PI and Fuzzy DC Voltage Control For Wind Pumping System using a Self-Excited Induction Generator

Rachid EL AKHRIF, Ahmed ABBOU, Mohamed BARARA, Youssef MAJDOUB and Noureddine SKIK
Electric Engineering Department,
The Mohammadia School's of Engineers
Avenue Ibn Sina, B.P 765, Agdal, Rabat
MOROCCO
elakhrif@gmail.com, abbou@emi.ac.ma, mohamed-barara@hotmail.fr,
youssef_maj@hotmail.com, noureddine.skik@gmail.com
http://www.emi.ac.ma

Abstract: - Self excited induction generator has become very popular for generating power from renewable energy source in isolated areas, Their main disadvantage is poor voltage regulation under varying speed and load condition, This paper present indirect vector control strategy using DC voltage regulators proportional integral (PI), classical and Fuzzy, applied to the wind pomping system using a Self-excited induction generator (SEIG), The comparison between the two methods under the same conditions is illustrated by simulations.

Key-Words: Wind pumping system, DC motor pump, Self-excited Induction generator, PI controller, Fuzzy logic controller.

1 Introduction

The growing demand of water in rural zones and remote areas where no electricity supply is available [1] made that a growing interest is done to the utilization of renewable energy as source for pumping system. The proposed system will make use of a clean energy.

Many types of generator concepts have been used and proposed in pumping system. The Self-excited induction generators (SEIG) are among the most popular especially in isolated areas, because they do not need an external supply to produce the excitation magnetic field.

The limitation of SEIG in autonomous systems is the inability to control the DC bus voltage and frequency with the variation in load and wind speed[2]. To resolve this issue different control strategies have been adopted by different searches: Indirect vector control and deadbeat current control used with a voltage source PWM converter [7], Space vector pulse width modulation technique in [6] and [9], a stator flux control strategy is adopted in [8]. The research is oriented more towards the application of modern control techniques, such as fuzzy logic [10], the adaptive control [11], Universal Learning Networks[5], Artificial Neural Networks[4], sliding mode control, etc.

the proposed method present many advantages over the already treated approaches [3] in terms of maintaining the DC bus voltage despite variations in speed and operation of the pumping system in good conditions.

In this paper, a vector control system of the SEIG based on an indirect rotor field-oriented (IRFO) control algorithm [12] is proposed to keep the DC voltage of wind pumping system constant for all conditions.

The system includes a SEIG as the primary energy source. The output of the SEIG is directly connected to the IGBT converter which converts it to a DC voltage. the output voltage fed a DC motor coupled with a centrifugal pump.

This work is organized as follows: in a first part we present the control system topology and in the second part we compare two methods of control strategy: A closed loop scheme employing a PI controller and Fuzzy logic based voltage controller. Simulation results are discussed in section four. Finally a conclusion resumes the developed work.

2 The proposed control of self-excited induction generator

The control block diagram of the wind pumping system is shown in fig.1.

The following section present the mathematical model of the proposed system.

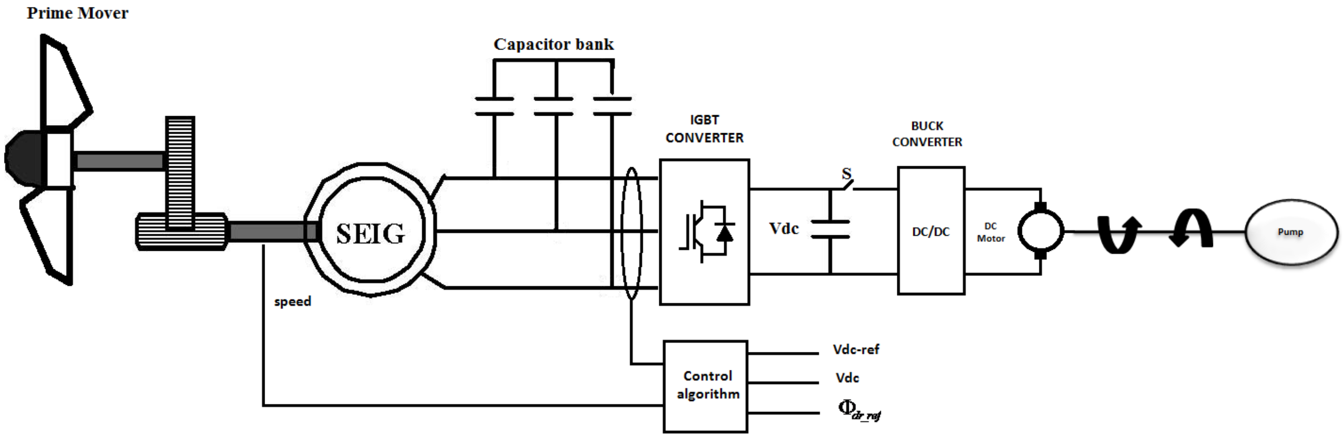

Fig. 1. The configuration of the proposed system

3 Modeling of the Control System Components

3.1 SEIG model

In general, application of the vector control algorithm requires a dynamic SEIG model to be defined. Such model can be obtained by modification of the conventional dynamic model of an induction machine, as described in [12]. The conventional dynamic SEIG model, expressed in the Laplace domain and suitable for use in MATLAB Simulink, is described in the stationary reference frame by the following 1st order differential equations:

$$\begin{cases} si_{s\alpha} = \dfrac{1}{\sigma L_s L_r}(L_m^2\omega_r i_{s\beta} - L_r R_s i_{s\alpha} + L_m\omega_r L_r i_{r\beta} + L_m R_r i_{r\alpha} - L_r u_{s\alpha} - L_m K_{r\alpha}) \\ si_{s\beta} = \dfrac{1}{\sigma L_s L_r}(-L_r R_s i_{s\beta} - L_m^2\omega_r i_{s\alpha} + L_m R_r i_{r\beta} - L_m\omega_r L_r i_{r\alpha} - L_r u_{s\beta} - L_m K_{r\beta}) \\ si_{r\alpha} = \dfrac{1}{\sigma L_s L_r}(L_m R_s i_{s\alpha} - L_s\omega_r L_m i_{s\beta} - L_s\omega_r L_r i_{r\beta} - L_s R_r i_{r\alpha} + L_m u_{s\alpha} - L_s K_{r\alpha}) \\ si_{r\beta} = \dfrac{1}{\sigma L_s L_r}(L_m R_s i_{s\beta} + L_s\omega_r L_m i_{s\alpha} - L_s R_r i_{r\beta} + L_s\omega_r L_r i_{r\alpha} + L_m u_{s\beta} - L_s K_{r\beta}) \end{cases} \quad (1)$$

where:

- $u_{s\alpha}$ and $u_{s\beta}$ are the α-axis and β-axis component of the stator phase voltage space-vector;
- $i_{s\alpha}$ and $i_{s\beta}$ are the α-axis and β-axis component of the stator phase current space-vector;
- $i_{r\alpha}$ and $i_{r\beta}$ are the α-axis and β-axis component of the rotor phase current space-vector;
- R_s and R_r are the stator and rotor resistance, respectively;
- L_s, L_r and L_m are the stator inductance, the rotor inductance and the magnetizing inductance, respectively;
- ω_r is the rotor angular speed;
- σ is the total leakage factor;
- $K_{r\alpha}$ and $K_{r\beta}$ are the α-axis and β-axis component of the voltage initially induced due to the residual rotor flux linkage.

Fig. 2 shows the conventional SEIG equivalent circuit described by (1).

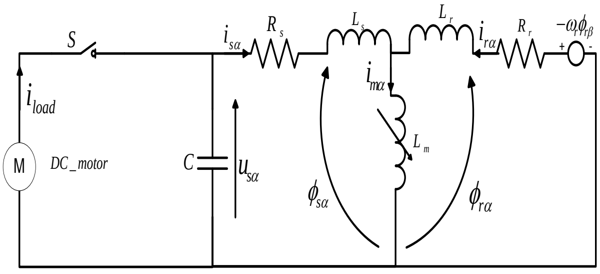

Fig. 2. The conventional SEIG equivalent circuit in α-axis

The DC link can be described by the following equation:

$$u_{dc} = -\frac{1}{C}\int_0^t (i_{dc} - i_{load})dt + u_{dc0} \quad (2)$$

The relation between magnetizing inductance (Lm) and phase voltage for induction machine was obtained experimentally taken from reference [13].

3.2 Buck Converter Model

The DC–DC converter is a buck. It is inserted between the IGBT converter and the DC motor in order to reduce the DC voltage. One can define the buck gain K as the ratio between the output and the input mean voltages or the input and output mean currents when the conduction regime is continuous. So, if the chopping frequency is sufficiently higher, which is the case at low power levels, one can replace the converter with an equivalent pure gain model [14].By considering the mean values of the electric quantities over a chopping period, on can write:

$$\begin{cases} Vm = K * u_{dc} \\ i_{load} = K * im \end{cases} \qquad (3)$$

3.3 DC motor pump model

The dynamics of a DC motor and centrifugal pump presented in Fig.3, may be expressed as [15]:

$$\begin{cases} V_m = R_m i_m + L_m \dfrac{di_m}{dt} + K_e \omega \\ J \dfrac{d\omega}{dt} = K_m i_m - K_r \omega^2 \end{cases} \qquad (4)$$

where ω and J are respectively the rotation speed and the moment of inertia of the group, K_m is the torque constant, M is the motor inductance, R is the resistance of motor K_r is the coefficient of the proportionality and K_e is the electromechanical coupling constant, i_m is the current motor and V_m is the voltage motor.

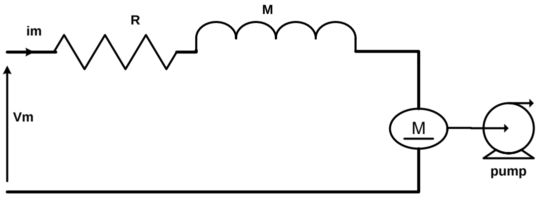

Fig. 3. Electrical model of the DC motor

3.4 Control Algorithm

We use the same control algorithm proposed in [12]. It is shown in Fig. 4.

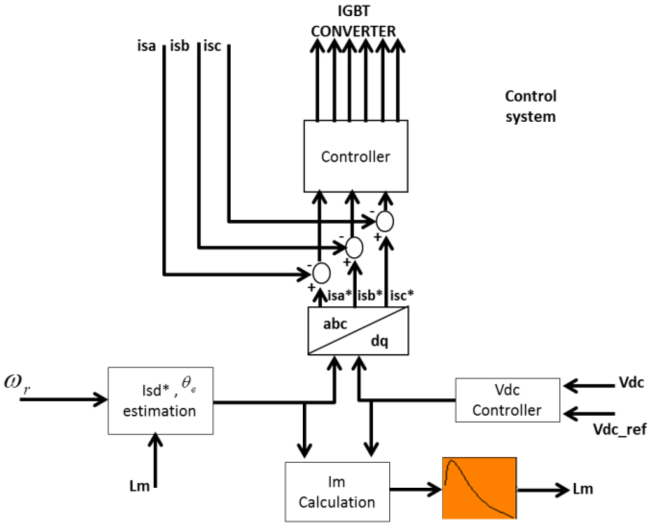

Fig. 4. Vector control algorithm

The block diagram of the proposed control system that
consists of two parts.

3.4.1 DC Voltage Regulation with Conventional PI

The corrector in the external control loop of the IRFO controller is used to regulate DC side voltage and to generate magnitude of the reference line current.

The error between the reference and actual DC voltage is processed by PI controller (Fig.7)

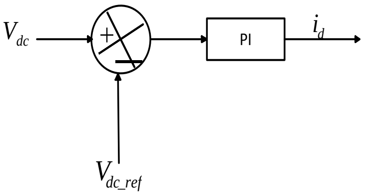

Fig. 5. Structure with classical PI

3.4.2 DC Voltage Regulation with Fuzzy Controller

In this paper, we are developed a fuzzy logic controller which the block diagram is shown in fig. 6, where the variables Kp, Ki and B are used to tune the controller.

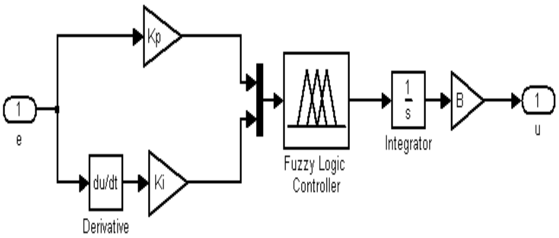

Fig. 6. PI Fuzzy controller

One possible initial rule base, that can be used in drive systems for a fuzzy logic controller, consist of 49 linguistic rules, as shown in Table 1, and gives the change of the output of fuzzy logic controller in terms of two inputs: the error (e) and change of error (de). The membership functions of these variables are given in Fig.7:

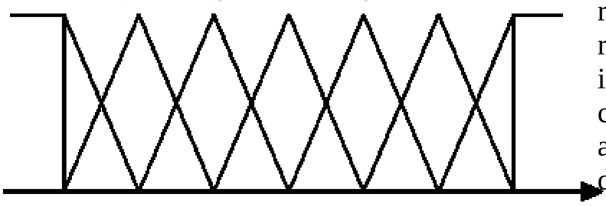

Fig. 7. Membership functions

TABLE.1:Fuzzy Rules Bases

e/de	**NL**	**NM**	**NS**	**ZR**	**PS**	**PM**	**PL**
PL	ZR	PS	PM	PL	PL	PL	PL
PM	NS	ZR	PS	PM	PL	PL	PL
PS	NM	NS	ZR	PS	PM	PL	PL
ZR	NL	NM	NS	ZR	PS	PM	PL
NS	NL	NL	NM	NS	ZR	PS	PM
NM	NL	NL	NL	NM	NS	ZR	PS
NL	NL	NL	NL	NL	NM	NS	ZR

In Table 1, the following fuzzy sets are used: **NL** negative large, **NM** negative medium, **NS** negative small, **ZR** zero, **PS** positive small, **PM** positive medium and **PL** positive large. For example, it follows from Table 1 that the first rule is:

IF e is **NL** and **de** is **NL** then **du** is **NL**

The linguistic rules are in the form of **IF-THEN** rules and take form: **IF** (**e** is **X** and **de** is **Y**) **THEN** (**du** is **Z**), where **X**, **Y**, **Z** are fuzzy subsets for the universe of discourse of the error, change of error and change of the output. For example, **X** can denote the subset **NEGATIVE LARGE** of the error etc. On every of these universes is placed seven triangular membership functions (fig.7). It was chosen to set these universes to normalized type for all of inputs and output. The range of universe is set to -1 to 1.

4 Simulation Results And Discussion

The simulation conditions are given in the appendix. In order to demonstrate the effectiveness of the proposed method, the controlled wind pumping system is tested when the system is subjected to step change in the wind speed at no-load and load condition .

4.1 Step Change In Wind Speed With No-Load

The proposed system starts excitation process from capacitors bank of 1000μF and variation rotor speed (Fig.8) 185 rad/s, 220 rad/s, 175 rad/s to 195 rad/s as shown in Fig.10, Fig.11, indicate the variation of the generated DC current (*idc*), and stator voltage, Its observed that any variation in rotor speed of the SEIG is directly indicated by the variation in the terminal voltage and current of the generator.

Fig.9 shows the simulation results of the control constant DC voltage technique used classical PI and of the proposed method (fuzzy controller) A small peaks in the DC bus voltage is observed, but it recovers quickly due to the corrective action of the PI controller. The effectiveness is very remarkable with the DC voltage fuzzy control.

We can see that the system became more stable and more robust than when the conventional PI regulator was used. in this figure the overshoot completely disappears without using a filter and the response time is reduced.

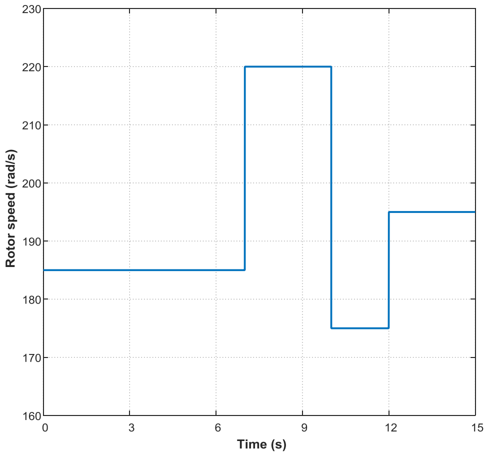

Fig. 8. Variation of rotor speed (rad/s).

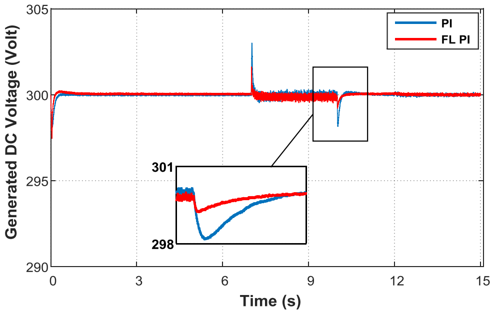

Fig. 9. Dc link voltage used classical PI and fuzzy controller during variable rotor speed

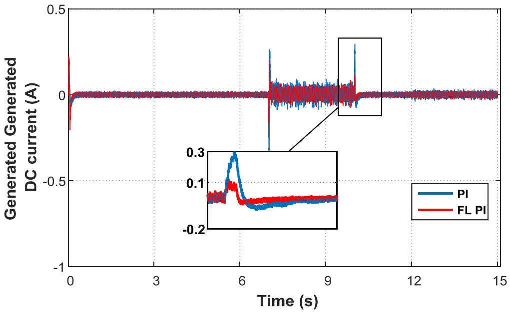

Fig. 10. Generated DC current used classical PI and fuzzy controller during variable rotor speed

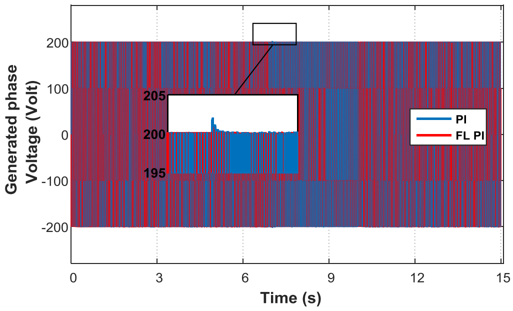

Fig. 11. Generated stator phase voltage(Va) during variable rotor speed

4.2 Step Change In Wind Speed With Load Condition

At constant speed , and after excitation we connect a DC-motorat t = 2s we, at t = 7s we chane speed (Fig.8).

Figs. [12-17] show the simulation responses of the actual DC voltage, generated DC current, reference d*q*-axis stator current, current and speed of the DC motor obtained for the fixed rotor speed. Its observed that the introduction of the DC motor is directly indicated by the variation in the terminal voltage and current of the generator.

The results confirm greater robustness of the FL controller to load variation in comparison with the classical PI.

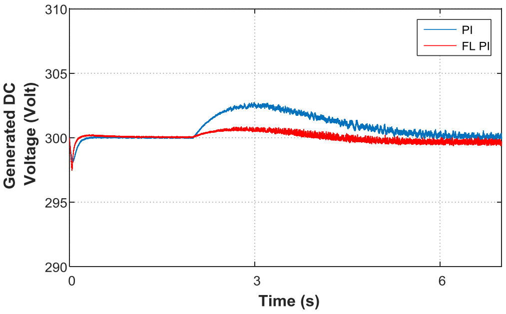

Fig. 12. Dc link voltage used classical PI and fuzzy controller during application of load (DC motor)

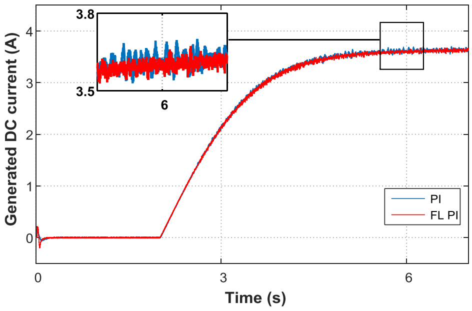

Fig. 13. Generated DC current used classical PI and fuzzy controller during application of load (DC motor)

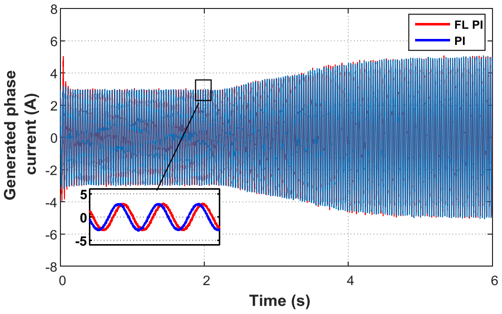

Fig. 14. Generated phase current used classical PI and fuzzy controller during application of load (DC motor)

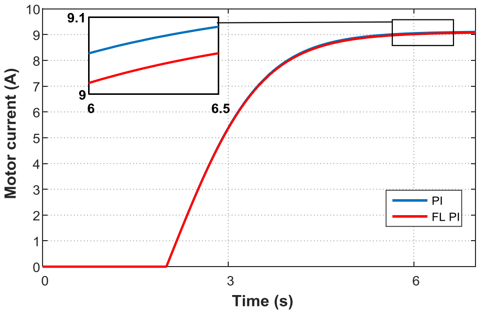

Fig. 15. Current of the DC motor

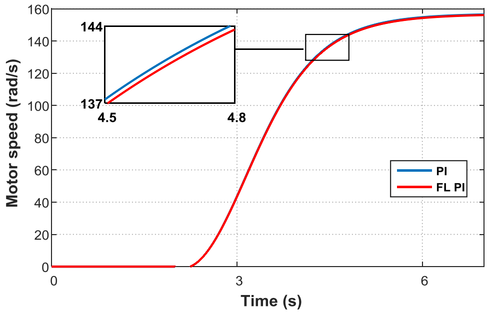

Fig. 16. speed of the DC motor

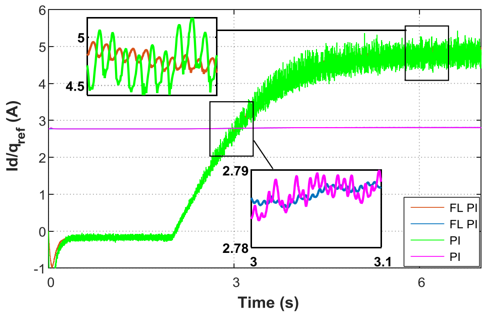

Fig. 17. Simulation for d-q-axis stator current

in Figs. [18-23] we observe the responses of the DC voltage, generated DC current, reference dq-axis stator current, current and speed of the DC motor. we confirm again that any variation in rotor speed of the SEIG is directly indicated by the variation in the terminal voltage and current of the generator. also the fuzzy logic controller give a good performance comparatively to the classical PI controller.

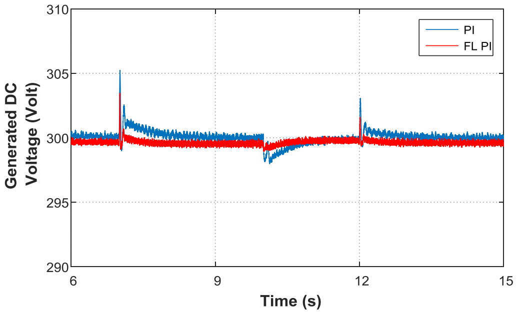

Fig. 18. Dc link voltage with load (DC motor) during variable rotor speed

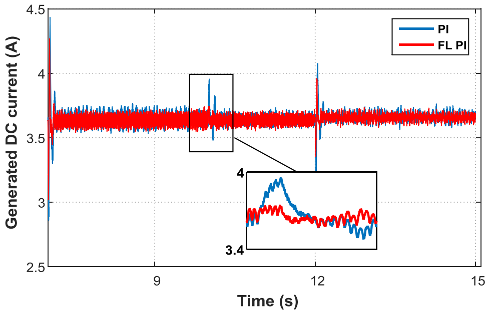

Fig. 19. Generated DC current with load (DC motor) during variable rotor speed

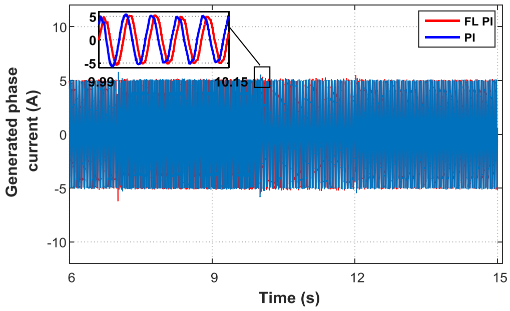

Fig. 20. Generated phase current with load (DC motor) during variable rotor speed

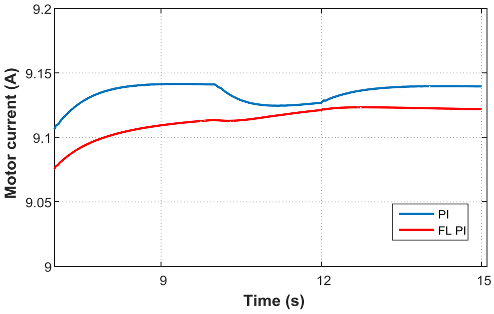

Fig. 21. Current of the DC motor during variable rotor speed

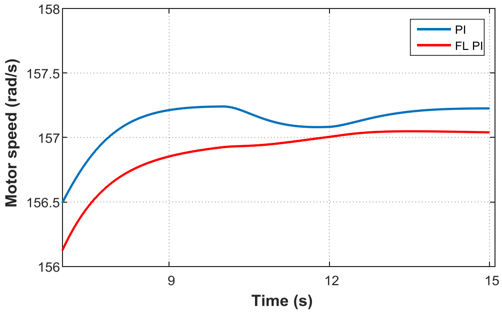

Fig. 22. speed of the DC motor during variable rotor speed

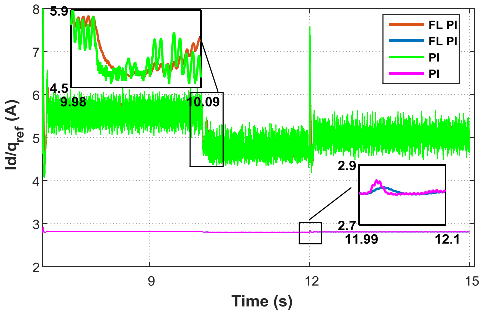

Fig. 23. Simulation for d-q-axis stator current

5 Conclusion

This paper is interesting on the modeling and simulation of wind pumping systems controlled by the vector oriented control, then the performance of the proposed FL controller was investigated and evaluated by comparison with the classical PI controller. The analysis covered rather wide ranges of rotor speed. The simulation results showed that the developed FL controller offer good performances in terms of overshoot/undershoot response time, settling time and robustness.

Appendix:

Induction machine parameters: Pn=1.5 kW, p=2, Un=380 V, Y, In=3.81 A, Nn=1391 rpm, Lm =0.4058 H, Lsσ=0.01823 H, Lrσ=0.02185 H, Rs=4.293 Ω, Rr=3.866 Ω (at 20 °C), Ψrn = 0.845 Wb.

DC motor-pump parameters: Vm=120 volt, Im=9.2A; J=0.02365 Kg.m2; R=1.5 Ω; M=0.2 H, Km=0.67609Nm.A-1; Kr=0.002387Nm.s.rad-1 Ke=0.00059 Nm.s.rad-1.

References:

[1] Marcos S. Miranda Renato O.C. Lyra and Selenio R. Silva, A Alternative Isolated Wind Electric Pumping System Using Induction Machine, IEEE Transactions on Energy conversion. 14(4): 1611- 1616, 1999.

[2] M. Barara, A. Abbou, M. Akherraz, A. Bennaser, D. Taibi, Comparative Study of PI and Fuzzy DC Voltage Control for a Wind Energy Conversion System, International Review on Modelling and Simulations (I.RE.MO.S.), Vol. 6, N. 2 April 2013.

[3] Miranda, M.S.; Lyra, R.O.C.; Silva, S.R, An alternative isolated wind electric pumping system using induction machines, Energy Conversion, IEEE Transactions, On page(s): 1611 - 16 Volume: 144, Issue: 4, Dec 1999.

[4] K. Premalatha, S. Sudha, Self-Excitation and Voltage Control of an Induction Generator in an Independent Wind Energy Conversion System, International Journal of Modern Engineering Research (IJMER) Vol.2, Issue.2, Mar-Apr 2012 pp. 454-461.

[5] M. Bašić, D. Vukadinović, and M. Polić, Fuzzy Logic vs. Classical PI Voltage Controller for a Self-Excited Induction Generator, in Proc. 4th Eur. Conf. AMATHI, Dubrovnik, 2013, pp. 189-194

[6] Karim H. Yousef, Manal A. Wahba, Hasan A. Yousef and Omar. A. Sebakhy, A New Method for Voltage and Frequency Control of Stand-Alone Self-Excited Induction Generator Using PWM Converter with Variable DC link Voltage, 2008 American Control Conference Westin Seattle Hotel, Seattle, Washington, USA June 1 1-13, 2008

[7] A. Abbou, M. Barara, A. Ouchatti, M. Akherraz, h.Mahmoudi, capacitance required analysis for self-excited induction generator, Journal of Theoretical and Applied Information Technology, Vol. 55, No.3,pp. 382-389, 2013.

[8] M.Bašić, D.Vukadinović, M.Polić, Fuzzy DC-Voltage Controller for a Vector Controlled Stand-Alone Induction Generator, International Journal Of Circuits, Systems And Signal Processing, Issue 3, Volume 7, 2013.

[9] Ahmed Hussein, Kotaro Hirasawa, Jinglu Hu, Online Identification And Control of A PV- Supplied DC Motor Using Universal Learning Networks, ESANN '2003 proceedings - European Symposium on Artificial Neural Networks Bruges (Belgium), 23-25 April 2003, d-side publi., ISBN 2-930307-03-X, pp. 173-178.

[10] Raja Singh Khela, K. S. Sandhu, ANN Model for Estimation of Capacitance Requirements to maintain Constant Air-Gap Voltage of Self-Excited Induction Generator with Variable Load, IJCST Vol. 2, Iss ue 4, Oct. - Dec. 2011

[11] Mohamed Barara, Ahemd Abbou, Mohammed Akherraz and abderrahim Bennasar, Modeling and Control Voltage of Wind Pumping Systems using a Self Excited Induction Generator, International Journal on Electrical Engineering and

Informatics - Volume 5, Number 2, June 2013.

[12] Mohamed Barara, Ahemd Abbou, Mohammed Akherraz and abderrahim Bennasar, Modeling and Control Voltage of Wind Pumping Systems using a Self Excited Induction Generator, International Journal on Electrical Engineering and Informatics - Volume 5, Number 2, June 2013.

[13] Raja Singh Khela, K. S. Sandhu, ANN Model for Estimation of Capacitance Requirements to maintain Constant Air-Gap Voltage of Self-Excited Induction Generator with Variable Load, IJCST Vol. 2, Iss ue 4, Oct. - Dec. 2011

[14] Ahmed Hussein, Kotaro Hirasawa, Jinglu Hu, Online Identification And Control of A PV- Supplied DC Motor Using Universal Learning Networks, ESANN '2003 proceedings - European Symposium on Artificial Neural Networks Bruges (Belgium), 23-25 April 2003, d-side publi., ISBN 2-930307-03-X, pp. 173-178.