DC Motor Speed Control using PI-Fuzzy Logic Technique via Positive Output Luo converter

Mohamed BOUTOUBA[#1], Abdelghani El Ougli[*2], Belkassem Tidhaf[#3]

#*SEEER Laboratory, ENSAO, Mohamed First University*
Oujda Morocco
[1]btba.med@gmail.com

Abstract— **This paper present a speed control of DC motor system powered by a photovoltaic source via Luo DC-DC. Luo converters are new generation of DC-DC converters on power electronics which presents better performances and high accuracy.**
As known, the produced voltage in a photovoltaic system is not stable, controller's techniques are required to guaranties a continuous voltage in the DC motor and thereafter the desired rotation speed. A PI-Fuzzy controller technique is proposed to control periodically the transferred voltage to the DC motor.
The mean goal of the proposed system is the use of new DC-DC converter as intermediate controlled by Fuzzy logic strategy in order to reach better pursuit with low ripples of the DC motor speed.
Multiples simulations are done to improve the functionality and the good behaviour of the proposed system.

Keywords—— **Speed control, DC motor, Luo converter, Fuzzy logic controller, Photovoltaic system.**

I. INTRODUCTION

A photovoltaic system has the advantage of a renewable energy, but on the other hand producing voltage and power dependent of many parameters such as irradiance and temperature… Then by controlling the effects of these parameters multiples applications of PV solar system are appeared.

Power conversion is one of the major requirement in various industries and in daily life. From where, DC-DC converter has appeared as the most used in industrials applications due to its high efficiency and yield with a stable output voltage.

The use of DC-DC converter has revealed new generation of Buck, Boost, Buck-Boost converter; Luo converter as well, one of the new generation has better yield, and lower output ripple voltage.

This paper as well, treats the speed control for a DC Motor as application.

Speed control means intentional change of the drive speed to a value required for performing the specific work process.

The speed control mechanism is applicable in many cases like controlling the movement of robotic vehicles, movement of motors in paper mills, the movement of motors in elevators...

Controlling speed rotation of the DC Motor is the mean goal of the paper by adjusting the voltage at its terminals using a PI-Fuzzy logic control technique to control the transferred power from Photovoltaic solar source to DC motor.

Fuzzy logic techniques are used specially when the design problem is very complicated, case of nonlinear system as DC-DC converter due to their switching property, time consuming or when the problem is new and algorithms for solving it have not yet been developed.

Fig. 1 shows the global block of the studied system Comprising the following sub-blocks:

- a PV source which powered the system,
- a buck DC-DC converter,
- The DC Motor.
- And control bloc which contains the Fuzzy control strategy.

II. STUDY AND MODELING OF THE DIFFERENT BLOCKS

This paragraph details all sub blocks of the studied system, namely the modeling of the PV module, of the DC-DC converter and the control technique used.
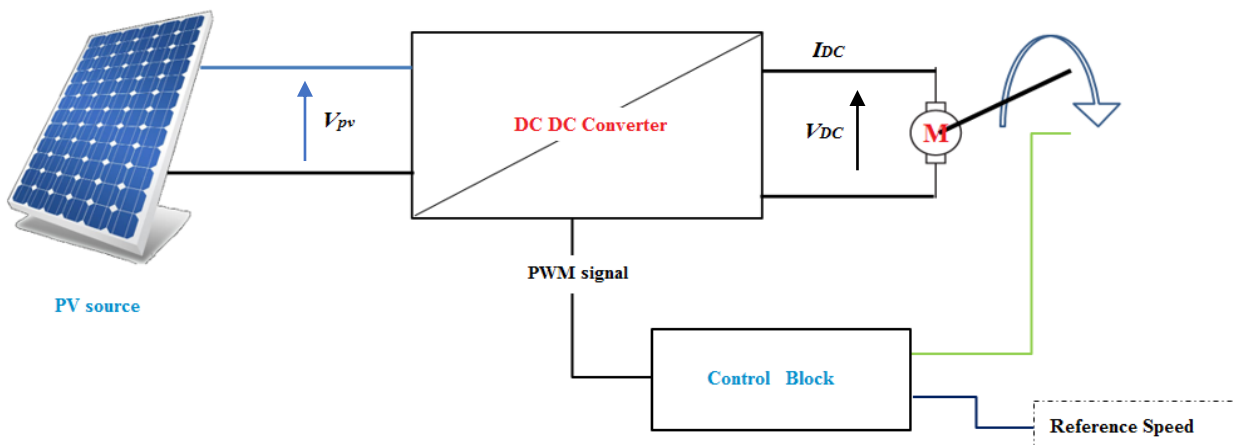

Fig. 1 general block of studied system

A. Modeling of the PV module:

Fig. 2 shows the equivalent circuit of a PV cell, The current source I_{ph} represents the cell photo-current.

R_{Sh} and R_S are, respectively, the intrinsic shunt and series resistances of the cell.

The voltage-current characteristic equation of a solar cell is provided as:

$$I = I_{ph} - I_0\left[\exp(\frac{V+I.R_S}{a})-1\right] - \frac{V+R_S.I}{R_{Sh}} \qquad (1)$$

With:

- I : PV cell current.
- I_{Sh} : the current leak in parallel resistor.
- I_0 : is the reverse saturation or leakage current of the diode
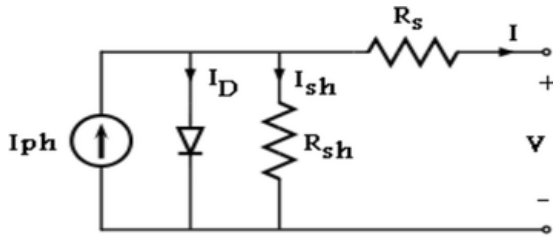- a is called 'the modified ideality factor'

Fig. 2 PV cell equivalent circuit

Thereafter, a set of PV cells are put in series to create larger units called the PV module, in order to obtain an exploitable voltage/power. (as shown in Fig. 3).

B. The Luo buck converter circuit:

An elementary circuit of positive output Luo-Converter is used for the conversion energy from source to DC motor.

Positive output Luo-converters perform the voltage conversion from positive to positive voltages using VL technique.
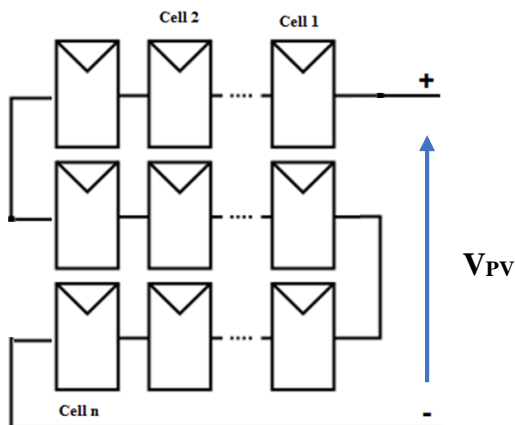
Fig. 3 PV module

The electronic circuit of the Luo converter is presenting in Fig. 3:

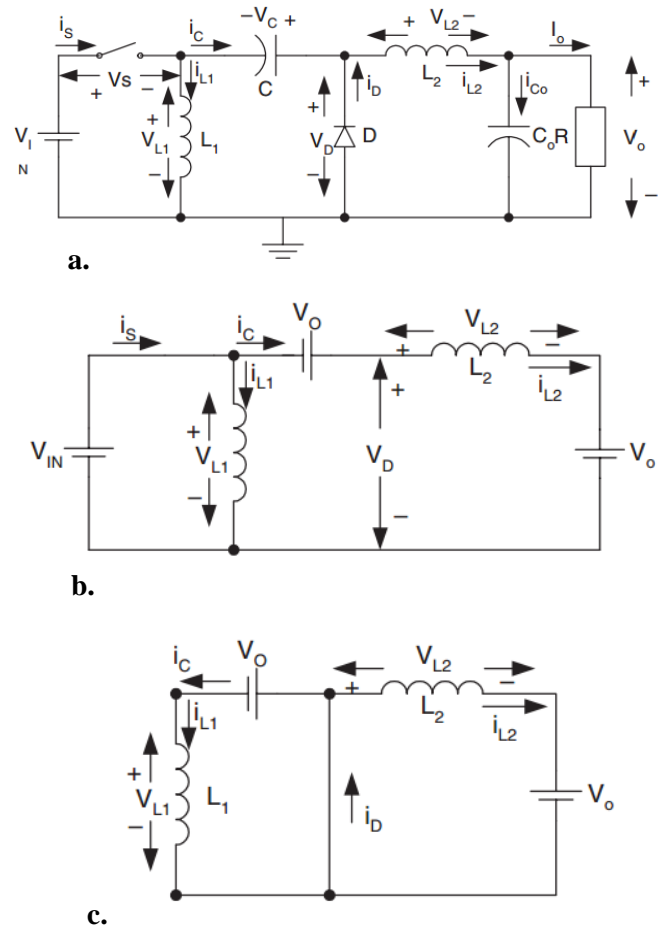Switch-on and switch-off equivalent circuits are shown in Fig. 3/a and b.

a.

b.

c.

Fig. 4 Elementary circuit of the Positive Luo converter.
- a. Topology.
- b. Switching-on circuit.
- c. Switching-off circuit

The elementary circuit can perform step-down and step-up DC-DC conversion.

When switch K is on, the source current $i_S = i_{L1} + i_{L2}$. The inductor L1 stores energy coming from the source, and L2 absorbs it from source and capacitor: i_{L1} and i_{L2} increase.

When the K switch is off, the diode turns on which let the current i_{L1} flows through it, whence the charge of the capacitor C while the coming energy from the inductor L1 decreases. Also the i_{L2} current flows through the output capacitor and Load, from where it decreases by his turn.

Equation describing the voltage transfer gain in CCM (continuous conduction mode) is written as well:

$$\frac{V_O}{V_{in}} = \frac{\alpha}{1-\alpha} \qquad (2)$$

Such: $\alpha = T_{on}/T$, with T_{on} is the operating range of the switch (K is on), and T represent the period of the switching control signal.

DC-DC converter output voltage is set by controlling the switch K with a PWM signal whose duty cycle could be variable.

One of the major advantages of the Luo converter is the lowest variation ratio of the output voltage and current. Therefore, the output voltage VO is almost a real DC voltage with very small ripple.

$$\varepsilon = \frac{\Delta v_o/2}{V_o} = \frac{\alpha T^2}{8 C_o L_2} \frac{V_{in}}{V_o} = \frac{\alpha}{8 M_E} \frac{1}{f^2 C_o L_2} \quad (3)$$

With M_E is the voltage transfer gain, and f the switching frequency.

Also to avoid the discontinuous mode operation (Fig. 5), it's necessary to study the limit condition of the CCM. The variation ratio of the current i_D is done on the equation below:

$$\xi = \frac{\Delta i_D/2}{I_D} = \frac{(1-\alpha)^2 T V_O}{2 L I_O} = \frac{\alpha(1-\alpha)R}{2 M_E fL} = \frac{\alpha^2}{M_E^2} \frac{R}{2fL} \quad (4)$$
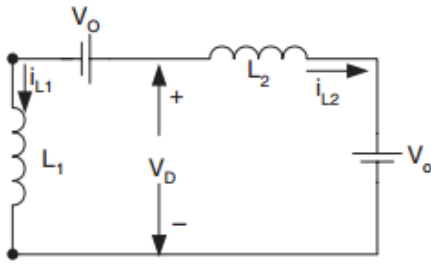

Fig. 5 Discontinuous conduction mode

Referring to Fig. 5, we can see that the diode current i_D becomes zero during switch off before next period switch on. The condition for discontinuous mode is: $\xi \geq 1$

i.e.: $$M_E \leq \alpha \sqrt{R/2fL} \quad (5)$$

C. Control Techniques:

To guaranties the pursuit of the speed reference, even in parameters changes in the photovoltaic panel, it was necessary to develop control techniques, so as to control the K switch on the DC-DC converter and thereafter the transmitted voltage to the motor.

Many algorithms could be used to control received power to the load. In this papers a PI-Fuzzy logic controller was proposed as shown in Fig. 6.

Unlike traditional controllers (P, PI, PID…) which, even if are efficient for linear system, it's become more difficult to control non-linear system as it is the case for the switched-mode converters.

Fuzzy logic control, one of new techniques, which is a relevant strategy offering outstanding performance, and has an interesting alternative approach, such a raisonnement similar to that of man, and to manage complex systems intuitively.

The idea of the PI-Fuzzy control system is to generate an appropriate response by comparing the real output speed of the motor by the reference one, all that to minimise the error between its.
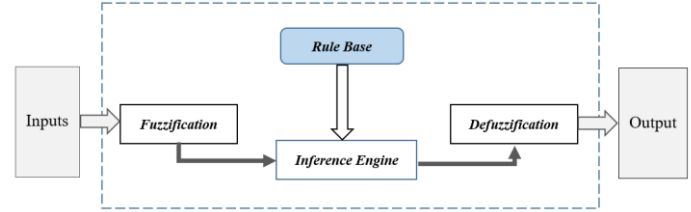

Fig. 6 Fuzzy logic controller

The fuzzy logic controller block is divided into 3 sub block, as shown the Fig. 6: Fuzzification, fuzzy inference engine with rules, and defuzzification.

The Fuzzification step is intended to transform the actual magnitudes linguistic variables for an inference processing.

For a PI-Fuzzy controller, two inputs variables are used:

$$\varepsilon = N_{ref} - N_{mes}$$
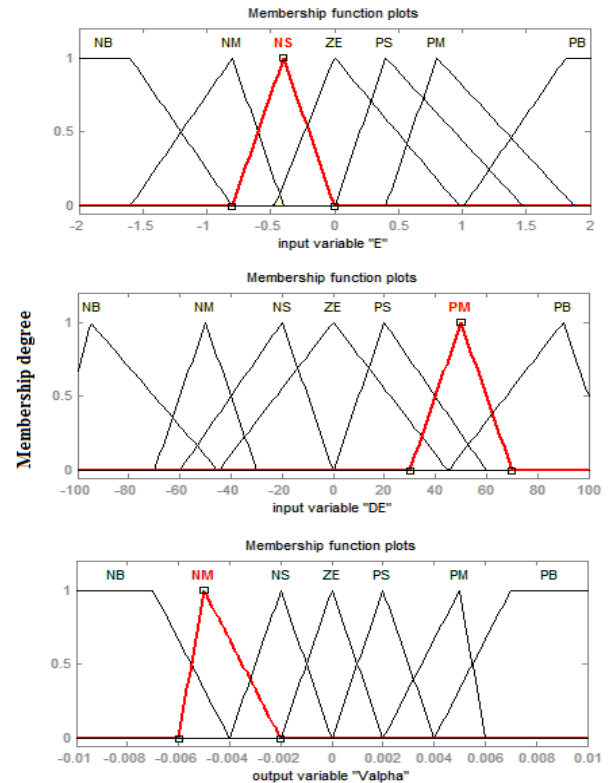$$\Delta\varepsilon = \varepsilon(t) - \varepsilon(t-1) \quad (6)$$

Fig. 7 Variables inputs/output linguistic

With N_{ref} and N_{mes} are respectively, the reference and the measured speed of the DC motor.

With ε : the error between measured motor speed and speed reference: The set point.

On this stage, the crisp variables are converted in to fuzzy variables using membership functions as shown in Fig. 7.

Seven memberships functions are used to describe inputs states for a better representation on fuzzy logic field.

The second block, the inference engine, comes to generate the appropriate response by using diverse inputs combinations between the error and the variation of error. Those combinations are collected on a fuzzy rules table as shown on Table 1:

TABLE I

E DE	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	ZE	PS	PM	PB	PB
NM	NS	ZE	ZE	PS	PM	PB	PB
NS	NM	NS	NS	ZE	PS	PM	PB
ZE	NB	NM	NS	ZE	PS	PS	PB
PS	NB	NM	NS	NS	ZE	PS	PM
PM	NB	NB	NM	NS	PS	ZE	PM
PB	NB	NB	NB	NB	PS	ZE	ZE

After inference step, the generated output value, which is a fuzzy response, should be converted to a crisp output, it is the defuzzification block role.

Multiples methods for defuzzification step can be used; such as center of gravity.

Next, the response value which is an analog signal must be converted to a PWM signal to control the switch in the Luo converter as the Fig. 7 shows. The method is based on the comparison of the analog signal by a periodic sawtooth signal, whose frequency depends on the desired switching frequency.

III. SIMULATION RESULT AND INTERPRETATION

By modelling the different blocks of the proposed system (Fig. 8) using the PI-Fuzzy logic technique, multiples simulations were treated to verify the good behaviour of it in terms of pursuit, precision, speed response in the cases of irradiation changes (and or temperature), speed references changes.

Table 2 shows the choose of the PI fuzzy controller parameters:

TABLE III

Parameters	Value
Kp	1/5500
Ki	1.5

As far as the sizing of the Luo converter components, table 3 shows the choice of the electrical and electronic components. As well as for the DC motor parameters:

TABLE IIIII

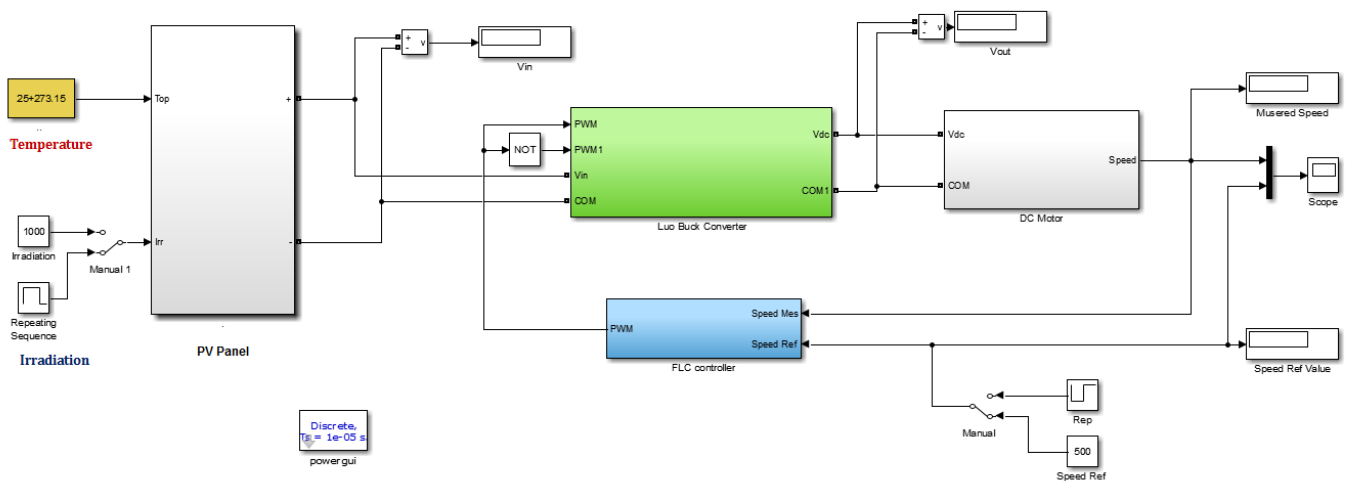| Component	Value or Reference type
Entrance capacity	Cin =220µF
Inductor L1	L1= 1mH
Inductor L2	L2= 2mH
Switch K and diode D	MOSFET
C capacitor	C = 220µF
Output capacity	Cout = 2000µF
DC motor Internal resistor	R=1Ω
DC motor Internal inductor	L=1mH
Electromotive force constant	Ke= 0.1V/(rad/s)

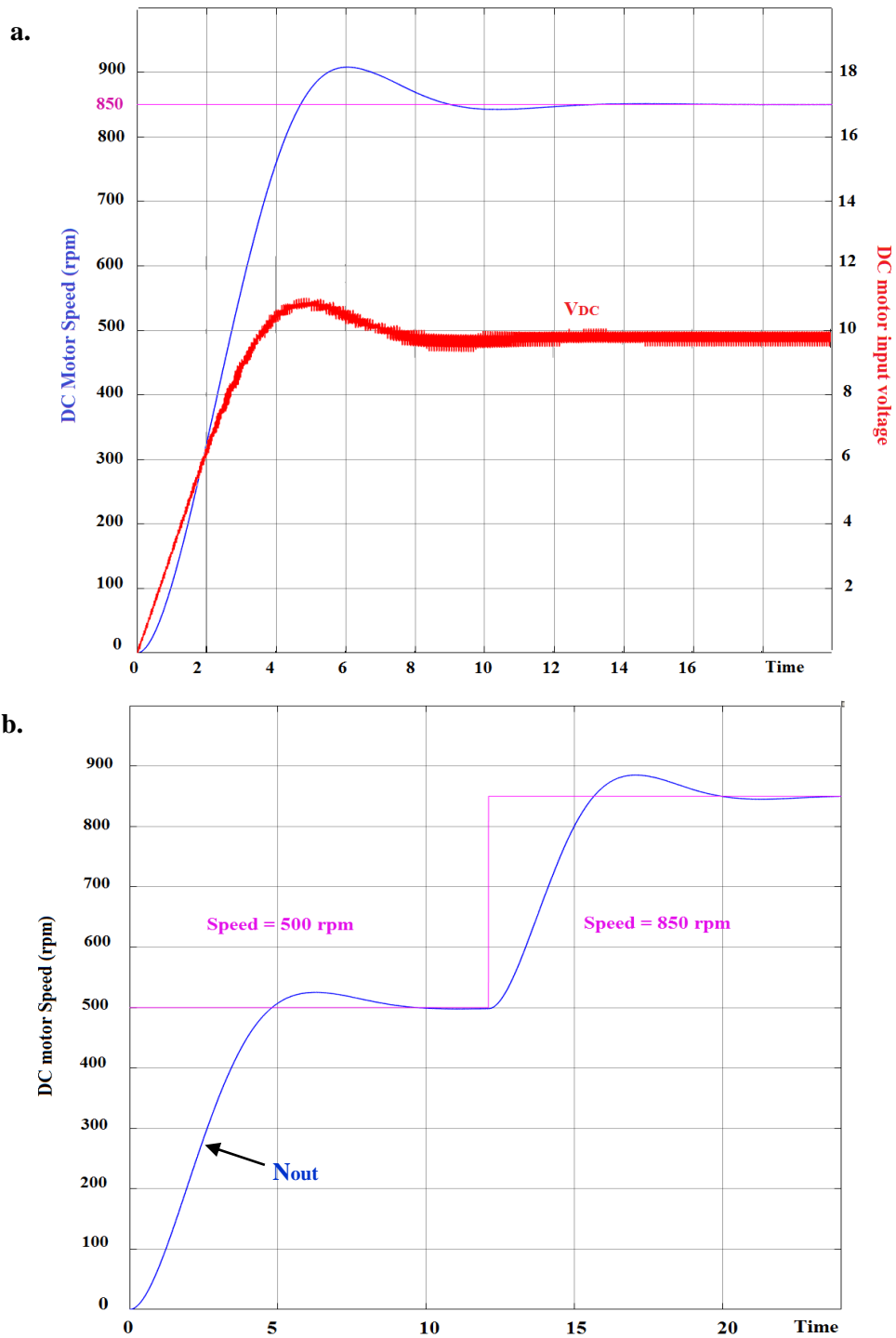
Fig. 8 Matlab Simulink system blocks

Fig. 9 Matlab Simulink system blocks
a. Speed reference pursuit.
b. Speed changes tracking.

A. Speed reference Pursuit (irradiation=1000 W/m²):

For the PV panel, irradiation was chosen as constant with 1000W/m² and the reference speed of the DC motor as 850 rpm.

Fig. 9/a shows the system response, the pursuit of the chosen reference. As we can see the measured speed of the DC motor pursuit exactly the fixed set point by controlling periodically the duty cycle of the PWM signal and by the end the input voltage of the motor. The input voltage of the DC motor is represented by the red response signal in the Figure, which is stabilized around 9.8V.
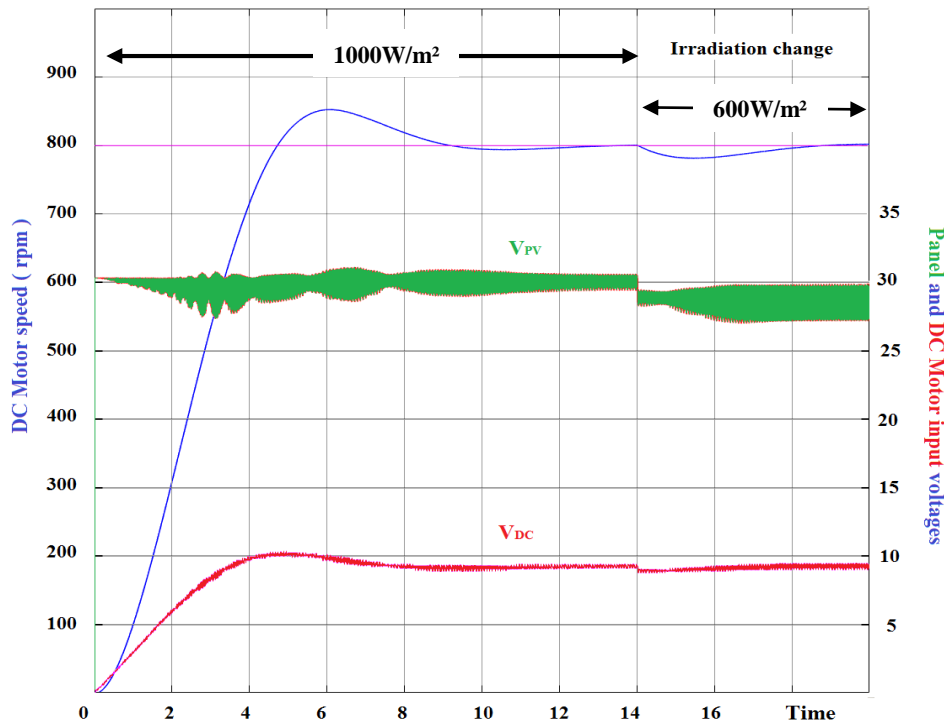
Fig. 10 Speed pursuit in irradiation change case.

B. Speed changes (irradiation=1000 W/m²):

Second simulation treats the pursuit of a variable speed reference with constant irradiation 1000W/m².
500 rpm is chosen as initial speed value, then it changed to 850 rpm.
Per Fig. 9/b, which represent the output response of the DC motor, the simulation validates the pursuit even with a speed change of the reference.

C. Pursuit with irradiation changes:

In this simulation, the produced voltage of the PV panel is considered as no regular by making the irradiation changes during system operation.
As shown in Fig. 10, the irradiation started with 1000W/m² as initial value and decreases thereafter to 600W/m².
From the instant of irradiation changes the output voltage of the PV panel drops to a lower value which create a decrease of the speed. Quickly, the system corrects this disturbance subsequently the DC motor output speed follows the fixed reference speed.

CONCLUSION:

In this paper, a DC motor speed control system was proposed; Controlling the motor speed with better pursuit and high accuracy were the goal of the use of new generation of DC-DC converter; the Positive output Luo converter which shows an improvement over conventional converter especially output ripple voltage, thereafter a better accuracy which is indispensable for many applications.

The simulation results of the proposed system, using the Luo converter as an intermediate between Photovoltaic supply voltage and the DC motor controlled by a PI-Fuzzy logic technique, demonstrate and approve the good behaviour of it and a perfect speed tracking with lesser rise time and settling time.

REFERENCES

[1] P. Thepsatorn, A. Numsomran, V. Tipsuwanporn and T. Teanthong, "DC Motor Speed Control using Fuzzy Logic based on LabVIEW," *2006 SICE-ICASE International Joint Conference*, Busan, 2006, pp. 3617-3620.

[2] P. Karthika, M. A. Basha, P. Ayyappan, C. K. Sidharthan and V. R. Rajakumar, "PV based speed control of Dc motor using interleaved boost converter with SiC MOSFET and fuzzy logic controller," *2016 International Conference on Communication and Signal Processing (ICCSP)*, Melmaruvathur, 2016, pp. 1826-1830.

[3] A. Baghramian and H. Ghorbani Eshyani, "Fuzzy Controller of luo converter for controlling of DC motors speed," *4th Annual International Power Electronics, Drive Systems and Technologies Conference*, Tehran, 2013, pp. 170-175.

[4] BOUTOUBA, Mohamed et al. Asymmetric Fuzzy Logic Controlled DC-DC Converter for Solar Energy system. Renewable Energy and Sustainable Development, [S.l.], v. 2, n. 1, p. 52-59, jun. 2016. ISSN 2356-8569.

[5] Habbati Bellia, Ramdani Youcef, Moulay Fatima, A detailed modeling of photovoltaic module using MATLAB, NRIAG Journal of Astronomy and Geophysics, Volume 3, Issue 1, June 2014, Pages 53-61, ISSN 2090-9977

[6] G. Găşpăresc, "PID control of a DC motor using Labview Interface for Embedded Platforms," 2016 12th IEEE International Symposium on Electronics and Telecommunications (ISETC), Timisoara, 2016, pp. 145-148.

[7] S. K. Suman and V. K. Giri, "Speed control of DC motor using optimization techniques based PID Controller," 2016 IEEE International Conference on Engineering and Technology (ICETECH), Coimbatore, 2016, pp. 581-587.