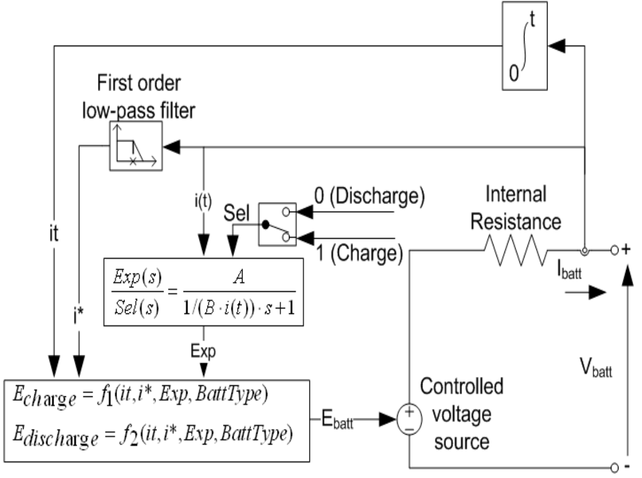

Fig. 6. Battery model [13]

The charge and discharge equations of the lead acid battery are given [11]:

Charge:

$$E_{batt} = E_o - R.i - K\frac{Q}{i_t - 0.1Q}i^* - K\frac{Q}{Q - i_t}i_t + Exp(t) \quad (7)$$

Discharge :

$$E_{batt} = E_o - R.i - K\frac{Q}{Q - i_t}(i_t + i^*) + Exp(t) \quad (8)$$

$$\dot{Exp}(t) = B.|i(t)|.(-Exp(t) + A.sel(t)) \quad (9)$$

Where :

Sel (t)= charge or discharge mode.
Exp(t)= exponentiel zone voltage (V).
E_{batt}= non lenear voltage (V).
V_{batt} = battery voltage (V).
E_0 = battery constant voltage (V).
K = polarization constant (V/Ah) or polarization resistance.
Q = battery capacity (Ah).
i_t = actual battery charge (Ah).
A = exponentiel zone amplitude (V).
B = exponential zone time constant inverse $(Ah)^{-1}$.
R = internal resistance (Ω).
i = battery current (A).
i^*= filtered current (A).

4. Topology of the Stand-Alone Photovoltaic System

The autonomous photovoltaic system consists of (Fig. 7):

1- Photovoltaic panels (Tab.1).
2- Means of storage: (batteries).
3- DC/DC converter.
4- DC/AC converter allowing to feed the alternative loads,
5- Transformer for increasing the alternative voltage.

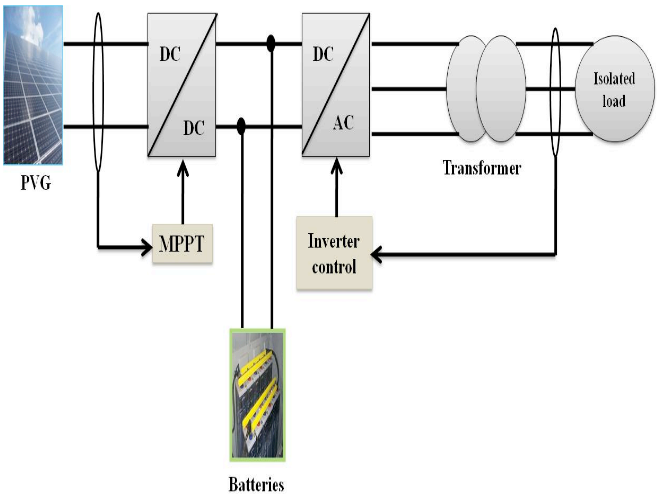

Fig. 7. Topology of the stand-alone photovoltaic system

The photovoltaic panels used in this work is a UDTS50 types (Fig. 8).

Fig. 8. UDTS50 photovoltaic panels

Table. 1. UDTS50 Panels charecteristic

Standard illumination G (W/m²)	1000
standard Temperature T (C°)	25
Short-circuit current I_{cc}(A)	3.43
Open circuit voltage V_{co}(V)	21.28
Optimal voltage V_{opt}(V)	16.65
Maximum power P_{max}(W)	52.66
Form Factor (%)	72
Output (%)	11
Series resistor R_s(Ω)	0.4
Cell surface S (cm²)	10*10
Number of the cell	36

The DC/DC converter is a boost chopper controlled to extract the maximum power from the photovoltaic panels for different values of illuminations and temperature.

The inverter is controlled to maintain the output voltage constant for any values of the load, in this reason a regulation of the rectified average voltage of the inverter is made.

The storage system consists of (lead-acid) electrochemical batteries (12V, 150Ah).

5. Control Strategy

The control system is composed of two parts, the control of the boost chopper and the three phase inverter.

Due to its nonlinear external current–voltage characteristic, the PVG maximum power output varies with its operating point. The latter being equally load related, this occurs even for a given solar irradiation and temperature. In this case only a unique load value may ensure the optimum operating point in terms of maximum power extraction from the PVG, which output voltage and current are then at their respective optimal values (V_{opt}, I_{opt}). Generally, all the inputs defining the optimum operating point of the PVG (Solar irradiation, temperature and load, shading being a particular situation), are imposed. However, it is known in power DC electrical circuits, that a switching DC-DC electronic power converter may be an efficient impedance adaptor tool. Hence, it may be used to adjust the equivalent load impedance to the needed value for PVG optimal operating point, whatever are the solar irradiance, temperature and eventually shading rate [7]. The MPPT algorithm used is a classical one and will not be detailed in this paper.

For the inverter, the control is achieved to have a constant alternating voltage for any values of the load; therefore a regulation of the rectified average voltage is necessary (Fig. 9).

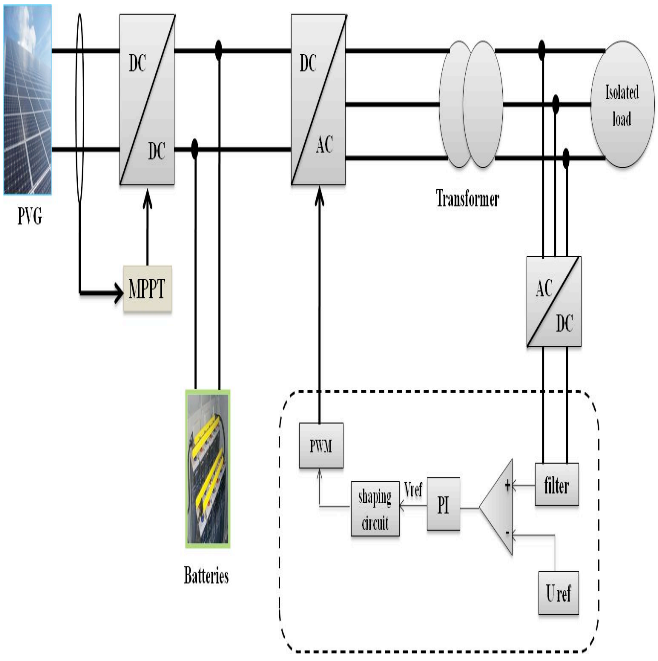

Fig. 9. Control circuit of the inverter

By using a three-phase rectifier with diode like a sensor of the continuous voltage at the boundaries load; the measured voltage will be compared with a reference continuous voltage corresponding to the standard nominal voltage necessary to feed the load. The result pass has through a PI regulator and a shaping circuit in order to have finally the reference voltage of the inverter.

6. Simulations results

During simulation we used 15 batteries (12V, 150Ah) in series, and an elevator transformer (Y/Y) (140/380V), commutation frequency (f=10 kHz), the simulation results obtained are exposed in (Fig. 10 to Fig. 15).

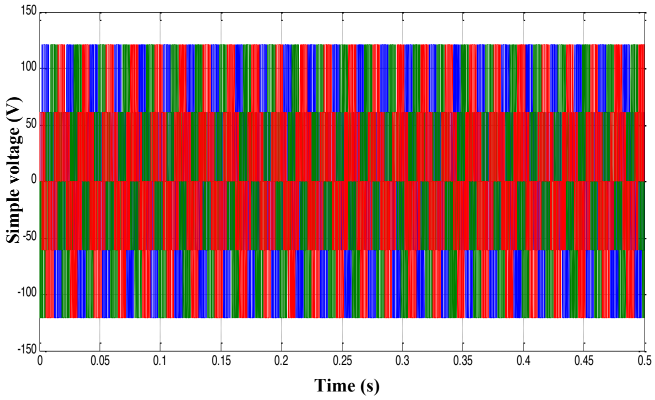

Fig. 10. The inverter simple voltage

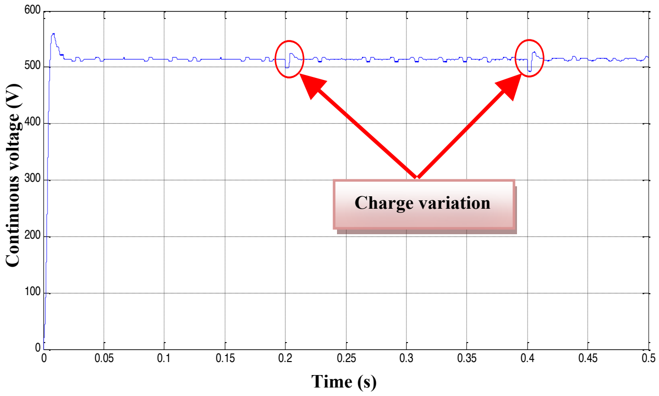

Fig. 11. Continuous voltage

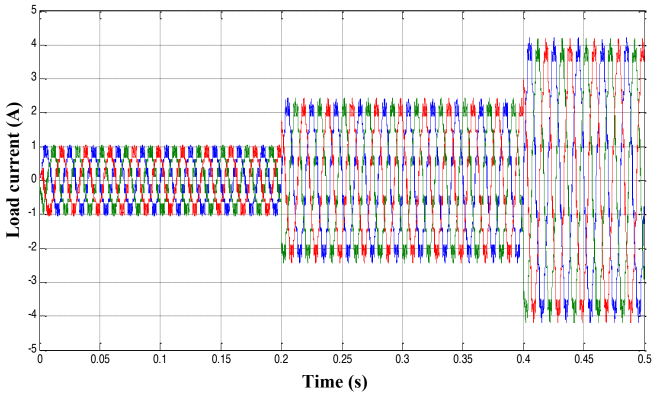

Fig. 12. Current variation for different load values

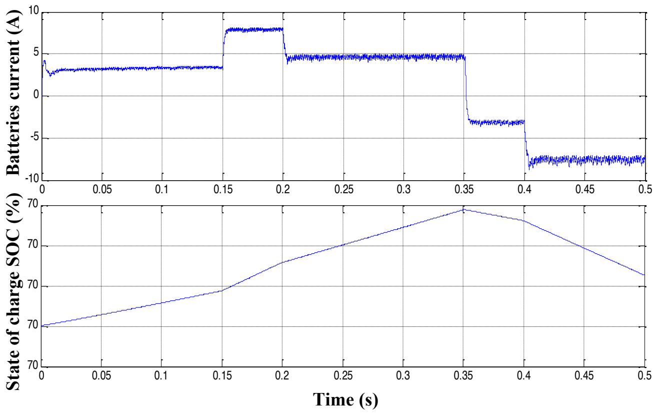

Fig. 13. Batteries current and state of charge SOC

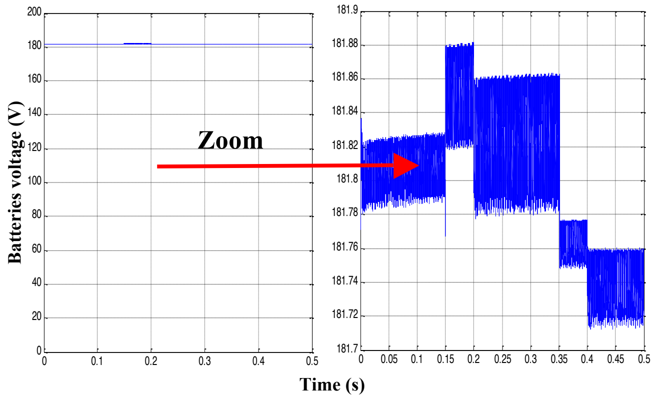

Fig. 14. Batteries voltage

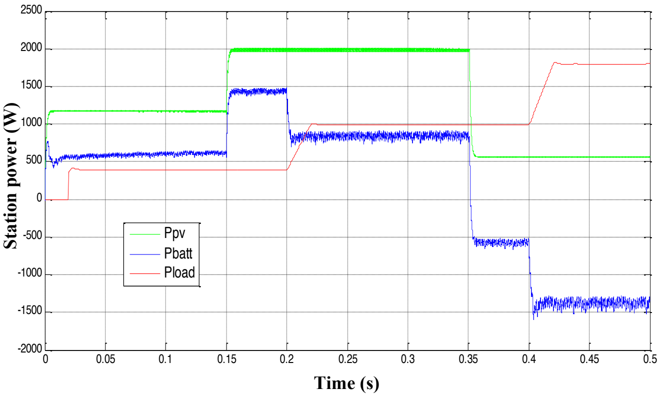

Fig. 15. Stand-alone photovoltaic power

During 0.2s and 0.4s, the currents are amplified because the loads power are increased, but the voltage delivered by the inverter remains constant, so for all load values the control device always keeps the U_{ref} value imposed (U_{ref} is selected according to the nominal voltage of load operation).

The battery load state follows the direction of the power exchange, if the current is positive, the load state increases and the battery charge, and conversely.

The storage system makes it possible to supplement the electric output required for the load in the moments when the photovoltaic power is not enough, which will make it possible in all time to ensure the installation service continuity.

To ensure the all real operation possibilities, a management system is necessary, because it is able to determine the period and the duration of each case in order to answer the objective of the application.

7. Experimental tests

To validate the simulations results obtained previously, we carried out the assembly of (Fig. 16). The control algorithm is implemented using the PCI6052E acquisition card.

The PCI-6052E is an acquisition card which belongs to the NI 6052E family of the national instruments firm; it can be directly connected to PCI bus of a computer. This card is compatible with MATLAB/SIMULINK tool environment, where it makes it possible to associate this Software environment that hardware (material), thus it enormously facilitates the control (a good simulation is enough) where one will gain over the programming time [14].

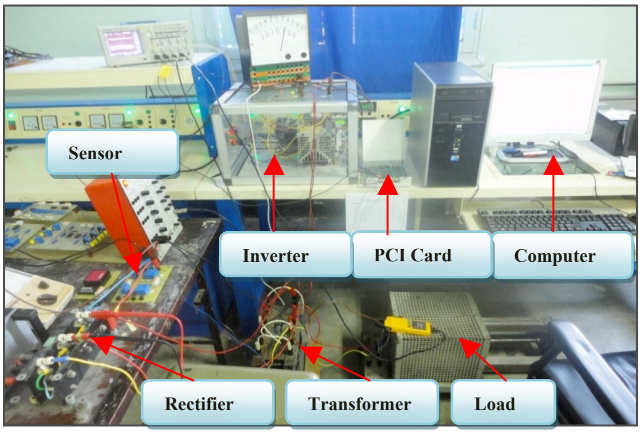

Fig. 16. Bench of the stand-alone photovoltaic system used

In experimental tests we will show the second part of the stand-alone installation which is the voltage control of the three-phase inverter with a variable load.

The simplified diagram of the installation carried out is shown in (Fig. 17).

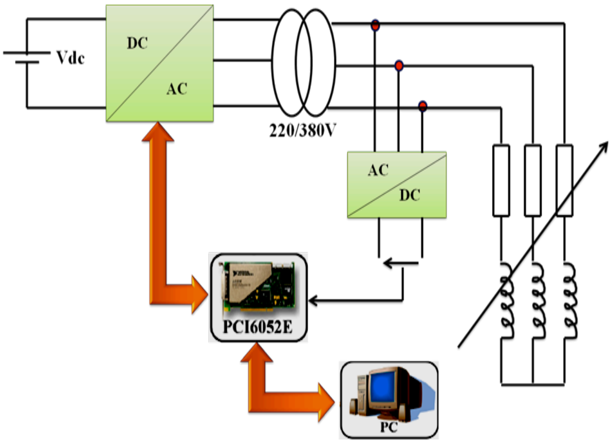

Fig. 17. Assembly used

The experimental results obtained are given in (Fig. 18 to Fig. 20) with:
V_{dc} = 120V, V_{ref} = 100V, F=2 kHz, load 4 kVA.
In these results we are using an insulation interface with:

- Attenuation composed voltage is 100.
- Attenuation continuous voltage V_c is 53.
- For the current (1A- 1V).

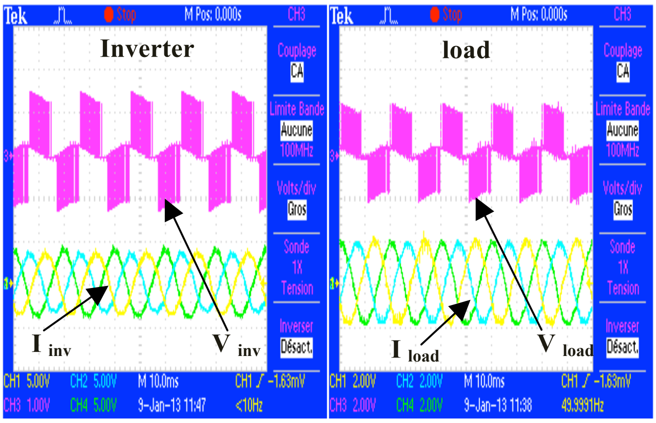

Fig. 18. voltages and currents variation

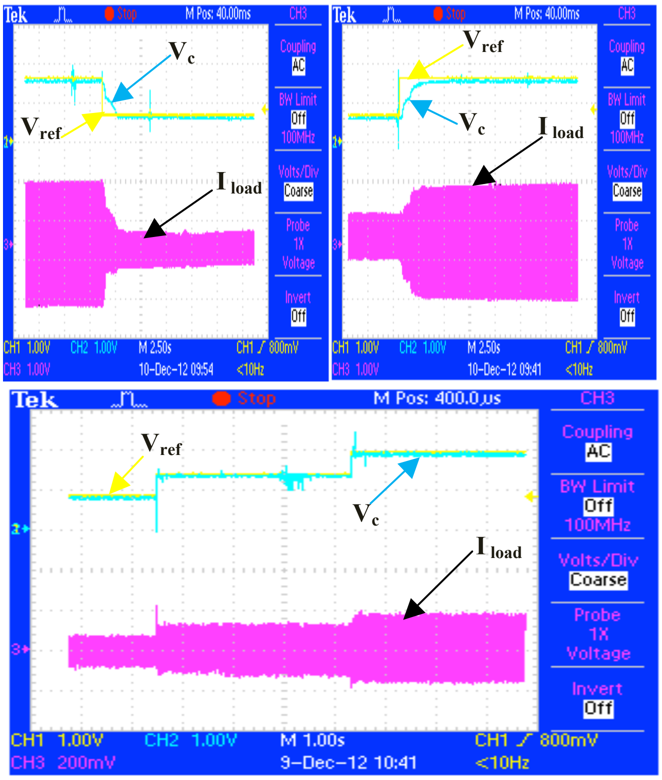

Fig. 19. reference voltage variation

When we apply a variable reference voltage to the control device, the load current follows the direction of this variation, and the continuous voltage V_c is controlled and will have the value of the reference voltage V_{ref}.

When we increase or decrease the load, the currents values change because it is the load which impose the current, but the inverter voltage value (in our case the rectified average voltage V_c) remains constant at the reference V_{ref}.

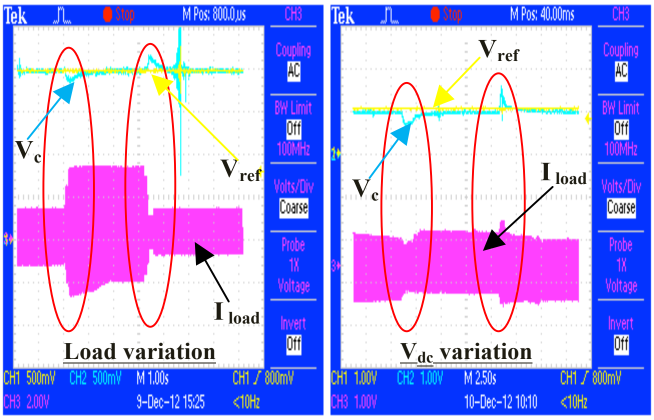

Fig. 20. Variation of the load and V_{dc} voltage

While we change the continuous voltage V_{dc} of the inverter (120V to 150V and 150V to 120V) (Fig. 20) the control always keeps the reference voltage with a small transition state in the variation moment.

8. Conclusion

In this paper, a simple control of a stand-alone photovoltaic station with lead-acid batteries storage has been presented in order to supply prescribed active power to stand-alone loads.

A specific voltage control algorithm used makes it possible to ensure the necessary photovoltaic power for the loads and guarantee a constant voltage inverter output for all load values.

The storage system makes it possible to supplement the electric output required by the load in the moments when the photovoltaic power is not sufficient, therefore the service continuity is ensured in all time.

The simulation and experimentation results obtained of this approach show and confirm the reliability and the simplicity of this type of control.

Concerning the future work in the field of standalone PV system, this study revealed that there is a need for:

- Addition of the over/under charging/discharging battery strategy protection in the control system.
- Management of the power flux in all component of standalone PV system.

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