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Simulation of Vector Controlled Adjustable speed System of Doubly Fed Induction Machine

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***Abstract*—** In this work the performance of vector speed control of doubly fed induction machine is considered. Based on the analysis of doubly fed induction machine dynamic mathematical model and the vector control principle, the construction of the motor control system has been completed. Doubly fed induction machine module, the vector controller module, Clark transform module, Park transform module, inverter module, flux module, speed-conditioning module have been set up by adopting the idea of modular in MATLAB/SIMULINK environment. Through the organic integration of functional modules, the vector control doubly fed induction machine system has been constituted. Simulation results show the changes in the machine electromagnetic torque, the dynamic changes of speed curve, which demonstrate that the real system can be well simulated with fast dynamic response speed, steady-state small of static error, and strong ability of anti-load disturbance.

Keywords- *Doubly fed induction machine (DFIM), Vector control and MATLAB/SIMULINK, etc…*

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I. Introduction

Since the early years of industrialization, the researchers were faced with "how to control the electric machines at variable speed." Electric drives require high performance, increased reliability, and reduced cost. Among these machines is doubly fed induction machine (DFIM) [1-3] is an asynchronous machine with wound rotor which can be supplied at the same time by the stator and the rotor with external source voltages [4].

The benefits of this machine are: reduced manufacturing cost, relatively simple construction, higher speed and do not require ongoing maintenance. In recent decades, the advances in technology of power electronics and microcomputer, different applications of DFIM became possible. The doubly fed induction machine (DFIM) or wound rotor induction machine (WRIM) are terms commonly used to describe an electrical machine, which has been used over many decades in various applications, often in the range of megawatts of power and also less commonly in the range of a few kilowatts. This concept of the machine is as an alternative to more common asynchronous and synchronous machines. It can be advantageous in applications that have a limited speed range, allowing a reduction in the size of the supplying power electronic converter as, for instance, in variable-speed generation, water pumping and so on. For operation at different speeds a converter PWM (Pulse Width Modulation) must be inserted between the machine and the network. Whatever the speed of the machine, the voltage is rectified and an inverter connected to the network side is responsible to ensure consistency between the network frequency and that delivered by the device. The DFIM is essentially nonlinear, due to the coupling between the flux and the electromagnetic torque. The vector control or field orientation control allows a decoupling between the torque and the flux [6] [7].

With the field orientation control (FOC) method, induction machine drives are becoming a major candidate in high-performance motion control applications, where servo quality operation is required. Fast transient response is made possible by decoupled torque and flux control.

II. Doubly fed induction machine modelling

Modelling of an induction machine in three phase reference is quiet a complex and tedious task. So to reduce the complexity the machine model is converted from 3 phase to 2 phase synchronously rotating reference frame [5].

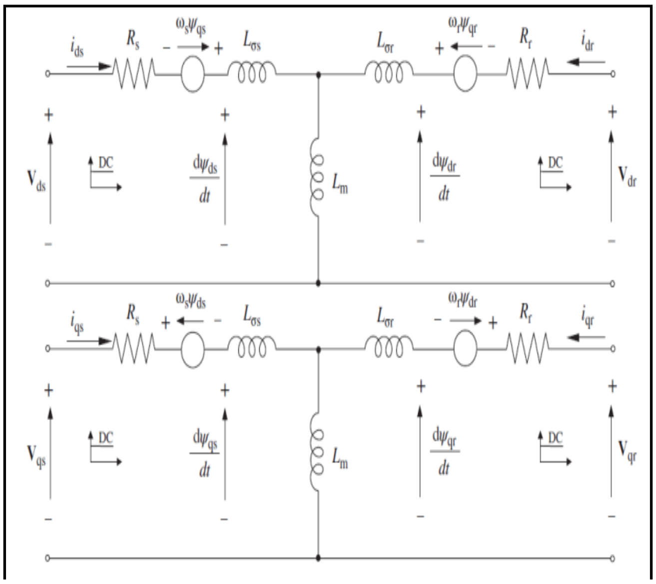

Fig -1: Model of the DFIM in dq reference frame.

The modified voltage equations for the rotor and stator on the synchronously rotating reference frame are as follows:-

$$V_{ds} = R_s I_{ds} + \frac{d}{dt}(\Psi_{ds}) - \omega_e \Psi_{qs} \quad (1)$$
$$V_{qs} = R_s I_{qs} + \frac{d}{dt}(\Psi_{qs}) + \omega_e \Psi_{ds} \quad (2)$$
$$V_{dr} = R_r I_{dr} + \frac{d}{dt}(\Psi_{dr}) - (\omega_e - \omega_r)\Psi_{qr} \quad (3)$$
$$V_{qr} = R_r I_{qr} + \frac{d}{dt}(\Psi_{qr}) + (\omega_e - \omega_r)\Psi_{dr} \quad (4)$$

The flux linkages in synchronous rotating frame can be expressed as

$$\Psi_{ds} = L_s I_{ds} + L_m I_{dr} \quad (5)$$
$$\Psi_{qs} = L_s I_{qs} + L_m I_{qr} \quad (6)$$
$$\Psi_{dr} = L_r I_{dr} + L_m I_{ds} \quad (7)$$
$$\Psi_{qr} = L_r I_{qr} + L_m I_{qs} \quad (8)$$

The electromagnetic torque of the induction motor is given as

$$T_e = \frac{3}{2}\frac{p}{2} L_m \left(I_{qs} I_{dr} - I_{ds} I_{qr}\right) \quad (9)$$

And the torque balance equation of the motor is

$$T_e = T_l + J\frac{d}{dt}(\omega_m) + B\,\omega_m \quad (10)$$
$$P = V_{ds} I_{ds} + V_{qs} I_{qs} \quad (11)$$
$$Q = V_{qs} I_{ds} - V_{ds} I_{qs} \quad (12)$$

III. VECTOR CONTROL OF A DOUBLY FED INDUCTION MACHINE

Among the different alternative control methods that have been developed for the DFIM, only the vector control technique is studied in this section, which is probably the most extended and established one. In an equivalent way to the classic vector control techniques of other different machines, the vector control of the DFIM is performed in a synchronously rotating dq frame, in which the d-axis is aligned. It is possible to perform dq rotor currents control, simply by using a regulator for each current component. Note that the stator flux and ω_r must be estimated for that purpose; however, this is simple and does not add extra difficulties. For the reference frame transformation, the angle θr must be estimated. The control must be performed in dq coordinates, but then the rotor voltage and currents must be transformed into DQ coordinates. First, it is possible to obtain the angle of the stator voltage space vector, and then subtract 90 degree from this estimated angle, and thus, obtain θs. A simple phase-locked loop (PLL) can be used to perform the stator voltage grid synchronization, providing robustness to the estimation and a rejection of small disturbances or harmonics. Note that if the DFIM employed presents a different turn's ratio at the stator and rotor, it must be considered at the control stage. In the control block diagram presented in Fig-2, the current loops work with the rotor currents referred to the stator side, while the conversion to rotor-referred quantities is performed at the measurement stage for the currents and before the creation of the pulses for the converter for the voltages.

However, Fig-3 shows that when choosing equal proportional-integral (PI) regulators for both loops, employing compensation of the cross terms, and neglecting the effect of the voltage source converter and the possible delays in computation or measurements, the equivalent closed-loop systems of both current loops are equal to a second-order system with two poles and a zero that can be placed by classic control theory choosing the appropriate gains of the PI regulators.

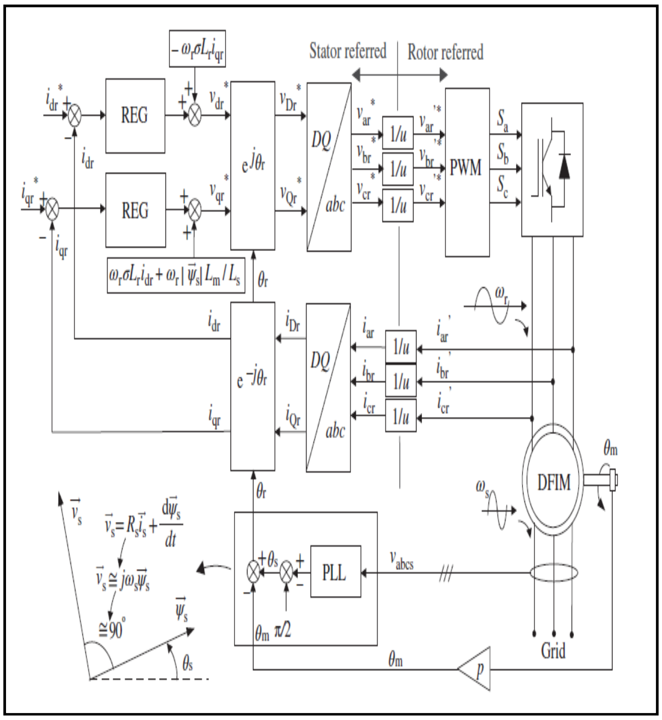

Fig -2: Current control loops of the DFIM.

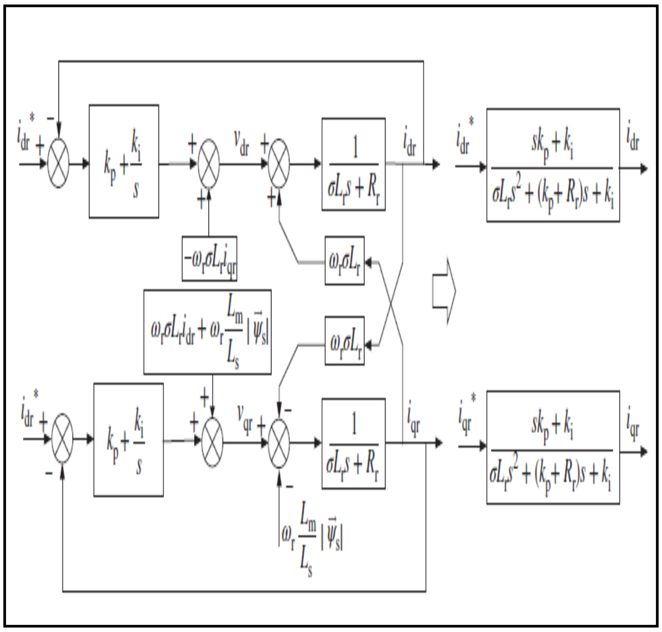

Fig -3: Equivalent second-order system of closed-loop current control with PI regulators.

Once the current control loops and the flux angle calculation have been studied, the complete control system can be introduced. As the d-axis of the reference frame is aligned with the stator flux space vector, the torque expression in the dq frame can be simplified as follows:

$$T_{\text{em}} = -\frac{3}{2} p \frac{L_{\text{m}}}{L_{\text{s}}} |\vec{\psi}_{\text{s}}| i_{\text{qr}} \tag{13}$$

This means that the q rotor current component is proportional to the torque, that is, with i_{qr} it is possible to control the torque and, consequently, the speed of the machine if the application requires it. In a similar way, by developing the stator reactive power expression in the dq frame, we obtain a compact expression, which reveals that i_{dr} is responsible of Qs.

$$Q_{\text{s}} = -\frac{3}{2} \omega_{\text{s}} \frac{L_{\text{m}}}{L_{\text{s}}} |\vec{\psi}_{\text{s}}| \left(i_{\text{dr}} - \frac{|\vec{\psi}_{\text{s}}|}{L_{\text{m}}} \right) \tag{14}$$

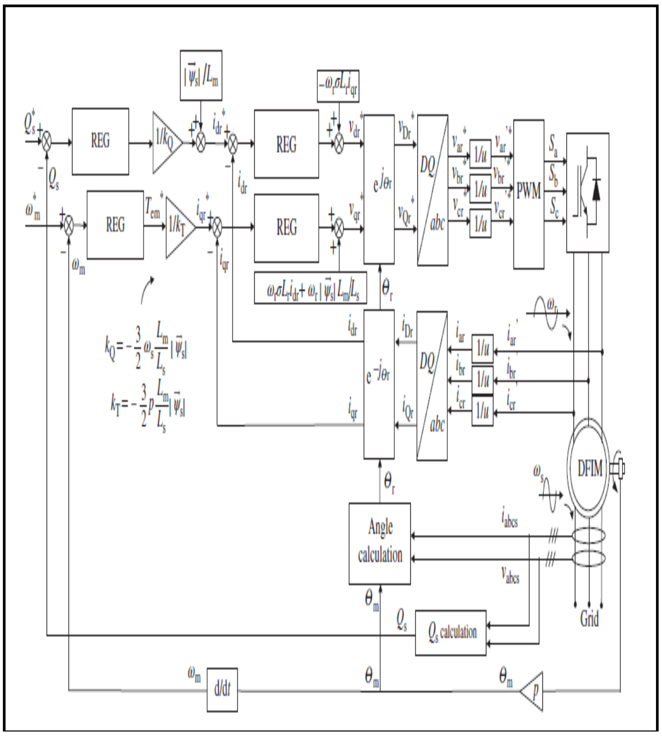

Fig -3: Complete vector control of the DFIM

Therefore, because of the orientation chosen, it can be seen that both rotor current components independently allow us to control the torque and reactive stator power. In this way, based on these expressions, Fig-3 illustrates the complete vector control of the DFIM. The necessity of the speed regulation depends on the application in which this machine is being used, and it could happen that the DFIM simply imposes an electromagnetic torque T_{em}, while the speed of the shaft is controlled by other elements. However, with the Qs loop, it is possible to control the magnetizing of the machine because, the stator of the machine is connected directly to the grid, and the stator flux amplitude is constant and provided by the grid voltage.

IV. RESULTS AND DISCUSSIONS

In order to validate the vector control algorithm in a DFIM, an example of one particular test is depicted. Simulation of the vector control of DFIM drive system using MATLAB/SIMULINK as shown in Fig-4.

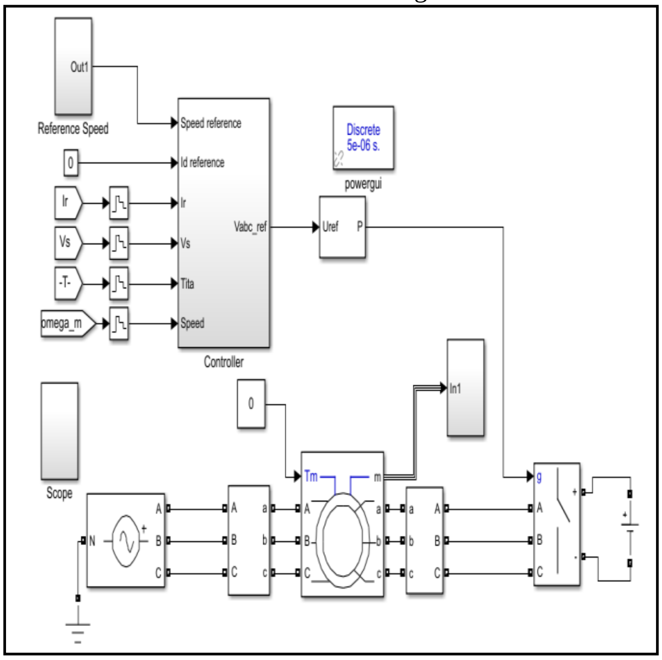

Fig -4: Simulink block diagram of Vector control of DFIM

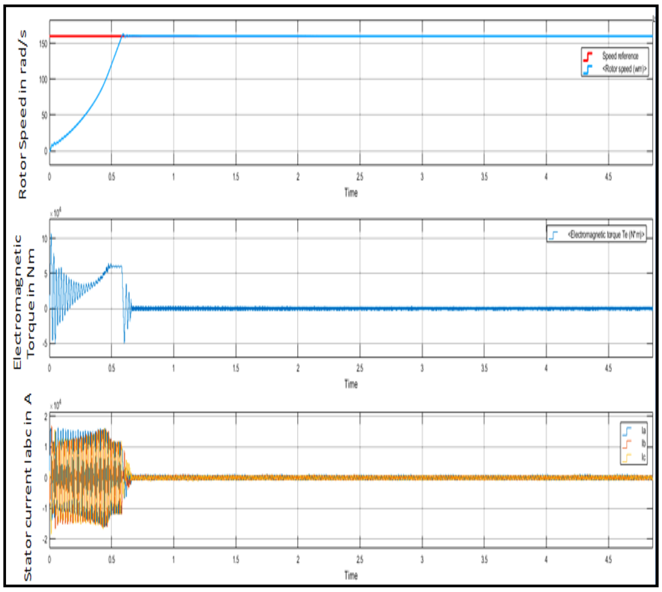

Fig -5: Performance of DFIM drive system when given reference speed is 160rad/sec at no load.

Fig-5, shows the performance characteristic of a 2MW, 690V, 50Hz DFIM, operating with a PI speed controller. The given reference speed is 160 rad/sec at no load. It is observed that motor pick up the speed 165 rad/sec at starting and also it draw high starting current. The phase current peak is relatively large during the accelerating process, which is 2-3 times larger than the rated current. When flux linkage reaches steady-state value, motor output

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the maximum torque and accelerate. Motor current reach a value of 850 Amps at t=0.6 sec and motor torque settle a value of 850 Nm after t=0.7 sec at the starting mode the high value error is amplified across the PI controller provoking high variations in the motor torque.

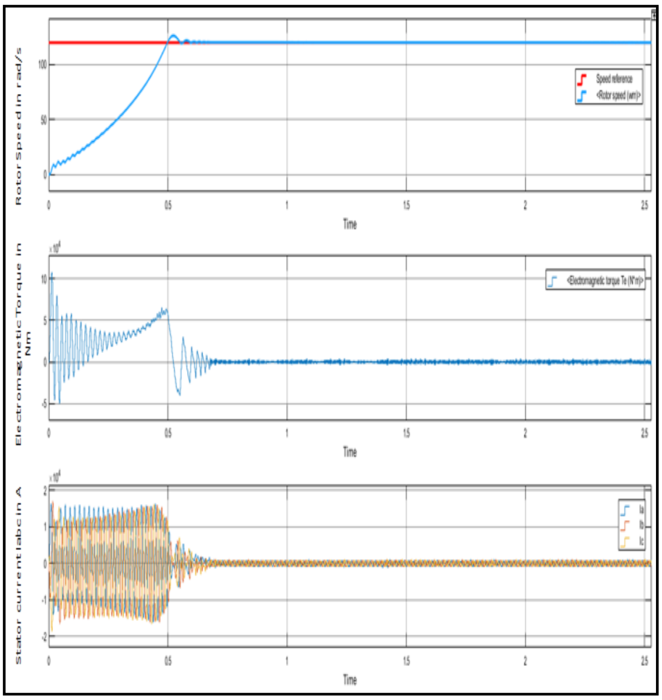

Fig -6: Performance of DFIM drive system when given reference speed is 120rad/sec at no load.

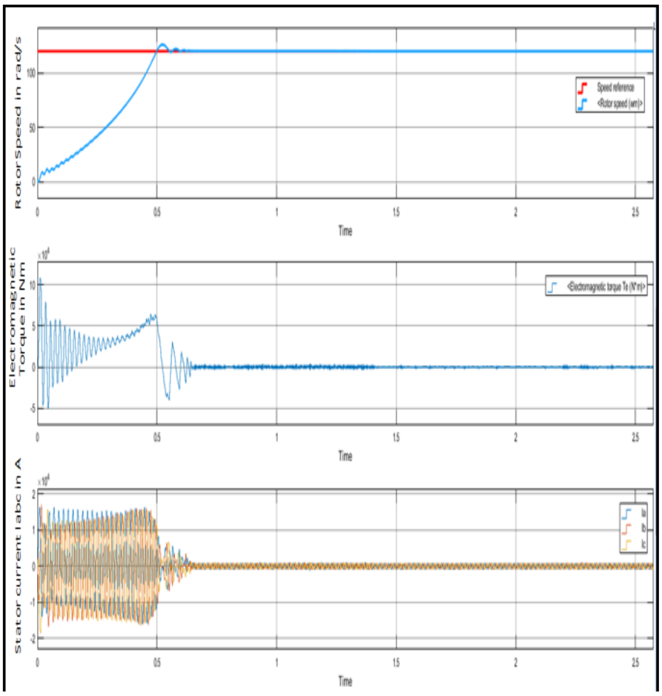

Fig -7: Performance of DFIM drive system when given reference speed is 120rad/sec at load 25Nm.

The simulation is carried out for a reference speed of 120rad/sec and no-load and the results have been verified. The controller yields optimum speed control for various speed values under no-load conditions. Digital Simulations have been performed under load conditions for a load torque of 25 Nm and a reference speed of 120 rad/sec. The simulation results shown in Fig-8 for a load torque of 25Nm indicate the speed response provided by the controller.

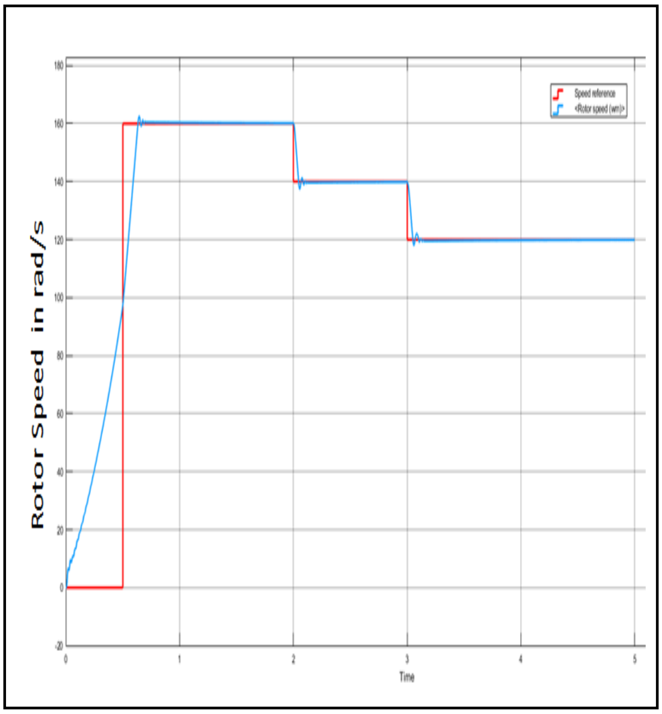

Fig -8: Rotor speed at variable reference speed condition.

Simulation analysis is carried for variable reference speeds at variable torque. The controller yields a stable response under varying load and provides constant speed control. The matching in speed is verified for both variable reference sped and constant reference speed. Also, the rise time taken for the actual speed to match the reference speed is less in case of vector control.

It can be seen from the graphical outputs that the vector control scheme provides better control when compared with other control scheme. The efficiency of vector control is more pronounced at the loaded conditions than the conventional speed control schemes.

V. CONCLUSIONS

Based on the adequate analysis of vector principle and DFIM mathematical model, simulation model in MATLAB/SIMULINK environment has been constructed. The simulation results show that the proposed controller which offers regulated responses in terms of fast tracking, small overshoot, zero steady-state errors, speed of the machine is controlled for the required speed and the torque response is obtained fast by estimating, measuring,

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calculating the position and magnitude of the motor flux in the machine.

The work presented here focuses on the simulation of vector control of DFIM. The performance can be analyzed through proper hardware configuration using FPGA. Further, this work can be expanded to obtain high performance sensorless control of induction motor.

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