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Simulation of a photovoltaic pumping system using the flux oriented control

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Abstract

The objective of this Work is to provide a vector control combined with an electric asynchronous motor. The configuration of this system includes a photovoltaic generator (PVG), a PV bus, a PV filter connected to a boost converter, a DC bus and a voltage inverter fed induction machine coupled to a centrifugal pump. To ensure operation at maximum power of PV system for various climatic conditions, the MPPT (Maximum power point tracking) control is used. At the end of control flow and total head of pumping station, the control strategy for flux vector oriented FOC (flux oriented control) served here as a solution. Simulation results show the effectiveness of different commands used in this system.

Key words: *Photovoltaic; MPPT; flux oriented control; asynchronous machine.*

1. Introduction

Since the widespread use of electricity, energy consumption has been increasing, the problem of conversion and energy storage has led to research and develop new sources of supply. PV pumping system usually consists of a PV generator, a power converter, motor and pump. The asynchronous machine occupies a very important industry and transport. It is valued for its strength, low purchase price and maintenance. The order is against more difficult than for other electrical machines [1]. It has not been immediately a boom since the regulations at the time, based on analogue components; the implementation of the order was difficult. We begin by modeling of the global system. Next, we explain the principle of FOC. Finally, simulation results based closed loop are presented to illustrate the validity and performance of the control study.

2. Modeling of the global system

The pumping system is the combination of a set of interconnected subsystems that are the PV array, the chopper adapter impedance (MPPT), the voltage inverter, the cage induction motor and centrifugal pump associated with a discharge line. Figure 1 the schematic block diagram of such a system.

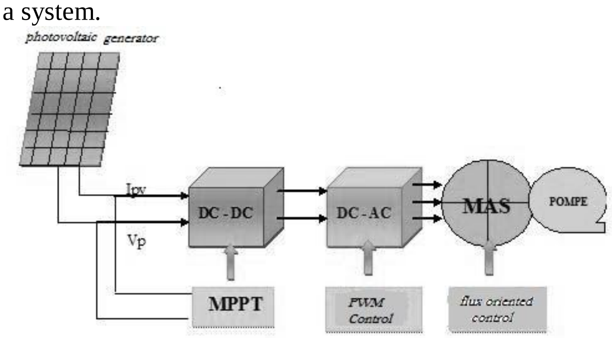

Figure.1 System overview.

2.1 Model of the Photovoltaic generator

The PVG has a current/voltage characteristic strongly nonlinear as a direct result of the behavior of semiconductor junctions that are the basis for its implementation. Studies conducted by specialists in various fields of application have led to the development of many models of generators. PVG is a made up of N_{bp} branches in parallel and each branch consists of modules in series with N_{ms} in turn N_{cs} cells in series [2].

The operation of this generator is modeled by the following approximate analytical expression:

$$I_p = N_{bp} \left[I_{ph} - I_s \left(e^{\frac{V_p}{V_T\, N_{cs} N_{ms}}} - 1 \right) \right] \quad (1)$$

$$I_{ph} = q\, g\, (L_n + L_p) \quad (2)$$

$$V_T = \frac{n\, K_B\, T}{q} \quad (3)$$

I_{ph}: Stock photo of a cell (A).
E: global solar irradiance (W/m2).
I_s: the saturation current of the diode (A).
V_T: thermodynamic potential of a cell (V).
I_p: Current supplied by the PVG (A).
L_n: electron diffusion length (m).
L_P: diffusion length of holes (m).
g: generation-recombination rate (m3/s).
Vp: the output voltage across the PVG (V).
n: ideality factor of the solar cell.

The PV array used in this system is the «Shell SP75» consists of eight modules, with their characteristics are listed in Tables II, II and III

2.2 Maximum power point tracking MPPT

Several MPPT algorithms have been proposed in the literature, including P&O (perturbation and observation), the method of load voltage, the method of short-circuit, the incremental conductance algorithm and the method of the network of artificial neural. The algorithm MPPT P&O is the most commonly used in commercial products PV [3]. P&O algorithm is detailed in Figure 2.

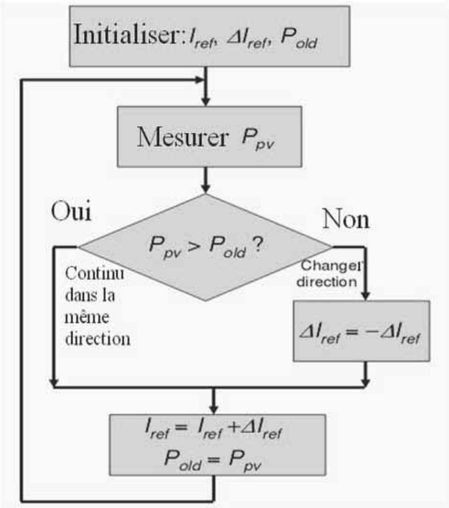

Figure.2 The P&O MPPT algorithm.

2.3 Model of the inverter

The three-phase inverter PWM (pulses with modulation) consists of three independent arms, each includes two switches. Each switch consists of a transistor (IGBT, MOSFET ...) and a diode connected in antiparallel. To avoid subjecting the output of the PVG to overvoltage from the inverter is inserted between the two capacitors [4].

The voltage across the capacitor is equal to Vp, the current ic is expressed as:

$$i_c = C \cdot \frac{d\, v_p}{dt} \qquad (4)$$

$$i_c = i_p - i_{eo} \qquad (5)$$

The relation which connects the input current and output current of the inverter is given by the following expression:

$$i_{eo} = i_a C_1 + i_b C_2 + i_c C_3 \qquad (6)$$

The switches of each arm of the inverter are complementary; it is the same for the associated control signals. We can write:

$$C_4 = 1 - C_1 \quad C_5 = 1 - C_2 \quad C_6 = 1 - C_3 \qquad (7)$$

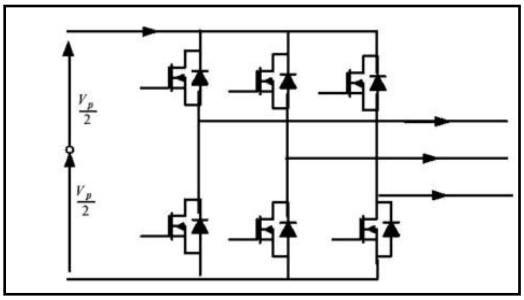

Figure.3 Voltage PWM Inverter.

3. Flux oriented control.

The principle of this control is to reduce the electromagnetic torque equation of the machine in order to be comparable to that of a DC machine.

The transient torque is expressed in the reference d, q as a cross product of currents or streams:

$$C_e = p\,\frac{M}{L_r}\,(\varphi_{dr} i_{qs} - \varphi_{qr} i_{ds}) \qquad (8)$$

We see that if one eliminates the second product (φ_{qr}, i_{ds}), while the couple looked very much like that of a DC machine. It is sufficient to do so, direct the d_q reference so as to cancel the component of flux in quadrature. That is to say, to choose the proper rotation angle Park so that the rotor flux is entirely focused on the direct axis (d) and therefore have $\varphi_{qr} = 0$. Thus $\varphi_r = \varphi_{qr}$ only (Figure 4).

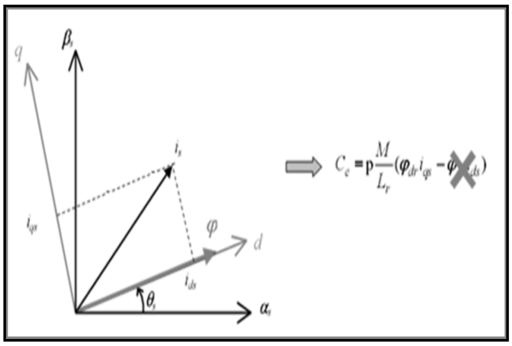

Figure.4 Principle of Vector Control.

The couple is then:

$$C_e = p\,\frac{M}{L_r}\,\varphi_r i_{qs} \qquad (9)$$

It should regulate the flow by acting on the component of the stator current ids and it regulates the torque acting on the component i_{qs}. Figure 3 summarizes this regulation because it shows a diagram of vector control of induction motor with speed control and regulation of the two currents ids and i_{qs}. We then have two action variables as in the case of DC machine. One strategy is to let the constant component ids. That is to say, to fix its reference so as to impose a nominal flux in the machine. The current controller handles i_{ds}* to maintain the current ids constant and equal to the reference

i_{ds}* (i_{ds} = i_{ds} Reference). If you want to speed up the machine, thus increasing its speed, it requires a reference current i_{qs}* positive. The current controller i_{qs} will impose the reference current to the machine [5]. The Figure 6 shows the Bloc of flux oriented control in SIMULINK.

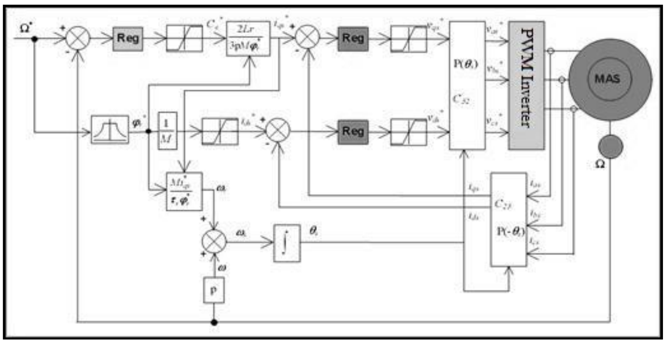

Figure.5 Speed control of induction motor in FOC.

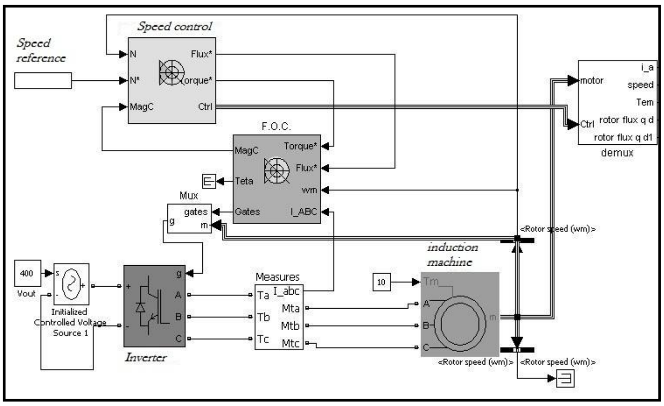

Figure.6 Bloc of flux oriented control in SIMULINK

4. Results

As part of this application, the choice of values has been fixed.

TABLE I. ELECTRICAL CHARACTERISTICS OF PVG (SHELL SP 75.) [6]

Electrical parameters of the panel in the STC: The **illumination** E = 1000W/m², the cell temperature T = 25°C.	
Maximum peak power, P_m.	**75 W**
Maximum voltage, V_m.	**17 V**
Maximum current I_m.	**4.4 A**
Open circuit voltage, V_{oc}.	**21.7 V**
Short-circuit current, I_{sc}.	**4.8 A**

TABLE II. INDUCTION MOTOR (3 HP DRIVE.)

Voltage	V = 220 V
Motor stator resistance	R_s = 0.01485 Ω
Motor rotor resistance	R_r = 0.00929 Ω
Self-inductance of a stator	L_s = 0.3027 mH
Self-inductance of rotor	L_r = 0.3027 mH
mutual inductances	L_m = 0.3027 mH
Number of pole pairs of the motor	p = 2

TABLE III. CHARACTERISTICS OF THE CENTRIFUGAL PUMP.

Performance of the pump at a speed of 2900 rev / min:
Maximum flow: Q_{max} = 30 m³ / h.
Maximum lift: H_r = 80 m.
Horsepower: P_m = 14 kW.

All simulations are performed in MATLAB/SIMULINK 7.10. The results are illustrated by the following figures:

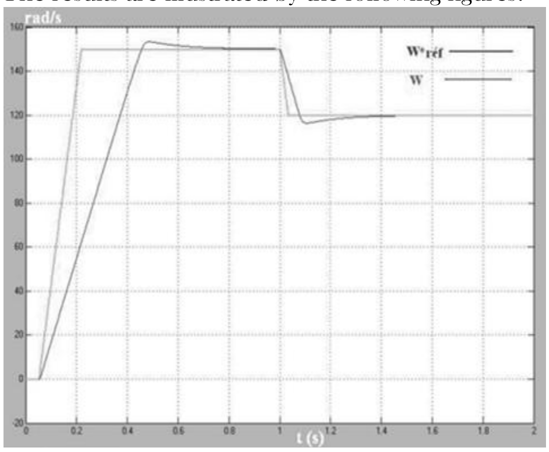

Figure.7 Rotor speed "ω" and its reference.

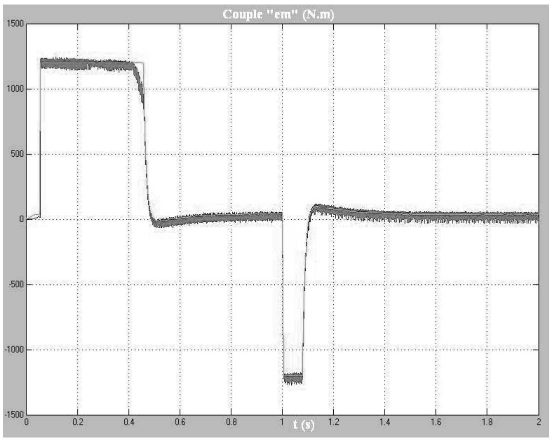

Figure.8 The electromagnetic torque and its reference.

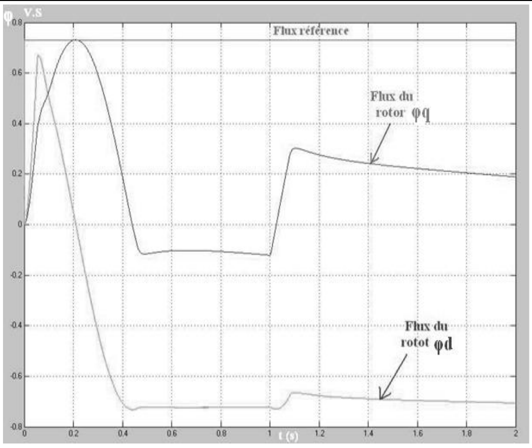

Figure.9 The quadratic and direct rotor flux.

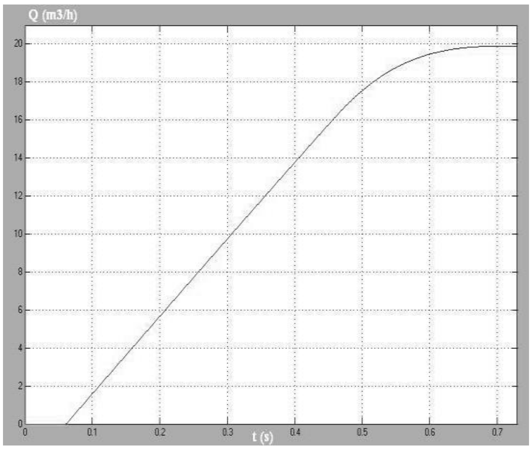

Figure.10 The pump flow Q (t).

In Figure 7, the speed of the machine follows its set point without overshoot showing the effectiveness of the control loop speed. This allows then to achieve the flow and total head desired. Figure 8 and 9 shows the appearance of the couple set superimposed on the torque simulated by the model of the machine and the mechanical speed, and the decoupling between the quadratic and the direct rotor flux, the rotor flux axis d and q along the same test, we see that the q-axis flux is very small as desired and the flow axis d is set, this is proof of decoupling of the axes of the rotor flux vector control with oriented. This result reveals the effectiveness of vector control in sudden changes in electromagnetic torque. At the last simulation of global system, the pump will reach a speed close to: 19m^3/h.

5. Conclusion

In this work, we studied and modelled the various components of a complex system, that of an asynchronous motor pump powered by PV generator through a chopper and an inverter. This paper shows that the model of the solar module, based on its equivalent circuit is nonlinear; in fact, it is based on the weather and its load. We chose to study the P&O algorithm to determine the source strength and its direction of variation. Since the model of the overall system is highly nonlinear, we used a robust control technique and more specifically FOC.

The simulation results showed that it is possible to adjust appropriately adapting MPPT, the stator currents and speed, regardless of the type proposed decoupling. The control strategy for flux vector oriented FOC served here as a solution to control the flow and head full of photovoltaic pumping station.

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