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Dynamic Modeling of Induction Machine Incorporating Transmission Line Impedance

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Abstract- **Induction motors are widely used mostly in the industry for process control. It has almost replaced the dc motor due to its simplicity in construction, reliability, efficiency and simple methods of speed control mostly the present hi-tech microprocessors. Other advantages include; low initial cost, easy operation and simple maintenance. A good mathematical model is therefore required in predicting the behavior of the induction machine under different dynamic conditions. In this paper, the effect of incorporating transmission line impedances in the modeling of the dynamic of the induction motor is investigated and the result deduced. A commercial software package, MATLAB, is used to simulate the dynamic behavior of a three phase 7.5kW induction motor with and without transmission line impedance. Results of the simulation of the conventional machine model are compared with the results of the simulation of the machine model with transmission line impedance.**

Keywords: **Dynamic analysis, Induction motor, MATLAB, Transmission line impedance.**

I. INTRODUCTION

DC drives have been widely used in various industrial applications but recent device technology and high-speed microprocessor have titled the balance and the induction motor has become the workhorse of the industry. Today, induction motors are used for most industrial drives, it is a simple, reliable and robust, induction machine have more advantages than the dc motor. They require limited maintenance even when subjected to high mechanical stresses incurred with repeated starts and reversals of direction. Over 85 % of the world's ac motors are induction machines [1,2] and they are manufactured in sizes ranging from fractional horse power to around 15,000hp.

The dynamic behaviour of induction motor can be predicted by dynamic models developed for different operational conditions. Due to the growing need of Induction motors in the industrial sector, there is a growing emphasis on an acceptable and adequate model representation of this machines for all modes of operation. Problems concerning stability of power systems, computer-aided simulation techniques are commonly used.

Akpama and Okoro [3] pointed out that in recent years, significant improvements have been obtained in the area of power system simulation; in particular, attention has been given to the statement of the mathematical problem suitable for computer implementation, as well as to the modeling and identification of a system(generators and motors).

Himanshu K. Patel [4], presented a quality mathematical model of induction machine for steady state and dynamic equations and d-q transformation technique, which is used for both steady and transient state analysis. The behaviour of the induction machine was observed with or without any supply harmonies. The simulation from Himanshu showed that there is the possibility of instability in large HP machines if connected directly to the grid. The transient studies of grid connected induction generators driven by wind turbine was considered in [6]. In [7] and [8] the study has been carried out for a large wind farm, with complete dynamic representation, including the mechanical dynamics of the windmill system. Even though a realistic wind farm has been considered in [7], the induction generators of the entire wind farm have been represented by a single equivalent machine. But in [8], all the machines within the farm are completely represented, the study focuses on analyzing the electromechanical oscillations within a wind farm. In [9] the stability has been analyzed for a wind-hydro hybrid system by linearizing the complete system model around the operating point. However, this cannot be used in cases where the disturbance is large, as the linearization may not be valid. Such a model [10] has been extensively used in the past for the study of single induction motors and drives. In [11] the simulation of direct-on-line starter of induction motor was presented to study the transient behavior of the motor. It was noticed that when the supply cable has a large resistance, the torque oscillations in the torque/speed characteristic are reduced and decay more rapidly, but the run up time of the motor was longer. Interaction of drive modulation and cable parameters on AC motor transients was investigated in [12].

Divya and Rao [13] carried out a study by simulating a single induction generator connected to the infinite bus through a double circuit transmission line, the dynamic behavior of the system was obtained by simulation with MALAB.

It is worthy to note that a lot of work has been done in the analysis of induction machine, yet the effect of transmission line parameters on the machine has not been investigated. If the transients in the grid are neglected, then there seems to be no justification for including stator transient. If the network transients are included, the problem could become computationally intractable. Moreover, the need for such a detailed representation is yet to be established. It is also not clear whether the inclusion of the exponentially decaying components of electrical transients is desirable. Never the less, the simulation of the induction machine and the effect when transmission line parameters are included is investigated here.

II. INDUCTION MACHINE MODELING

The modeling of induction machine is not new, depending on the complexity and details investigated by the modeller. No model is complex or simple, it all depends on what the modeller is actually looking. Machine modeling takes a detailed form only when its modeling becomes perfect to a greater accuracy. When the stator eddy current path is taken into account, the uniform air-gap theory in phase model analysis becomes inefficient to take care of the transients. This drawback necessitates the introduction of analysis of the machine in d-q axis Frame.

The two axes modeling (d-q model) using Park's transformation theory in state space representation converts the machine from phase model to dq model.

A. Conventional Model of the Machine

In order to develop an acceptable model of an induction machine, numerous non-linear differential equations are developed from the dq equivalent circuit of the machine using Kirchhoff's voltage and current law. First the conventional machine models is developed following assumptions below, [14];

1. The machine is symmetrical with a linear air-gap and magnetic circuit
2. Saturation effect, skin-effect and temperature effect are neglected
3. Harmonics is neglected and the stator voltages are balanced.

The transients performance of the induction machine are governed by differential equations which can be described in several ways; they only differ in minor details and in their suitability for use in a given application. The d-q axis formulation provides a convenient way of modelling the machine and is most suitable for numerical solutions. This is preferable to the space-vector machine model that describes the machine regarding complex variables. Figure 1 show the d-q equivalent circuits of the induction machine.

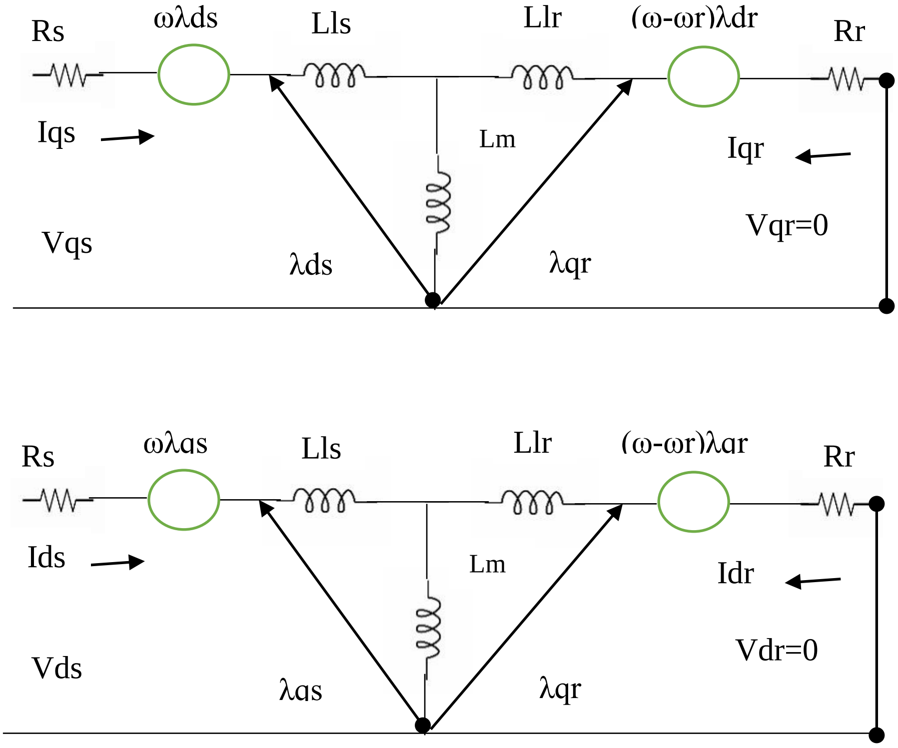

Figure 1: Q- and D-axis Equivalent circuit of an Induction Machine

The voltage balance equation for the d,q coils in arbitrary reference frame readily written as in [15]:

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s\rho & \omega L_s & L_m\rho & \omega L_m \\ -\omega_c L_s & R_s + L_s\rho & -\omega L_m & L_m\rho \\ L_m\rho & (\omega-\omega_r)L_m & R_r + L_r\rho & (\omega-\omega_r)L_r \\ -(\omega-\omega_r)L_m & L_m\rho & -(\omega-\omega_r)L_r & R_r + L_r\rho \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix} \quad (1)$$

Where $L_s = L_{ls} + L_m$, $L_r = L_{lr} + L_m$, (2)

It is always recommended to transform equation (1) to d-q axis fixed either to stator, the rotor or rotating in synchronism with the supply voltages. In order to study the effects of rotor side disturbances (such as sudden change in shaft load, moment of inertia etc) of the machine, rotor reference frame may be adopted successfully. For rotor reference frame

$\omega_c = \omega_r$ (3) stator supply angular frequency (radian/sec)

Equations (1) and (3) gives equation (4)

$$\begin{bmatrix} V^r_{qs} \\ V^r_{ds} \\ V^r_{qr} \\ V^r_{qr} \end{bmatrix} = \begin{bmatrix} R_s + L_s\rho & \omega_r L_s & L_m\rho & \omega_r L_m \\ -\omega_r L_s & R_s + L_s\rho & -\omega_r L_m & L_m\rho \\ L_m\rho & 0 & R_r + L_r\rho & 0 \\ 0 & L_m\rho & 0 & R_r + L_r\rho \end{bmatrix} \begin{bmatrix} i^r_{qs} \\ i^r_{ds} \\ i^r_{qr} \\ i^r_{qr} \end{bmatrix} \quad (4)$$

$P[i] = -[L]^{-1}([R] + \omega_r [G])[i] + [L]^{-1}[V]$ (5)

For the purpose of digital simulation, equation (4) is represented in state variable form with currents as state variables.

Where

$[V] = [V_{qs} \ \ V_{ds} \ 0 \ \ 0]^t$ (6)

$$[R] = \begin{bmatrix} \mathrm{R}_s & 0 & 0 & 0 \\ 0 & \mathrm{R}_s & 0 & 0 \\ 0 & 0 & \mathrm{R}_r & 0 \\ 0 & 0 & 0 & \mathrm{R}_r \end{bmatrix} \quad (7)$$

$$[L] = \begin{bmatrix} \mathrm{L}_s & 0 & \mathrm{L}_m & 0 \\ 0 & \mathrm{L}_s & 0 & \mathrm{L}_m \\ \mathrm{L}_m & 0 & \mathrm{L}_r & 0 \\ 0 & \mathrm{L}_m & 0 & \mathrm{L}_r \end{bmatrix} \quad (8)$$

$$[G] = \begin{bmatrix} 0 & \mathrm{L}_s & 0 & \mathrm{L}_m \\ -\mathrm{L}_s & 0 & -\mathrm{L}_m & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} (9)$$

$$[\mathrm{i}] = \left[i_{qs} \;\; i_{ds} \;\; i_{qr} \;\; i_{dr}\right]^t \qquad .(10)$$

The electromagnetic torque ,T_e is expressed as:

$$T_e = \frac{3}{2} p L_m \left(i_{qs} i_{dr} - i_{ds} i_{qr}\right) \quad (11)$$

Where, P = Number of pole pairs

This requires a modification to the computer program. The schematic diagram of motor and the transmission line circuit is illustrated in figure 2.

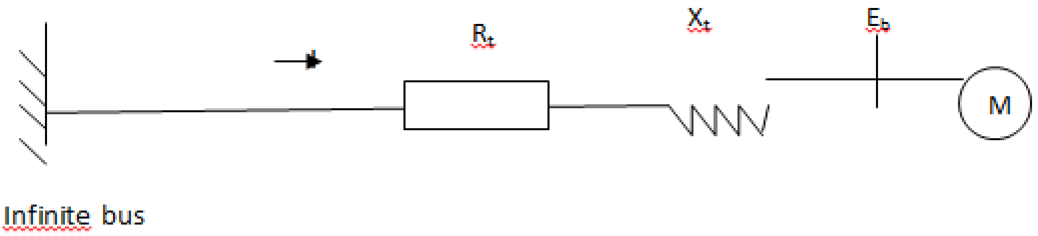

Figure 2 Induction motor connected to infinite bus-bar

In this case, the parameters of the transformed stator circuits are modified to take account of the circuit parameters and the coefficient matrices of equation (4) are likewise modified and redefined as:

$$[\mathrm{R}] = \mathrm{diag}\,[\mathrm{R}_s + \mathrm{R}_t,\ \mathrm{R}_s + \mathrm{R}_t,\ \mathrm{R}_r\ \mathrm{R}_r] \quad (12)$$

$$[L] = \begin{bmatrix} \mathrm{L}_s + \mathrm{L}_t & 0 & 0 & 0 \\ 0 & \mathrm{L}_s + \mathrm{L}_t & 0 & 0 \\ 0 & 0 & \mathrm{L}_r & 0 \\ 0 & 0 & 0 & \mathrm{L}_r \end{bmatrix} \quad (13)$$

$$[G] = \begin{bmatrix} 0 & \mathrm{L}_s + \mathrm{L}_t & 0 & \mathrm{L}_m \\ -(\mathrm{L}_s + \mathrm{L}_t) & 0 & -\mathrm{L}_m & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \quad (14)$$

The inclusion of the simple transmission circuit representation enables realistic modeling of those situations where a motor draws a high current from the supply over a relatively long transmission link [1].

III. SIMULATION AND RESULTS

In this paper, simulations have been developed in MATLAB. The simulations have been carried out using the motor and transmission line data. The simulation results for the induction motor are presented in figures, 3-8, and compared to investigate the effects of incorporating transmission line impedance in the dynamic analysis of induction motor. The following were observed from the simulation results:

i. The Peak phase currents and electromagnetic torque in the transient region at start up is higher when transmission line impedance is neglected than when the impedance is considered. Also the phase currents reaches steady state faster when transmission line impedance is neglected than when the impedance is considered.
ii. The mechanical Rotor speed reaches synchronous speed faster when transmission line impedance is neglected than when the motor is connected to a line with impedance.

IV. CONCLUSION

This paper presents a quality and comprehensive model for induction motor which can be used for studying the behavior under different operating conditions. The paper also shows that MATLAB software package is highly suitable for the dynamic simulation of induction motor with and without transmission line impedance.

The induction motor was simulated with and without transmission line impedance and comparison made to investigate the effect of neglecting the transmission line impedance. The general conclusion based on the comparison can be summarized as follows:

(a) The induction motor has higher starting current and torque when the transmission line impedance is neglected than when the impedance was considered in the simulation.

(b) There is a significant difference between the results of the simulation of the induction motor when the transmission line impedance is neglected and when the impedance is incorporated in the simulation.

(c) The simulated induction motor model with transmission line impedance included gives comparatively good result and can therefore be conveniently used to predict the actual motor performances in dynamic state.

Machine Data :

Machine rating : 7.5kW, 340V, 4 Poles Delta connected.
Stator and Rotor Resistances is given as 2.5Ω and 0.9Ω respectively,
Stator and Rotor reactance is given as 1.9Ω and 3.0Ω respectively,
Magnetising Reactance is 55.3Ω.
The motor Inertia is 0.11kgm^2.
The Transmission Line Resistance and Inductance is 0.55Ω and 0.006H respectively.

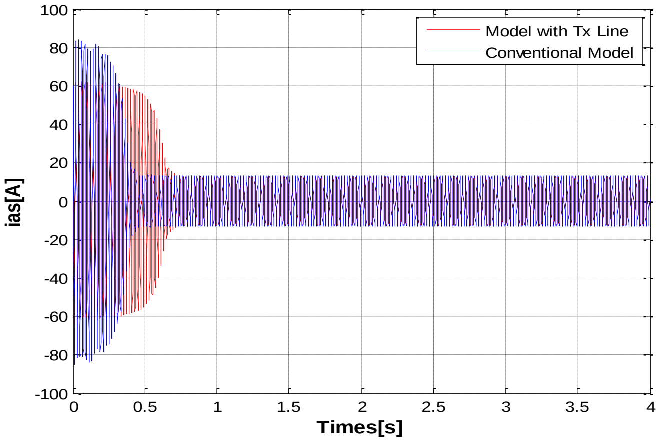

Figure 3 : A graph of Ias current against time

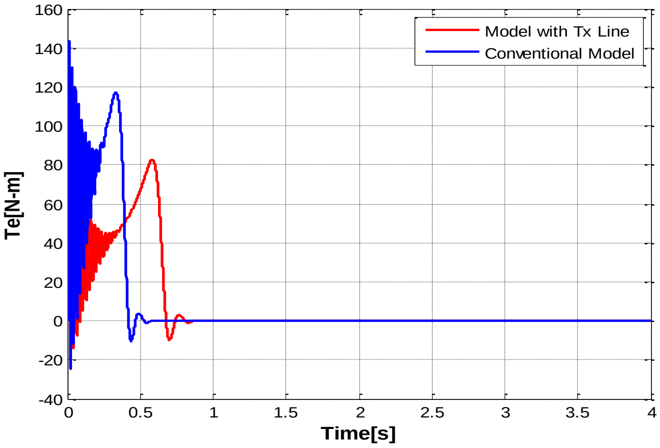

Figure 6 : A graph of Te current against time

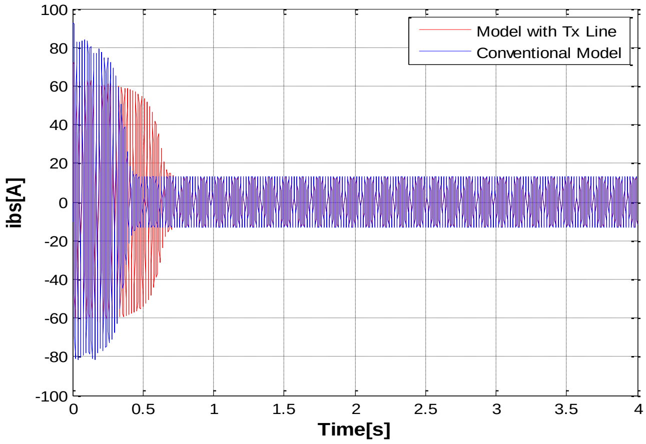

Figure 4 : A graph of Ibs current against time

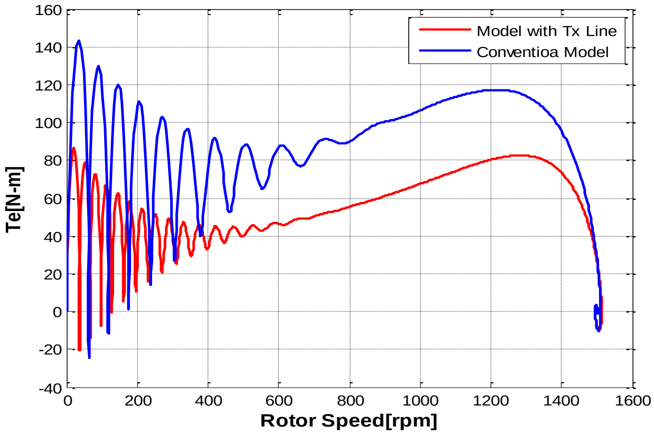

Figure 3 : A graph of Te against Rotor Speed

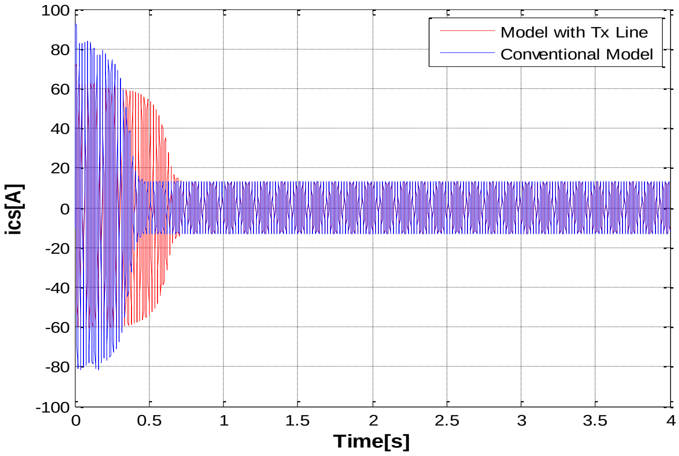

Figure 5 : A graph of Ics current against time

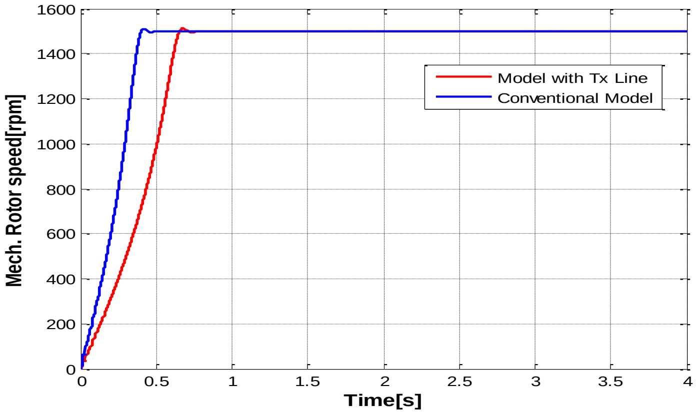

Figure 8 : A graph of Mech. Speed against time

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