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Dual Star Induction Motor Supplied with Double Photovoltaic Panels Based on Fuzzy Logic Type-2

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Abstract: Production of electrical energy is carried out mainly from fossil fuels and nuclear fuel. The excessive consumption of these energies during the 20th century has led to an aggravated pollution of the atmosphere. Since this form of energy covers most of the current energy production, it is necessary to find alternative solutions. The constraint is therefore to have an economical and sustainable source of energy, since environmental protection has also become a very important point. Several studies have been carried out in the field of renewable energies, such as photovoltaic energy, it has gained a lot of attention in recent years because it is environmentally friendly and sustainable compared to traditional energy sources. We can consider also the direct torque control (DTC) as an alternative to conventional methods of control by pulse width modulation (PWM) and by field oriented control (FOC), the direct torque control (DTC) found by Takahashi offers high performance in terms of simplicity in control and fast electromagnetic torque response. With dominant characteristics, the direct torque control for AC electric motor drive supplied by a solar energy is alternative in industrial applications. This paper discusses and presents the application of direct torque control (DTC) in open and closed loop, using voltage source inverter to control motor torque and flux with maximum power point tracking in weather conditions and load variation.

The P&O MPPT algorithm is mostly used, due to its ease of implementation, however, this MPPT algorithm gives us more torque ripples mainly with load variation. To resolve this problem, we will propose in this paper a fuzzy logic type-2 technique to replace the first one (P&O).

Keywords: *DTC; DSIM; Photovoltaic (PV) array; MPPT; DC/DC converter; P&O; FLC type-2.*

Mathematics Subject Classification (2010): 03B52, 93C42, 94D05.

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1 Introduction

At present, photovoltaic (PV) cell arrays are a promising source of renewable energy since solar energy is free, abundant and readily available in many locations [1]. It is durable, clean and environmentally friendly. Solar energy is an attractive alternative solution to the energy of fossil fuels. Photovoltaic energy develops very quickly. It is multidisciplinary in nature, involving mechanics, power electronics, control theory, and other fields.

In order to control the electrical power delivered by PV panel, various methods are used: the action on the physicochemical properties of the cells, the action on the mechanical trackers for automatic orientation of the solar panels, and the action on the interface power electronics that connects the PV generator with its load. This last action is commonly called the electrical control of PV systems. It consists in the development of topologies of static converters and the development of MPPT (Maximum Power Point Tracking) control algorithms for the best capture of maximum power. Several studies have dealt with the problem of finding the operating point to draw the maximum energy from the PV modules using different MPPT methods. However, the non-linearity of the characteristic of the PV modules, their dependence on temperature, sunlight and the level of degradation of the characteristic make the implementation of these methods very complex. In the case of variations in weather conditions, these methods also exhibit poor convergence or oscillation around the optimum power point under normal operating conditions. If the transfer of power between the renewable energy sources and the load is not optimal, the overall efficiency of the system will be greatly affected. The research is going on to make these methods more effective.

The perturbation and observation (P & O) and incontinence (IncCond) techniques are widely used in the literature, but they fail under a rapid variation of weather conditions. This is why many researchers have made changes to these algorithms to improve their performance. Kook Soon et al. proposed an improvement of the IncCond algorithm to attenuate inaccurate responses during abrupt changes in the level of sunlight. There are also other techniques such as the method based on short-circuit current measurement, the method based on open-circuit voltage measurement, the method based on artificial neural networks and the method based on fuzzy logic [2–5].

Among the techniques mentioned above, the MPPT method based on fuzzy logic type-2 is presented in this paper. The application of this method allows to adapt the load to the PV modules and to follow the PPM whatever the variations of the meteorological conditions. In recent years, the field of the AC machines application is significantly expanded with the development of power electronics, the Microelectronics and computer engineering. Indeed, technological developments have allowed alternative machines, especially the double stator machine DSM, to acquire the control flexibility and dynamic performance naturally obtained. Since the late 1920s, stator machines with two three-phase windings were introduced to increase the power of synchronous generators of high-power. Multi-phase machines have subsequently been a growing interest, especially the dual star induction machine (DSIM), which has many advantages compare to asynchronous machines. Indeed, multiphase drives have several advantages over conventional three-phase machine, such as power segmentation, minimizing torque ripples and rotor losses, reduction of harmonic currents, high reliability and high power etc. Multi-phase machines are used much more in high power applications. Among these applications there are pumps, fans, compressors, compressor mills, cement mill. It uses a power electronics devices which allow a higher commutation frequency if compared to the simple three phases machines. Usually, high performance motor drive systems used in robotics, rolling mills, machine tools etc. require fast and accurate speed response, quick recovery of speed from any disturbance and uncertainties [6]. The introductions of new control such as DTC are very promising. In PV systems, they achieve great performance, fast responses and less fluctuations in steady state, for rapid irradiance and/or temperature variation improving the amount of energy effectively extracted from PV generator [7], the first idea of direct torque control was developed in 1986. This method of controlling that has progressed during past decade, provides a fast torque response and also it is robust against machine parameter variations [8–10].

In this paper, we study and discuss the application of Fuzzy logic type-2 for DTC-DSIM which is supplied with photovoltaic energy.

2 PV Module

A practical PV array consists of a collection of solar cells connected in series and/or parallel. An equivalent circuit model for a solar cell is shown in Fig. 1. The model consists of a current source, a diode, a shunt resistor R_P and a series resistance R_S.

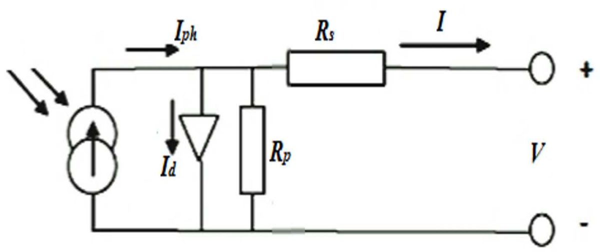

Figure 1: PV cell model.

The topology of boost converter is shown in Fig. 2. For this converter, the output voltage is always higher than the input PV voltage. Power flow is controlled by the on/off duty cycle of the switching transistor.

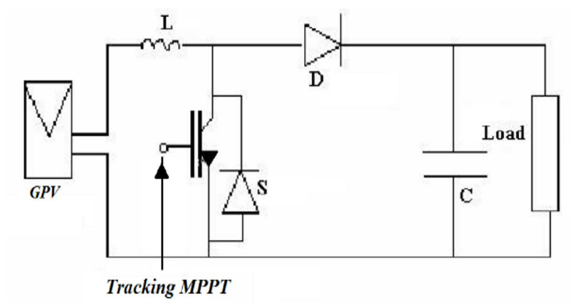

Figure 2: Boost converter DC/DC.

For sizing a photovoltaic system, we have to specify first the motor consumption in order to define the energy need for the load. Second we must take into account the obtained results and also the meteorological data as the input parameters of the photovoltaic installation of the input program. The sizing of the photovoltaic system is carried out according to the algorithm [11].

3 MPPT Control

To optimize the power provided by the generator, a static converter which operates as an adapter must be added as cited below. It exploits the MPPT technique, there are many algorithms that are used to control the MPPT, classical as P and O or artificial intelligent technique as ANN.

The commercialized solar modules are formed generally by a number of cells assembled in parallel N_P or /and in series N_S. In addition, a data sheet is provided and includes the following main information about the product presented in Table 1. 12 panels are assembled in series and parallel to generate a DC voltage range in a MPP operation under different load changes.

The nominal open-circuit voltage	42.1V
The nominal short-circuit current	3.87A
The voltage at the MPP	33.7V
The maximum experimental peak output power	120W
The current at the MPP	3.56A
Parallel resistance Rs	0.473Ω
Serie resistance Rp	1367Ω

Table 1: Data sheet information on a PV panel BP MSX120.

The algorithms that are most commonly used are the perturbation and observation method (P&O), the dynamic approach method and the incremental conductance algorithm. The P&O method is used because of its simplicity [11]. The Perturbation and observation (P&O) method has a simple feedback structure and fewer measured parameters. The P&O method is the most widely applied method in PV industry. It is based on the idea of introducing perturbation to the operating voltage and observing whether the power increases or decreases [12].

However, when we use this method on the panel related to the DTC-DSIM we face a problem to couple the inverter and the boost chopper, which appears in high torque ripples (Fig. 8) to resolve this problem, we propose in this paper to replace P&O by fuzzy logic type-2 approach (Fig. 3).

4 MPPT With Fuzzy Logic Type-2

Fuzzy logic is an approach for easy and flexible modeling of complex systems whose modeling is difficult and in some cases impossible by mathematics or classic modeling methods [10, 13–15].

In this section, we will replace the most algorithms of P&O (used to get the maximum of power provided by the PVG), by fuzzy logic type-2. The Fig. 4 presents the structure

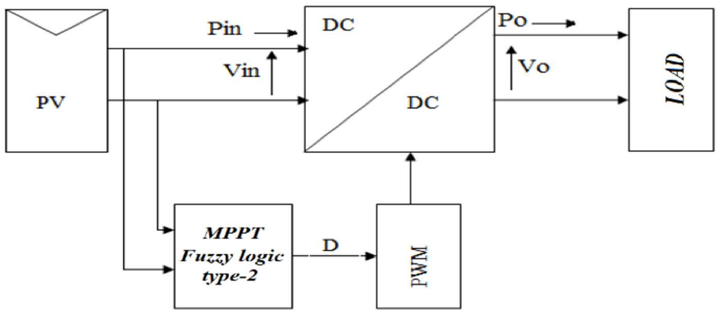

Figure 3: Boost converter DC/DC using MPPT-FL2.

of fuzzy logic type-2.

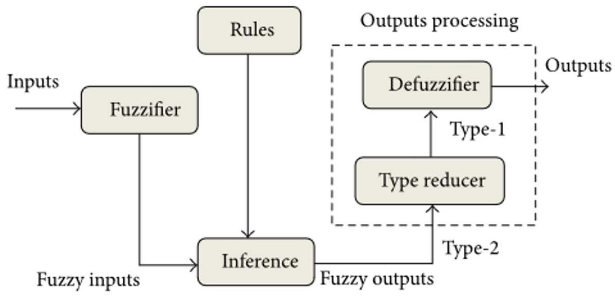

Figure 4: Structure of type-2 fuzzy logic system.

Fuzzy controller contains the five Gaussian membership function forms. The FL2 membership function has lower and upper bounds, their rules are almost similar to those for the conventional type-1.

The Reduction type used in this paper is centroid. The input and the output present respectively the power error and the duty cycle of the switching transistor.

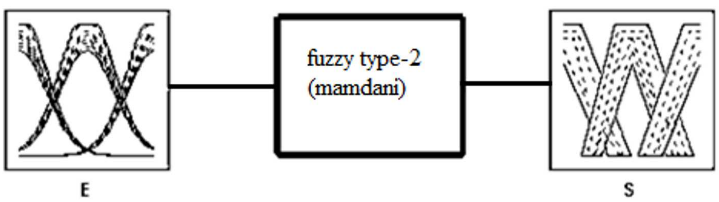

Figure 5: Fuzzy logic-2 MPPT.

5 Dual-Star Induction Motor

The most used example of multi-phase motors is the dual-star induction motor. In the conventional configuration, the double stator induction machine needs a double three-phase supply; the two stars share the same stator and are shifted by an electrical angle α(in this work $\alpha = 30^o$) and a rotor is either wound or a squirrel cage. To simplify the study, we consider the electrical circuits of the rotor as equivalent to a three-phase short-circuit winding.

The position of the winding axes of the nine phases constituting the machine is shown in Fig. 6. There are six phases for the stator and three phases for the rotor. The six-stator phases are divided into two wyes-connected three phase sets labeled A_{S1}, B_{S1}, C_{S1}, and A_{S2}, B_{S2}, C_{S2}, The windings of each three phase set are uniformly distributed with their axes spaced by $2\pi/3$ in the space. The three phase rotor windings A_r, B_r, C_r are also sinusoidal distributed and have axes that are displaced apart by $2\pi/3$ [17].

The following assumptions are made [18]:

- Motor windings are sinusoidal distributed.
- The two stars have same parameters.
- Symmetrical construction machine.
- The magnetic saturation, the mutual leakage inductances and the core losses are negligible.
- Resistances of the windings do not vary with the temperature and neglect the effect of skin (skin effect).
- Flux path is linear.

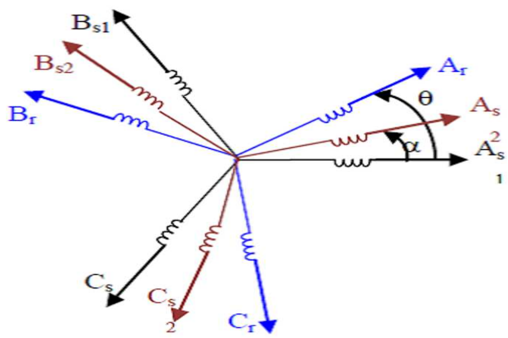

Figure 6: Windings of the six phase induction machine [18].

The equations for the stator are calculated in the reference frame related to the rotor.

$$\begin{aligned}
\frac{d\varphi_{sd1}}{dt} &= V_{sd1} - R_{s1}I_{sd1} + \omega_s\varphi_{sq1},\\
\frac{d\varphi_{sq1}}{dt} &= V_{sq1} - R_{s1}I_{sq1} - \omega_s\varphi_{sd1},\\
\frac{d\varphi_{sd2}}{dt} &= V_{sd2} - R_{s2}I_{sd2} + \omega_s\varphi_{sq2},\\
\frac{d\varphi_{sq2}}{dt} &= V_{sq2} - R_{s2}I_{sq2} - \omega_s\varphi_{sd2},\\
\frac{d\varphi_{rd}}{dt} &= V_{rd} - R_rI_{rd} + (\omega_s - \omega_r)\varphi_{rq},\\
\frac{d\varphi_{rq}}{dt} &= V_{rq} - R_rI_{rq} + (\omega_s - \omega_r)\varphi_{rd},
\end{aligned} \tag{1}$$

where the expressions for the stator and rotor flux are:

$$\begin{aligned}
\varphi_{sd1} &= L_{s1}I_{sd1} + L_m(I_{sd1} + I_{sd2} + I_{rd}),\\
\varphi_{sq1} &= L_{s1}I_{sq1} + L_m(I_{sq1} + I_{sq2} + I_{rq}),\\
\varphi_{sd2} &= L_{s2}I_{sd2} + L_m(I_{sd1} + I_{sd2} + I_{rd}),\\
\varphi_{sq2} &= L_{s2}I_{sq2} + L_m(I_{sq1} + I_{sq2} + I_{rq}),\\
\varphi_{rd} &= L_rI_{rd} + L_m(I_{sd1} + I_{sd2} + I_{rd}),\\
\varphi_{rq} &= L_rI_{rq} + L_m(I_{sq1} + I_{sq2} + I_{rq}).
\end{aligned} \tag{2}$$

The electromagnetic torque is obtained by:

$$T_e = \frac{PL_m}{L_r+L_m}[(\varphi_{rd}(I_{sq1} + I_{sq2}) - \varphi_{rq}(I_{sq1} + I_{sq2})]. \tag{3}$$

6 Direct Torque Control (DTC)

With the development of power electronics components, numerous studies of AC drive control have been proposed.One of most known, presents the vector control, which was in latest years the most important field research and most suitable to industrial requirements; however, this structure suffers from some drawbacks because it need establishment of a mechanical sensor and it is very sensitive to parameter variations.To resolve these problems,a new technique called control DTC (the Direct Torque Control) has been applied as an alternative.

The basic idea of DTC focuses on the flux orientation, using the instantaneous values of voltage vector. An inverter provides eight voltage vectors, among which two are zeros [19]. These vectors are chosen from a switching table according to the flux and torque errors as well as the stator flux vector position. In this technique, we do not need a modulator and a mechanical sensor to ensure feedback of speed or position [18].

To determine the electromagnetic state of the motor in order to determine the control of the inverter switches, a suitable model of the machine must be available. From the measurements of the DC voltage at the input of the inverter and of the stator currents, the model gives at each moment:

- actual stator flux of the machine,
- the real torque that it develops,
- its rotor speed.

Measurement of the rotor speed is not necessary, which is a great advantage of these methods. Which is independent of the rotor machine parameters, it provides a faster torque response and it has a simpler configuration. The structure of the DTC-DSIM fed by double PV panel is shown in Fig 7, the basic idea of DTC control is to choose the best stator voltage vector, which is taken from a switching table according to the stator flux vector position, the flux and torque errors. During this rotation, the amplitude of the flux rests in a pre-defined band [20], [21]. In this technique, we do not need the rotor position in order to choose the voltage vector. This particularity defines the DTC as an adapted control technique of AC machines and is inherently a motion sensor-less control method [19].

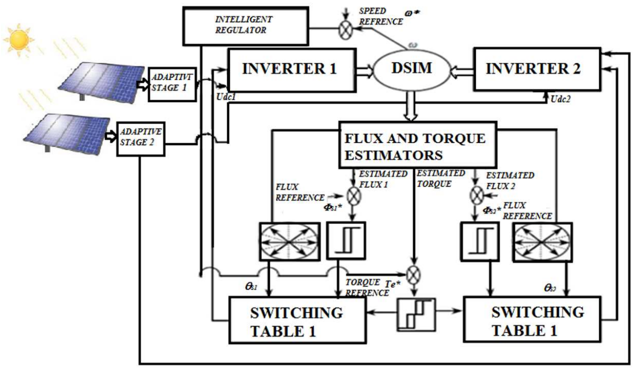

Figure 7: Schematic diagram of DTC-DSIM supplied by double PVG.

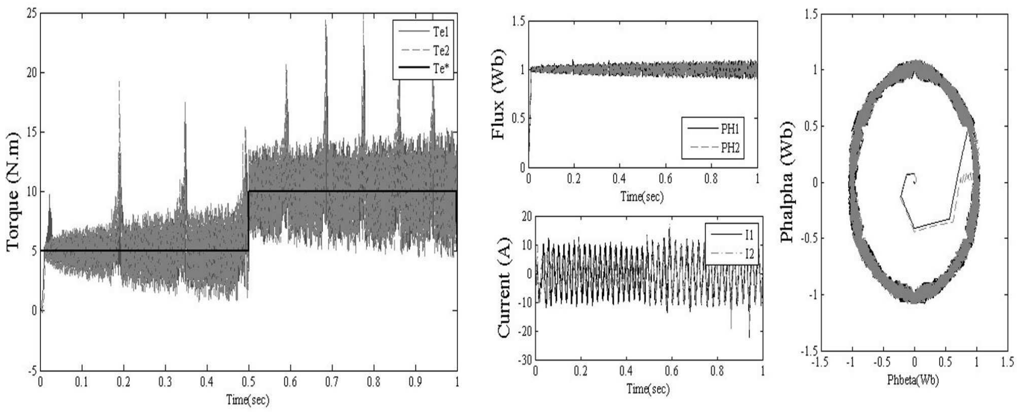

Figure 8: Torque, flux and current responses using DTC-DSIM in open loop with P&O method and load variation (G=1000W/m ^{2}, T=298K).

The stator flux vector can be estimated using the measured current and voltage vectors [20]:

$$\frac{d\varphi_s}{dt} = V_s - R_s I_s \quad (4)$$

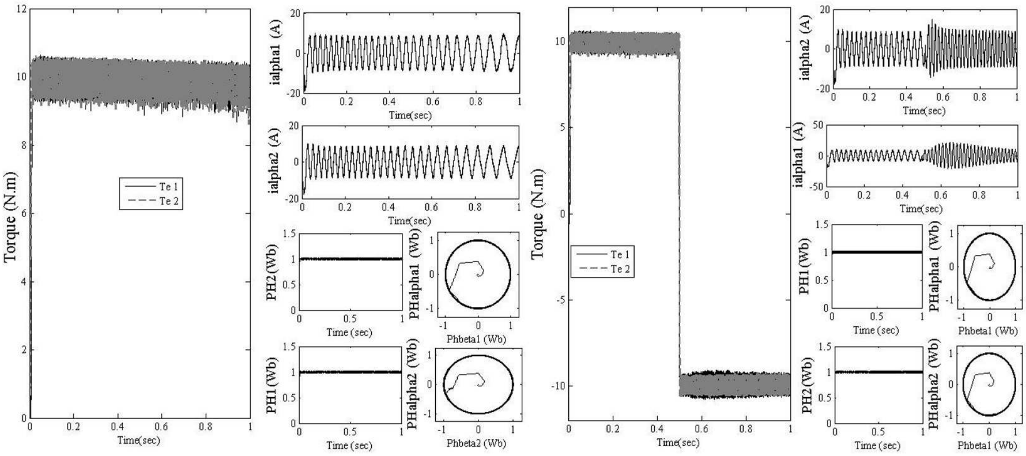

Figure 9: Torque, flux and current responses using DTC-DSIM in open loop by using Fuzzy logic type-2 with T=298K°, G=1000W/m ^{2}.

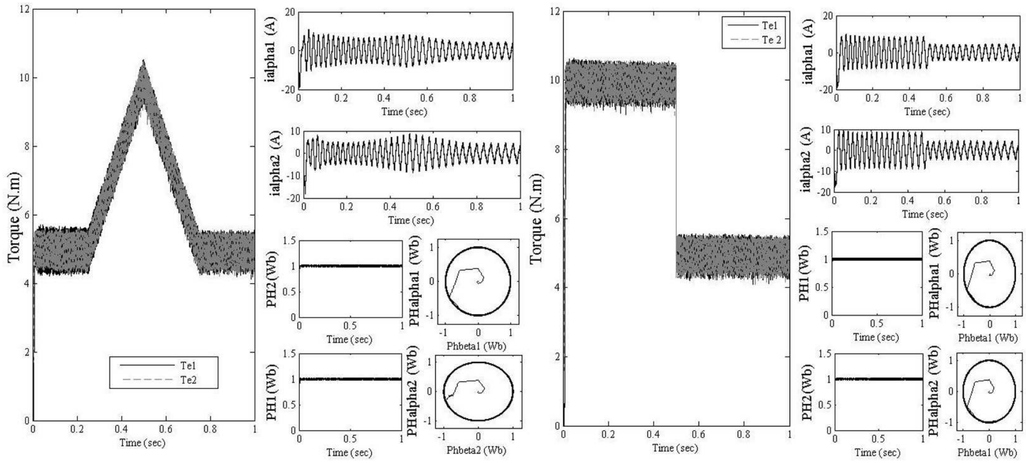

Figure 10: Torque, flux and current responses using DTC-DSIM in open using Fuzzy logic type-2 with T=298K°, G=1000W/m ^{2}.

or

$$\varphi_s = \int (V_{s-}R_s I_s)\, dt. \tag{5}$$

7 Digital Simulation

Firstly, our system has been simulated in the same conditions to compare the performances of dynamic torque control with and without speed control. To verify the effectiveness of the proposed techniques, simulations are performed in this section by using MATLAB/SIMULINK. In this simulation of dual-star asynchronous machine, the nom-

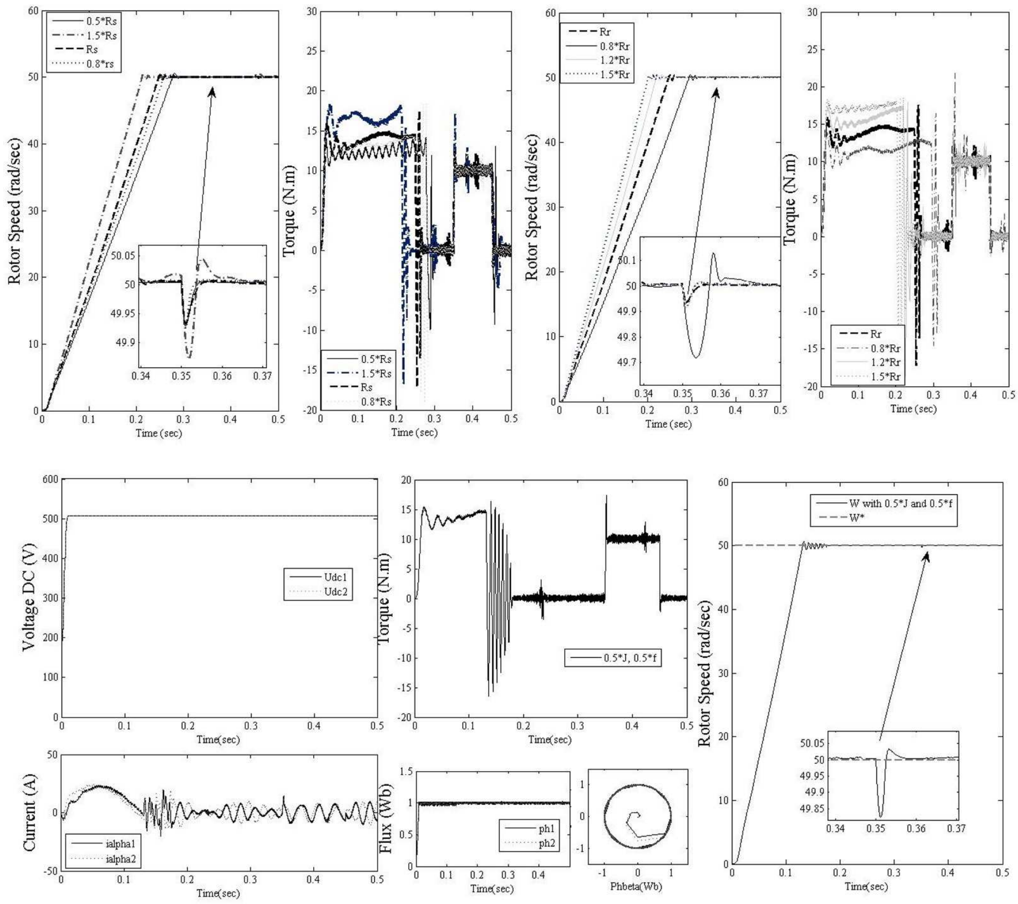

Figure 11: Torque and rotor speed responses using DTC-DSIM in closed loop using Fuzzy logic type-2 with T=298K°, G=1000W/m2 and load parameters variation (stator and rotor resistance, friction f and moment of inertia J).

inal voltage is 220V, nominal power is 4.5kw, stator resistances are 3.72 Ohm, rotor resistance is 2.12Ohm, mutual inductance is 0.3672H, rotor inductance is 0.006H, moment of inertia is 0.0662kg.m ^{2} and friction coefficient is 0.001.

8 Discussion of Results

As a first step, we have presented simulation results of DTC-DSIM without speed regulation (in open loop) as shown Figs. 8,9 and 10.

It can be seen that the estimated values follow their references by applying a load torque 10N, with a changing load torque applied from 10Nm to -10Nm (at 0.5sec) and constant command flux of 1Wb.

It can be noticed that these results obtained by using P&O algorithm give us higher torque and flux ripples (Fig 8) than the results obtained by using fuzzy logic type-2 (Fig.

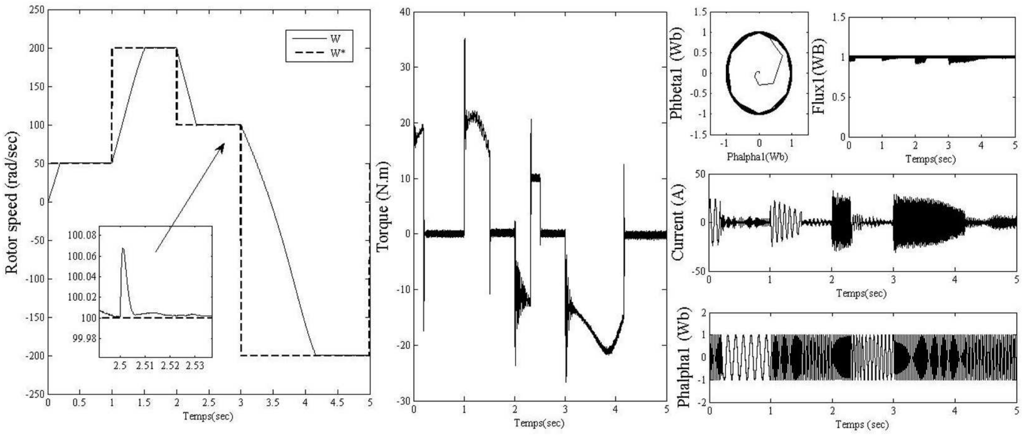

Figure 12: Torque, flux, current and rotor speed responses using DTC-DSIM (in closed loop) with load torque, speed variation.

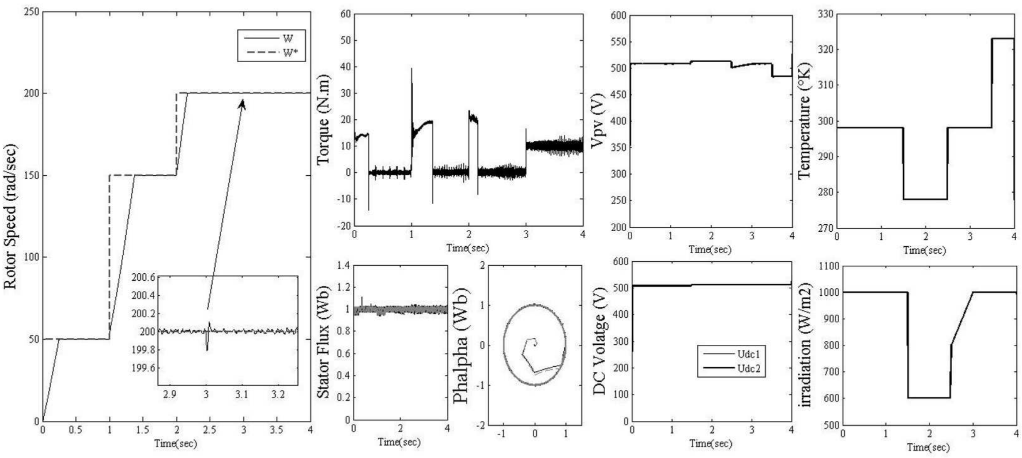

Figure 13: Torque and rotor speed responses using DTC-DSIM (in closed loop) with load torque, speed, irradiation and temperature variation.

9 and Fig. 10).

In order to verified the robustness of the proposed approach under load parameters variation (stator and rotor resistance, friction f and moment of inertia J) we carried out a test for DTC-DSIM in closed loop as is shown in Fig. 11.

Fig. 12 depicts, during the starting up with no load,the system simulated with changing speed reference; (50rad/sec changed to 200 and 100 rad/sec, at 3sec the rotor speed is inversed to -200rad/sec). The speed reaches quickly its reference value without overshoot, however, when the nominal load is applied at 2.5sec, a little overtaking is noticed and the command reject rapidly the disturbance.

Fig. 13 presents also the same responses as the first one but simulated under different conditions, that means by changing the load (electromagnetic torque) and weather conditions such the temperature and irradiation. From this figure, it can be found that our system has satisfactory performance.

9 Conclusion

Direct torque controlling dual star induction motor with and without speed regulation has been discussed in this paper. As can be analyzed from current waveforms,it shows that it is nearly sinusoidal; stator flux and electromagnetic torque track their references. So, the obtained results were very successful and confirm the validity of the proposed technique. It has been possible to obtain satisfactory results using DSIM supplied by double PVG which alone fed power to the AC motor and maintained the output voltage at a predetermined value. Summing up the results, it can be concluded that this study show the feasibility of fuzzy logic type-2 approaches and the improved dynamic performance of the machine in the case of variations in weather conditions or load. This can offer a very interesting solution to the conventional controller, and give us a control of the AC motor in a friendly and clean environment.

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