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Field Oriented Control of a Dual Star Induction Generator using Fuzzy PI Controller

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***Abstract*— This paper presents a vector control of self-excited dual star induction generator equipping a wind turbine in remote site. The induction generator is connected to non linear load trough two PWM rectifiers. The fuzzy logic controller is used to ensure the DC bus voltage a constant value when change in speed and load conditions.**

***Keywords*— Self-excited dual star induction generator, vector control, fuzzy logic controller, PWM rectifiers, magnetizing current and magnetizing inductance estimation.**

I. INTRODUCTION

The first record of a multiphase motor drive, known to the authors, dates back to 1969, when a five phase voltage source inverter fed induction motor drive was proposed. During the next 20 years multiphase motor drives have attracted a steady but rather limited attention [1].

At present, the application area of multiphase induction machine is more and more abroad due to its advantages. First, there is reduction of the harmonic torque pulsations at a high frequency and of rotor harmonic currents, thereby minimizing rotor losses and the phase current in the machine and inverter without increasing the phase voltage. Other potential advantages are their high reliability and the possibility to divide the controller power on more inverter legs [2][3].

II. MODELLING OF SELF-EXCITED DUAL STAR INDUCTION GENERATOR

The model of dual star induction generator is the same as the dual star induction motor. The DSIG is composed of stator having two identical phase winding offset by an electrical angle $\alpha = 30°$, and a squirrel cage rotor [4-5].

The park model of the dual star induction generator in the references frame at the rotating field (d, q) is represented in Figure 1.

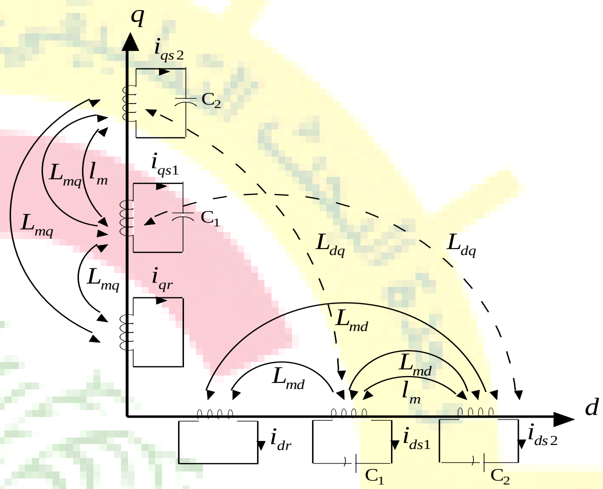

Fig. 1 Representation of dual star induction generator in the park frame

The electrical equations of the dual stator windings induction generator in the synchronous reference frame (d-q) are given as [6]:

$$v_{ds1} = -r_1 i_{ds1} - \omega_e \psi_{qs1} + p\psi_{ds1} \quad (1)$$

$$v_{qs1} = -r_1 i_{qs1} - \omega_e \psi_{ds1} + p\psi_{qs1} \quad (2)$$

$$v_{ds2} = -r_2 i_{ds2} - \omega_e \psi_{qs2} + p\psi_{ds2} \quad (3)$$

$$v_{qs2} = -r_2 i_{qs2} - \omega_e \psi_{ds2} + p\psi_{qs2} \quad (4)$$

$$v_{dr} = 0 = r_r i_{dr} - (\omega_e - \omega_r)\psi_{qr} + p\psi_{dr} \quad (5)$$

$$v_{qr} = 0 = r_r i_{qr} + (\omega_e - \omega_r)\psi_{dr} + p\psi_{qr} \quad (6)$$

The expressions for stator and rotor flux linkages are:

$$\psi_{ds1} = -L_{l1} i_{ds1} - L_{lm}(i_{ds1} + i_{ds2}) - L_{dq} i_{qs2} + L_{md}(-i_{ds1} - i_{ds2} + i_{dr}) \quad (7)$$

$$\psi_{qs1} = -L_{l1} i_{qs1} - L_{lm}(i_{qs1} + i_{qs2}) - L_{dq} i_{ds2} + L_{mq}(-i_{qs1} - i_{qs2} + i_{qr}) \quad (8)$$

$$\psi_{ds2} = -L_{l2} i_{ds2} - L_{lm}(i_{ds1} + i_{ds2}) - L_{dq} i_{qs1} + L_{md}(-i_{ds1} - i_{ds2} + i_{dr}) \quad (9)$$

$$\psi_{qs2} = -L_{l2} i_{qs2} - L_{lm}(i_{qs1} + i_{qs2}) - L_{dq} i_{ds1} + L_{mq}(-i_{qs1} - i_{qs2} + i_{qr}) \quad (10)$$

$$\psi_{dr} = -L_{lr} i_{dr} + L_{md}(-i_{ds1} - i_{ds2} + i_{dr}) \quad (11)$$

$$\psi_{qr} = -L_{lr} i_{qr} + L_{mq}(-i_{ds1} - i_{ds2} + i_{qr}) \quad (12)$$

The electromagnetic torque is evaluated as:

$$T_{em} = \frac{3}{2}\frac{P}{2}\frac{L_m}{L_r}[(i_{qs1} + i_{qs2})\psi_{dr} - (i_{ds1} + i_{ds2})\psi_{qr}] \quad (13)$$

The magnitude of the magnetizing current $|i_m|$ is calculated as:

$$i_m = \sqrt{(-i_{ds1} - i_{ds2} + i_{dr})^2 + (-i_{qs1} - i_{qs2} + i_{qr})^2} \quad (14)$$

It must be emphasized that the generator needs residual magnetism so that the self excitation process can be started. The magnetizing inductance, L_m used in this work is given in Figure 2.

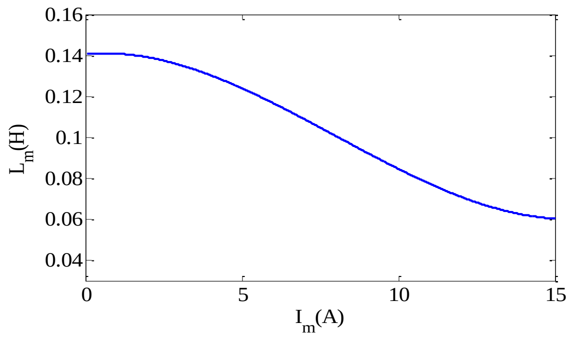

Fig. 2 Variation of magnetizing inductance with magnetizing current.

III. Field Oriented Control

The goal in controlling system is to ensure DC bus voltage to its reference. This obtained by controlling the flux and the power transmitted by the generator.
The objective of the direct field oriented control theory applied to the DSIG is, as in DC machine, to independently control the torque and the flux. In ideal field oriented control, the rotor flux linkage axis is forced to align with the d-axis and it follows that:

$$\psi_{dr} = \psi_r^* \quad (15)$$

$$p\psi_{dr} = \psi_{qr} = 0 \quad (16)$$

From the desired value of the DC voltage, it is possible to express that the reference power by:

$$V_{DC\_ref} i_{dc} = P^* = P_{ele} = T_{em}\Omega \quad (17)$$

Neglecting the losses, the torque expression can be written as:

$$T_{em} = \frac{P^*}{\Omega} \quad (18)$$

The component references of stator current and slip speed ω_{sl} can be expressed as:

$$i_{qs1}^* = \frac{(L_{lr} + L_m)}{pL_m\psi_r^*} T_{em}^* \quad (19)$$

$$\omega_{sl}^* = \frac{R_r L_m}{(L_m + L_{lr})\psi_r^*} i_{qs}^* \quad (20)$$

Where:

$$i_{qs1}^* + i_{qs2}^* = i_{qs}^* \quad (21)$$

The flux controlled by i_{ds}

$$\psi_r = p\frac{L_m}{1 + s\tau_r} i_{ds} \quad (22)$$

Where:

$$i_{sd1} + i_{sd2} = i_{ds} \quad (23)$$

$$\tau_r = \frac{L_r}{R_r} \quad (24)$$

The implementation of the control is presented in Figure 3.

IV. Fuzzy Logic Controller

The main feature of fuzzy logic controllers (initiated by Mamdani and Assilian based on fuzzey set theory suggested by Zadeh in 1965) is that linguistic, imprecise knowledge of human experts is used [7-8].
The proposed voltage fuzzy PI controller block diagram is shown in Figure 4, it has two inputs and one output.
Where E is the error, expressed by:

$$E(k) = V_{DC\_ref}(k) - V_{DC}(k-1) \quad (25)$$

dE is derived from the error approximated by:

$$dE(k) = E(k) - E(k-1) \quad (26)$$

The output of the regulator is given by:

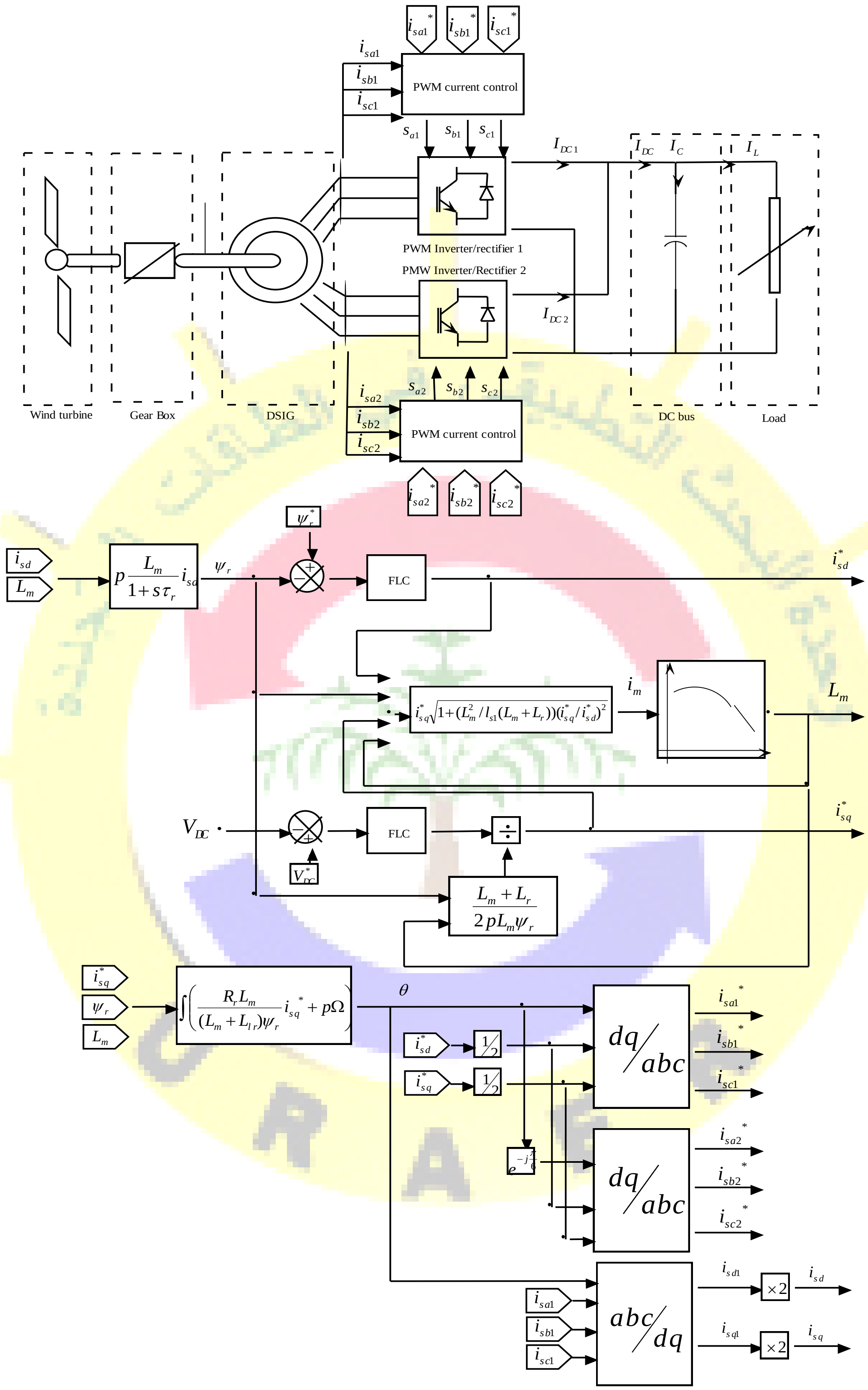

Fig. 3 Algorithm of control

$$P_{ref}(k) = P_{ref}(k-1) - dU(k) \quad (27)$$

FE, FdE, FdU are gains called "scale factor". The fuzzy controller is composed of three blocks:

- Fuzzification,
- Rules bases,
- Deffuzzification.

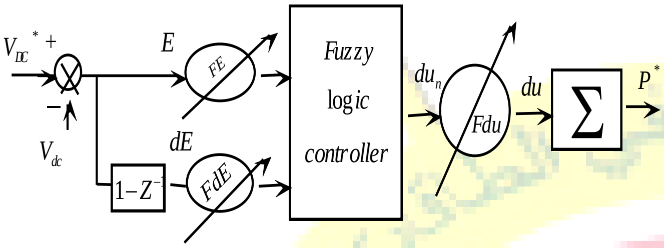

Fig. 4 Structure of Fuzzy logic controller.

The crisp input variables are E(k) and dE(K) are transformed into fuzzy variables referred to as linguistic labels. The membership functions associated to each label have been chosen with triangular shapes.

Figure 5. Show the function of membership of each input signals (*E*, *dE*). The fuzzy subsets are as follows: NB (Negative Big), NM (Negative Medium), NS (Negative Small), Z (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big).

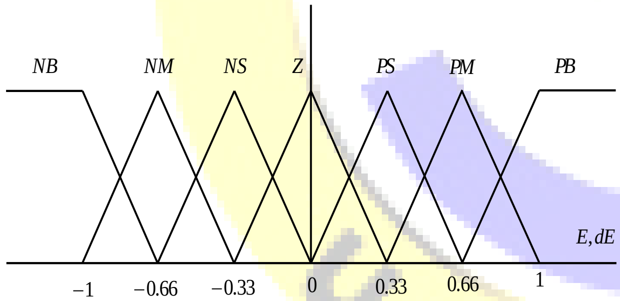

Fig. 5 Membership functions.

A. *Rules Bases*

Fuzzy logic rule database consists of series if-and-then fuzzy logic condition sentences. Table 1 shows the corresponding rule table for the fuzzy controller, the design of these rules is based on a qualitative knowledge, deduced from extensive simulation tests [9]. There are 7 fuzzy subsets for each variable, which gives 7*7=49 possible rules.

TABLE I
RULES BASES

dE \ dU	NB	NM	NS	Z	PS	PM	PB
PB	Z	PS	PM	PB	PB	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PS	NM	NS	Z	PS	PM	PB	PB
Z	NB	NM	NS	Z	PS	PM	PB
NS	NB	NB	NM	NS	Z	PS	PM
NM	NB	NB	NB	NM	NS	Z	PS
NB	NB	NB	NB	NB	NM	NS	Z

B. *Defuzzification*

In this step, the fuzzy variables are converted into crisp variable. In this paper, the centre of gravity defuzzification method is adopted here and the inference strategy used in this system is the Mamdani algorithm.

V. Interpretation of Results

The simulation of the proposed control scheme has been implemented using Matlab/Simulink. The sample time used $T_s = 50\mu s$.

Figure 6 shows the DC bus voltage. The reference of the DC bus voltage is set at 900 V. According to this figure, the DC bus voltage is perfectly controlled to its reference with the proposed control technique.

During the simulation the system has been exposed to a speed and load variation to see the response of the control. These variations can be seen in the Figure 7 and Figure 8.

In Figure 9, the stator phase current is shown to be successfully maintained within the imposed hysteresis band limits for different load values.

Figure 10 shows that the rotor flux ψ_r is constant during entire operation.

Figure 11 shows the magnetizing current and magnetizing inductance within estimator.

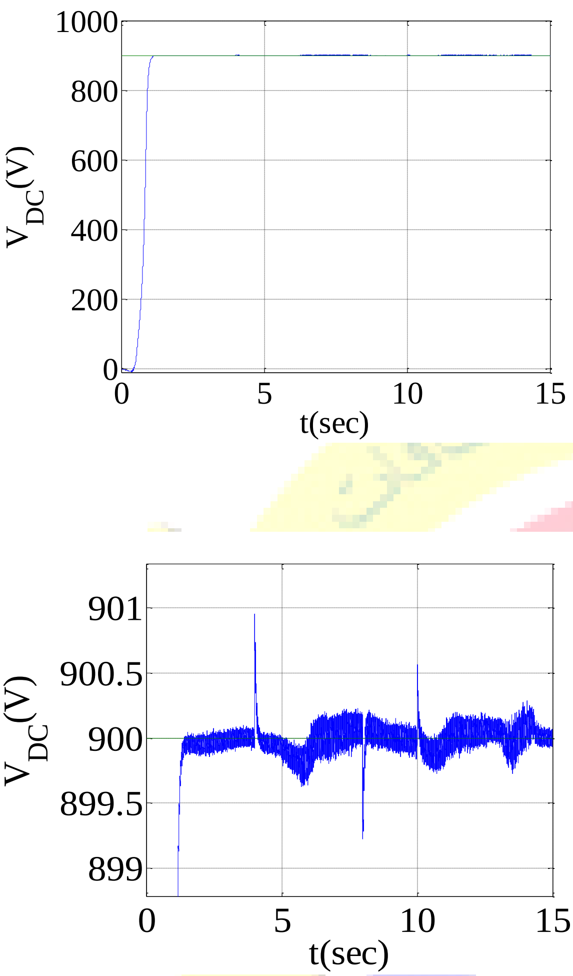

Fig. 6 DC link voltage and zoom of DC link voltage

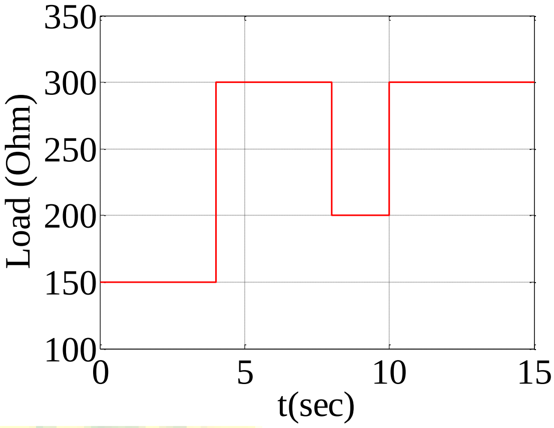

Fig. 8 Load variation

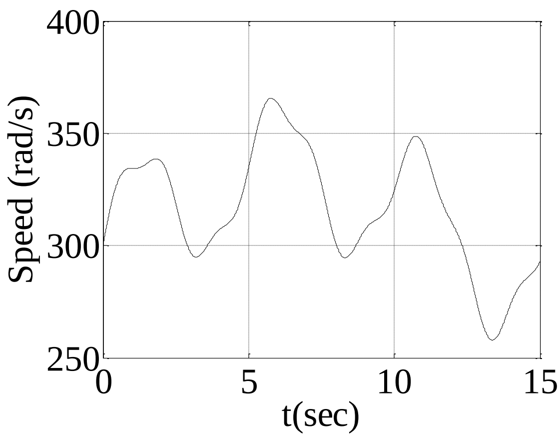

Fig. 7 Rotor speed

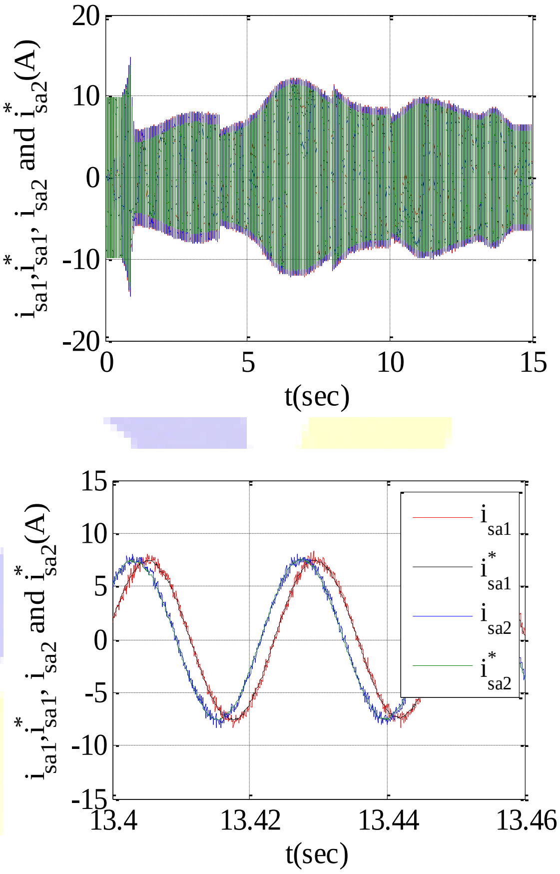

Fig. 9 The star phase currents

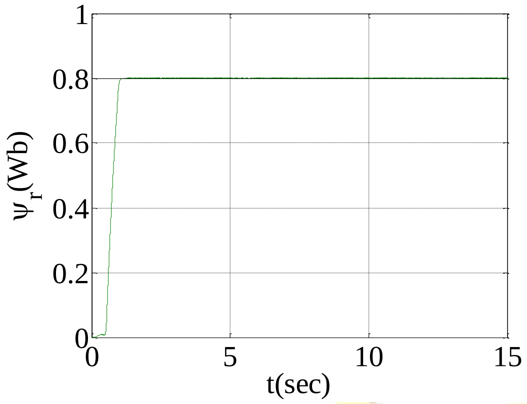

Fig. 10 Rotor flux

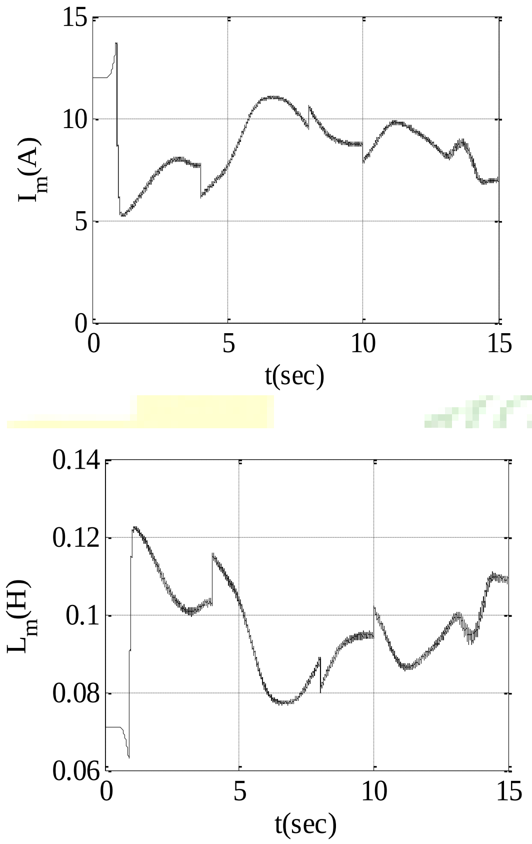

Fig. 11 Magnetizing current and magnetizing inductance

VI. Conclusion

In this paper, a rotor flux oriented control using fuzzy logic applied to self-excited dual star induction generator, in a variable speed wind system, have been presented and studied. The proposed scheme control offer a perfect DC bus and rotor flux magnitude tracking. The proposed system conversion control can be exploited in the wind power generation.

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