Direct Torque Control (DTC) SVM Predictive of a PMSM Powered by a photovoltaic source

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ABSTRACT

This article is part of the study of the Predictive Vector PWM-based Couple Direct Control (DTC-SVM-predictive) of a permanent magnet synchronous motor (PMSM) powered by a photovoltaic (PV) source. The Direct Torque Control (DTC-SVM-Predictive) where the control of the switching frequency is well controlled and therefore the ripples are weakened at the torque and flux levels.

I. Introduction

In recent years, there has been a steady increase in demand for electrical power to meet industrial and daily requirements; one method is to find and develop new sources of energy called the renewable energies. Algeria has a considerable solar potential especially in Adrar, for this reason solar energy can be a very good solution for our study. In the field of variable speed, the permanent magnet synchronous machine currently provides a very large and ever-increasing market share due to its simplicity, robustness and low manufacturing cost. Despite all these advantages, his order remains one of the most complex; compared to that of the DC machine [1]. The quantities processed are in fact average quantities over the period of control of the inverter. These quantities are realized by the implementation of a pulse width modulation (PWM) method to provide the desired supply voltages, but the performances in this type of control converge towards the ideal case [2]; On the other hand, the control of the synchronous machine with permanent magnets shows a strong coupling between the flux and the electromagnetic torque. It is therefore interesting to find a way to make their independent control to improve their performance. The most suitable solution now is direct torque control. The basic principle of the direct torque control (DTC) is characterized by the direct choice of the stator voltage vectors according to the differences between the references of the torque and the stator flux and their real values. Current controllers followed by a PWM comparator are not used in DTC control systems; and the parameters of the machine are not used also except for the stator resistance of the motor [3].

The DTC has a major disadvantage is the lack of control of the harmonics of torque and flux due to the variable frequency. To find a constant frequency and minimize the ripple of torque and flux, a direct predictive torque control (predictive DTC-SVM) based on the replacement of the hysteresis comparators (calculates the torque error) has been implemented. By PI regulators and the selection table (used in classical DTC) by pulse width modulation (vector PWM) [1]. The purpose of this paper is to improve the torque and flow of a PMSM using the DTC-SVM-Predict command.

II. Solar Energy

The photovoltaic effect is a process of transforming the energy emitted by the sun, in the form of photons, into electrical energy using a semiconductor component called a solar cell. The photovoltaic effect used in solar cells makes it possible to directly convert the light energy of solar rays into electricity through the production and transport in a semiconductor material of positive and negative electrical charges under the effect of light. This material comprises two parts, one having an excess of electrons and the other a deficiency of electrons, respectively called n-type doped and p-type doped. When the first is brought into contact with the second, the electrons in excess in the material 'n' diffuse into the material 'p'.

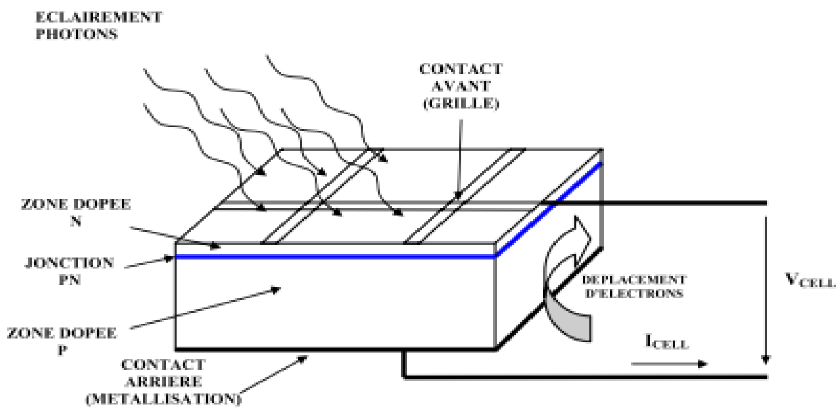

Figure 1. Description of a photocell or photovoltaic cell

II.1 Modelling Solar Cell

In the ideal case, the cell of a PN junction subjected to photovoltaic illumination connected to a load can be schematized by a current generator I_{ph} in parallel with a diode delivering a current according to Figure 2, which represents the equivalent circuit of a 'an ideal solar cell.

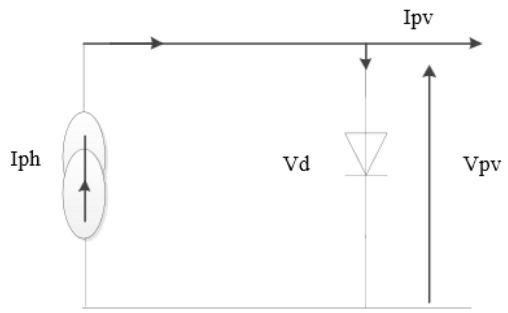

Figure 2. Equivalent diagram of an ideal cell.

The equation of an ideal solar cell is in the form:

$$I = I_{Ph} - I_D \qquad (1)$$

$$I_D = I_0\left(e^{\frac{V_D}{V_t}} - 1\right) \qquad (2)$$

I_0: reverse saturation current of the diode; V_t: thermal tension (V_t = NKT / q);
N: factor of ideality of the solar cell; K: constant of Boltzmann ($1.38.10^{-23}$J / K);
q: charge of the electron ($1.6.10^{-19}$C).

The equivalent diagram of the real photovoltaic cell takes into account parasitic resistive effects due to manufacture and shown in Figure 3This equivalent diagram consists of a diode (d) characterizing the junction, a current source (I_{ph}) characterizing the photo-current, a series resistor (Rs) representing the losses by Joule effect, and a shunt resistor (R_{sh}) characterizing a leakage current between the upper gate and the rear contact which is generally much greater than (Rs).

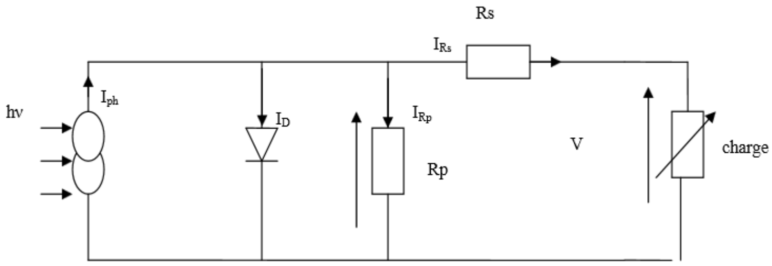

Figure 3. Equivalent electrical diagram of a PV cell

The current delivered by the cell is the algebraic sum of three currents:

$$I = I_{ph} - I_D - I_{RP} \qquad (3)$$

Iph: current picture independent of V (or of Rs), it is proportional to the incident flux (generation rate - recombination) and to the diffusion lengths of the carriers:

$$I_{ph} = qg(L_n + L_p) \qquad (4)$$

IRP: Rp through current, if Rp is very large, it becomes very weak is independent of the voltage:

$$I_{RP} = \frac{V_D}{R_P} \qquad (5)$$

Because: $V_D = R_P I_{RP} = V + R_S I$

I_D: diode current, it is of the same order of magnitude as I_{RP} for low voltages and it becomes very large approximately V_{CO}, it written in the form:

$$I_D = I_0\left(e^{\frac{qV_D}{AKT}} - 1\right) \qquad (6)$$

Replace (3) in equations (5), (6), the characteristic equation becomes:

$$I = I_{ph} - I_0\left[e^{\frac{q}{AKT}(V + R_S I)} - 1\right] - \frac{V + R_S I}{R_P} \qquad (7)$$

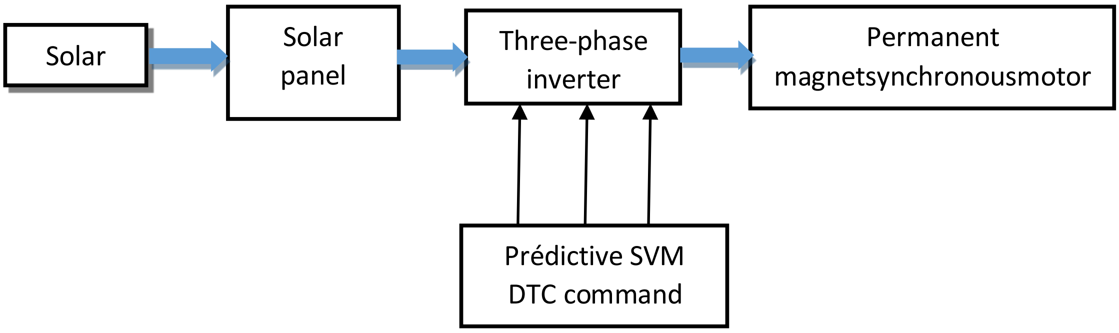

Figure 4. Structure of the studied system

A: ideality factor of the cell that depends on the recombination mechanisms in the area space charge. For cells currently marketed with silicon: A = 1.

II.2 Model of the PMSM

The permanent magnet synchronous motor (PMSM) is conventionally modeled in the (α, β) frame, giving rise to the following equation:

$$\begin{cases} Vs\alpha = R_s . I_{s\alpha} + L_s \dfrac{d\, I_{s\alpha}}{dt} - \omega . \phi_f .\sin\theta \\ Vs\beta = R_s . I_{s\beta} + L_s \dfrac{d\, I_{s\beta}}{dt} + \omega . \phi_f .\cos\theta \\ J \dfrac{d\omega}{dt} = \phi_f .P.\sin\theta . I_{s\alpha} + \phi_f .P.\cos\theta . I_{s\beta} - f\omega - C_r \\ \dfrac{d\theta}{dt} = \omega \end{cases} \quad (8)$$

With:

R_s : The stator resistance; L_s : The inductance of the stator; ϕ_f : The flux generated by the magnet; θ : Electric angle ω : The speed of rotation of the machine (rotor).

III. Direct Control of Torque PMSM

The direct torque control of a permanent magnet synchronous machine based on the determination of the control sequence applied to the switches of a voltage inverter. This choice based on the use of hysteresis regulators whose function is to control the state of the system namely here the amplitude of the stator flow and the electromagnetic torque. A voltage inverter achieves seven distinct positions in the phase plane, corresponding to the eight sequences of the voltage vector at the output of the inverter. This strategy has the major disadvantage of the lack of control of the switching frequency of the inverter. For improvement, this method uses direct predictive torque control (predictive DTC-SVM)

III.1 Control Predictive DTC-SVM

The strategy of the DTC-SVM command with a predictive controller uses a vectorial PWM with a fixed and constant switching frequency. This fixed frequency DTC no longer has hysteresis correctors, this considerably relaxes the computation time constraints. In addition, this methodology relies on an explicit calculation of the control to satisfy the objective of torque, so the oscillations of it are considerably reduced. This is a strategy for generating a stator reference voltage that should be applied to the MSAP and which will be introduced into a PWM block. The block diagram of the predictive (DTC-SVM) command of a PMSM powered by a voltage inverter from a PV source is shown in Figure 5 and 6 [4].

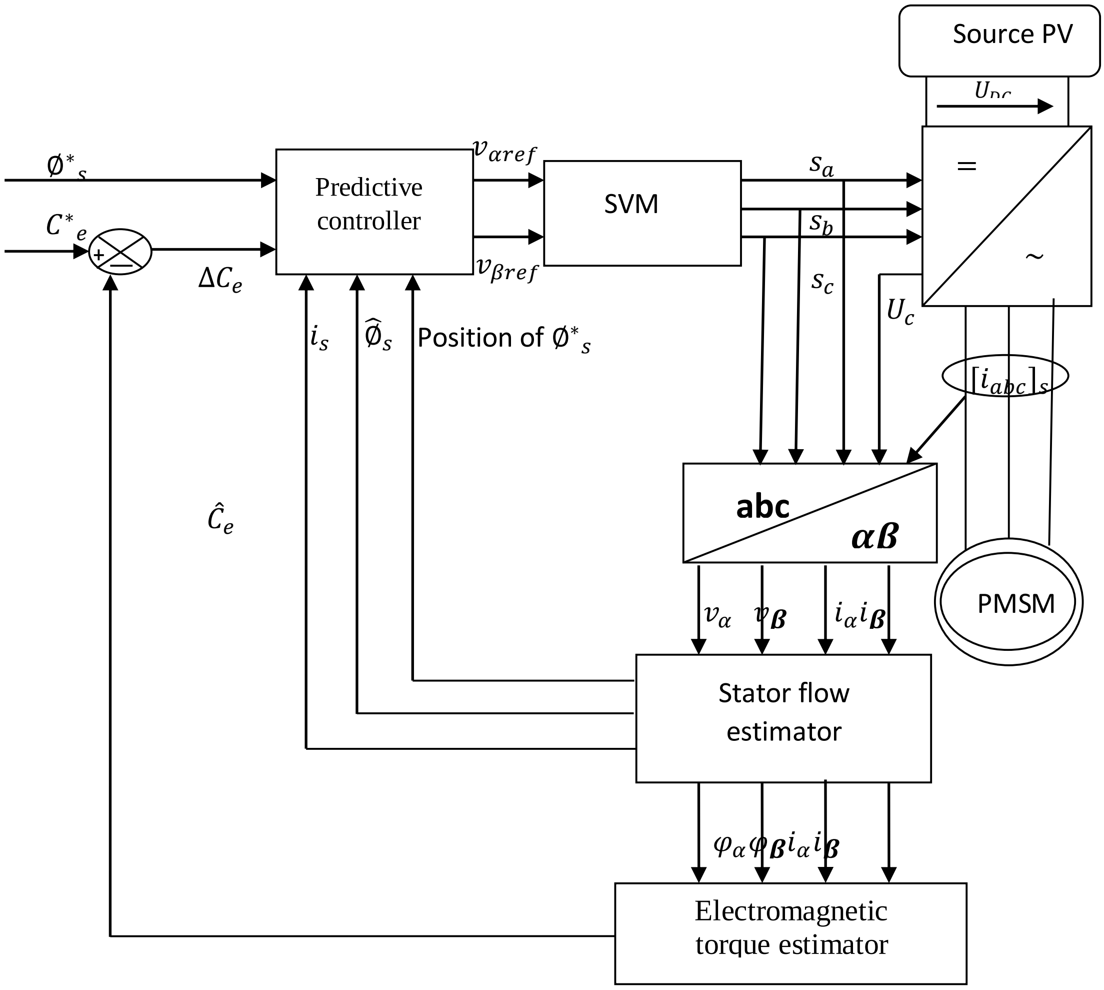

Figure 5. Predictive DTC-SVM command schema of PMSM

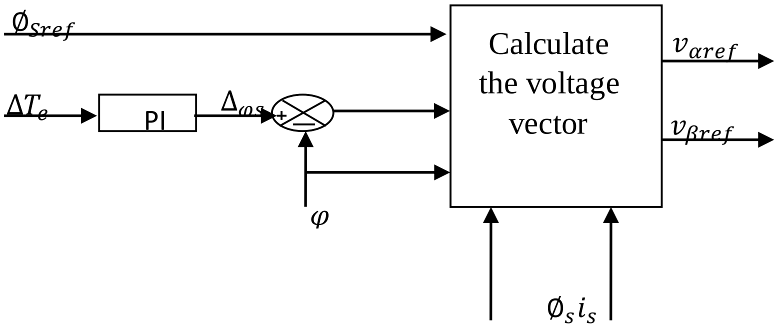

Figure 6. Predictive Controller

The relationship between the torque pulses

$$\frac{\Delta\Gamma_e}{\Gamma_{eref}} = K_Ø \left|\frac{\Delta Ø_s}{Ø_{sref}}\right| + K_\varphi \Delta Ø_s \qquad (9)$$

Where, Γ_{eref} is the reference torque, $\Delta\emptyset_s$ and $\Delta\varphi$ are the deviations from $|\emptyset_s|$ and φ which are defined by:

$$\Delta\emptyset_s = |\emptyset_{sref}| - |\emptyset_s| \quad (10)$$

$$\Delta\varphi = \angle\emptyset_{sref} - \angle\emptyset_s \quad (11)$$

Or K_φ and $K_\emptyset$ are constants derived from the PMSM specifications.

As a result, the torque ripple can be attenuated if $\Delta\varphi$ is kept close to zero. For DTC-SVM control, the generation of the control pulses (S_a, S_b, S_c) applied to the inverter switchesis generally based on the use of a predictive controller, which receives information about the error of the controller. $\Delta\Gamma_e = (\Gamma_{e-ref} - \Gamma_e)$

The reference stator flux amplitude $\emptyset_{ref}$, the amplitude and the position of the estimated stator flux vector and the current value to be measured.

Next, the predictive controller determines the control reference stator voltage vector in the polar coordinates $V_s = [V_{sref}\ \Delta\varphi]$. The equation shows that the relationship between the torque error and the increment of the angle $\Delta\varphi$ is linear.

Therefore, a predictive PI that generates the changing load angle to minimize the instantaneous error between the reference and the actual torque, from the predictive torque controller and stator flow structure, is shown in Figure.6. , we see that the torque error $\Delta\Gamma_e$, and the stator reference flow, are delivered to the predictive controller which gives the deviation of the stator flux angle $\Delta\varphi$ [5].

IV. Simulation and Interpretation

In these simulation results we have DTC-predictive control of an inverter powered PMSM to a photovoltaic source.We found that the speed responds without overshoot at the start and during the inversion of direction of rotation (t = 0.25) with a response time t = 0.025, when applying a load of 5N.ma (t = 0.4) the speed makes a disturbance but the PI regulator caught up with the reference. At the start the electromagnetic torque reaches its maximum value (17Nm) and this stabilized has a value practically zero with an oscillation of 0.8Nm The stator flux immediately reaches its reference value of 0.12 Wb with a slight ripple of 0.006 Wb amplitude around the reference value and a response time t = 0.007. We also observed an almost sinusoidal shape when the charge is applied at (t = 0.4) for the stator current.

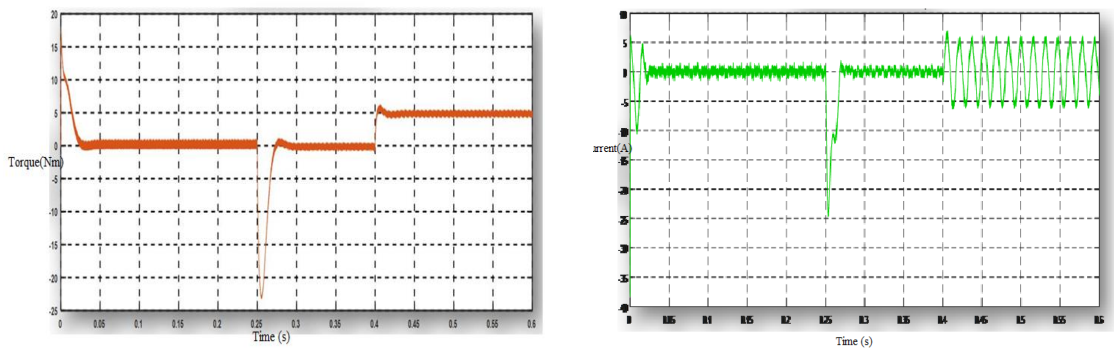

Figure 7: The variation as a function of time [s]: (a) of the current [A]; (b) of the torque [Nm]

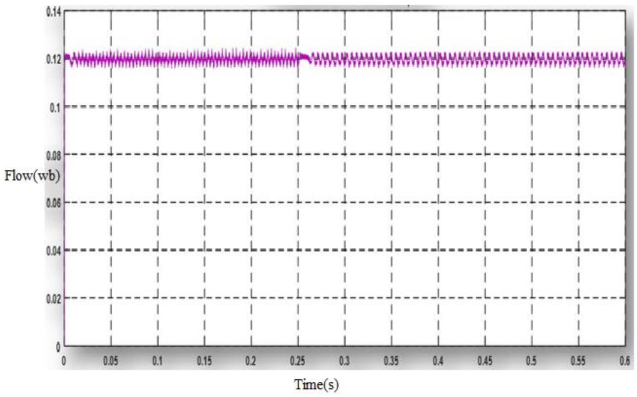

Figure 8: The variation of the flow [webs] as a function of time [s]

V. Conclusion

The work presented in this paper focuses on the study of direct torque control (predictive DTC-SVM) of the permanent magnet synchronous machine; indeed, this strategy based on the direct determination of control sequence applied to the inverter.

This control is less sensitive to the variation of the machine parameters and does not require mechanical sensors that are fragile. We concluded that the predictive SVM DTC control is to minimize ripple at the torque and flux, with a high switching frequency.

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