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Control of an Induction Machine Coupled in a Two Tanks System

Fares Sassi and Abdelkader Mami

Laboratory of Analyze, Conception and Control of Systems (LACCS), Team: Modelisation and Control of renewable Energies Systems, Faculty of Sciences of Tunis Campus El Manar, Tunis, Tunisia
Fares.Sassi.TN@ieee.org; mami.abdelkader@planet.tn

Abstract

This article proposes the study and simulation of an induction machine supplied with a photovoltaic generator to ensure the designed volume control of two coupled tanks. We propose a sliding mode control technique to make the speed and the flux of the induction machine robust to parameter variations and control the volume of water containing in the second tank. The results of simulations of all the chain of conversion, carried out under MATLAB/Simulink software, made it possible to evaluate the performances of the proposed system.

Keywords: *Sliding mode control, photovoltaic generator, coupled tanks, induction motor, MATLAB/Simulink*

1. Introduction

The use of solar energy is the subject of the current investigation. Solar panels are the basic element in every photovoltaic system. They are composed of interconnected photocells. Each cell converts the rays from the sun into electricity through the photovoltaic effect. Photovoltaic panels have a specific electrical characteristic which is given by the manufacturer in the form of curves. In general, these curves represent the evolution of current and power depending on the panel voltage [1].

In this paper, we start by presenting the induction machine model alimented by photovoltaic panel. After that, we develop a control algorithm with variable structure for the sliding mode control of speed independently of flow with limitation of the current with a further switching path. Secondly, we will focus on investigating the volume control in the coupled tanks [9].

This document is presented as following: In section 2, the model of process is presented. Section 3 is devoted to control system. To validate the proposed approach, different simulation results are presented in Section 4.

2. Process description

2.1. Induction motor

The induction motor is now widely rumored to its well known qualities. However, the control of this machine is against more difficult than for other electrical machines because of the lack of natural flows and decoupling torque. Modeling this machine is an essential step for the development of his control [6]. An induction machine can be represented by three identical to the stator windings.

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The equation of the machine is then written in the following form [3]:

$$[V_{s123}] = [R_s][I_{s123}] + \frac{d}{dt}[\Phi_{s123}]$$

$$[V_{r123}] = [R_r][I_{r123}] + \frac{d}{dt}[\Phi_{r123}] = 0$$

Noting that:

$$[\Phi_{r123}] = [\Phi_{r1} \quad \Phi_{r2} \quad \Phi_{r3}]^t$$
$$[I_{r123}] = [I_{r1} \quad I_{r2} \quad I_{r3}]^t$$
$$[V_{r123}] = [0 \quad 0 \quad 0]^t$$

$$[V_{s123}] = [V_{s1} \quad V_{s2} \quad V_{s3}]^t$$
$$[\Phi_{s123}] = [\Phi_{s1} \quad \Phi_{s2} \quad \Phi_{s3}]^t$$
$$[I_{s123}] = [I_{s1} \quad I_{s2} \quad I_{s3}]^t$$
$$[R_s] = diag(R_s)\ ;\ \ [R_r] = diag(R_r)$$

Hence:

$$[V_{sdq}] = [R_s][I_{sdq}] + \frac{d}{dt}[\Phi_{sdq}]$$

$$[V_{rdq}] = [R_s][I_{rdq}] + \frac{d}{dt}[\Phi_{rdq}] = 0$$

Where

$$[\Phi_{rdq}] = [\Phi_{rd} \quad \Phi_{rq}]^t$$

$$[I_{rdq}] = [I_{rd} \quad I_{rq}]^t$$

$$[V_{rdq}] = [0 \quad 0]^t$$

$$[V_{sdq}] = [V_{sd} \quad V_{sq}]^t$$
$$[\Phi_{sdq}] = [\Phi_{sd} \quad \Phi_{sq}]^t$$
$$[I_{sdq}] = [I_{sd} \quad I_{sq}]^t$$

$$\Phi_{ds} = L_s i_{ds} + L_m i_{dr} \qquad \Phi_{qs} = L_s i_{qs} + L_m i_{qr}$$

$$\Phi_{dr} = L_r i_{dr} + L_m i_{dr} \quad \Phi_{qr} = L_r i_{qr} + L_m i_{qr}$$

$$L_s = l_s + L_m$$
$$L_r = l_r + L_m$$

$$P[\theta_s]\frac{dP[\theta_s]}{dt} = \omega_s\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$P[\theta_s - \theta]\frac{dP[\theta_s - \theta]}{dt} = \omega_r\begin{pmatrix} 0 & -1 \\ 1 & 0 \end{pmatrix}$$

$$\omega_s = \frac{d\theta_s}{dt}$$

$$\omega_r = \omega_s - \omega = \frac{d(\theta_s - \theta)}{dt}$$

The park model leads to several expressions of the electromagnetic torque C_{em} we retain:

$$C_{em} = n_p \frac{L_m}{L_r}(i_{qs}\Phi_{dr} - i_{ds}\Phi_{qr})$$

2.2. Coupled tanks system

This process behaves two vertical tanks coupled by a flow canal, a manual valve used to change the canal section, in consequently, to change the flow characteristics between the reservoirs [8]. A level sensor is installed at the top of every reservoir. The relation between the speed of the IM Ω and the entry debit of the second reservoir q_2 :

$$q_2 = a_1.a_2.G_p.\Omega$$

The second reservoir can be filled from the first reservoir by the intermediary of the canal 1, while the debit of the second reservoir towards the first is assured by the canal 2. The equilibrated equation of the flow, for the first reservoir [9] is given by:

$$\dot{V}_1 = q_{21} - q_1$$

For the second reservoir:

$$\dot{V}_2 = q_2 - q_{21}$$

Such as:

$$q_1 = s_1.\sqrt{2gV_1}$$

$$q_{21} = s_2.a_0\sqrt{2g(V_2 - V_1)}$$

Finally, the model of coupled tanks is:

$$\begin{cases} \dot{V}_1 = s_2.a_0\sqrt{2g(V_2 - V_1)} - s_1.\sqrt{2gV_1} \\ \dot{V}_2 = a_1.a_2.G_p.\Omega - s_2.a_0\sqrt{2g(V_2 - V_1)} \\ y = k_s.V_2 \end{cases}$$

2.3. Photovoltaic panel

An ideal photovoltaic cell is presented as an electric current generator which behavior is equivalent to a current source shunted by a diode which expression is [1] [2]:

$$I = I_{pv,cell} - I_d$$

With: $I_d = I_{0,cell}[\exp(\frac{qV}{aKT}) - 1]$

Where:

- $I_{pv,cell}$: the current generated by the solar light, which is proportional to the irradiance (in A).
- I_d : the diode current, given by Shockley law (in A).
- $I_{0,cell}$: the leakage current of the diode (in A).
- q is the electron charge which is equal to $1,60217646.10^{-19}$ C .
- k is the Boltzmann constant, which is equal to $1,3806503.10^{-23}$ $J.K^{-1}$;
- T is the temperature of the PN junction (K).
- a is the ideality constant of the diode. Nearer the value is close to unity, the diode is considered ideal.

In the model "one diode" of a solar cell, the series resistance is due to the contribution of base resistances. The shunt resistance is the consequence of the surface along the periphery of the cell;

The current-voltage characteristic of an actual solar cell I-V is derived from the following equation:

$$I = I_{pv} - I_d - I_r$$

With:

$$I_r = \frac{V + R_s I}{R_p}$$

Where:

- I_{pv} is the photo-cell current, which is proportional to the illumination G.

- I_r is the leakage current through the shunt resistor.

$$I = I_{pv} - I_0[\exp(\frac{V + R_s I}{V_t a}) - 1] - \frac{V + R_s I}{R_p}$$

Where:

- R_s is the equivalent series resistance of the solar cell (in Ω).
- R_p is the equivalent parallel resistance (in Ω).
- $Vt = \frac{N_s.K.T}{q}$ is the thermal potential of the photovoltaic module for N_s cells connected in series.

The photovoltaic generator was developed in Matlab/Simulink, for a set of N_s*N_p photovoltaic module. N_s and N_p are respectively the number of photovoltaic modules in series and in parallel. Each module is packaged here by N_s photovoltaic cells assembled in series. In general, a module may include sets of cells connected in series or in parallel to increase the tension and intensity produced respectively. Note also that a solar panel may be constituted by a set of modules comprising a defined number of cells.

3. Control system

3.1. Sliding mode control current stator

The control law sliding mode must simultaneously satisfy the conditions of invariance and attractiveness. For this purpose, the switching function *S (y)* must satisfy [4] [5]:

-The invariance condition
$$\begin{cases} S(y) = 0 \\ \dot{S}(y) = 0 \end{cases}$$

- The attractiveness condition:

$$\begin{cases} \dot{S}_i(y) < 0 \rightarrow if \rightarrow S_i(y) > 0 \\ \dot{S}_i(y) > 0 \rightarrow if \rightarrow S_i(y) < 0 \end{cases} \rightarrow for(i = 0 \cdots m)$$

These conditions lead to determining a new vector control:

$$u^* = u_{eq} + u_{att}$$

The vector control comprises two terms [7]:

- The first is the control vector specifying the equivalent control for the system to stay on the sliding surface.

- The second is the vector control that ensures the attractive control system outside the sliding surface. It also requires the system dynamics starting from an initial point until it reaches the sliding surface.

The indirect control by sliding mode stator current vector of induction machine ensures the calculation of direct and inverse components of the reference voltage vector expressed in the *d*-*q* plane. Therefore, each component U_{ds}^* and U_{qs}^* is composed by two terms. The first term is the equivalent voltage vector that is active in steady state, while the second term is the voltage vector which is attractive assets in transition.

$$\begin{cases} U_{ds}^* = U_{dseq} + U_{dsatt} \\ U_{qs}^* = U_{qseq} + U_{qsatt} \end{cases}$$

For trajectories currents i_{ds} and i_{qs} remained on their sliding surfaces ($S_{ids} = 0$ and $S_{iqs} = 0$), we apply the voltage vectors U_{dseq} and U_{qseq} on the axis *d* and axis *q*. These vectors can be calculated taking into account the following invariance conditions:

$$\begin{cases} S_{ids} = (i_{ds}^* - i_{ds}) = 0 \\ \dot{S}_{ids} = 0 \end{cases} \quad and \quad \begin{cases} S_{iqs} = (i_{qs}^* - i_{qs}) = 0 \\ \dot{S}_{iqs} = 0 \end{cases}$$

From this attractive voltage vector system of reference voltage vector involves the switching function derivative $\dot{s}_{ids}$ and $\dot{s}_{iqs}$. A structure of attractiveness is chosen at a constant speed and proportional action, which gives:

$$\begin{cases} U_{dsatt} = Q_d \operatorname{sgn}(S_{ids}) + K_d S_{ids} \\ U_{qsatt} = Q_q \operatorname{sgn}(S_{iqs}) + K_q S_{iqs} \end{cases}$$

In summary:

$$\begin{cases} U_{ds}^* = L_s(\dot{i}_{ds} + \omega_s i_{ds} + Q_d \operatorname{sgn}(S_{ids}) + K_d S_{ids}) \\ U_{qs}^* = L_s(\dot{i}_{qs} + \omega_s i_{qs} + Q_q \operatorname{sgn}(S_{ids}) + K_q S_{iqs}) \end{cases}$$

3.2. Sliding mode control speed of induction motor

Addressing the same principle given by the preceding paragraph, we can construct the block allowing the control of the rotor speed [4]:

$$i^*_{qs} = i_{qseq} + i_{qsatt} = G_1\Omega^* + G_2 C_r + G_3(Q \operatorname{sgn}(S_\Omega) + K S_\Omega)$$

Where: G_1, G_2, G_3, Q and K are positive constant related to the asynchronous machine.

4. Simulations Results

The operation of the entire environment was simulated under MATLAB ®, Simulink ®. The speed and flux references are respectively: $X_{m0} = 2864.79$ rpm, $U_{r0} = 0.93$ Wb. The initial volume of water in the second tank is $V2 = 0.2$ m^3.

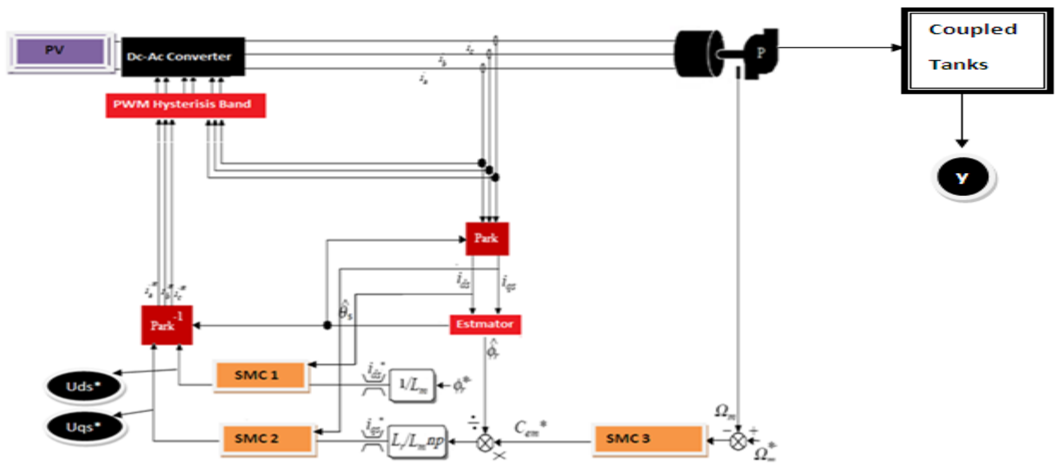

Figure 1. Block Diagram Control of an Induction Machine Coupled in a Two Tanks System

●The Asynchronous motor-pump is characterized by:

Numbers of poles: 2,
Nominal voltage: 230/400 V,
Nominal current: 1.6 A,
Nominal power output: 750 W,
Nominal frequency: 50 Hz,
Total moment of inertia J: 0.0015 kg m^2,
Constant of pump torque Kr: 2.772 kg m^2 rd^{-1}
Coefficient of friction F: 3.44 · 10^{-5} kg m^2 s^{-1},
Stator resistance R_s: 10.621 Ω,
Rotor resistance Rr: 7Ω,

●The photovoltaic panel is characterized by:
Total cell in series in a module: 72,
Resistance series: 2.7 Ω,
Shunt resistance: 1 M Ω,
Short circuit current: 1.2 A,
Open circuit voltage: 92 V,
Ideality factor: 630,
Number of Module in Series: 4,
Number of Module in parallel: 1,
Tr is the reference temperature = 298 K,
G is the PV module illumination: 1000W/m^2,

●The parameters of reservoirs:
Initial volume of water in both tanks: V1=V2=0.2 m^3
Section of pipe s_1, s_2: 7.9 10^{-3} m^2

Coefficients landfills a_0, a_1, a_2 =1
Gain pump G_p=500 $m^3.s^{-1}.v^{-1}$
Sensor gain k_s=24.5 $v.m^{-1}$
Gravitational constant g=9.8 $m.s^{-2}$

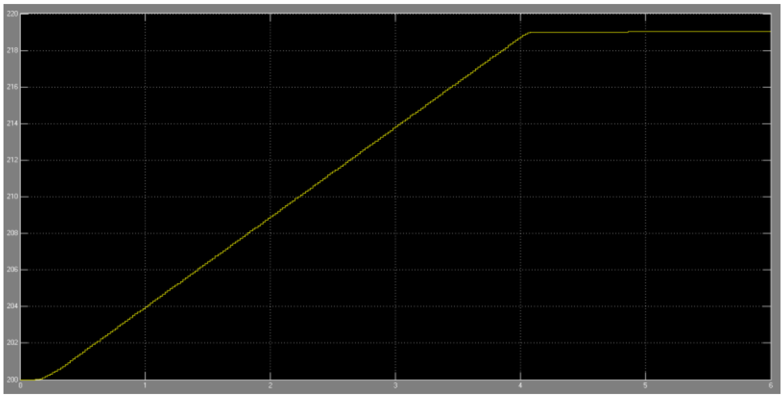

Figure 2. Simulation Response of Water Volume in the Second Tank

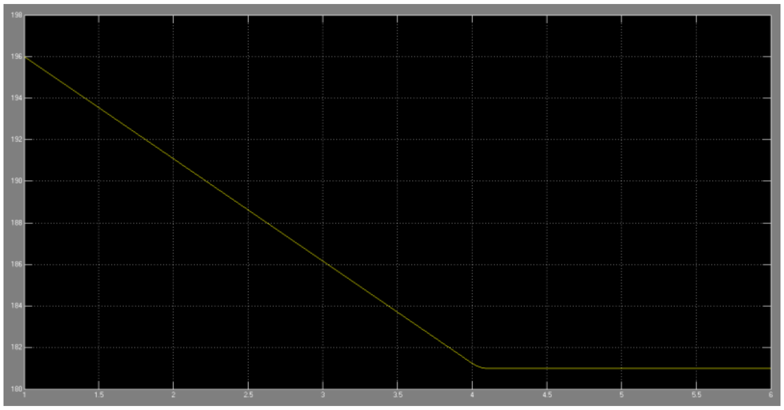

Figure 3. Simulation Response of Water Volume in the First Tank

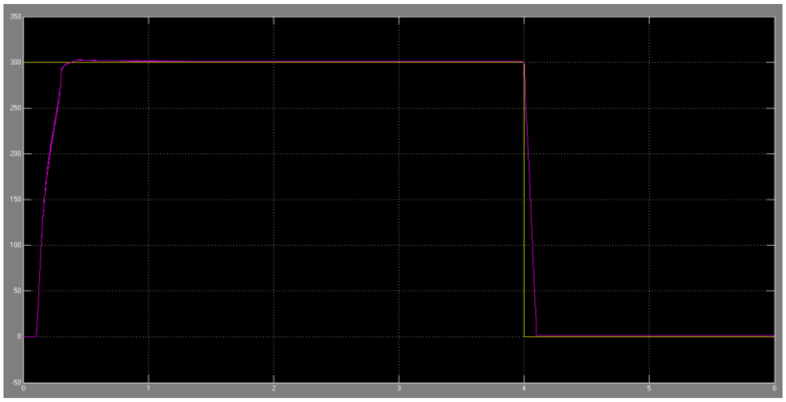

Figure 4. Simulation Response of Speed Induction Motor

5. Conclusion

In this document, we have developed an adjustment method with a variable structure. This method includes the sliding mode approach to control the speed of the induction machine which is coupled to photovoltaic panel. The control of two coupled tanks is ensured by the speed variation.

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Authors

Fares Sassi, was born in 1987 in Tunis, Tunisia. She received the diploma of master degrees in electronics in the Faculty of Sciences of Tunis in 2012. Actually, he is a PhD student in electronics in the Faculty of Sciences of Tunis, and he works on sliding mode control of a photovoltaic chain: Implementation on a FPGA, in the laboratory of analysis and control systems (ACS) at the National School of Engineering of Tunis (ENIT).

Abdelkader Mami, was born in Tunisia, he is a Professor in Faculty of Sciences of Tunis (FST). He was received his Dissertation H.D.R (Enabling To Direct of Research) from the University of Lille (France) 2003, he is a member of Advice Scientific in Faculty of Science of Tunis (Tunisia), he is a President of commutated thesis of electronics in the Faculty of sciences of Tunis, He is a person in charge for the research group of analyze and command systems in the ACS- laboratory in ENIT of Tunis and in many other fields.