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IMPROVED PUMPING SYSTEM SUPPLIED BY DOUBLE PHOTOVOLTAIC PANEL

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Key words: Photovoltaic (PV), Photovoltaic generation (PVG), Direct torque control (DTC), Fuzzy logic type-2, Doubly fed induction generator (DFIG).

We will discuss in this work the application of hybrid technique on one of the most fast ac motor control called direct torque control (DTC). This control offers on one side better performance, and fast torque response but on the other side, it suffers from some drawbacks as the high torque ripples. These difficulties guided us to use a hybrid intelligent technique. Therefore, our contribution in this paper is to control DFIM by using DTC and supplied by photovoltaic energy, *i.e,* in one hand, this work aims to control the voltage by using maximum power point tracking (MPPT) technique combined with artificial intelligent as Fuzzy logic type 2, which have been successfully applied to several industrial areas to replace tracking power point perturb and observe (P&O). To improve the classical DTC performance and to reduce high torque ripples caused by the use of hysteresis comparators in classical DTC, we propose a fuzzy logic type-2 controller to replace these hysteresis comparators. So, this paper will present a novel fuzzy logic DTC with less torque ripple, controlled a doubly fed induction motor with durable energy, clean and environmentally friendly.

1. INTRODUCTION

Energy production and energy storage are a major challenge for the coming years. In fact, the industrialized countries energy needs are constantly increasing. Today, we can distinguish several sources of clean energies such as wind and solar energy [1]. Their development at the residential and industrial level is very considerable.

So photovoltaic modules are considered as good option to generate electricity [2], the solar energy comes from the direct transformation part of the solar radiation into electrical energy. This conversion of energy called photovoltaic (PV) cell based on a photovoltaic effect, consists in producing an electromotive force when the surface of this cell exposed to light. The voltage generated may vary depending on the material used for making the cell. The combination of several PV cells in series / parallel present a photovoltaic generator (GPV) which has a nonlinear current-voltage (I-V) characteristic with a maximum power point when load is connected.

PV systems must be operated with maximum efficiency, i.e., they must be operated on maximum power point trajectory [3]. (I-V) characteristic depends on the level of illumination and the temperature of the cell. Moreover, its operating point of the GPV depends directly on the load. Thus, in order to extract at each instant the maximum power available at the terminals of the GPV, we introduce an adaptation stage between the generator and the load to couple the two elements as perfectly as possible. However, the problem of transferring the maximum power of the generator (GPV) and to the load that often suffers from poor adaptation. The use of dc motors was incorporated with the first generation of PV pumping system. With the development of power electronics, the use of ac motors was widely deployed. The literature proposes a large quantity of solutions on the control algorithm, which performs a maximum power point search when the GPV coupled to a load through a static converter. Their objective is to adapt the electrical energy coming from the photovoltaic panels, in order to be able to supply alternative loads.

As the use of an asynchronous motor, driving a centrifugal pump, which is equipped with a speed control system in order to have the possibility of adjusting the flow of water. By using doubly fed induction machine, many benefits can be obtained; the most of them are DFIM can be fed and controlled stator and rotor by various possible combinations; in recent years, several DFIM control methods have been proposed, developed and implemented in both applications as motors or generators. One of the most widely used technique is called DTC. The basic principle of DTC that is used in our work to control the DFIM is to select stator voltage vector according to the differences between the references of torque and stator flux linkage and their actual values.

The main reason for its popularity is due to its simple structure, particularly when compared with FOC scheme [4], the DTC has many advantages such as less machine parameter dependence, simpler implantation and quicker dynamic torque response. However, this direct control has some shortcomings, one more significant disadvantage of conventional DTC is ripples [5] .To resolve this problem, several studies are planned to improve DTC performance.

The authors in [6–10] propose a fuzzy logic controller type-1 (with 180 rules) to replace hysteresis comparators and switching table exist in classical DTC. In [11] a new approach is proposed to reduce the size of rules from 180 to 132, others methods is used fuzzy controller with different rules (from 120 to 30 rules) which are presented in [12–15] respectively, and reduce it again to 22 rules in [16,11]. Most works, who proposed fuzzy logic type-2, as authors in [17–19], have only introduced it in SVM. The concept of type-2 fuzzy sets (T2 FSs), primarily proposed by Zadeh, can be regarded as an extension of the concept of fuzzy logic type 1. The main difference between the two types of fuzzy sets is that the memberships of first are crisp numbers whereas the memberships of second are T1 FSs; complexity system only, whereas the fuzzy-2 control (T2 FSs) effectively deals the large footprint of uncertainty (FOU) with three-dimensional control, which is represented as two MF[17].

Our purpose in this paper is the use of the fuzzy logic type 2 to resolve the problems cited above, that means, replace on one hand only the hysteresis comparators without switching table and SVM. On the other hand, to

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replace the most used algorithm to track the maximum power point P&O by T2 FSs

2. PHOTOVOLTAIC PANEL

A practical PV module (Fig.1) consists of solar cells connected in series then these modules are connected in parallel. An equivalent circuit model for a solar cell is shown in Fig. 1.

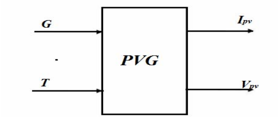


Fig. 1 – Structure block of PVG.

The model consists of a current source (I_{source}), a diode, shunt resistor R_p and a series resistance (R_s). The series resistance must be smaller than possible and the shunt resistance must be very large, to get the maximum current that delivered to the load.

3. MAXIMUM POWER POINT TRACKING CONTROL

To optimize the power provided by the generator, a static converter, which operates as an adapter, must be added. The Fig. 2 shows the converter, (in our work, we present a boost chopper). It consists essentially of a switch (such as IGBT or MOSFET) and a diode D. The switch is controlled by a pulse width modulation (PWM) signal as shown Fig. 3.

The operating power of the solar panels is easy to calculate. It is based on the product of voltage and current. However, the determination of the power reference is more delicate, because it depends to meteorological parameters (temperature and irradiation). This variable reference, characterized by a non-linear function, makes operation at maximum power is more difficult to achieve. Therefore, maximum power point tracking is required. This control, known as the MPPT algorithm, can be more or less complicated. It is generally based on the adjustment of the duty cycle of the static converter until it is placed on the maximum power point (MPP).

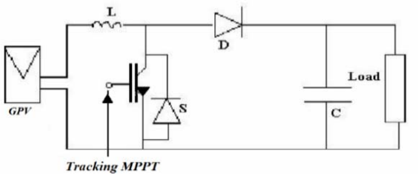


Fig. 2 – Boost converter DC/DC

Many algorithms are used to control the MPPT, The algorithms that are most commonly used are the perturbation and observation method (P&O), dynamic approach method and the incremental conductance algorithm.

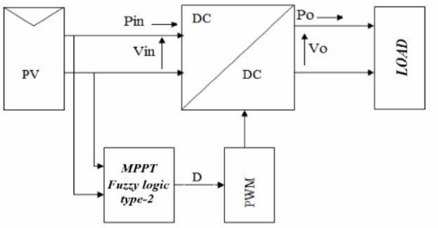


Fig. 3 – Boost converter dc/dc using MPPT-FL2.

The P&O method is used because of its simplicity [21]. Perturbation and observation (P&O) method has a simple feedback structure and fewer measured parameters. However, when, we use this method on panel that related to the direct torque controlled DFIM, we find problem to couple the inverter and the boost chopper, to resolve this problem, we propose in this paper to replace P&O by fuzzy logic type-2 approach.

4. PROPOSED MPPT BASED ON FLC TYPE-2

As is known in the literature, T2FSs systems are constructed from a set of rules based generally on uncertain knowledge. We introduce in this section a new class of fuzzy logic systems called fuzzy logic type-2 in which the membership values of the premises or the consequences are themselves fuzzy sets. The type-2 arrays are very efficient in the case where it is difficult for us to determine exactly the membership functions; hence, they are practical for the incorporation of uncertainties.

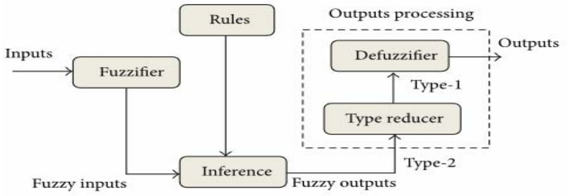


Fig. 4– Structure of type-2 fuzzy logic system [22].

As shown Fig. 7, the first proposed fuzzy logic type-2 called T2FSs used in this paper, has Gaussian five T2 fuzzy sets. To transform T2FSs output into fuzzy logic type-called T1FSs, the center of sets method is used

The rules structure of fuzzy logic type 2 will remain the same. *i.e.*, all rules are almost similar to those for the conventional type-1.However, the output of the inference system of fuzzy type-2, must it be reduced before it will be defuzzified, and so reduction type used is centroid (Fig. 4).

The input and the output present respectively power error and the duty cycle of the switching transistor as shown fig.5.

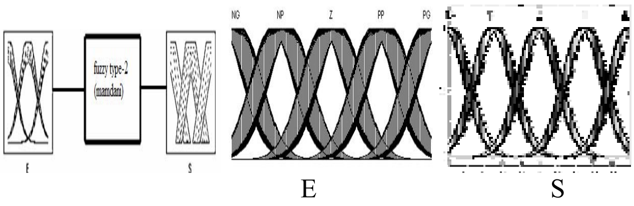


Fig. 5– Membership function of input and output MPPT controller.

5. DOUBLY FED INDUCTION MOTOR

The state all-current of the DFIM is given by:

$$\begin{aligned}\frac{\mathrm{d}I_s}{\mathrm{d}t} &= \frac{R_s}{\sigma L_s} I_s + \frac{M_{sr} R_r}{\sigma L_s L_r} I_r + \frac{1}{\sigma L_s} V_s - \frac{M_{sr}}{\sigma L_s L_r} V_r \\ \frac{\mathrm{d}I_r}{\mathrm{d}t} &= \frac{R_r}{\sigma L_r} I_r + \frac{M_{sr} R_s}{\sigma L_s L_r} I_r + \frac{1}{\sigma L_r} V_r - \frac{M_{sr}}{\sigma L_s L_r} V_s\end{aligned} ,(1)$$

$$\sigma = 1 - \frac{M_{sr}^2}{L_s L_r}.$$

This electrical model is completed by the mathematical equation.

$$\frac{J}{p}\frac{\mathrm{d}\omega}{\mathrm{d}t} = T_e - \frac{F\omega}{p} - T_r \ . \tag{2}$$

6. **DIRECT TORQUE CONTROL**

In the DTC, the stator and rotor flux vector is estimated by taking the integral of difference between the input voltage and the voltage drop across the resistance given by:

$$\begin{aligned} \phi_s &= \int (V_s - R_s i_s)\mathrm{d}t \\ \phi_r &= \int (V_r - R_r i_r)\mathrm{d}t \end{aligned} \tag{3}$$

Let us replace the estimate of the (stator or rotor) voltage V with the true value and write it as:

$$V(S_a, S_b, S_c) = \frac{2}{3} U_{dc} (S_a + S_b e^{\frac{\mathrm{j}2\pi}{3}} + S_c e^{\frac{\mathrm{j}4\pi}{3}}) \tag{4}$$

S_a, S_b, S_c, represent the state of the three phase legs, 0 meaning that the phase is connected to the negative and 1 meaning that the phase is connected to the positive leg.

The current space vector is calculated from measured (stator and rotor) currents i_a, i_b, i_c:

$$i = \frac{2}{3}(i_a + i_b e^{\frac{\mathrm{j}2\pi}{3}} + i_c e^{\frac{\mathrm{j}4\pi}{3}}) \tag{5}$$

The component α and β of vector φ can be obtained:

$$\begin{aligned} \phi_{s\alpha} &= \int (V_{s\alpha} - R_s i_{s\alpha})\mathrm{d}t \\ \phi_{s\beta} &= \int (V_{s\beta} - R_s i_{s\beta})\mathrm{d}t \\ \phi_{r\alpha} &= \int (V_{r\alpha} - R_r i_{r\alpha})\mathrm{d}t \\ \phi_{r\beta} &= \int (V_{r\beta} - R_r i_{r\beta})\mathrm{d}t. \end{aligned} \tag{6}$$

Stator and rotor flux amplitude and phase angle are calculated in expression (7):

$$\begin{aligned} &\begin{cases} \phi_s = \sqrt{\phi_{s\alpha}^2 + \phi_{s\beta}^2} \\ \angle\phi_s = \mathrm{arctg}\dfrac{\phi_{s\beta}}{\phi_{s\alpha}} \end{cases} \\ &\begin{cases} \phi_r = \sqrt{\phi_{r\alpha}^2 + \phi_{r\beta}^2} \\ \angle\phi_r = \mathrm{arctg}\dfrac{\phi_{r\beta}}{\phi_{r\alpha}}. \end{cases} \end{aligned} \tag{7}$$

Once the two components of flux are obtained, the electromagnetic torque can be estimated from the relationship cited below:

$$T_e = \frac{3}{2} p(\phi_{s\alpha} i_{s\beta} - \phi_{s\beta} i_{s\alpha}) \tag{8}$$

the voltage plane is divided into six sectors so that each voltage vector divides each region into two equal parts.

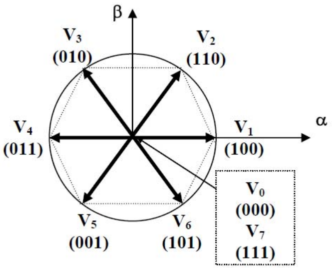


Fig. 6 – Spatial vectors created by the inverter.

These vectors are shown in Fig. 6, where six active vectors of same magnitude are presented and two remaining vectors are zero.

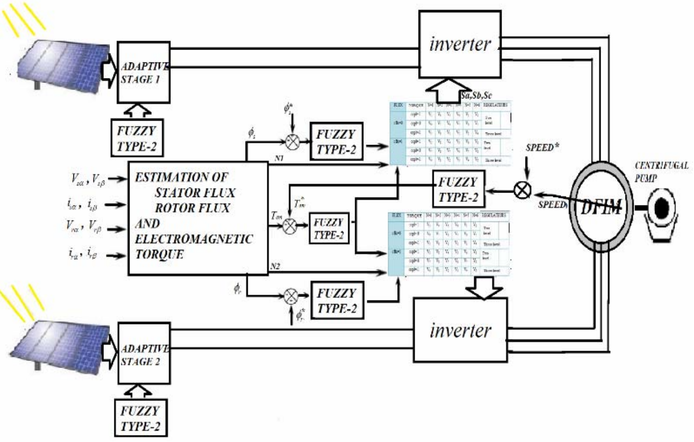


Fig. 7 – Schemc of DTC-DFIM supplied by PVG.

7. **PROPOSED DIRECT TORQUE CONTROL BASED ON FUZZY TYPE-2**

The input and the output present respectively torque or flux error and cflx or ccpl as presented in switching table of Fig. 7. So, in this section we have two fuzzy regulators, which will replace the traditional hysteresis comparators of flux and torque. This controller has Gaussian seven T2 fuzzy sets as presented in Fig. 8 and the reduction type used is centroid.

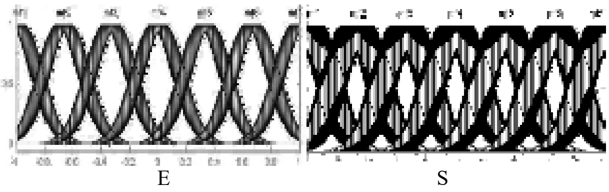


Fig. 8– Membership function of input and output fuzzy controller.

8. **PROPOSED ROTOR SPEED CONTROLLER BASED ON FUZZY TYPE-2**

We have defined, for each input of first T2FSs to replace PI speed controller, five T2 fuzzy sets interval: Negative Grand (NG), Negative Petit (NP), Zero (Z), Positive Petit (PP), Positive Grand (PG), described by Gaussian membership functions uniformly distributed on the discourse universe [-1, + 1] (fig 9). The input and the output present respectively error or variation error of the rotor speed and the output is presented by electromagnetic torque reference as shown fig 7 and fig 9.

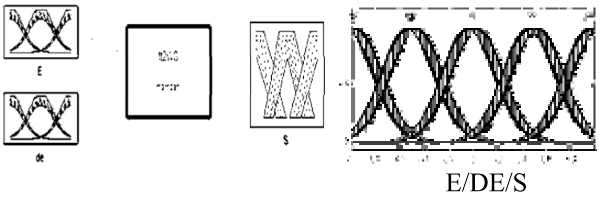


Fig. 9– Membership function of input and output fuzzy speed controller.

9. DIGITAL SIMULATION

To verify the effectiveness of the proposed techniques, simulations are performed in this section by using MATLAB/SIMULINK. In this simulation of doubly fed induction machine, the machine parameters are listed in Table 1.

Table 1

DFIM parameters

Parameters of DFIM setting		
P	Power	1.5 kW
R_s	Stator resistance	1.75 Ohm
R_r	Rotor resistance	1.68 Ohm
J	Inertia	0.01 kg.m^2
f	frequency	50 Hz
Ls	Stator inductance	0.295 H
Lr	Rotor inductance	0.104 H
Msr	Mutual inductance	0.165 H
p	Poles	2

10. DISCUSS RESULTS

As shown all figures, the system is simulated with constant load torque (5 N.m), and to investigate the performance of the proposed technique on the DTC-DFIM system supplied with double PVG, a simulation was run in closed loop. Figure 10 presents a comparison between two MPPT techniques used in this paper. The first traditional technique based on P&O algorithm and second proposed technique based on T2FSs (fuzzy t2). It can be noticed that torque, current and flux have high ripples by using P&O compared to the second (T2FSs), same figure show also, that estimated values flow their reference. We can observe that T2FSs gives us better performance than the first one but with ripples which it is created by the use of hysteresis comparators. Figure 11 presents a comparison between classical DTC (with hysteresis comparators), T1FSs-DTC (replace hysteresis by T1FSs controller 'fuzzy-t1), the principal of this type is presented and discussed in [11, 12] and T2FSs-DTC (replace T1FSs by T2FSs controller), this figure confirms that we succeeded to reduce significantly the high ripple torque by using fuzzy logic controller compared to the classical DTC.

The showing results offer to us a robust DTC with less torque ripples compared to classical DTC and as shown in Table 2, we have calculated the criteria of performance (integral square error ISE) in presence of measurement noise. Fuzzy logic 2 controller give us a better performance than the other types of control.

Table 2

Data obtained by applying noise measurement on currents and speed.

	ISE_{Te}	ISE_{ω}
CLASSICAL DTC	4x10^{-2}	72 x 10^{-2}
DTC-FLC TYPE-1	1.6 x10^{-3}	2.5 x 10^{-3}
DTC-FLC TYPE-2	2.95 x10^{-4}	3.32 x 10^{-5}

To show the effectiveness of the proposed technique, Fig. 12 present comparative rotor speed response of traditional one as proportional integral (PI) controller and fuzzy logic type-2 controller. Figure 13 presents different responses under a rapid variation of weather conditions (irradiation and temperature) and with load torque applied in each variation of speed (ω/2, ω and –ω/2 with ω = 160 rad/s). Figure depicts, during the starting up with no load, the speed reaches quickly its reference value without overshoot and the command rejects quickly the disturbance. Also in Fig. 13 and to show again the robustness mainly against variation on the load and weather conditions in the same time, the results have presented with variation of machine parameters, (stator and rotor resistance, friction fr and moment of inertia *J*), load torque applied in different variation of speed and with temperature and irradiation changes. So it can be found that the proposed technique offers better performance compared to traditional techniques. Finally, Fig. 14 presents the hybrid pumping system with load and weather condition variation.

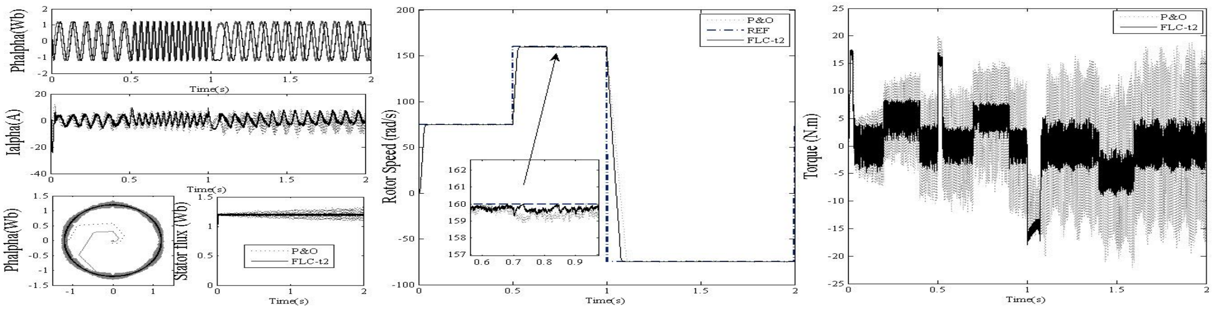


Fig 10. Different responses using DTC-DFIM with P&O and Fuzzy logic type 2 methods (with load variation in *G* = 1000 W/m^2, *T* = 298 K)

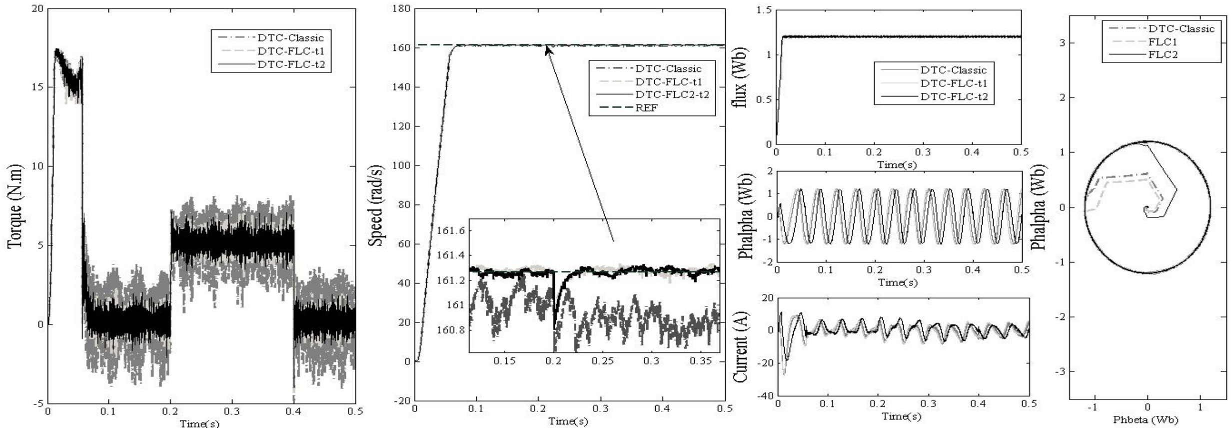


Fig.11 – Torque, flux and cuurent responses using DTC-DFIM with FL2-MPPT method and load variation (G =1000 W/m^2, T = 298 K)

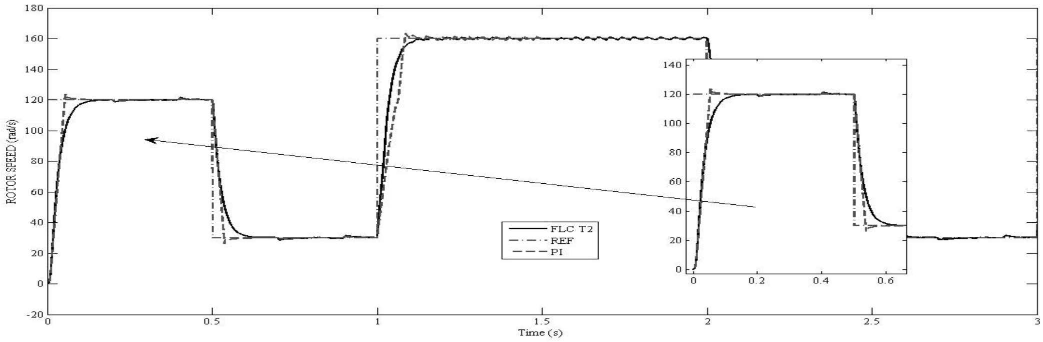
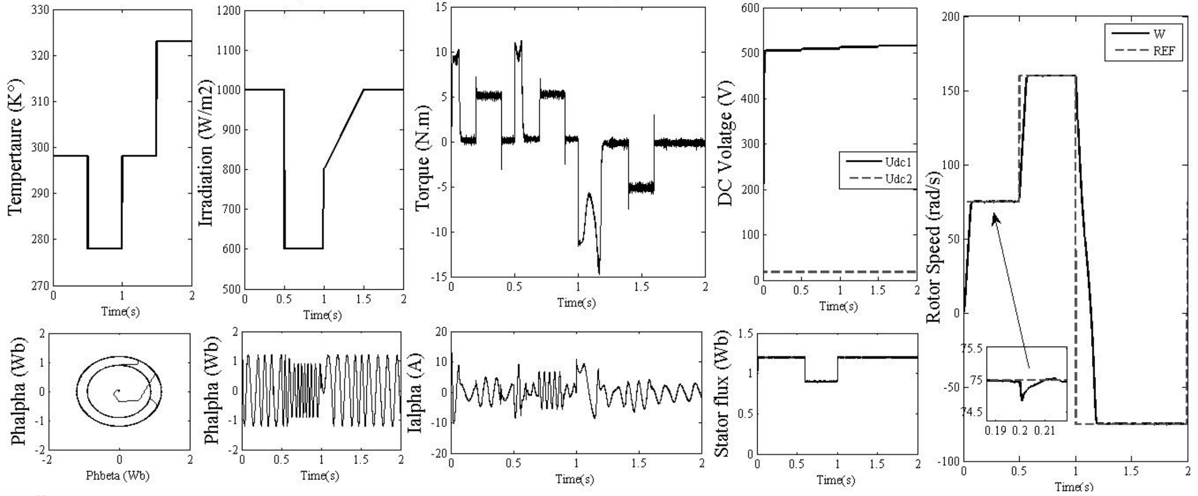
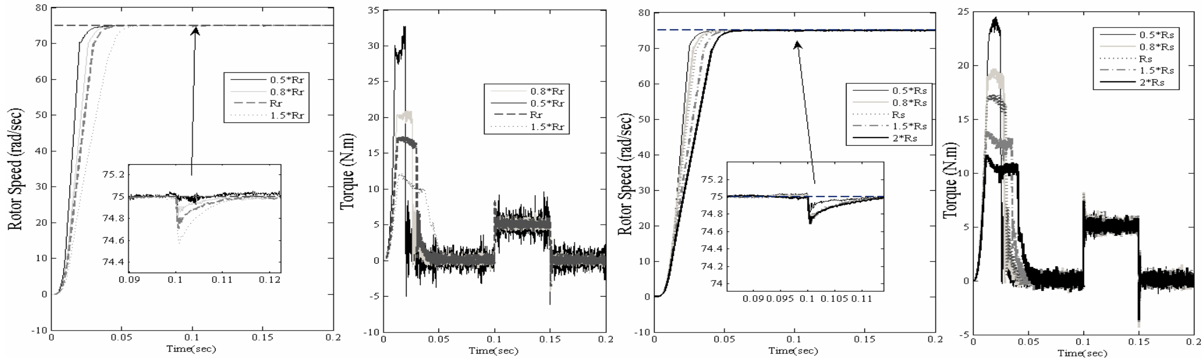


Fig. 12 –Rotor speed response by using PI controller and fuzzy logic type-2

With parameters machine variation (Rs*1.5, Rr*1.5, J*1.5, f*1.5)





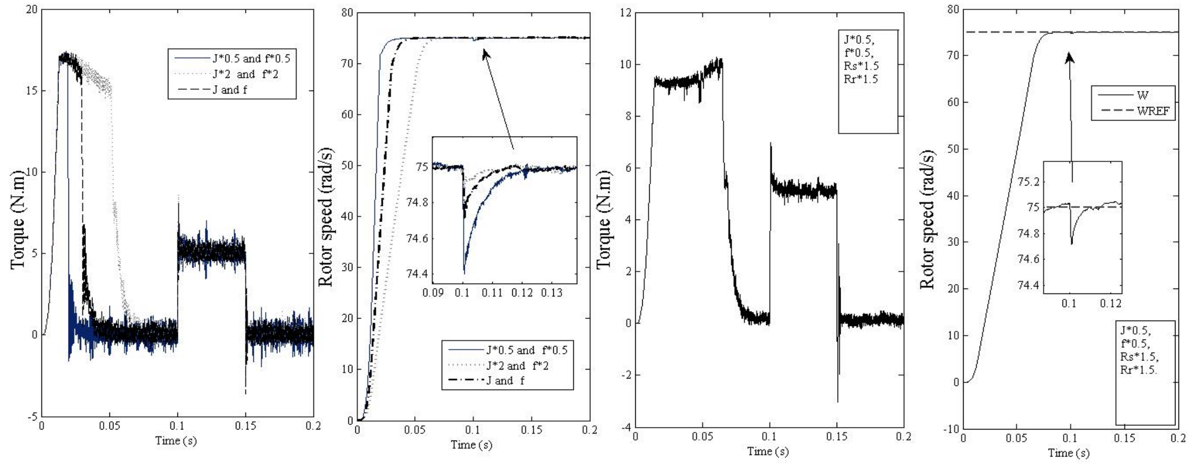


Fig. 13 – System responses of new DTC-FL2 with load (parameters machine,stator flux, rotor speed) and weather (temperature and irradiation) changes.

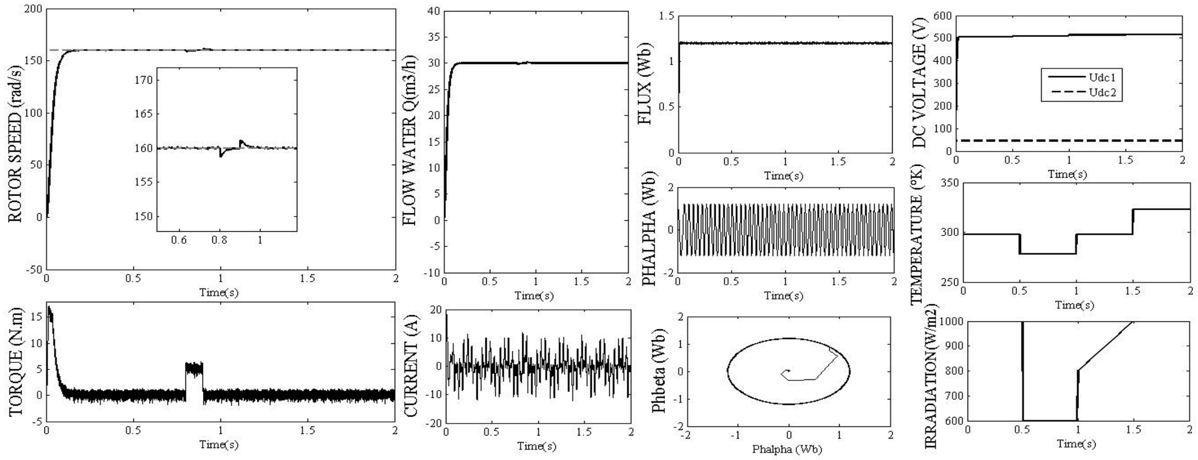


Fig. 14– Pumping system responses using FL2-DTC-DFIM with FL2-MPPT method (with load, irradiation and temperature changes).

8. CONCLUSION

Up to now, limited studies have focused on interval type-2. We presented in this work a solution to two problems, the first is related to technique used to control the DFIM, that means to obtain a robust control (DTC), with less torque ripples, we have replaced the hysteresis comparators by FL2 controllers, to minimize the high torque ripples and to get better performance by replacing rotor speed PI controller with FLC.

In the second part, we have treated the problem related to the type of energy used to supply our machine. This paper propose the use solar source, which consist to use double PVG controlled by MPPT based on fuzzy logic type-2. This work indicates that the employ of these techniques becomes a necessity to achieve high performance in variable speed drive in friendly and clean environment. The simulation results show that proposed techniques give satisfactory results, it also show the feasibility of these intelligent approaches and improving dynamic performance of the machine compared to the conventional one, these approaches are very attractive mainly DTC-FL2 which offer a very interesting solution.

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