International Journal of Chemical and Petroleum Sciences
ISSN 2253-0932

SIMULATION FOR STRATEGY OF MAXIMAL WIND ENERGY CAPTURE OF DOUBLY FED INDUCTION GENERATORS

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ABSTRACT

In the control of the wind generation, the maximal power point tracking (MPPT) control plays important role in the efficiency. This paper presents the simulation results of the MPPT control based DFIG model. At first, it analyzes the vector-control scheme for the MTTP, which results in independent control of active and reactive power of the generator. And then, it develops the MPPT controller implemented on the rectifier and inverter based on PI control.

Keywords*: Wind energy, DFIG (doubly-fed induction generator), Stator flux-oriented, Maximal power point tracking.*

1. INTRODUCTION

Generation of power from renewable energy sources is more promising due to its clean character and free availability. In the last two decades, research is been carried out specifically on wind power generation systems to capture more power at fluctuating wind speeds. With rapid development of wind turbine and power electronic technology [1].

The variable speed wind generation is used more and more widely in wind energy conversion systems for its enhanced efficiency in wind energy harvesting. Among them, doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) are two most popular wind generators [2].In the variable-speed generation system, the wind turbine can be operated at the maximum power operating point for various wind speed by adjusting the shaft speed optimally. In order to achieve the maximum power point tracking (MPPT) control, some control schemes have been studied.

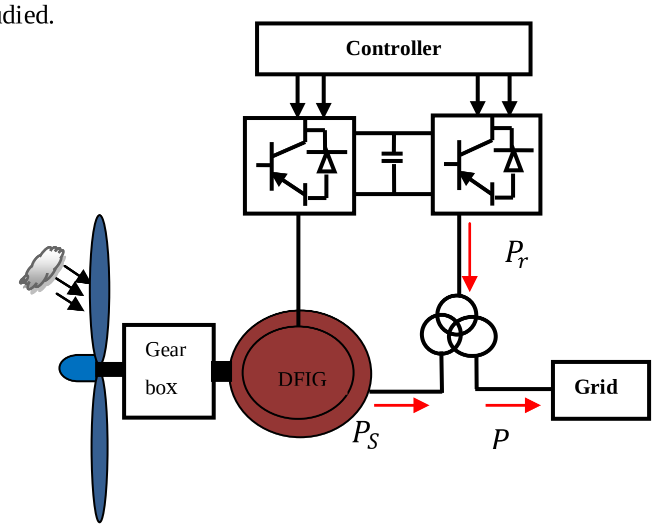

Figure.1 General structure of a double fed wind generator.

The double fed induction generator allows power output into the stator winding as well as the rotor winding of an induction machine with a wound rotor winding. Using such a generator, it is possible to get a good power factor even when the machine speed is quite different from synchronous speed .The stator of the wound rotor induction machine is connected to the low voltage balanced three-phase grid and. The rotor side is fed via the back-to-back IGBT voltage-source inverters with a common DC bus. The front–end converter controls the power flow between the DC bus and the AC side and allows the system to be operated in sub-synchronous and super synchronous speed. The vector control strategy of the power[3].

2. STATOR FLUX-ORIENTED VECTOR CONTROL OF DFIG

A. *The mathematical model of DFIG based on dq coordinate system*

In a synchronous rotating reference frame (the stator side using generator convention and the rotor side using machine convention in the equivalent circuit), the mathematical model can be expressed as:

$$\begin{cases} v_{ds} = R_s i_{ds} + \dfrac{d\emptyset_{ds}}{dt} - \omega_s \emptyset_{qs} \\ v_{qs} = R_s i_{qs} + \dfrac{d\emptyset_{qs}}{dt} + \omega_s \emptyset_{ds} \\ v_{dr} = R_r i_{dr} + \dfrac{d\emptyset_{dr}}{dt} - (\omega_s - \omega)\emptyset_{qr} \\ v_{qr} = R_r i_{qr} + \dfrac{d\emptyset_{qr}}{dt} + (\omega_s - \omega)\emptyset_{dr} \end{cases} \quad (1)$$

The stator flux linkage equation[9]:

$$\emptyset_{ds} = L_S . i_{ds} + M . i_{dr} \quad (2)$$

$$\emptyset_{qs} = L_S . i_{qs} + M i_{qr} \quad (3)$$

The rotor flux linkage equation:

$$\emptyset_{dr} = L_r . i_{dr} + M . i_{ds} \quad (4)$$

$$\emptyset_{qr} = L_r . i_{qr} + M . i_{qs} \quad (5)$$

Electromagnetic torque equation:

$$C_e = p . M (i_{qs} . i_{dr} - i_{ds} . i_{qr}) \quad (6)$$

B *.Decoupling Control Strategy of Grid Connection DFIG*

As the stator of DFIG is always connected to grid that the frequency is 50Hz, the resistance of the stator windings is much smaller than its reactance; the voltage drop on the stator windings can be negligible. Stator flux linkage and stator voltage vector are approximate perpendicular to each other, when using stator flux d-axis orientation, stator flux component is zero, phase voltage vector lag flux vector 90 ˚ so overlap with the negative direction of q-axis.

$$\begin{cases} V_{dr} = R_r . i_{dr} + s\left(L_r - \frac{M^2}{L_S}\right) . i_{dr} - g\omega_s \left(L_r - \frac{M^2}{L_S}\right) . i_{qr} \\ V_{qr} = R_r . i_{qr} + s\left(L_r - \frac{M^2}{L_S}\right) . i_{qr} + g\omega_s \left(L_r - \frac{M^2}{L_S}\right) . i_{dr} + g\frac{M . V_S}{L_S} \end{cases} \quad (7)$$

The stator active and reactive power, the rotor voltages can be written according to the rotor currents as:

$$\begin{cases} P_S = -\dfrac{3V_S.M}{2L_S}.i_{qr} \\ Q_S = \dfrac{3V_S^2}{2\omega_S.L_S} - \dfrac{3V_S.M}{2L_S}.i_{dr} \end{cases} \quad (8)$$

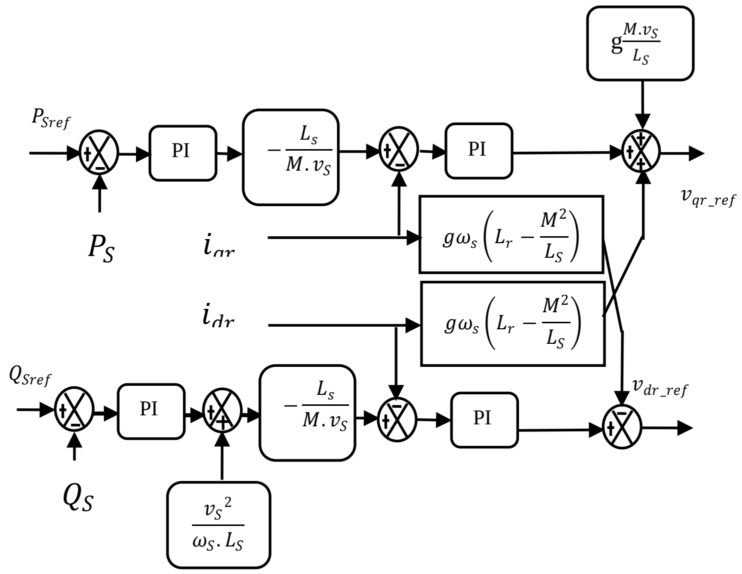

Figure.2 block diagram of the control of DFAM

We can notice in the equations of v_{dr} (control variable of Q_S) and v_{qr} (control variable of P_S) that these two control variables are coupled. The decoupling is obtained by compensation in order to assure the control of P_S and Q_S independently. Then, the rotor circuit can be represented in d-q frames by the transfer function presented:

$$\frac{i_r(S)}{v_r(S)} = \frac{1}{s\left(L_r - \frac{M^2}{L_s}\right) + R_r} \quad (9)$$

Based on the errors in i_{dr} and i_{qr} components, the voltage v_{dr_ref} and v_{qr_ref} to be applied to the rotor are generated using identical *PI* controllers. The rotor current closed control loop diagram is shown in Fig.3

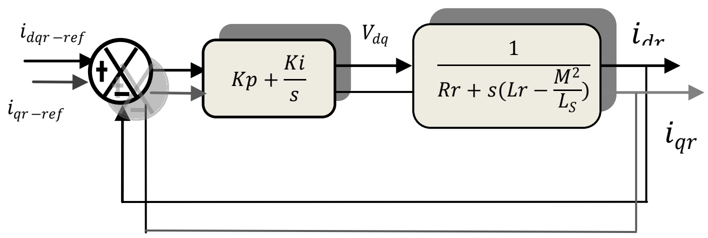

Figure.3 Rotor current inner control loop.

The active and reactive powers control can be derived similarly as shown in Fig. 4.

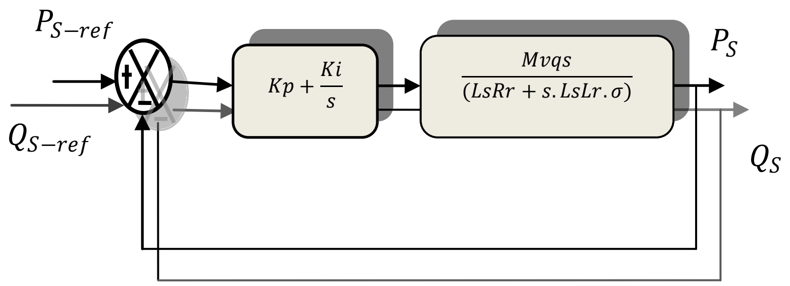

Figure.4 Active and reactive power outer control loop.

$\sigma = (1 - \frac{M^2}{L_s.L_r})$

The pole-compensation method is utilized to design PI-controllers in current and powers control loops.

3. WIND TURBINE OPTIMUM POWER CURVE

Wind turbine characteristics have to be analyzed for getting optimum power curve P_{opt} . The output power of wind turbine is:

$$P_{a\acute{e}ro} = C_P.P_v = C_P(\lambda,\beta)\,\frac{\rho.S.V^3}{2} \qquad (10)$$

The wind power is defined as follows:

$$P_v = \frac{1}{2}\rho.S.V_{vent}^3 \qquad (11)$$

Where ρ is air density; v is wind speed. Cp represents the power conversion efficiency of wind turbine it is a function of the tip-speed ratio λ and the blade pitch angle β in a pitch-controlled wind turbine

$$\lambda = \frac{\Omega_{turbine}\,.R}{v} \qquad (12)$$

Where λ is the ratio of tip speed of the turbine blades to
Wind speed; R is blade radius; $\Omega_{turbine}$ is the angular speed of the turbine. C_P can be calculated using the formula:

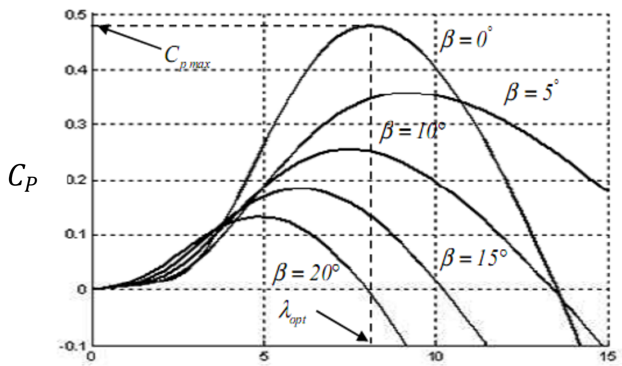

Figure.5 Wind Turbine Generator λ $-C_P$ Characteristics.

$$C_P = 0.5176 * \left(116 * \left(\frac{1}{\lambda_i}\right) - 0.4\beta - 5\right) * e^{-21\left(\frac{1}{\lambda_i}\right)} + 0.068 * \lambda$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \qquad (13)$$

The turbine torque is the ratio of the output power to the angular speed Ω_t , namely, $T_t = {}^{P_t}/_{\Omega_t}$
The turbine is normally coupled to the generator shaft through a gearbox whose gear ratio G is chosen so as to maintain the generator shaft speed within a desired speed range. Neglecting the transmission losses, the torque and shaft speed of the wind turbine, referred to the generator side of the gearbox, are given by:
$T_m = {}^{T_t}/_{G}$ and $\Omega_r = G\,\Omega_t$ respectively where T_m is the driving torque of the generator and T_t is the generator shaft speed. the rated power, the MPPT mode consist to track the rotor speed with changing wind velocity so that the power coefficient is always maintained at its maximum value (C_{Pmax}) and blades angle of attack at its minimal value(β = 0). Beyond the rated power, the blade angle of attack (pitch mechanism) is turned in order to decrease the power coefficient in order to keep the power constant .Maximum power from the wind turbine is:

$P_{max} = K\Omega^3$

Where K=0.5$* \rho * C_{Pmax} * S * \left(\frac{\lambda_{opt}}{R}\right)^3$ (14)

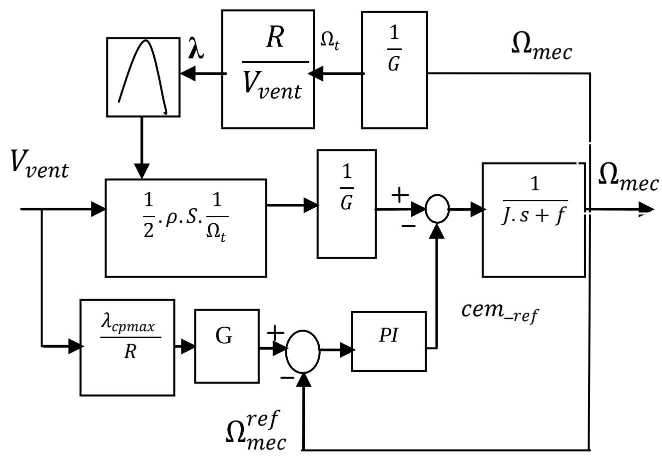

Figure.6 Wind turbine control.

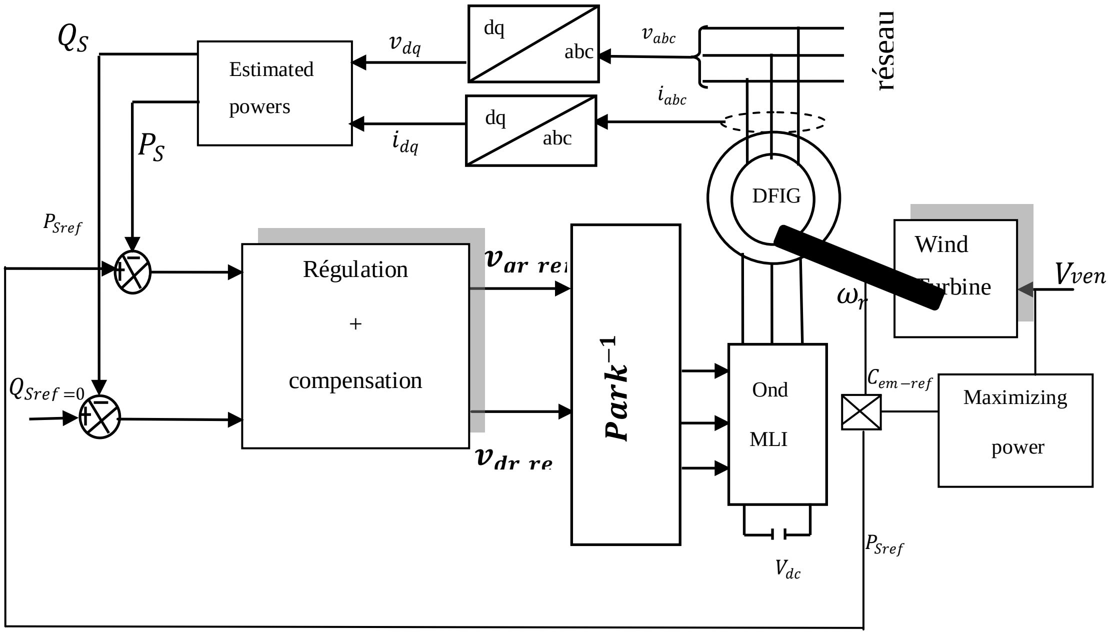

Figure.7 Control structure of on-grid DFIG.

4. SIMULATION RESULTS

For evaluate The dynamic performance of sensor less maximum power point tracking of the system proposed a step change in wind speed is simulated in Fig.8, the wind speed is start at 5m per second , at 4 second, the wind speed suddenly become 7 m per second , as 8 second, the wind speed is 11 m per second. Fig.15 illustrates the active power of DFIG accorder with the optimal value, these results realizes the maximum wind energy tracking control, and so clear by wind turbine maximum power trajectory which represent in Fig.9. And power coefficient Cp variation in Fig.13 and the tip speed ratio λ in Fig.10.

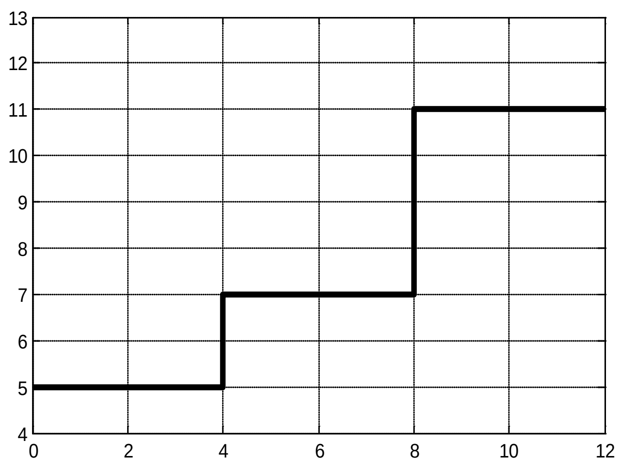

Figure.8 Wind speed.

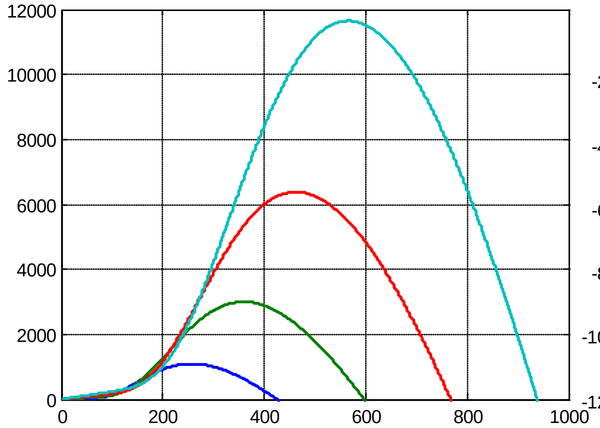

Figure.9 Wind Turbine Generator power- rotor speed Characteristics.

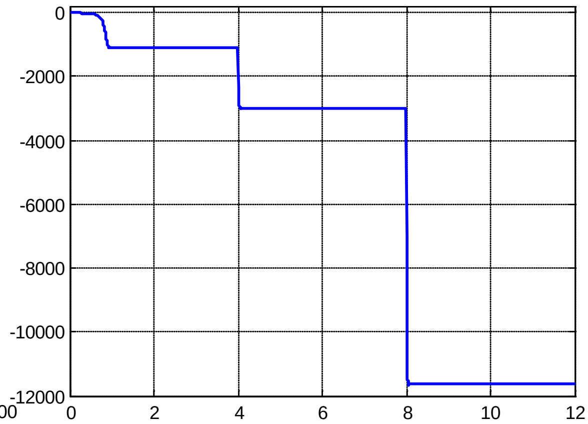

Figure.12 The reference active power.

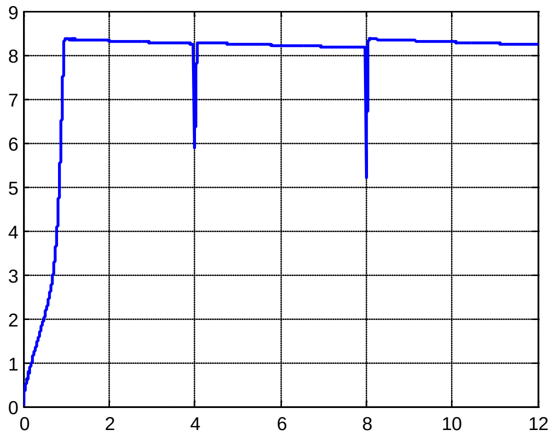

Figure.10 The tip speed ratio λ.

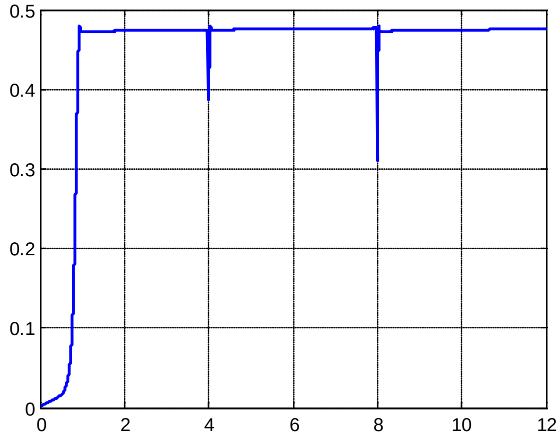

Figure.13 Power Coefficient Cp.

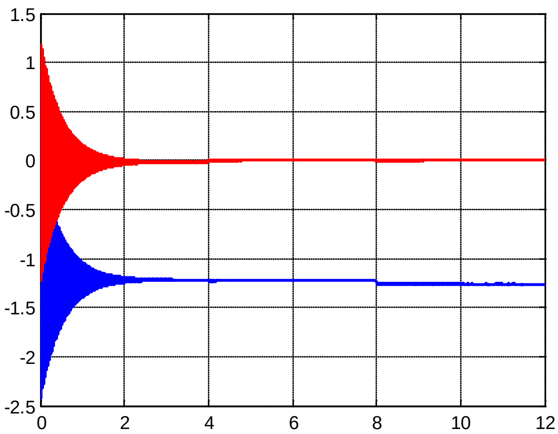

Figure.11 The flux statorique.

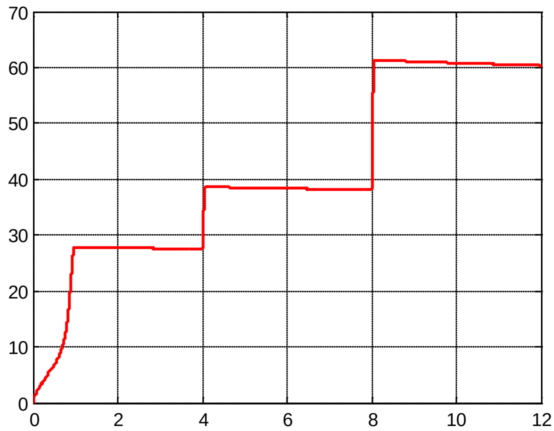

Figure.14 Rotor speed.

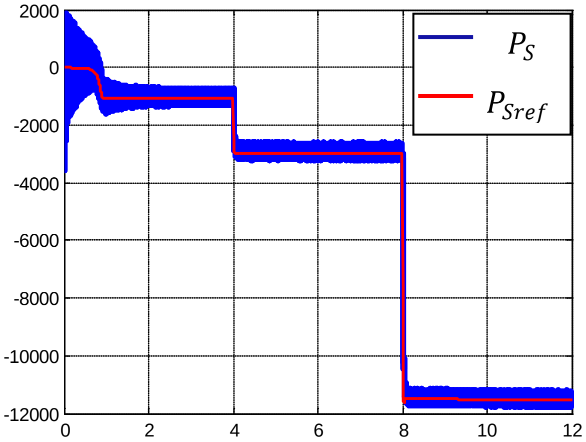

Figure.15 Results on stator active output power curve.

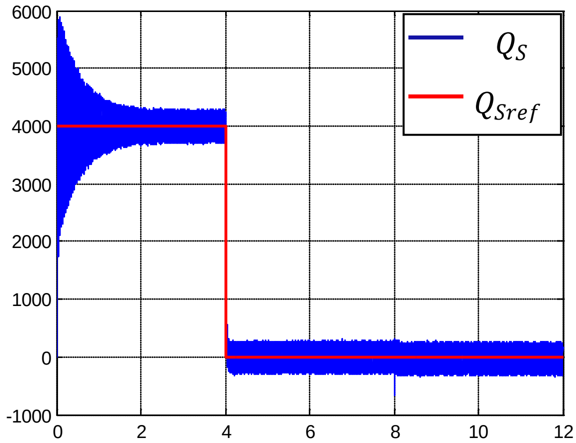

Figure.17 Results on responses to step changes in stator reactive.

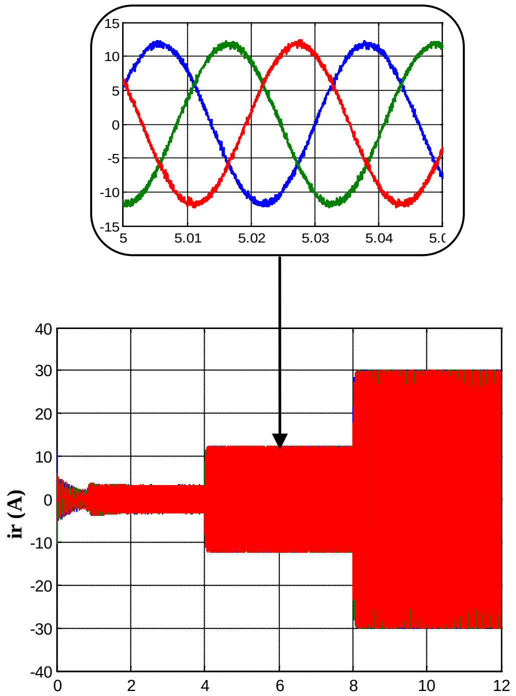

Figure.16 The rotor current.

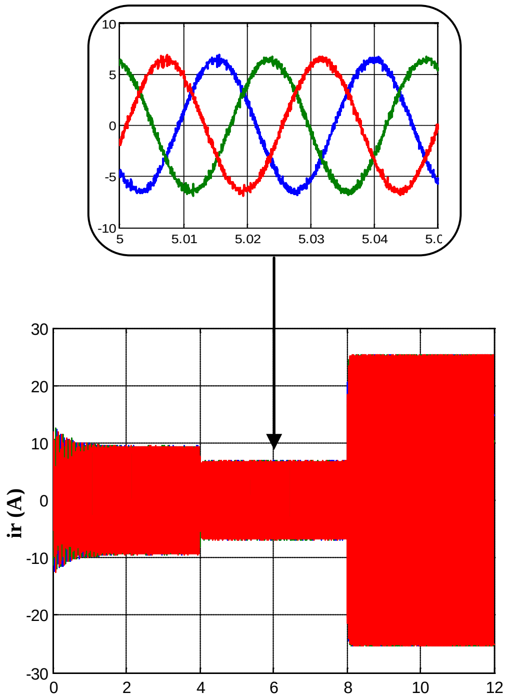

Figure.18 The stator current.

5. CONCLUSION

This paper analyzed the performance characteristics of wind generators and presented a control strategy to capture the largest wind power in order to achieve maximum wind power tracking. When the wind speed is certain, the speed difference will make a different output power of wind generator. There is always a fixed maximum speed to make the wind generator run in this speed to reach the optimum tip speed ratio and the maximum wind capture and maximum power output.

APPENDIX

The electrical parameter of DFM:
Rated power 7.5kW, four poles, Rr =0.7614**Ω**,
Rs =0.474**Ω**, Ls =0.12H, M=0.107H, Lr =0.122H.

6. REFERENCES

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