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MODELING OF INDUCTION MOTOR USING A QD FORMULATION

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ABSTRACT

This paper presents the type of models using in modeling of three phase induction motor and consider the modeling of induction motor using phase variables in a q-d formulation. Three phase induction motors are continuing to remain as work horses in industrial applications. The accuratebehavioral modeling of induction motor helps in designing controller for the machine and also useful in detection of faults in machines. Almost all faults in the induction motor affect the flux in the air gap. These fluxes can be measured virtually using dq model of induction motor by feeding voltage and current values extracted in real time and stored. In this paper, DQ model is developed in stator reference frame using MATLAB-SIMULINK platform and a data acquisition system supported with LabVIEW is used to obtain motor terminal voltage and current signals which are useful in estimation of flux in an actualmachine.

Keywords: component; DQ model, Data acquisition system, Induction motor, modeling.

NOMENCLATURE

v_{as}, v_{bs}, v_{cs}	- Input voltage for phase a, b, c respectively in Volts.
v_{qs}, v_{ds}	- Stator q and d axis voltages in Stationary reference frame respectively in Volts.
v_{qr}, v_{dr}	- Rotor q and d axis Voltages in Stationary reference frame respectively in Volts.
i_{qs}, i_{ds}	- Stator q and d axis current in Stationary reference frame respectively in Volts.
i_{qr}, i_{dr}	- Rotor q and d axis current in Stationary referece frame respectively in Volts.
$R_{S,}$	- Stator Resistence/phase in Ω.
L_S	- Stator Self Inductance/phase in H.
L_M	- Mutual Inductance in H.
R_r	- Rotor Resistance/phase in Ω.
L_r	- Rotor self inductance in H.
ω_r	- rotor speed in rad/sec.
J	- Inertia of Motor in Kg- m^2 .
T_e	- Electrical Torque in N-m.
$T_{L.}$	- Load Torque in N-m.
p	- Number of Poles.
$\lambda_{mq}, \lambda_{md}$	- q and d axis magnetizing flux linkage

I. INTRODUCTION

The induction motor (IM) is largely used in many industrial applications due to low cost, good torque density and robustness. Analytical model are commonly used and are appreciated for their speed. The modeling approach for this machine may be roughly divided into three categories: finite element method; equivalent magnetic circuit approach; and coupled electric approach [1].

The most popular representation for ac machines for transient simulation is the so-called *qd* model based on a series of mathematical transformations. The direct and quadrature axis model based on the space phasor theory is widely used to study the dynamic behavior of three-phase inductor motor. Rotating reference frame, e.g. stationary, rotor or synchronous are used to transform physical (*abc*) variables of the machine into fictitious (*qd*) variable [1][5] . By having the voltage and current quantities in *qd* frame, it is possible to control the speed of the machine by controlling the flux and torque independently. It is also a method of sensor less measurement.

The advantages of the *qd* induction machine models: 1) the time –varying inductances between stator and rotor winding are eliminated; 2) the flux linkage equations are decoupled; 3) zero sequence quantities disappear for balanced operation; 4) the average-value modeling of machine converter system is simplified when expressing the machine in terms of *qd* variables [1].

d-q model is extensively used in control applications as it has the capability to convert sinusoidal variable quantities to dc quantities using suitable reference theory. By having the voltage and current quantities in *d-q* frame, it is possible to control the speed of the machine by controlling the flux and torque independently. It is also a method of sensor less flux measurement. The direct and quadrature axis model (*d-q* model) based on the space phasor theory is widely used for simulation the dynamic behavior of three-phase induction motor. In this model 3 phase machine (*abc*) is transformed into two phase machine (*dq0*). The equivalence is based on the equality of the magneto motive force (mmf) produced in the two phase and three phase windings and equal current magnitudes.
For the purpose of control, there is a need to express sinusoidal system variables as dc quantities. This can be accomplished by selecting one of the three reference frames given below

- **Stator reference frame:** ω_c =0, the frame is fixed in stator
- **Rotor reference frame:** $\omega_c = \omega_r$, the frame is fixed in rotor
- **Synchronous reference frame:** $\omega_c = \omega_s$, the frame is fixed in synchronously rotating mmf

The dynamic model of induction machine considers the instantaneous effects of varying voltages, currents, stator frequency and torque disturbances.
The following assumptions are required to derive the dynamic model.

- Uniform airgap.
- Balanced stator and rotor windings, with sinusoidally distributed mmf.
- Inductance versus rotor position is sinusoidal.
- Saturation and parameter changes are neglected.

A three-phase IM consists of three-phase windings on the stator and three-phase windings on the rotor. To describe the dynamic model, all the stator and rotor differential equations should include the time-varying mutual inductances. Such a dynamic model turns to be very complex.
A conceptual simplicity is obtained by transforming the variables (i.e. instantaneous voltages, currents, flux-linkages) from the three-phase '*a-b-c*' reference frame to two-phase '*d-q*' reference frame where the direct axis '*d*' and quadrature axis '*q*' are orthogonal to each other. This simplification can be done on both, the stator and rotor sides.

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II. QD MACHINE MODEL

The CC induction machine models is often transformed into the *qd* arbitrary reference frame (ARF) [1], where the flux linkages become decoupled. For convenient derivation of the VBR models, the *qd* model is included in decoupled form. In particular, the voltage equations in the ARF are given as,

(2)

(3)

(4)

(5)

(6)

The flux linkage equations are expressed as

(7)

(8)

(9)

(10)

where magnetizing fluxes are defined as

(11)

(12)

(13)

The developed electromagnetic torque in terms of transformed *qd* variables is given as

(14)

III. THE DYNAMIC EQUIVALENT CIRCUITS OF A THREE PHASE IM

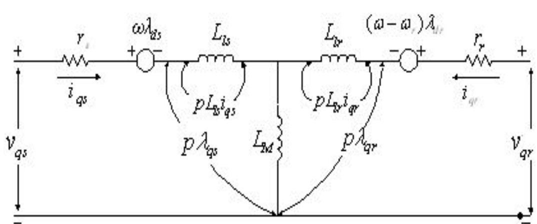

Fig. 1. Dynamic equivalent circuits of 3-phase IM along q-axis

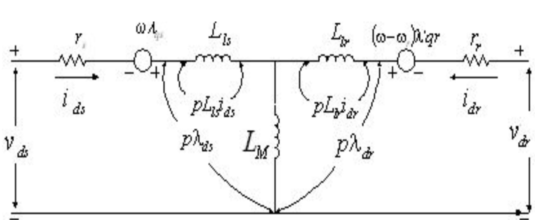

Fig. 2. Dynamic equivalent circuits of 3-phase IM along d-axis

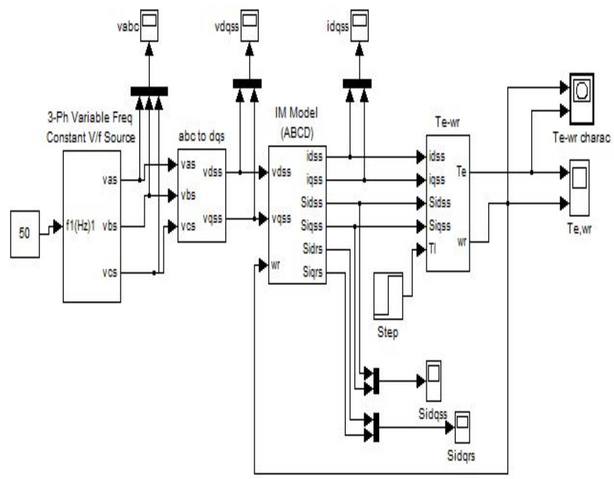

Fig .3. Simulink Model of a 3-ph induction motor (based on d-q theory)fed from a 3-ph variable frequency source

IV. SIMULATION RESULT

The interfacing model is based on the voltage-behind-reactance formulation developed in MATLAB/SIMULINK platform. The simulations are carried out using the motor data obtain from the No load test. 2.2KW motor used, motor line voltage is 415V, frequency is given 50 Hz,and dc voltage is given 800V. Variable-step type (stiff/Mod. Rrosenbrock) solver used for simulation work. The simulated waveforms are shown in Fig.7 to 11

Table 1. Induction motor parameters

Parameter	Machine
Ls(H)	0.70608
Lr(H)	0.70608
Lm(H)	0.59181
Rs(Ω)	9.1091
Rr(Ω)	8.00634
J(Kg-m)	0.01
P	4

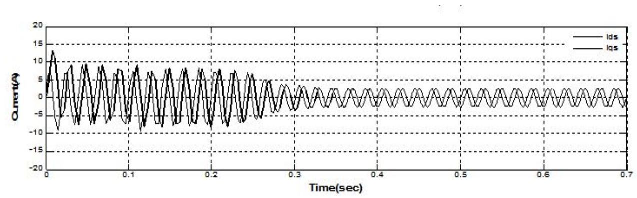

Fig. 4. Stator current, in q and d axis

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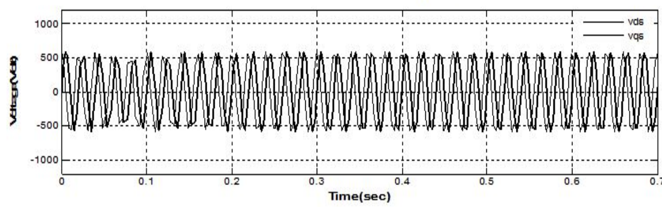

Fig.5. Stator voltage, in q and d axis

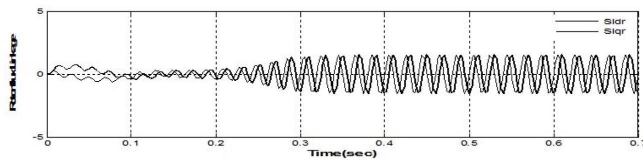

Fig. 6. Rotor flux linkage in q and d axis

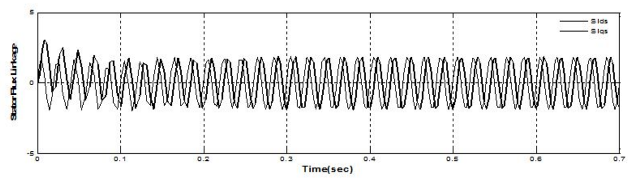

Fig.7. Stator flux linkage in q and d axis

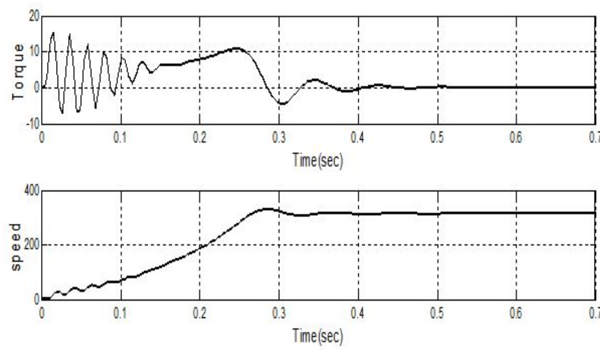

Fig. 8. Torqe and speed of motor

During free acceleration at no-load condition

The machine is allowed to accelerate from zero speed to rated speed at no –load. The steady state was reached at 0.4s. The instantaneous rotor speed and torque are presented in Figures.

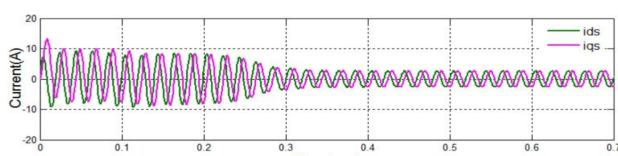

Fig. 9. Stator current, in q and d axis

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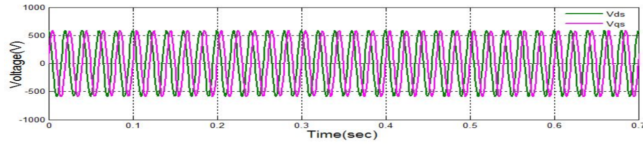

Fig. 10. Stator voltage, in q and d axis

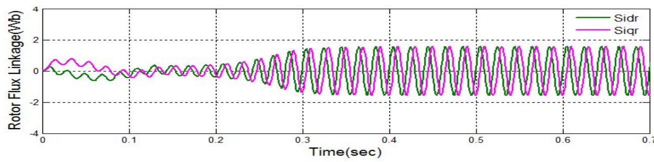

Fig. 11. Rotor flux linkage in q and d axis

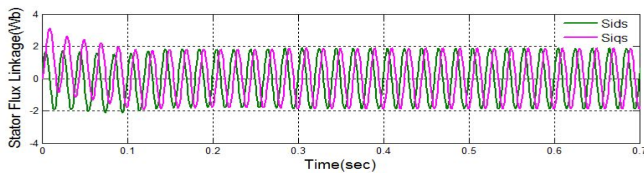

Fig. 12 Stator flux linkage in q and d axis

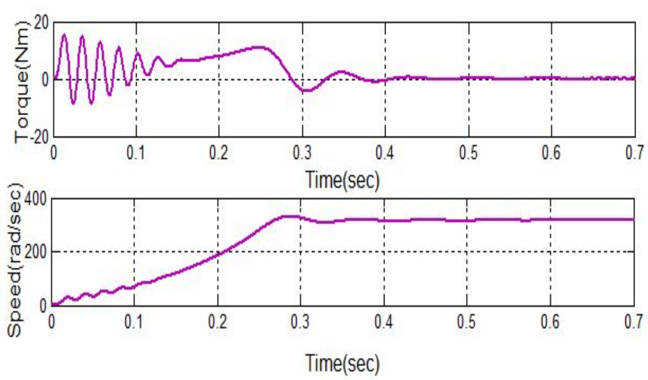

Fig. 13. Torque and speed of motor

V. CONCLUSION

The dq modeling of the induction motor has been developed Specially to estimate virtual flux. In case of noninvasive method of fault detection scheme for eccentricity detection, this model can be adopted to estimate the flux, as flux is the primary parameter to get affected by air gap eccentricity. Any asymmetry in the air gap gives rise to nonuniform distribution of the flux and harmonics are induced in the stator current. Using these stator currents, fluxes can be estimated after Simulating the model. The model developed also can be used to estimate the dynamic torque as this is another parameter to get affected by air gap asymmetry in the machine. This model can also be used to study the effect of variable frequency

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