Direct Active and Reactive Power Control for DFIG using Instantaneous Rotor Current Control

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Abstract: This paper presents a proposed technique for controlling of the power for doubly fed induction generator (DFIG) which is produced the electric vitality in wind turbines and is controlled of the dynamic power which is transferred from grid and DFIG. Model of a DFIG with wind turbine is presented in the d-q reference frame and control the machine with the strategy for control in view of direct power control. The objective is controlled by the diverse value between the set reference value and measure value of dynamic power. Indirect control method can be utilized to control of the rotor current by utilizing PID controller for control direction. Proposed control model of wind turbine with doubly fed generator is illustrated. In this paper and is controlled by stator and rotor energy of the DFIG utilizing programming MATLAB/Simulink and presented a better performance, with the absent of oscillation in transient mode. In this manner, it is directed to a superior control of the power between the grid and the machine.

Keywords: Doubly Fed Induction Generator (DFIG), Wind Turbine, Direct power control, current control

1. INRODUCTION

Variable speed wind turbines have been widely used because of their advantages such as decreasing the mechanical structure stresses, minimizing the noise, controlling of power. A wind power has been controlled based all on doubly fed induction generator (DFIG) with variable speed. It has one of a better technology for wind power generation. Many advantages of using DFIG, minimizing the cost of inverter, consuming less power resulting less losses due to its current carrying. Generator systems based on variable speed wind turbine have wide range of practical applications in electric networks as a form of renewable energy sources (RESs). A DFIG system has extensively great importance. DFIG based AC-DC-AC converters in the rotor circuit has long been the most effective drive option for high power applications including limited speed ranges [1], [2], [3]. In DFIG wind turbine-generator systems, the rating of the power converters is typically rated one-third the rated power. This characteristic leads to many distinctive features, such as, reduced converter filter cost, less switching losses, reduced harmonic injections into the grid, and improved overall efficiency [4]. This paper introduces a control method to manage the energy between DFIG and network.

2. MODEL OF DFIG MACHINE

In the DFIG scheme, the two converters with a DC connection can actualize advanced control assignments which are utilized to control the rotor-side circuit to the network [5]. Especially, the rotor-side circuit comprises of a rotor-side converter (RSC) connected through a DC capacitor to a network side converter (GSC) and a R– L channel [5], as appeared in Fig. 1. Two converters are voltage source utilizing switches like protected entryway bipolar transistor (IGBT) as controlled power [5], [6].

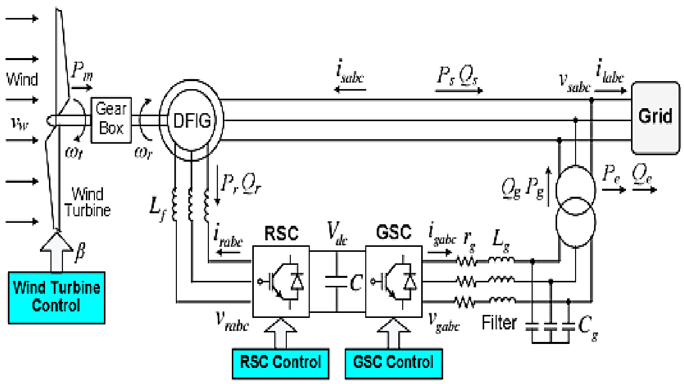

Fig. 1 DFIG wind turbine system.

The stator of DFIG is connected with the grid while the rotor is feed through a voltage source converter. The stator and rotor voltages conditions can be composed as takes after [7], [8]:

$$V_{ds} = R_s i_{ds} + \frac{d\phi_{ds}}{dt} - \omega_e \phi_{qs} \quad (1)$$

$$V_{qs} = R_s i_{qs} + \frac{d\phi_{qs}}{dt} + \omega_e \phi_{ds} \quad (2)$$

$$V_{dr} = R_r i_{dr} + \frac{d\phi_{dr}}{dt} - (\omega_e - \omega_r)\phi_{qr} \quad (3)$$

$$V_{qr} = R_r i_{qr} + \frac{d\phi_{qr}}{dt} + (\omega_e - \omega_r)\phi_{dr} \quad (4)$$

$$\phi_{ds} = L_s i_{ds} + m.L_m i_{dr} \quad (5)$$

$$\phi_{qs} = L_s i_{qs} + m.L_m i_{qr} \quad (6)$$

$$\phi_{dr} = L_r i_{dr} + m.L_m i_{ds} \quad (7)$$

$$\phi_{qr} = L_r i_{qr} + m.L_m i_{qs} \quad (8)$$

By neglecting the power losses in the stator and rotor resistances, the power equations are [9], [10]:

$$P_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) \quad (9)$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} - V_{ds} i_{qs}) \quad (10)$$

$$P_r = \frac{3}{2}(V_{dr} i_{dr} + V_{qr} i_{qr}) \quad (11)$$

$$Q_r = \frac{3}{2}(V_{qr} i_{dr} - V_{dr} i_{qr}) \quad (12)$$

3. PROPOSED CONTROL MODEL

To create the power at consistent voltage and frequency to the grid which is working at a wide range and extent the power transfer between the rotor circuit and grid. The voltage converter control makes out of two IGBT-PWM converters as take after: the rotor side converter RSC and grid side converter and is connected otherwise by DC link. The task of the proposed technique is depended on control system which is divided to control of rotor side and grid side, which is comprises of the electrical control of the doubly fed induction generator as appeared in Fig. 1 [11].

The direct power control (DPC) model as shown in Fig. 2 is based on d-q theory which the instantaneous active and reactive powers are calculated from estimate source voltage and current. The waveforms of power will contain ripples. Thus, under distorted voltage and current waveforms, the extraction of the ripple components from active and reactive power is essential to generate ideal reference values [12].

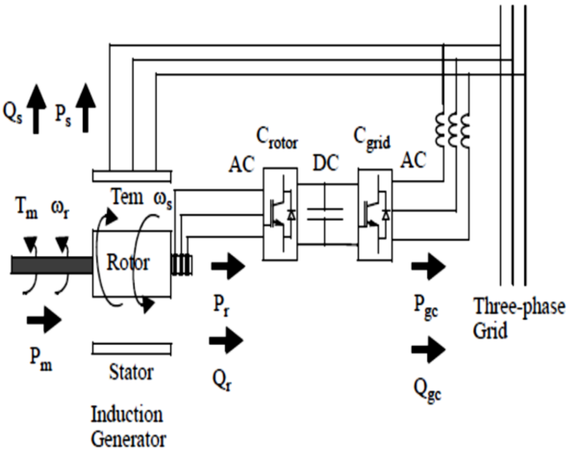

Fig. 2: Power flow system

3.1 Rotor Side Control

A control the electromagnetic torque and stator reactive power are introduced by controlling the d-q axes rotor currents of the doubly fed induction generator. The stator field rotates in steady state at the synchronous speed. This field is symbolized by the stator flux vector which gives a visual idea of the phase and flux amplitude. By choosing the two-phase d-q related to rotate stator field and place the stator flux vector on the d-axis, it can be written as flows:

$$\begin{cases} \phi_{sd} = \phi_s \\ \phi_{sq} = 0 \end{cases} \quad (13)$$

Considering the choice of reference related to d-q rotating stator field and neglecting the resistance of the stator windings, then the equations of doubly fed induction generator in the d-q reference can be obtained from equation (1), (2) [13], [14].

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$$\left.\begin{aligned} V_{qs} &= \omega_s \phi_{ds} \\ V_{ds} &= 0 \end{aligned}\right\} \quad (14)$$

$$V_{dr} = R_r i_{dr} + \frac{d\phi_{dr}}{dt} - \omega_r i_{qr} \quad (15)$$

$$V_{qr} = R_r i_{qr} + \frac{d\phi_{qr}}{dt} + \omega_r i_{dr} \quad (16)$$

From equations (5) , (6) of the flux in dq axes, the stator currents can be obtained from the following expressions:

$$I_{ds} = \frac{\phi_{ds} - m.L_m I_{dr}}{L_s} \quad (17)$$

$$I_{qs} = \frac{m.L_m}{L_s}.I_{qr} \quad (18)$$

These equations are substituted into the equations (7), (8) , they become:

$$V_{qr} = R_r i_{qr} + L_r.\sigma.\frac{dI_{qr}}{dt} + e_{qr} + e_{\phi} \quad (19)$$

$$V_{dr} = R_r i_{dr} + L_r.\sigma.\frac{dI_{dr}}{dt} + e_{dr} \quad (20)$$

Where: σ: is the dispersion coefficient of the DFIG
By replacing the expressions of direct and quadrature components of rotor flux (19), (20) in equations (15), (16) it obtained [15] , [16]:

$$\phi_{qr} = L_r.I_{qr} - \frac{(m.L_m)^2}{L_s}.I_{qr} = L_r.\sigma.I_{qr} \quad (21)$$

$$\phi_{dr} = (L_r - \frac{(m.L_m)^2}{L_s}).I_{dr} + \frac{m.L_m}{Ls}.\phi_{ds} \quad (22)$$

Where:

$$e_{dr} = -\sigma.L_r.\omega_r.I_{qr} \quad (23)$$

$$e_{qr} = -\sigma.L_r.\omega_r.I_{dr} \quad (24)$$

$$e\phi = \omega_r.\frac{m.L_m}{L_s}.\phi_{ds} \quad (25)$$

So, power equations of the DFIG are equal:

$$p_s = \frac{3}{2}(V_{ds} i_{ds} + V_{qs} i_{qs}) = -\frac{3}{2}\frac{m}{L_s} V_{qs} i_{qr} \quad (26)$$

$$Q_s = \frac{3}{2}(V_{qs} i_{ds} + V_{ds} i_{qs}) = -\frac{3}{2} V_{qs} (\frac{V_{sq}}{\omega_s L_s} - \frac{m}{L_s} i_{dr}) \quad (27)$$

By using equations (13), (14) above equations become:

$$p_s = -k_\sigma \omega_s \phi_{ds} \phi_{qr} \quad (28)$$

$$Q_s = k_\sigma \omega_s \phi_{ds} (\frac{L_r}{m}\phi_{ds} - \phi_{qr}) \quad (29)$$

Where $k_\sigma = 1.5 L_m/(\sigma L_s \ L_r)$. Substituting equations (28), (29) in equations (3), (4) so the rotor voltages are equal [14], [17]:

$$V_{dr} = (K_{p1} + \frac{K_{i1}}{s})(Q_s - Q_s^{ref}) + \omega_{ss}\frac{p_s}{k_\sigma \omega_s \phi_{ds}} \quad (30)$$

$$V_{qr} = (K_{p2} + \frac{K_{i2}}{s})(p_s - p_s^{ref}) + \omega_{ss}(\frac{L_s}{m} - \frac{Q_s}{k_\sigma \omega_s \phi_{ds}}) \quad (31)$$

Where ω_{ss} is slip angular frequency.

The electromagnetic torque T_{em} can be expressed from the flux and the stator currents by:

$$T_{em} = P(\phi_{ds} i_{qs} - \phi_{qs} i_{ds}) \quad (32)$$

The reactive power and torque are controlled as shown in Fig.3 which is presented control of the rotor side.

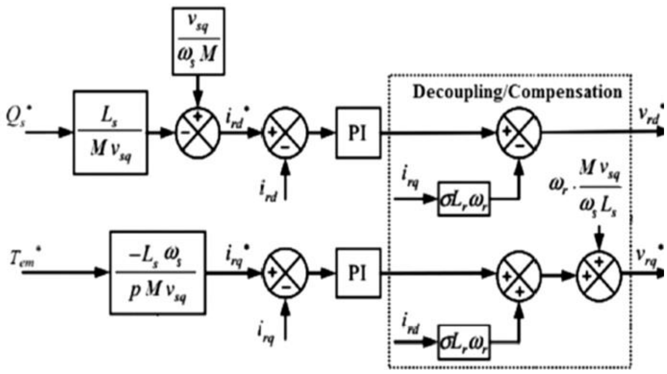


Fig. 3: Proposed Control of RSC.

It also can be expressed in terms of the rotor currents and stator flux:

$$T_{em} = P\frac{mL_m}{L_s}(\phi_{ds}i_{dr} - \phi_{ds}i_{rq}) \quad (33)$$

From equation (13), the electromagnetic torque becomes [15]:

$$T_{em} = -P\frac{mL_m}{L_s}\phi_{ds}i_{qr} \quad (34)$$

$$T_{em} = -V_{qs}\frac{mL_m}{L_s}\phi_{ds}i_{qr} \quad (35)$$

The equations of the stator powers are:

$$P_s = -V_{qs}.\frac{m}{L_s}\ i_{qr} \quad (36)$$

$$Q_s = V_{qs}^{\ 2}\ -\frac{mV_{sq}}{L_s}\ i_{dr} \quad (37)$$

The DFIG model explained before shows that the electromagnetic torque generated via DFIG is dependent on the selection of d-q axis, the power in stator circuit is proportional to the rotor current (q). the reactive power generated in stator is related to the rotor current in d-axis. The reference rotor current in q-axis is controlled by inserting the proposed closed-loop regulator via the reference electromagnetic torque.

From Eqns. (34), (35) and (37) we obtain:

$$I_{dr}^{\ *} = -\frac{L_S}{m.V_{qs}}Q_S^* + \frac{V_{qs}}{\omega_S m} \quad (38)$$

$$I_{qr}^{\ *} = -\frac{\omega_S L_S}{pm.V_{qs}}T_{em}^* \quad (39)$$

.4.2 Control currents in the RL filter

Control of the rotor side converter as shown in Fig. 4 introduces the rotor current control pass in the RL filter and control voltage of the DC link and Fig. 5 presents the proposed technique of the rotor current by using Matlab / Simulation.

$$V_{f1} = -R_f i_{f1} - L_f\frac{dI_{f1}}{dt} + V_{s1} \quad (40)$$

$$V_{f2} = -R_f i_{f2} - L_f\frac{dI_{f2}}{dt} + V_{s2} \quad (41)$$

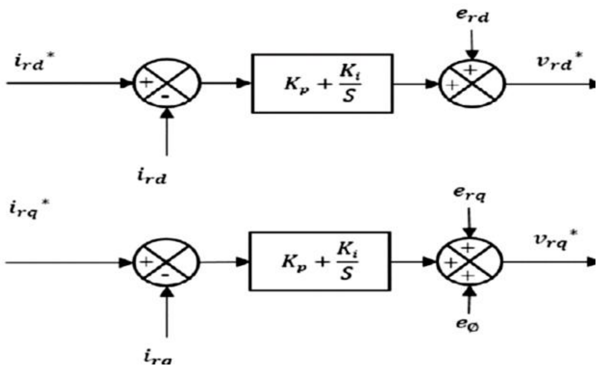
$$V_{fa} = -R_f i_{fa} - L_f\frac{dI_{fa}}{dt} + V_{sa} \quad (42)$$

$$V_{fd} = -R_f i_{fd} - L_f\frac{dI_{fd}}{dt} + e_{fd} \quad (43)$$

$$V_{fq} = -R_f i_{fq} - L_f\frac{dI_{fq}}{dt} - \omega L_f i_{fq} + e_{fq} \quad (44)$$

Where:

$$e_{fq} = -\omega_S.L_f.I_{fd} + V_{fq} \quad (45)$$



$$e_{fd} = \omega_S.L_f.I_{fd} \quad (46)$$

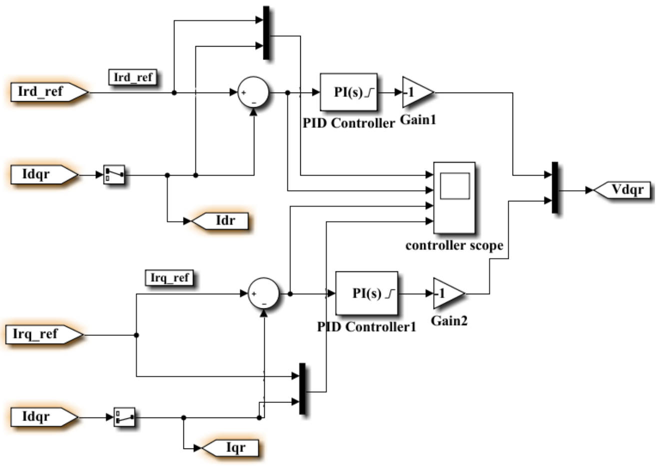


Fig. 4 Control currents flowing in the RL filter.

Fig. 5 The proposed control model.

4.3 Grid Side Control

Voltages of grid in stationary reference frame equals:

$V_{dg}=0; V_{qg}=V_x$ (47)

where Vx is grid voltage. The power of GSC can be calculated as:

$P_g = V_{qg} I_{dg}$ (48)

$Q_g = V_{qg} I_{qg}$ (49)

In control plan of GSC which a PI controller has been utilized for DC voltage control and creates d-reference current. Also, q - reference current set to zero for task of GSC with unity power factor.

5. SIMULATION AND RESULTS

The proposed control strategy for DFIG based on generation system is performed to confirm the ability of the direct power control (DPC) for operation with fast dynamic response and the validity of controlling the power in stator circuit. The converter in grid side is maintaining a constant DC voltage; also, it is controlled by DC voltage regulator in rectifier of voltage source. AC filter high frequency is coupled with the stator side to reduce the harmonics generated from switching process performed by the two converters.

In Fig. (6-a, 6-b) show stator currents and voltages while Fig.(6-c, 6-d) present d-q stator currents and voltages. While, Fig. (6-e, 6-f) introduce the active and reactive powers of the grid. The simulation results present for stator current and voltage control as shown in Fig.(7-a, 7-b) and Fig. (7-c, 7-d) illustrate d-q rotor currents and voltages. The active-reactive stator power is reported in Fig. (7-e, 7-f) The obtained curves confirm the superiority of the proposed controller . These figures represent a good performance, except that the presence of the oscillations during the transient mode in stator voltage and current. Thus, from two curve of power, it is leaded to a better control of the power flow between the grid and the machine so, the proposed direct power control using instantaneous rotor current strategy has a faster dynamic response and reach to steady state at low time period.

6. CONCLUSION

This research suggests a new control strategy for the variable speed DFIG using direct power control to enhance the grid power quality under non-linear loads. By rotor side converter, the active and reactive powers are decoupled and the harmonics generated by the load current are compensated. The separation of the harmonic components as well as reactive power components of the non-linear load are achieved to be added to the control loop for generating the reference current required to PWM converter.

In addition, the controller of grid connected converter provides improved power factor at constant and smoothing DC-link voltage. Thus, the energy transferred to the mains has a high quality where the injected current has almost sinusoidal waveform with low harmonic distortion. The proposed control scheme is implemented by the simulation platform, and the results obtained exhibit the effectiveness and rigid performance of overall system for active and reactive power decoupling and harmonic extraction.

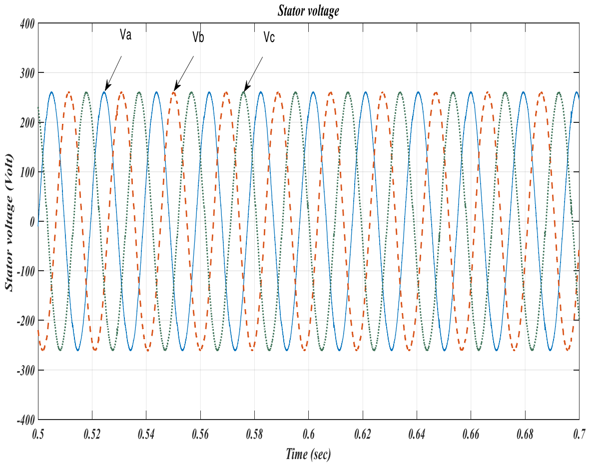


Fig. 6-a Stator voltages

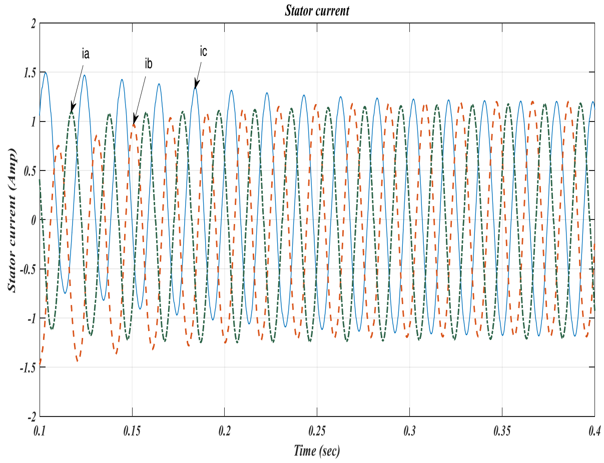


Fig. 6-b Stator currents

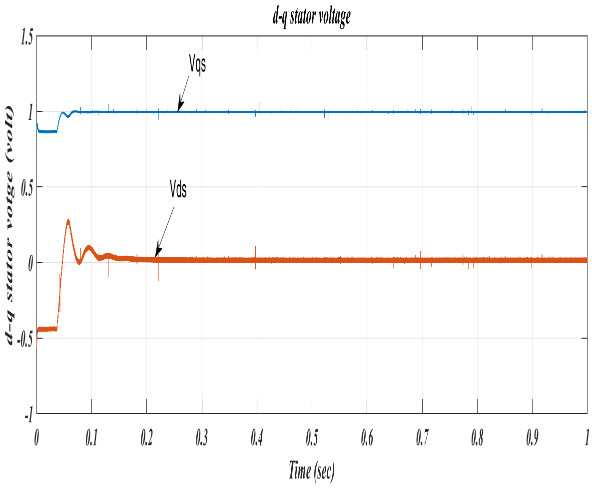


Fig. 6-c d-q stator voltages

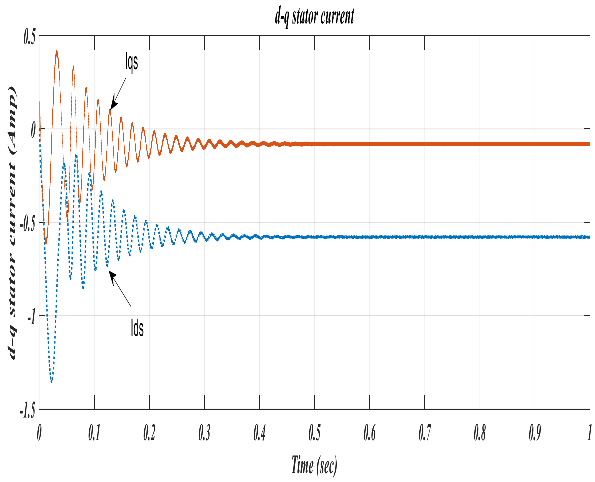


Fig. 6-d d-q stator current

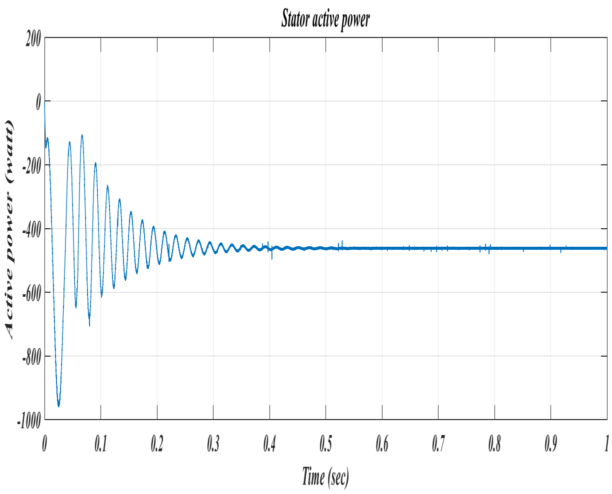


Fig. 6-e Stator active power

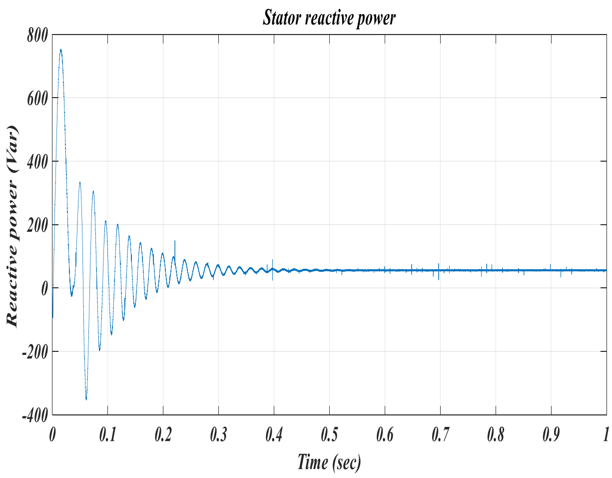


Fig. 6-f Stator reactive power

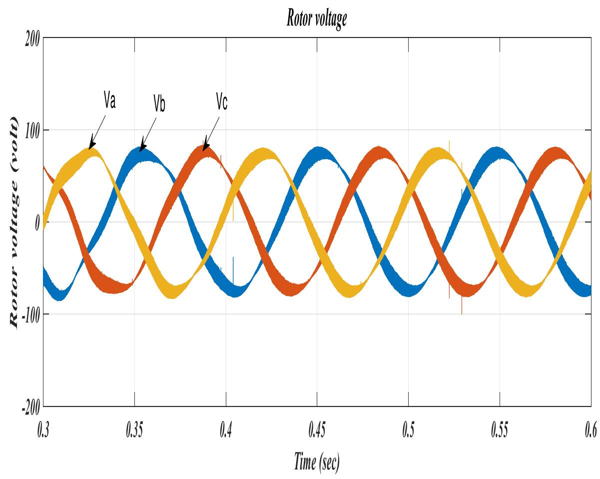


Fig. 7-a Rotor voltages

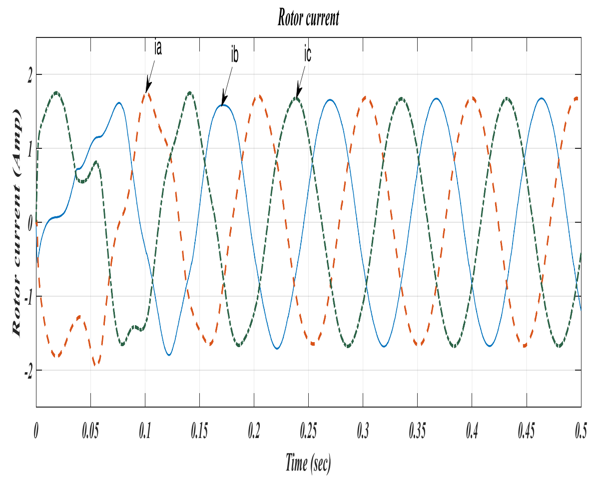


Fig. 7-b Rotor currents

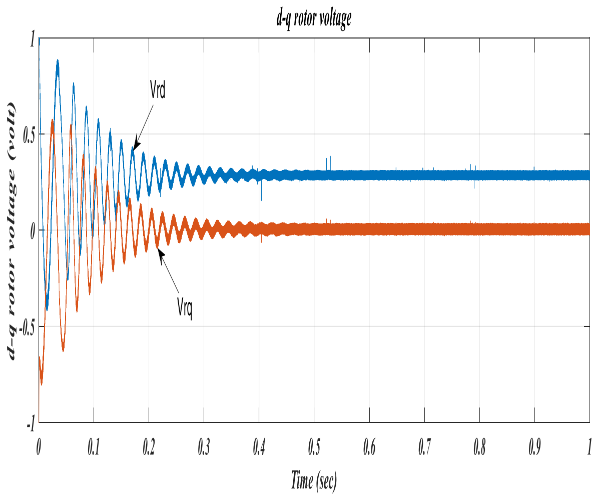


Fig. 7-c d-q rotor voltage

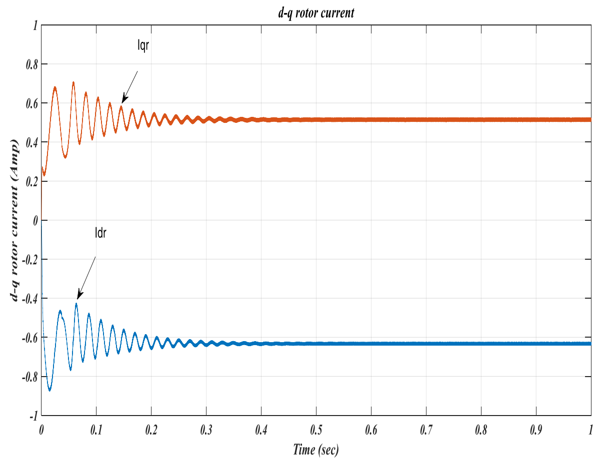


Fig. 7-d d-q rotor current

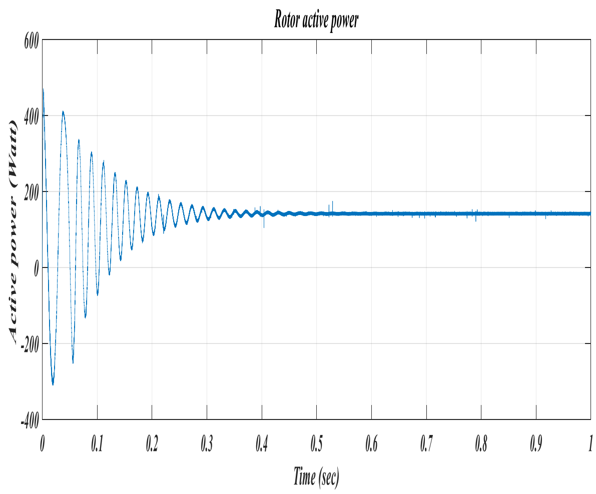


Fig. 7-e Rotor active power

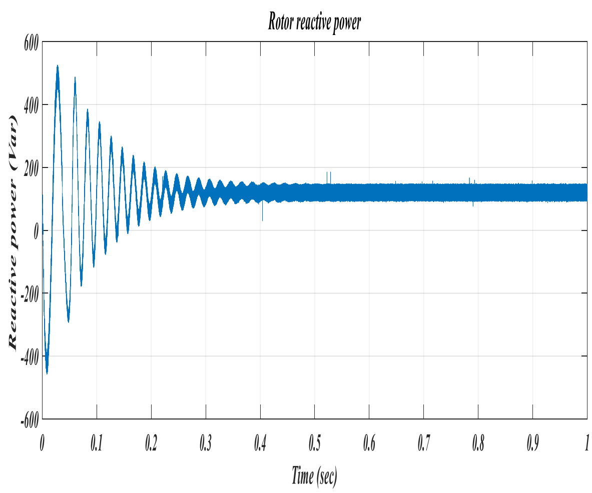


Fig. 7-f Rotor reactive power

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