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Modeling and Fuzzy Logic Control of the Doubly Fed Induction Generator used in Wind Power and Application to the Industrial Context with an Equivalent Photovoltaic System

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Abstract: ***In this paper, we are first going to present two different renewable energy systems based on wind and photovoltaic energy in order to provide an industrial site with electrical power. This study will continue with the sizing of these systems and the assessment of their performances through a technical and economic comparison. The results show that wind energy have a low impact and a reasonable economic cost. In the second part of this paper, we are going to focus on the modelling of a Doubly Fed Induction Generator (DFIG) used in wind systems in order to compare its performances to a squirrel cage generator (SCG). Final part has been attempted to presents the comparative study of Proportional Integral (PI), Proportional Integral Derivative (PID) and fuzzy controllers. The simulations of the operation of the different generators are done with MATLAB/SIMULINK and our results are presented and analysed at the end of this work.***

Keywords: Photovoltaic Energy, Wind Energy, DFIG, SCG, Fuzzy.

I. INTRODUCTION

During recent decades, wind and solar systems have received increased attention, and have been widely used as a suitable power sources:

- Wind energy is defined simply as the technology that convert the kinetic energy of wind into electricity through electrical generators. Nowadays, the most widely used generator type in wind system is the doubly fed induction machine. Indeed, doubly fed induction machines allow active and reactive power control through a rotor-side converter, while the stator is directly connected to the grid.

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- Photovoltaic energy is also a different renewable energy and it is defined as the technology that changes sunlight energy into electricity without using moving parts.
  A photovoltaic system employs very often solar modules, each comprising a number of solar cells, which generate electrical power. Photovoltaic installations may be ground-mounted, rooftop mounted, wall mounted or floating. The mount may be fixed, or use a solar tracker to follow the sun across the sky.

The paper is organized as follows. Section 2 is devoted to the comparison of technical and economic performances of wind and photovoltaic energy used to provide an industrial site with electricity. Section 3 presents an analysis of the two generators performances used in wind systems asynchronous generator: Doubly Fed Induction Generator (DFIG) and Squirrel Cage Generator (SCG). Section 4 is devoted to the control and assessment of three regulators used in the vector control for the DFIG: Proportional Integral (PI), Proportional Integral Derivative (PID) and fuzzy logic controller rectification is not possible.

II. INTEGRATION OF PHOTOVOLTAIC AND WIND ENERGY AT AN INDUSTRIAL SITE

The purpose of this study is to establish a technical and economic comparison of wind and photovoltaic energy wile used as main power sources (3MW) of an industrial site:

- The solar irradiance and ambient temperature data are provided by local weather reports as shown in " Fig. 1" , " Fig. 2" and " Fig. 3" .
- The wind speed data is provided by a website specialized in weather measurements as shown in " Fig. 3" .

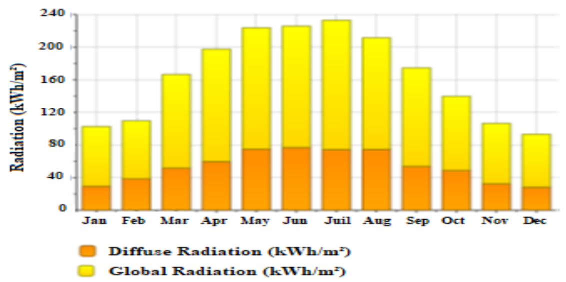


Fig. 1.Region radiation

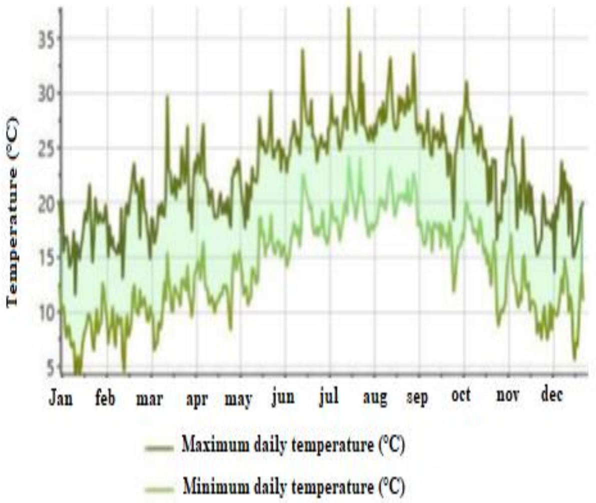


Fig. 2.Maximum and minimum temperature of the region

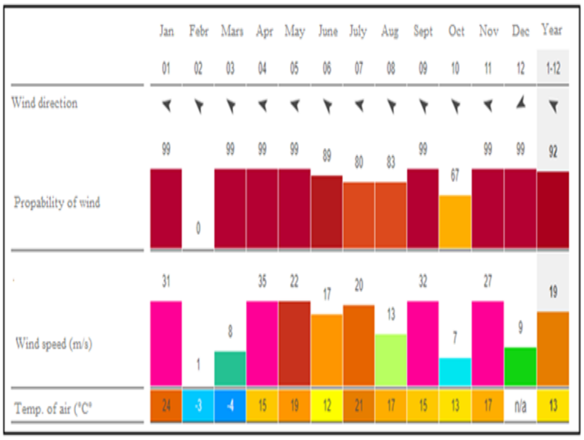


Fig. 3.Wind statistics for ELJADIDA from the year 2018

According to these data, both photovoltaic and wind energies potential can be interesting for this industrial site. Therefore, to make comparison between these two systems, we need to size these wind and solar systems and to compare their investment cost and environment impact.

A. Wind system

The choice of the axis and the generator type is an important criteria for the sizing of any wind system. For this study, the wind turbine with a horizontal axis and a doubly fed induction generator is chosen for its obvious benefits. The model of our system is schematized in the "Fig. 4".

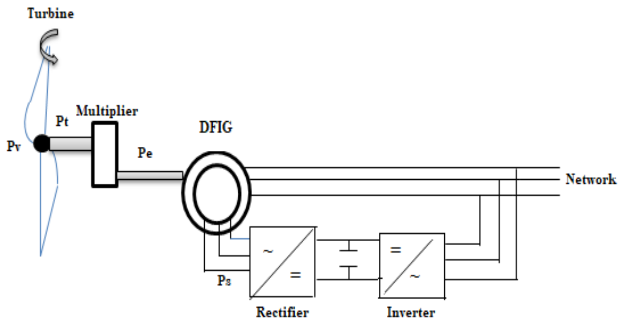


Fig. 4.Power transmission energy model

The wind turbine have a nominal power transmitted to the grid of 3 MW and the following data:

Table- I: Calculations assumption

Description	*Value*	*Symbol*
Rotation speed	1500 tr/min	N
Density of the air	1,5 kg/m^3	φ
Voltage at the generator output	690 V	U
Nominal wind speed	10 m/s	v
Aerodynamic coeffcient	0,48	Cp
Multiplier yield	96%	η
Power factor	0,86	Cos (Ø)
Genrator type	DFIG	

The entering mechanical power of the generator is given by the following formula:

$$Pe = Ps\,/\,\eta \;= 3{,}1\ MW \quad (1)$$

The mechanical power transmitted to the multiplier is given by the following formula:

$$Pt = Pe\,/\,\eta \;= 3{,}2\ MW \quad (2)$$

The power of the wind transmitted to the turbine is given by the following formula:

$$Pvent = Pt\,/\,Cp \;= 6{,}7\ MW \quad (3)$$

The surface swept by the blades is given by the following formula:

$$S = 2.\ Pvent\,/\,(\varphi.v^3) \;= 8933\ m^2 \quad (4)$$

After the comparison of different wind turbines, we are going to chise the characteristics shown in the following table because they are the most suitable to our case.
This wind turbine provides its nominal power while wind speed is above 10 m/s.
The three blades have a length of 132 m. The nominal power of the turbine is 3,4 MW.

Table- II: Wind turbine characteristics

Description	*Value*	*Symbol*
Nominal Power	3,4 MW	P
Surface swept by the blades	13685 m²	S
Length of the three blades	132 m	D
Voltage at the generator output	690 V	U
Frequency	50 Hz	F

B. Solar system

The sizing of photovoltaic system is done according to the following methodology:Each author profile along with photo (min 100 word) has been included in the final paper.

- Determination of losses and peak power;

$$Pc = Pond\,/\sum Pertes \;= 3{,}47\ MWc \quad (5)$$

- Choice of panels and inverter: solar panel based on polycrystalline Si & centralized topology of inverter;
- Calculation of the number of panel;

$$N = 1 + E\,(Pc\,/\,Ppv) = 1 + E\,(3,47\,/\,275) = 12619 \quad (6)$$

- Sizing of the inverters: according to the manufacturer data, we are going to chose two inverters with a 2800 KWp power each of them. The choice is done by using the following formulas;

$$Nmaxs = E\ (Umax\ /\ (Uco\ .Ku)) = 36 \quad (7)$$

$$Nmins = E\ (Umin\ /\ (Umpp\ .Ku)) = 27 \quad (8)$$

$$Nmaxp = E\ (Imax\ /\ (Impp\ .Ku)) = 215 \quad (9)$$

With:

N: Number of panels
E(x): Integrer part of x
Pc: Peak power of the panel
Ppv: Peak power of each PV panel used
Pond: Nominal wind speed
∑*Pertes*: Major losses likely to disrupt the production of a photovoltaic installation
Umax, Umin: Maximum and minimum permissible input voltage of the inverter
Umpp: Maximum power voltage of the photovoltaic modules
Uco: Open circuit voltage of the photovoltaic modules
Ku: Coefficient, which is written in the following equation:

$$Ku = 1 + (\alpha U\ /\ 100).\ (T - 25) \quad (10)$$

αU: Coefficient of variation of the module in temperature (% / °C)
T: Nominal temperature of use of the cells
Nmaxs: Maximum number of modules in series
Nmins: Minimum number of modules in series
Nmaxp: Maximum number of modules in parallel

The following tables show the characteristics of the selected inverters and photovoltaic panels.

Table- III: Inverters characteristics

Description	*Value*
Recommended PV array power range	2778 – 3648 KWp
Maximum voltage	1500 V
Maximum current	1850 A per power block
N° input with fuse holders	Up to 12 with the combiner box
Frequency	50/60 Hz

Table- IV: Photovoltaic panels characteristics

Description	*Value*
Maximum power	275 Wp
Maximum power voltage	32 V
Maximum power current	8,61 A
Nominal operating cell temperature (NOCT)	45 +- 2°C
Open circuit voltage (Uco)	39,1 V
Temperature coefficients of Uco	-0,30 %/°C
Temperature coefficients of Pmax	-0,40%/°C

C. Profitability of photovoltaic & wind energy systems

The cost of the wind system of the wind turbine, which produce an energy of 3,4MW, is equal to 4,4M€ (This cost also includes the installation price). The annual maintenance cost of a similar wind system is equal to 200k€ [1].

The total cost of investment and maintenance of the photovoltaic panel are respectively equal is around 3,7M€ (including the installation of a 240k€ inverter and its annual maintenance).

Therefore, compared to a wind system with the same nominal power, the price of the photovoltaic panels is less expensive.

To calculate the CO_2 eq. Emissions (quantity of non-renewable energy used for the manufacturing of photovoltaic or wind power installations), we are going to use the data issued from the ADEMEE's database (Agency of the environment and the mastery of the energy). This analysis demonstrates that the PV systems have an important effect on the environmental impact estimated to 55 g CO_2 eq. /KWh compared to 12,7g CO_2 eq. / KWh for wind system [2]. In addition, the area occupied by the photovoltaic panels is very important (around 20655m²) contrary to wind turbines (around 13685m²).

In conclusion, the energy produced with wind systems needs less component/space- and is more cost efficient but with a low environmental impact compared to photovoltaic energy.

III. PERFORMANCES BETWEEN OF TWO ASYNCHRONOUS GENERATOR IN WIND CHAIN

A. The models of SCG and DFIG machines

For the 3-phase stator and rotor, the model of asynchronous squirrel cage machine is summarized by the following condensed equations:

$$[Vsabc] = [Rs].\ [Isabc] + d/dt\ [Øsabc] \quad (11)$$

$$[Vrabc] = [Rr].\ [Irabc] + d/dt\ [Ørabc]\ \#\ 0 \quad (12)$$

With:

[Vsabc]& [Vrabc]: Three phase stator and rotor voltage of the asynchronous machine
[Rs]& [Rr]: Resistance of stator and rotor phase
[Isabc]& [Irabc]: Three phase stator and rotor current of the asynchronous machine
[Øsabc]& [Ørabc]: Feed phase stator and rotor current of the asynchronous machine.

After the transformation (Park), we get the following components along the axis d and q, for the stator voltages:

$$Vds = Rs.\ Ids + d/dtØds - \omega sØqs \quad (14)$$

$$Vqs = Rs.\ Iqs + d/dtØds - \omega sØqs \quad (15)$$

$$Vdr = Rs.\ Idr + d/dtØdr - \omega rØqr \quad (16)$$

$$Vqr = Rs.\ Iqr + d/dtØdr - \omega rØqr \quad (17)$$

To adequately control the electricity production of the wind, we will achieve independent control of active and reactive powers Ps and Qs stator. The reference (dq) is oriented so that:

$$Ps = -(Vs.M)/(Ls.iqr) \quad (18)$$

$$Qs = -(Vs.M)/(Ls.idr) + Vs^2/(Ls.\omega s) \quad (19)$$

$$Cem = -p.M/(Ls.\O ds.iqr) \quad (20)$$

$$\O ds = Ls.\,Ids + M.idr \quad (21)$$

$$\O qs = Ls.\,Iqs + M.iqr \quad (22)$$

$$\O dr = Lr.\,Idr + M.ids \quad (23)$$

$$\O qr = Lr.\,Iqr + M.iqr \quad (24)$$

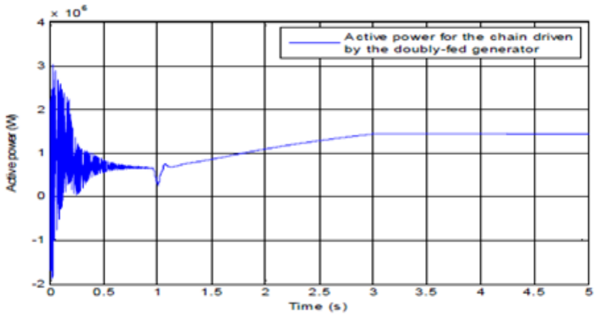
With:

Ls & Lr: are respectively cyclical inductance of a stator and rotor phase

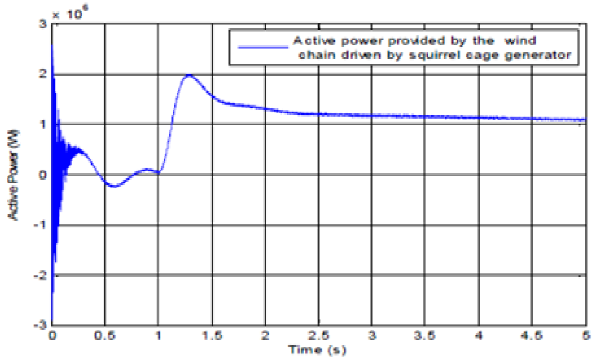
p: number of pair of pole.

B. Results of the comparison between this two type of machines

With the same characteristics (nominal power: 1,5MW, voltage: 660V…), we observe the following results:

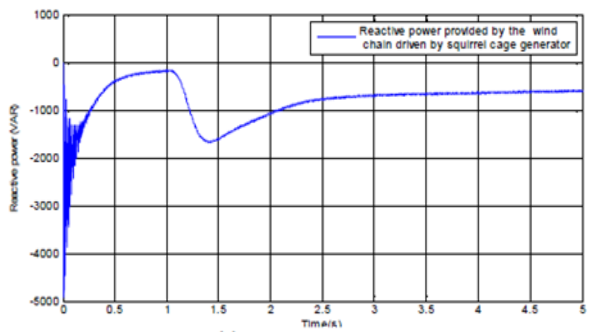


(b)

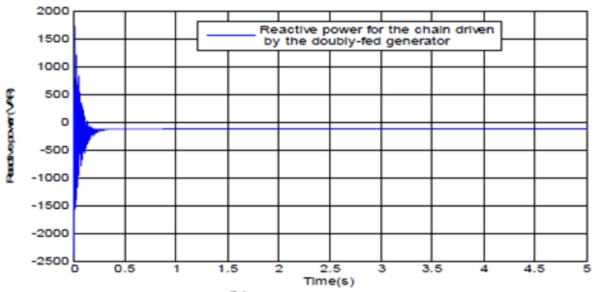


(a)

Fig. 5.(a) Active power supplied by the chain driven by SCG. (b) by DFIG.



(a)



(b)

Fig. 6.(a) Reactive power supplied by the chain driven by SCG. (b) by DFIG

In this paragraph, we note that the two channels go through a transitional period of almost 3 seconds.

The active power is more important in the DFIG machine more than 27%.

The difference between the reactive powers for two-output machine is obvious: the machine with a DFIG has a reactive power of almost zero [3].

IV. DFIG AND CONTROL METHODS

A. The different models of the vector control

To facilitate the control of the electrical production of the wind turbine, we are going to realize an independent control of active and reactive stator powers Ps and Qs [4].

The currents Iqr and Idr are such that:

$$Vdr = Rr.idr + (Lr - M^2/Ls).\,d/dt\ idr - g.\omega s(Lr - M^2/Ls).iqr \quad (25)$$

$$Vqr = Rr.iqr + (Lr - M^2/Ls).\,d/dt\ iqr - g.\omega s(Lr - M^2/Ls).idr + g.(M.Vs/Ls) \quad (26)$$

From “(18)”, “(19)”, “(25)”and “(26)”, we can establish the relations between the voltages applied to the rotor of the machine and the stator powers that this generates, which allows us to describe the Block of the doubly fed induction generator (DFIG).

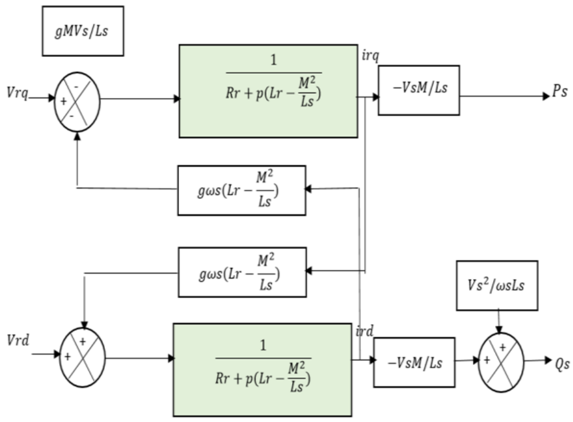


Fig. 7.Block diagram of the DFIG

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We note that with a low value of slip g, we can establish the vector control because the influences of the couplings will remain low and the axes d and q can be separately controlled with their own controllers [5].
The direct control consists to neglecting the terms of coupling between both axes because of the low value of the slip.
The indirect control takes into account the coupling between d and q axis.
We obtain then a vector control with a single regulator per axis for the direct control and with two regulators per axis for the indirect control as shown in "Fig.8", "Fig.9", "Fig.10" and "Fig.11".

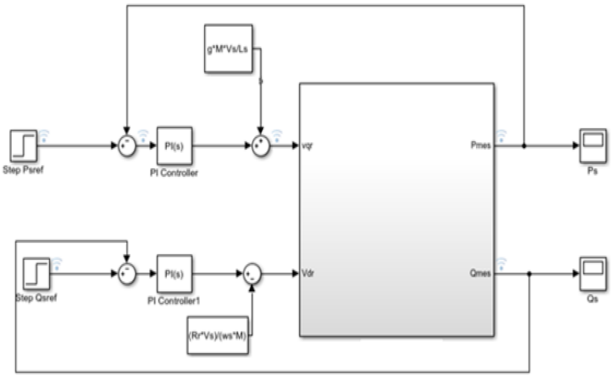

Fig. 8.Direct vector control with classical regulator PI

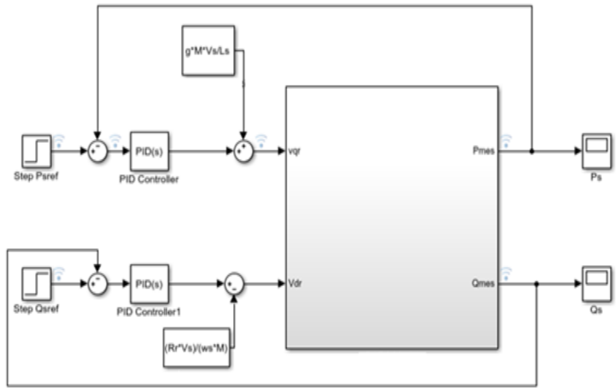

Fig. 9.Direct vector control with regulator PID

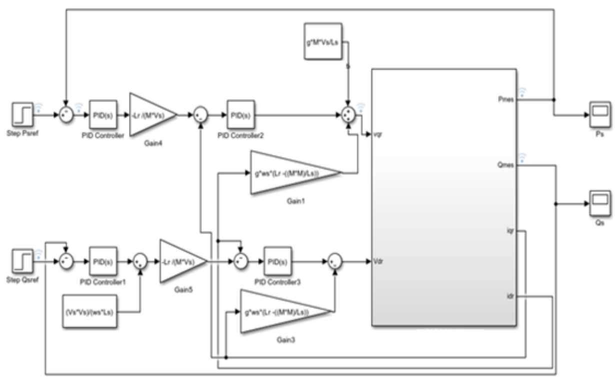

Fig. 10. Indirect vector control with classical regulator PID

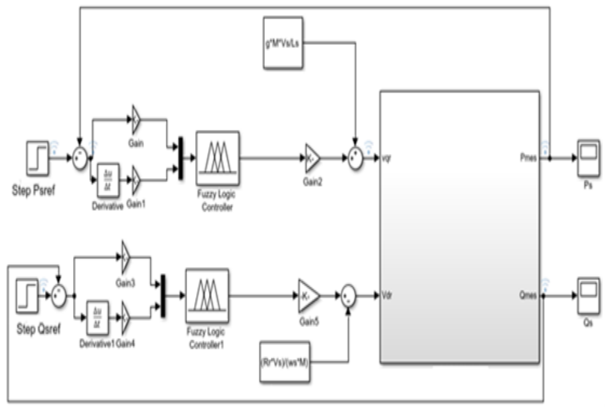

Fig. 11. Direct vector control with fuzzy logic controller

We tested these systems under different parameters of active and reactive power in order to observe the behavior of its regulation and the response of the regulators [5].

B. Results of this types of vector control

The following figures show the powers generated under different reference signals.

We observe that the response is similar to the reference despite the use of different types of controllers. We also note that the fuzzy logic controller is faster than PID and PI controller.

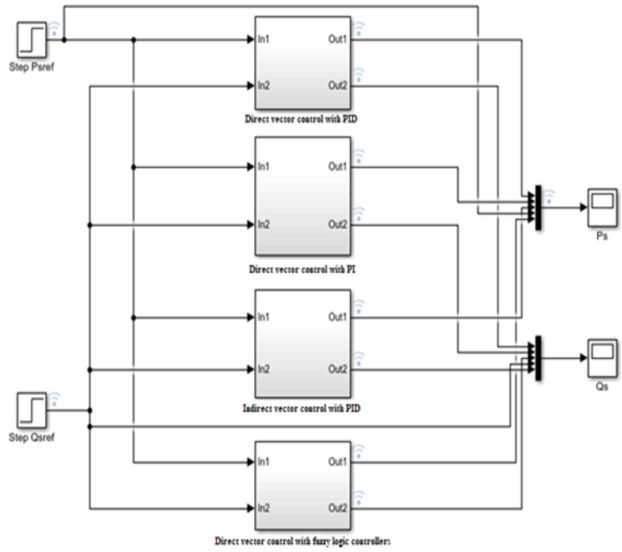

Fig. 12. Block diagram of the different proposed systems

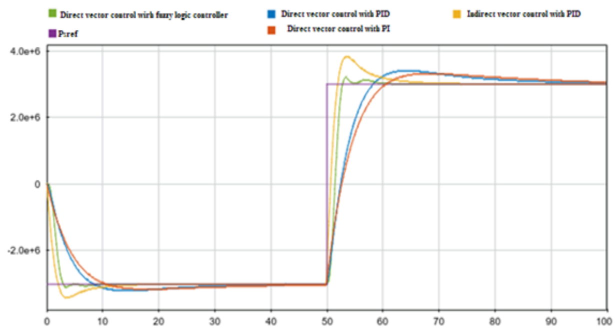

Fig. 13. Active stator power in different vector control types

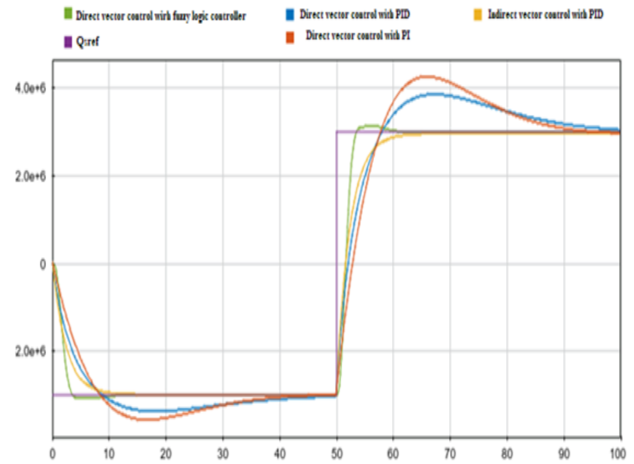

Fig. 14. Reactive stator power in different vector control types

The comparison between these different types of regulation is presented in the following table:

Table- V: Name of the Table that justify the values

Type of control	*Response time*	*Rise time*	*Peak time*	*Overflow*
Fuzzy control	P: 4,3 s	P: 2,2 s	P: 3,8 s	P: 6,66 s
	Q: 8,1 s	Q: 2,6 s	Q: 5,5 s	Q: 4,33 s
Direct control based on PI controllers	P: 37,4 s	P: 9,4 s	P: 16,97 s	P: 10 s
	Q: 37,4 s	Q: 6,9 s	Q: 16,6 s	Q: 42 s
Direct control based on PID controllers	P: 33,2 s	P: 8,4 s	P: 13,7 s	P: 13,3 s
	Q: 43,5 s	Q: 7,5 s	Q: 18,2 s	Q: 28,6 s
Indirect control based on PID controllers	P: 12,6 s	P: 2,17 s	P: 3,6 s	P: 0 s
	Q: 10 s	Q: 9,2 s	Q: 0 s	Q: 0 s

V. CONCLUSION

In the first part, the experimental results show that the wind system can produce more power than photovoltaic panels and use less components/space and is more cost efficient.

In the second part, we can conclude also from this study that, for both types of machines (DFIG and SCG), all variables are stable during continuous operation, which shows that the system works properly. Indeed, the active power produced is more important while using the DFIG.

Finally, we noticed that the use of the fuzzy control improves the robustness of the system despite of any variation of meteorological parameters. Indeed, if the set points are changing, the response of the system remains perfectly controlled with the fuzzy control method.

On the next step, we are going continue our works on the DFIG machines in order to study others types of controls like: RST regulation and fuzzy neuro. We are also going to study a wind system without multipliers/reducers.

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REFERENCES

1. (Environnment and energy control agency, Cost of renewable in France). (2016). Available: https://www.ademe.fr/couts-energies-renouvelables-france (URL)
2. (Sustainable network, thinking about networked energy. (2016). Available: https://reseaudurable.com/bilan-carbone-production-electricite-france (URL)
3. A. Wahabi, F. Bounifli, and A. Elmoudden, "Comparaison of the performances of two asynchronous generators used in wind energy conversion", IJIET, vol. 9, December 2017, pp. 1–8.
4. F. Bounifli, A. Elmoudden, A. Wahabi, and A. Hmidat, "Vector control of a doubly fed induction generator by using a classical PI and fuzzy controllers", WJIR, vol. 1, December 2016, pp. 18–24.
5. F. Bounifli, A. Wahabi, and A. Elmoudden, "The modeling of the wind system and contribution to the control of doubly fed induction generator with using fuzzy logic", IJIET, vol. 8, April 2017, pp. 311–318.
6. F. Bounifli and A. Elmoudden, "Comparison of the performances between vectoriel control and fuzzy logic control of doubly fed induction generator", AMT conference, April 2018.
7. S. El Aimani, B. François and B. Robynus, "Modeling and simulation of doubly fed induction generator for variable speed wind turbines integrated in distribution network", 10th European conference on power electronics and applications, Toulouse, France, 2003.
8. C. Bourillon, "Wind energy clean power for generations, renewable energy", vol. 16, pp. 948-953, 1999.
9. G. ABAD "Predictive direct control techniques of the doubly fed induction machine for wnd energy generation applications", PhD Thesis, Spain, 2008.
10. Y. Djeriri and A. Meroufel "A comparative study between field oriented control stratefy and direct power control strategy for DFIG", JEE, vol. 14, pp. 159-168, June 2014.
11. A. Wahabi, A. Elmoudden, F. Bounifli and K. Senhaji Rhazi, "Comparative study between two types of wind chains", IJARSET, vol. 3, October 2016, pp. 2840–2846.
12. A. Wahabi, A. Elmoudden, F. Bounifli and A. Aarib, "Improved performance of a wind energy conversion chain driven by an asynchronous generator doubly fed and using a R-L filter", IJECCE, vol. 6, March 2015, pp. 255–262.
13. A. Elmoudden, A. Aarib, A. Wahabi and F. Bounifli, "Command of active and reactive stator powers of the doubly fed induction generator used in wind energy", IJETAE, vol. 4, October 2014, pp. 79–87.
14. A. Elmoudden, A. Wahabi, F. Bounifli and A. Sandali, "Control and oprimization of the energy produced by a chain of wind energy conversion controlled by a double fed asynchronous generator", CTTS, vol. 3, June 2016, pp. 260–267.

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