Pspice Model for Three Phase Induction motor

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Abstract - PSPICE program packages are widely used in the area of electronics, but these programs can be used to simulate electrical machines and electromechanical systems. In this paper a systematic procedure is proposed for simulation of a three phase induction motor using a circuit analysis package called PSPICE. The modelling technique can be used to represent other DC and AC electric machines.

Keywords - Induction motor, electromechanical system, PSPICE.

I. Introduction

Transient analysis of electrical machines is traditionally performed by solving a system of differential equations. These equations are usually based on two-axes model of the machine. The solution lead to the required performance for various operating conditions. This process is very hard and user is ocupated by mathematics rather than getting a feel for the transient behaviour of the machine. Transient analysis of electrical machines supplied from variable frequency voltage source and current source inverters is more complicated because of the complexity of power electronic circuit. An alternative method in dealing with transient cases is the use of available CAD (Computer Aided Design) software package, for example, PSPICE.

Possibility of the PSPICE software package application on simulation of induction motor is presented in this paper. This paper introduce no new equations or new theory about induction machine modelling. Instead it illustrates a systematic procedure in order to study the behaviour of the motor using PSPICE. Investigation is also extended to determine this behaviour for different operating conditions.

II. Induction motor model

Considerable research over the years has been devoted to the mathematical modelling of induction motors, using both frequency-domain and time-domain representations. The Frequency-domain motor representations are limited to steady-state motor performance studies. Time-domain representation can be used for both steady-state and transient performace studies. Whilst it is possible to develop a motor model in the physically existing 3-phase (or 3 axis) reference frame the presence of the mutual inductance terms, which are nonlinear functions of rotor positions, make model extremely and computationally inefficient. Since it is generally recognised [1, 2] that the two axis motor model can be used in the vast majority of operational circumstances, and is considerably less complex compared to the 3-phase model.

The 2-axis machine equations [1, 2, 3] can be formulated in various reference frames including: stator-fixed axis, rotor fixed axis, synchronously-rotating axis and variable-speed axis, each of which has advantages depending upon the machine geometry, excitation, and operational modes under study. It is of course theoretically possible to produce a equivalent circuit for the motor based on any of these reference frames.

The three-phase induction motor terminals are connected to the electric distribution network or to the power electronic converter. Terminal instantaneous phase voltages are v_a, v_b and v_c. By choosing a stationary reference frame we have the simplest equations. We can derive the d-axis time varying stator side voltage v_{ds} and q-axis stator side voltage v_{qs} by using the following axis transformation:

$$\begin{bmatrix} v_{qs} \\ v_{ds} \\ v_{s0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} \tag{1}$$

where v_{s0} is the possible zero sequence voltage component. The zero-sequence component does not exist in balanced three phase cases.

Axis transformation for rotor circuit is:

$$\begin{bmatrix} v_{qr} \\ v_{dr} \\ v_{r0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\beta & \cos(\beta - \frac{2\pi}{3}) & \cos(\beta + \frac{2\pi}{3}) \\ \sin\beta & \sin(\beta - \frac{2\pi}{3}) & \sin(\beta + \frac{2\pi}{3}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix} \tag{2}$$

where $\beta = \theta - \theta_r$. For stationary reference frame θ=0 and

$$\theta_r = \int_0^t \omega_r dt + \theta_r(0). \tag{3}$$

After axis transformation we have the following stator voltage equations for both axis:

$$v_{qs} = \frac{2}{3}\left(v_{as} - \frac{1}{2} v_{bs} - \frac{1}{2} v_{cs} \right) \tag{4}$$

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$$v_{ds} = \frac{1}{\sqrt{3}}\left(v_{bs} - v_{cs}\right) \tag{5}$$

$$v_{0s} = \frac{1}{3}\left(v_{as} + v_{bs} + v_{cs}\right) \tag{6}$$

Voltage equations for the *qd*0 axis are:

$$v_{qs} = r_s i_{qs} + \frac{d\Psi_{qs}}{dt} \tag{7}$$

$$v_{ds} = r_s i_{ds} + \frac{d\Psi_{ds}}{dt} \tag{8}$$

$$v_{0s} = r_s i_{0s} + \frac{d\Psi_{0s}}{dt} \tag{9}$$

$$v_{qr} = r_r i_{qr} + \frac{d\Psi_{qr}}{dt} - \omega_r \Psi_{dr} \tag{10}$$

$$v_{dr} = r_r i_{dr} + \frac{d\Psi_{dr}}{dt} + \omega_r \Psi_{qr} \tag{11}$$

$$v_{0r} = r_r i_{0r} + \frac{d\Psi_{0r}}{dt} \tag{12}$$

where r_r is rotor resistance, r_s is stator resistance and ω_r electrical angular speed of the rotor. Rotor voltage exist only for double fed induction motor. For singly fed machines the rotor voltage iz zero. Latest terms in the rotor side voltage equations $\omega_r \psi_{qr}$ and $-\omega_r \psi_{qr}$ are so-called rotation voltages. They are due to the rotation with respect to the stationary reference frame fixed to the stator.
Flux linkages component are:

$$\Psi_{qs} = L_{ls} i_{qs} + L_m i_{qm} \tag{13}$$

$$\Psi_{ds} = L_{ls} i_{ds} + L_m i_{dm} \tag{14}$$

$$\Psi_{0s} = L_{ls} i_{0s} \tag{15}$$

$$\Psi_{qr} = L_{lr} i_{qr} + L_m i_{qm} \tag{16}$$

$$\Psi_{dr} = L_{lr} i_{dr} + L_m i_{dm} \tag{17}$$

$$\Psi_{0r} = L_{lr} i_{0r} \,. \tag{18}$$

The voltage and flux linkage equations suggest the equivalent circuit shown in Fig.1.

The angular speed of the rotor ω_r is not constant in transient situations. It can be related to torque balance as:

$$T_e - T_m = J\frac{d\omega_m}{dt} \tag{19}$$

where T_e is the momentary electrical torque and T_m is the load mechanical torque.

The electric torque can be written by using the components of the stationary reference frame:

$$T_e = \frac{3}{2} p L_m \left(i_{qs} i_{dr} - i_{ds} i_{dr}\right) \tag{20}$$

The stationary frame model is very suitable to be used in circuit simulator. The synchronous angular velocity is not needed to be given for the simulator model since the equations used do not contain this variable. This is useful when we simulate a variable stator frequency motor drive.

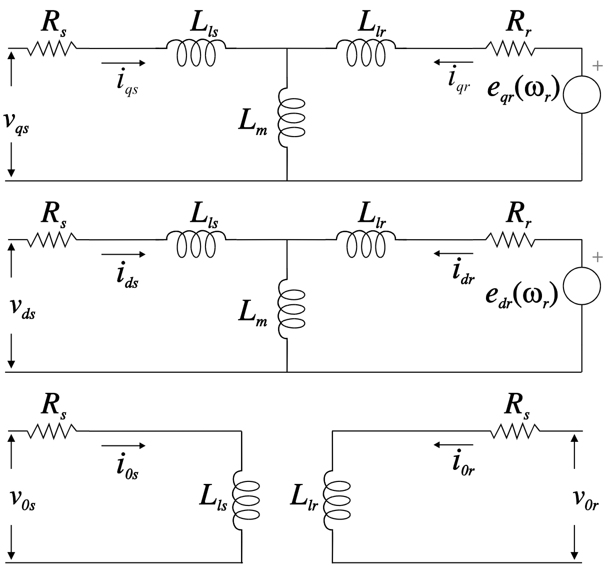

Fig.1. Induction motor equivalent circuit

III. PSPICE INDUCTION MOTOR MODEL

The developed induction motor model which is adjusted to the specific requirements of the PSPICE program package is shown in Fig. 2. Motor terminals A, B and C are conected to nodes *ua*, *ub* and *uc*.

The *qd0*-axis stator voltages are ABM blocks (Analog Bihavioural Modeling) [4] whose output voltage expression are given by Eqs. (2), (3) and (4):

2/3*(*V*(*ua*)-0.5**V*(*ub*)-0.5**V*(*uc*)),

(-*V*(*ub*)+*V*(*uc*))/*sqrt*(3),

1/3*(*V*(*ua*)+*V*(*ub*)+*V*(*uc*)).

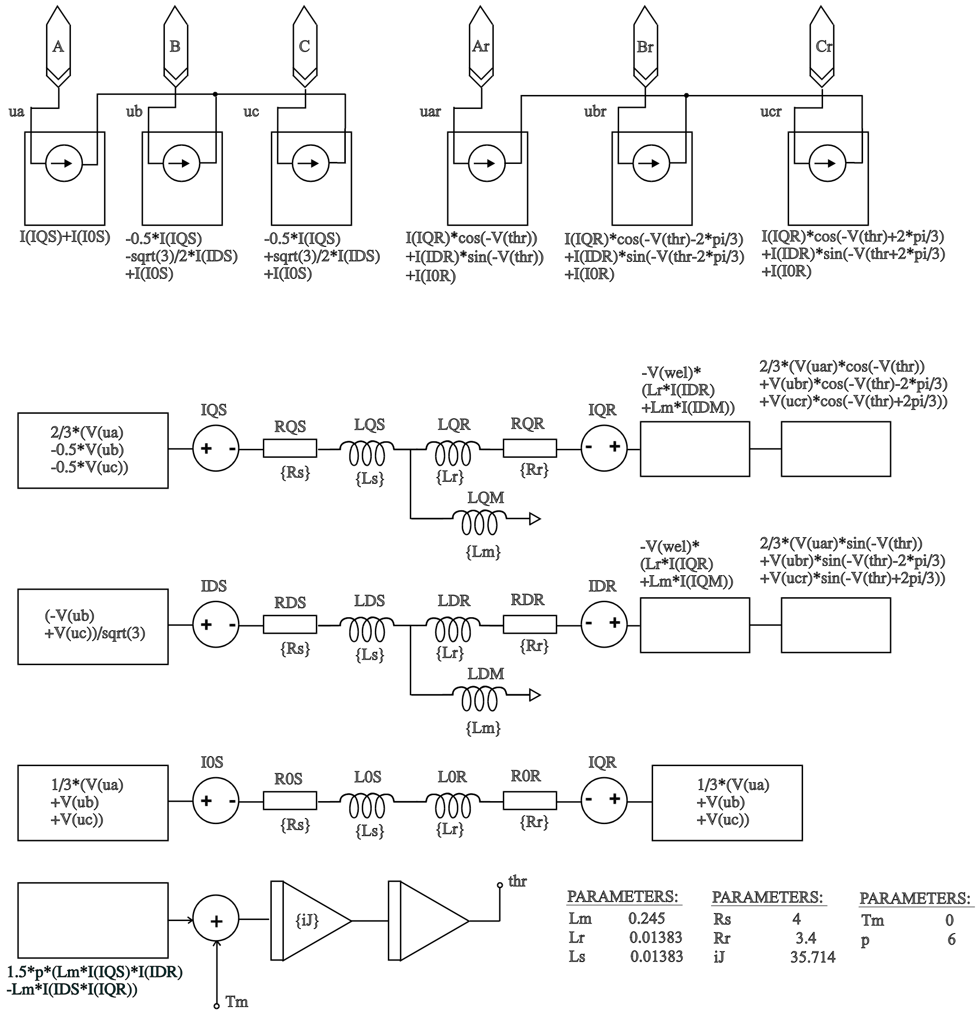

Fig.2 Induction motor model for PSPICE

where $V(ua)$ is the voltage of the node *ua*, $V(ub)$ is voltage of the node *ub* and $V(uc)$ is the voltage of the node *uc*.
The stator *qd0*-axis current is measured by the zero voltage source *IQS*, *IDS* and *I0S*. The notation *I*(*IQS*) is for the current through *IQS*, *I*(*IDS*) is for current through *IDS* and *I*(*I0S*) for current through *I0S*.

Stator *qd0* axis resistance are *RQS*, *RDS* and *R0S* respectively. These parameters have same numerical value {*Rs*}. The stator *qd0* leakage inductance *LQS*, *LDS* and *L0S* have the same value {*Ls*} given as a parameter. In the similar manner magnetising inductanes *LQM* and *LDM* have the same numerical value {*Lm*}. The *q*-axis magnetising current is measured by *IQM* and the *d*-axis magnetising current is measured by *IDM*.

In the similar manner, rotor side voltage can be presented by appropriate ABM blocks. *qd0* resistances and rotor leakage inductance have the same value {*Rr*} and {*Lr*}. The rotor *qd0*-axis currents are measured by *IQR*, *IDR* and *I0R*.

The *q* and *d*-axis rotational voltages are presented by ABM blocks. Output voltage for q-axis is expressed by:

$$-V(wel)*(Lr*I(IDR)+Lm*I(IDM)),$$

and for d-axis by:

$$-V(wel)*(Lr*I(IQR)+Lm*I(IQM)),$$

according to Eqs. (17) and (18). *V*(*wel*) is the voltage of the node *we* corresponding electrical angular speed.

The electric torque T_e is calculated by an ABM block. Its output voltage is determined by expression:

$$1.5*p*(Lm*I(IQS)*I(IDR)-Lm*I(IDS)*I(IQR))$$

according to Eq. (20). The voltage in node T_m is the applied mechanical torque (1Nm=1V). The rotor electrical angular velocity is solved by an integration block. Its input is the sum of the electric and mechanical torques. The gain of integration block $1/J$ is given as a parameter *iJ* [1/kgm^2].

The rotor position angle that is necessary for the rotor voltage transformation is obtained by the rotor speed integration.

The three phase stator currents are derived from stator *qd0*-axis currents by using inverse axis transformation from Eq. (1). The current sources connected to nodes *ua*, *ub* and *uc* fullfill these equations. The three phase rotor currents are obtained in the similar manner applying the rotor transformation given in Eq. (2).

IV. Simulation Result

To study start-up induction motor dynamic using PSPICE, a symmetrical three phase induction motor is considered. The parameters of the machine are given in Table 1. Core losses and mechanical losses are neglected.

The induction machine variables during free acceleration are shown if Fig. 2-4. The machine is initially stalled when rated balanced voltage is applied.

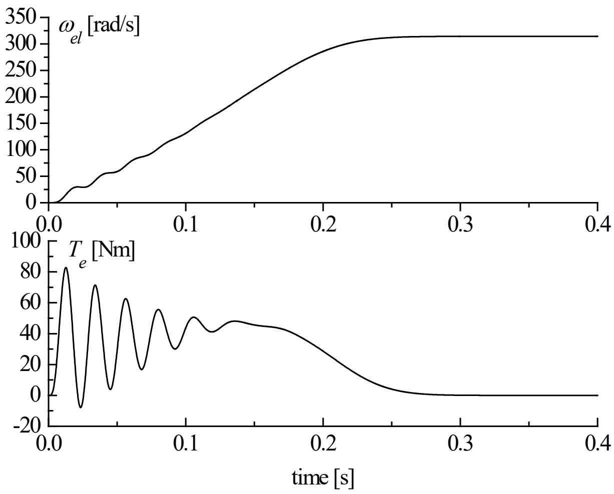

Fig.3. Speed and electric torque during free acceleration

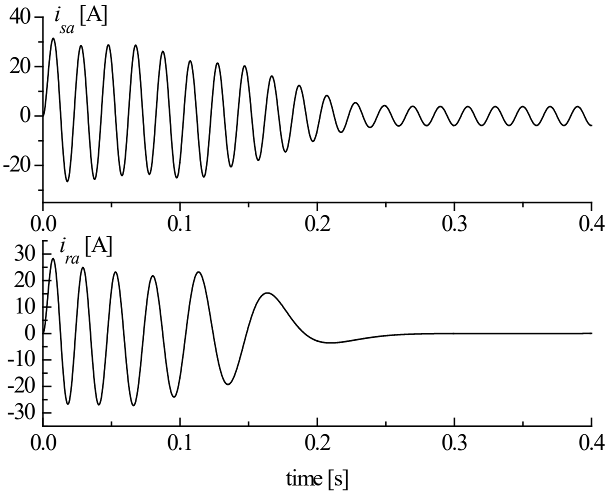

Fig.4. Stator and rotor current during free acceleration

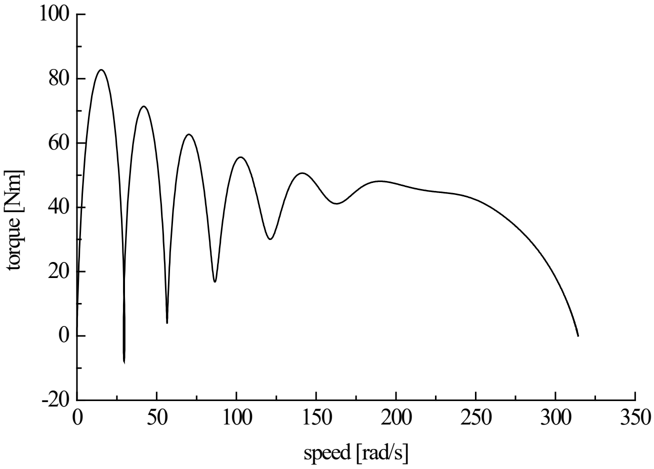

Fig.5. Torque-speed characteristics

The results are in close agreement with [1, 4].

TABLE I.
Motor data

P=4 kW; U_n=380 V; I_n=4 A		
L_{lr}=0.01383 H	L_{ls}=0.01383 H	L_m=0.245 H
r_s=4 Ω	r_r=3.4 Ω	p=6

V. Conclusion

As a software package PSPICE provides a simulation environment in which the design and application engineer can investigate practical drive system problems which may be encountered at the development stage or in an existing installation.

Presented model of the induction motor enables one simple model forming based on the equivalent scheme in *qd0* reference frame. Represented induction motor model contains the available electrical connections on the stator and rotor side so the motor coupling to feeding source is easy without regard is it power distribution network or power converter. Also, shown model can be applied for the analysis of single fed and double fed induction motor.

References

[1] Paul C. Krause, Oleg Wasynczuk, Scott Sudfoff, Steven Pekarek, Analysis of Electric Machinery and Drive Systems, Third Edition, IEEE press, 2013.

[2] B. K. Bose, Modern Power Electronics and AC Drives, Prentice Hall PTR, Upper Saddle River, 2002.

[3] F. L. Alvardo, A. Keyhani, B. Coates, "Instructional Use of Declarative Languages for the Study of Machine Transients" *IEEE Tran. on Power Systems*, Vol.6, No.1, pp.407-413, February. 1991.

[4] Cociu L., Cociu R., Aspects Regarding Pspice Electrical Machines Simulation. The 5th Internat. Conf. on Electromech. and Power Syst. SIELMEN'05, Chisinau, Rep. Moldova, Oct.6-8, 2005, II, 842-845.