Modeling of Induction Motor

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Abstract— This paper present a modular Simulink implementation of an induction machine model is described in a step-by-step approach. With the modular system, each block solves one of the model equations; therefore, unlike black box models, all of the machine parameters are accessible for control and verification purposes.

I. INTRODUCTION

Usually, when an electrical machine is simulated in circuit simulators like PSpice, its steady state model is used, but for electrical drive studies, the transient behavior is also important. One advantage of Simulink over circuit simulators is the ease in modeling the transients of electrical machines and drives and to include drive controls in the simulation.

As long as the equations are known, any drive or control algorithm can be modeled in Simulink. However, the equations by themselves are not always enough; some experience with differential equation solving is required.

Simulink induction machine models are available in the literature [1-3], but they appear to be black-boxes with no internal details. Some of them [1-3] recommend using S- functions, which are software source codes for Simulink blocks. This technique does not fully utilize the power and ease of Simulink because S-function programming knowledge is required to access the model functions run faster than discrete Simulink blocks, but Simulink models can be made to run faster using "accelerator" functions or producing stand-alone Simulink models. Both of these require additional expense and can be avoided if the simulation speed is not that critical. Another approach is using the Simulink Power System Blockset [4] that can be purchased with Simulink. This blockset also makes use of S-functions and is not as easy to work with as the rest of the Simulink blocks.

In this paper, a modular, easy to understand Simulink induction motor model is described. With the modular system, each block solves one of the model equations; therefore, unlike black box models, all of the machine parameters are accessible for control and verification purposes.

II. INDUCTION MOTOR MODEL

The induction machine d-q or dynamic equivalent circuit is shown in Fig. 1. One of the most popular induction motor models derived from this equivalent circuit is Krause's model detailed in [13]. According to his model, the modeling equations in flux linkage form are as follows:

$$\frac{dF_{qs}}{dt} = w_b\left[v_{qs} - \frac{w_e}{w_b}F_{ds} + \frac{R_s}{X_{ls}}\left(F_{mq} + F_{qs}\right)\right] \quad (1)$$

$$\frac{dF_{ds}}{dt} = w_b\left[v_{ds} + \frac{w_e}{w_b}F_{qs} + \frac{R_s}{X_{ls}}\left(F_{md} + F_{ds}\right)\right] \quad (2)$$

$$\frac{dF_{qr}}{dt} = w_b\left[v_{qr} - \frac{(w_e - w_r)}{w_b}F_{dr} + \frac{R_r}{X_{lr}}\left(F_{mq} - F_{qr}\right)\right] \quad (3)$$

$$\frac{dF_{dr}}{dt} = w_b\left[v_{dr} + \frac{(w_e - w_r)}{w_b}F_{qr} + \frac{R_r}{X_{lr}}\left(F_{md} - F_{dr}\right)\right] \quad (4)$$

$$\frac{dFqs}{dt} = Wb[Vqs - \frac{We}{Wb}Fds + \frac{Rs}{Xls}\left[\frac{Xml}{Xlr}Fqr + \left[\frac{Xml}{Xls} - 1\right]Fqs\right]] \quad (5)$$

$$\frac{dFds}{dt} = Wb[Vds + \frac{We}{Wb}Fqs + \frac{Rs}{Xls}\left[\frac{Xml}{Xlr}Fdr + \left[\frac{Xml}{Xls} - 1\right]Fds\right]] \quad (6)$$

$$\frac{dFqr}{dt} = Wb[-\frac{(We - Wr)}{Wb}Fdr + \frac{Rr}{Xlr}\left[\frac{Xml}{Xls}Fqs + \left[\frac{Xml}{Xlr} - 1\right]Fqr\right]] \quad (7)$$

$$\frac{dFdr}{dt} = Wb[\frac{(We - Wr)}{Wb}Fqr + \frac{Rr}{Xlr}\left[\frac{Xml}{Xls}Fds + \left[\frac{Xml}{Xlr} - 1\right]Fdr\right]] \quad (8)$$

$$\frac{dWr}{dt} = \left(\frac{p}{2J}\right)(Te - Tl) \quad (9)$$

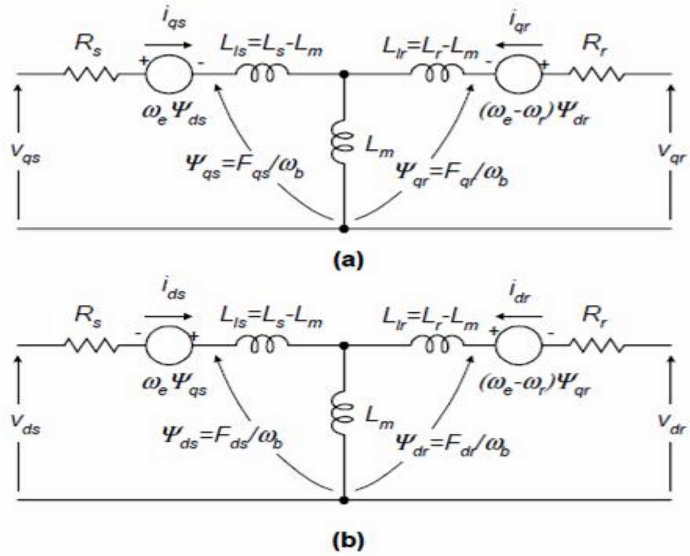


Figure 1 Arbitrary reference frame equivalent for induction motor

$$F_{qs} = X_{ls} i_{qs} + X_M (i_{qs} + i'_{qr}) \tag{10}$$

$$F_{ds} = X_{ls} i_{ds} + X_M (i_{ds} + i'_{dr}) \tag{11}$$

$$F'_{qr} = X'_{lr} i'_{qr} + X_M (i_{qs} + i'_{qr}) \tag{12}$$

$$F'_{dr} = X'_{lr} i'_{dr} + X_M (i_{qs} + i'_{qr}) \tag{13}$$

The equation convenient for simulating the induction machine in arbitrary reference frame may be established by flux linkages equations Thus we can write stator and rotor current equation:

$$i_{qs} = \frac{1}{x_{ls}} (F_{qs} - F_{mq}) \tag{14}$$

$$i_{ds} = \frac{1}{x_{ls}} (F_{ds} - F_{md}) \tag{15}$$

$$i_{qr} = \frac{1}{x_{lr}} (F_{qr} - F_{mq}) \tag{16}$$

$$i_{dr} = \frac{1}{x_{lr}} (F_{dr} - F_{md}) \tag{17}$$

$$T_e = \frac{3}{2} \left(\frac{p}{2}\right) \frac{1}{w_b} qs(F_{ds} I_{qs} - F_{qs} I_{ds}) \tag{18}$$

$$T_e - T_l = j \left(\frac{2}{p}\right) dt \frac{dwr}{dt} \tag{19}$$

$$F_{mq} = X_{ml} \left[\frac{F_{qs}}{X_{ls}} + \frac{F_{qr}}{X_{lr}}\right] \tag{20}$$

$$F_{md} = X_{ml} \left[\frac{F_{ds}}{X_{ls}} + \frac{F_{dr}}{X_{lr}}\right] \tag{21}$$

III. SIMULATION IMPLEMENTATION

A. o-n conversion block

This block is required for an isolated neutral system, otherwise it can be bypassed.

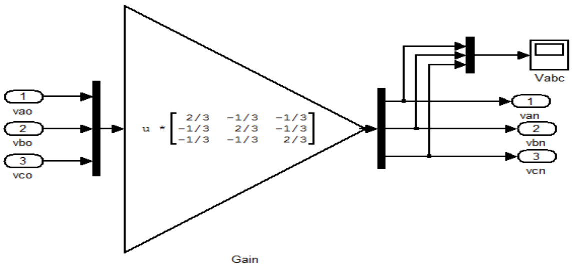


Figure 2 Subsystem (0-n conversion)

B. Unit vector calculation block:

Unit vectors $cos\theta_e$ and $sin\theta_e$ are used in vector rotation blocks, “abc-synchronous conversion block” and “synchronous-abc conversion block”.

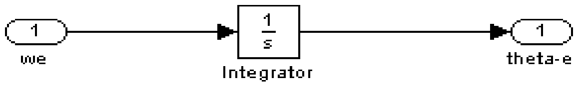


Figure 3 Unit vector block

C. abc-synchronous conversion block:

To convert three-phase voltages to voltages in the two-phase synchronously rotating frame.

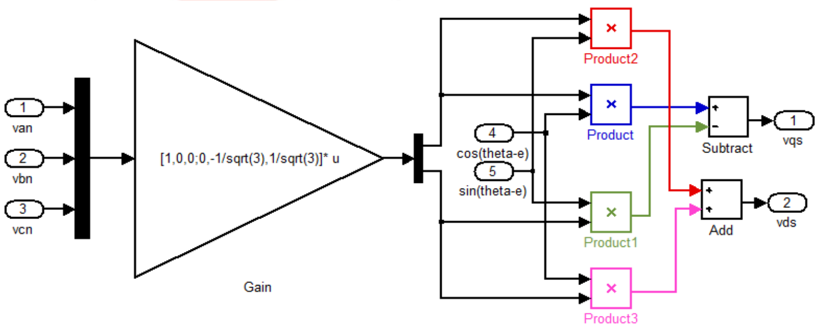


Figure 4 Sub system for abc-synchronous conversion

D. synchronous-abc conversion block:

This block is conversion of *synchronous* to *abc* current variables.

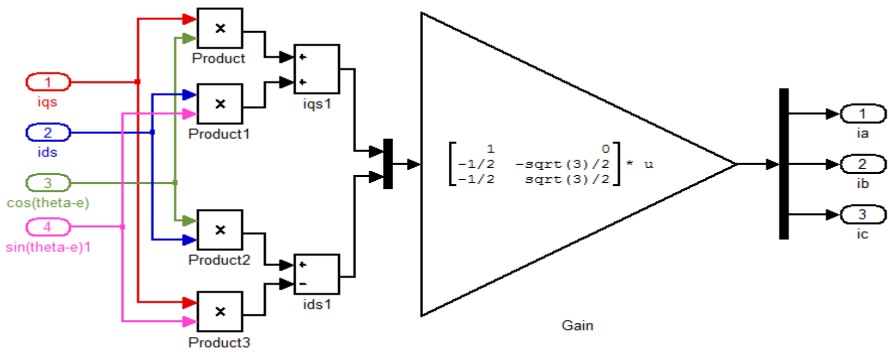


Figure 5 Sub system for synchronous-abc conversion

E. Induction machine d-q model block:

According Krause’s equation [6].the induction motor d-q model shown in fig.9.

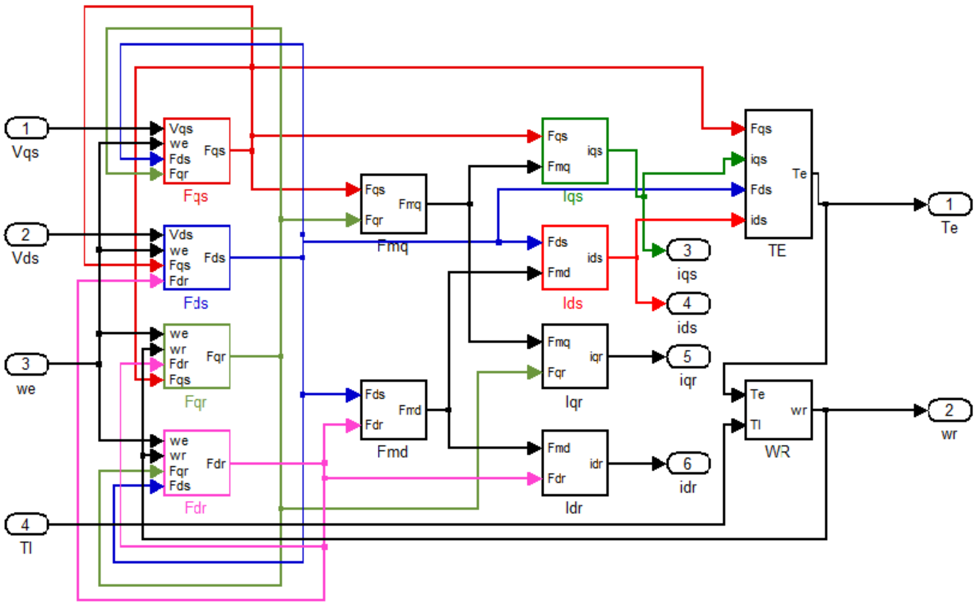


Figure 6 Sub system for d-q model

An induction machine *d-q* model can be represented with five differential equations. To solve these equations, they have to arranged in state space form, $\dot{x} = Ax + b$ where $x = \left[F_{qs}\ F_{ds}\ F_{qr}\ F_{ds}\ \omega_b\right]^T$ is the state vector.

F. Overall model:

The d-q model requires that all the three-phase variables have to be transformed to the two-phase synchronously rotating frame. Consequently, the induction machine model will have blocks transforming the three-phase voltages to the d-q frame and the d-q currents back to three-phase. .

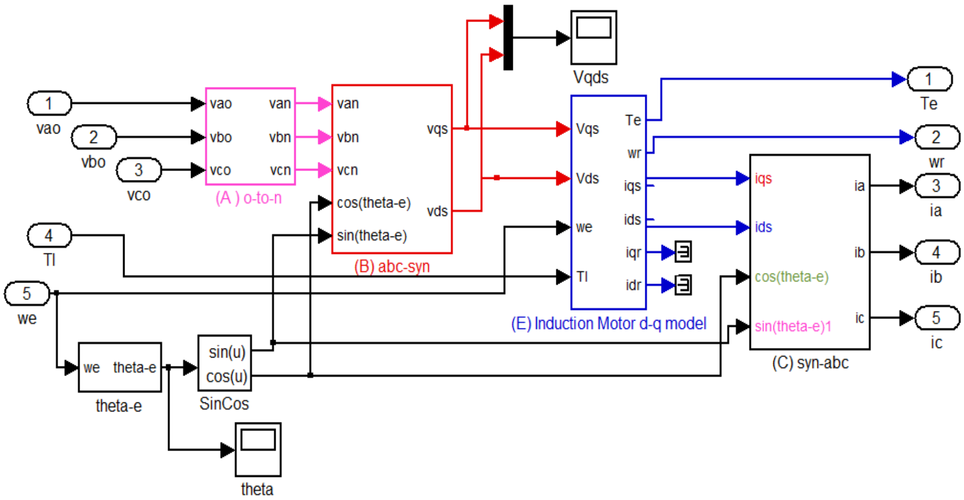


Figure 7 Overall simulation model

The 30kW induction motor parameter feed using m-file in matlab program. There is the following parameter of an induction motor:

R_r	= 0.39;	Rotor resistance
R_s	= 0.19;	Stator resistance
L_{ls}	= 0.021e-3;	Stator inductance
L_{lr}	= 0.6e-3;	Rotor inductance
L_m	= 4e-3;	Magnetizing Inductance
fb	= 50;	Base frequency
p	= 4;	Number of poles

J = 0.0226; Moment of inertia

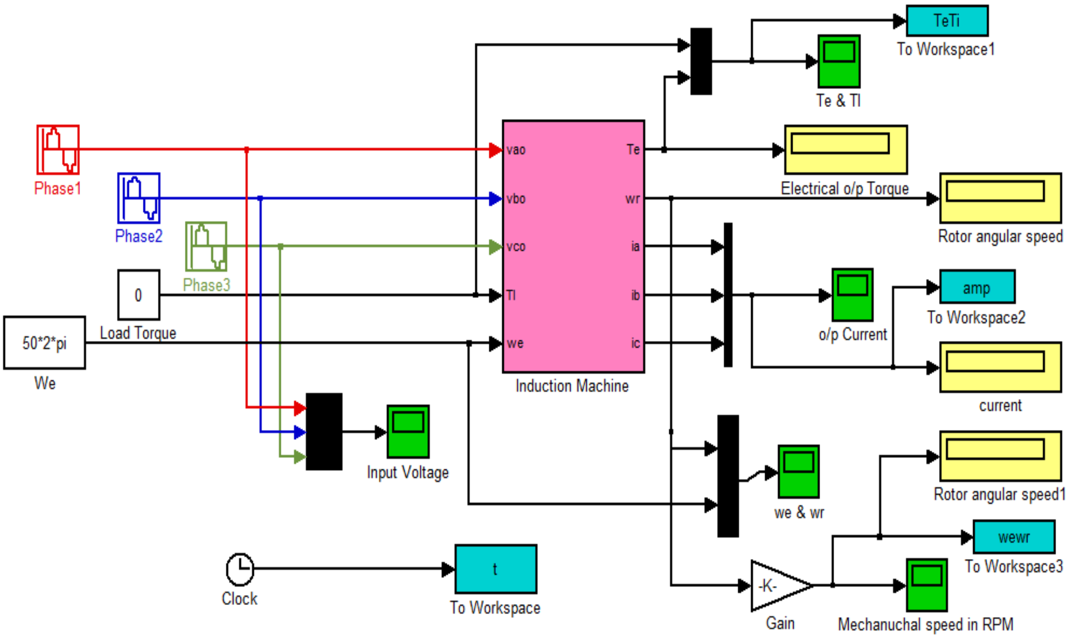
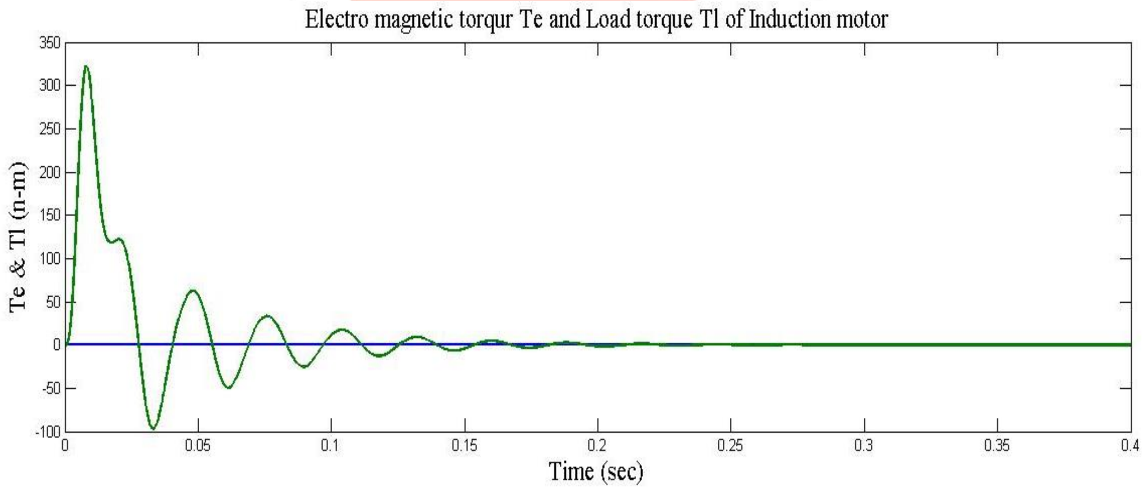
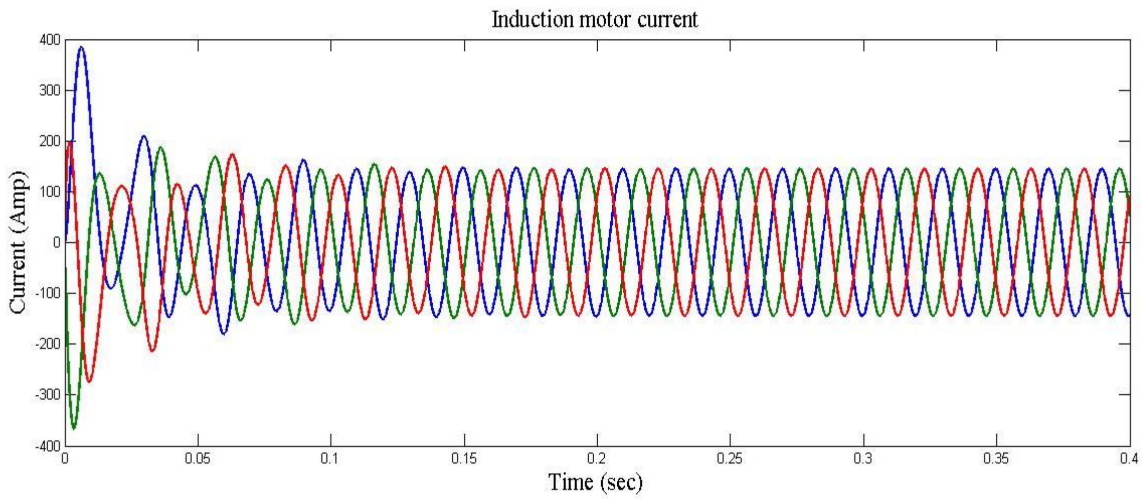


Figure 8 Final Induction motor model

IV. SIMULATION RESULTS





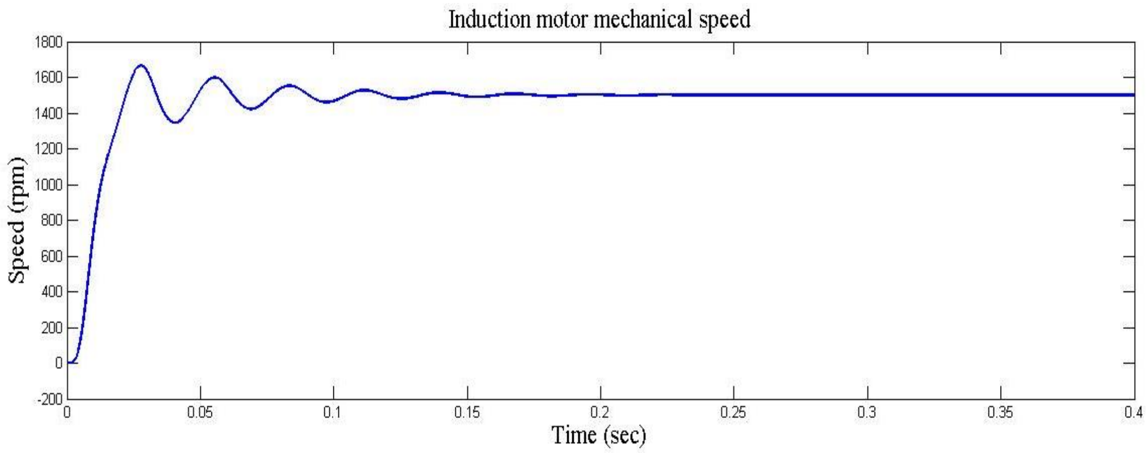


Figure 9 Simulation results of induction motor

V. CONCLUSION

In this paper, implementation of a modular Simulink model for induction machine simulation has been introduced. Unlike most other induction machine model implementations, with this model, the user has access to all the internal variables for getting an insight into the machine operation. Any machine control algorithm can be simulated in the Simulink environment with this model without actually using estimators. If need be, when the estimators are developed, they can be verified using the signals in the machine model. The ease of implementing controls with this model is also demonstrated with several examples.

REFERENCES

[1] M. L. de Aguiar, M. M. Cad, "The concept of complex transfer functions applied to the modeling of induction motors," *Power engineering Society Winter Meeting*, 2000, pp. 387 -391.

[2] A. Dumitrescu, D. Fodor, T. Jokinen, M. Rosu, S. Bucurencio, "Modeling and simulation of electric drive systems using Matlab/Simulink environments," *International Conference on Electric Machines and Drives (IEMD)*, 1999, pp. 451-453.

[3] S. Wade, M. W. Dunnigan, B. W. Williams, "Modeling and simulation of induction machine vector control with rotor resistance identification," *IEEE Transactions on Power Electronics*, vol. 12, no. 3, May 1997, pp. 495 -506.

[4] H. Le-Huy, "Modeling and simulation of electrical drives using Matlab/Simulink and Power System Blockset," *The 27th Annual Conference of the IEEE Industrial Electronics Society (IECON'01)*, Denver/Colorado, pp. 1603-1611.

[5] L. Tang, M. F. Rahman, "A new direct torque control strategy for flux and torque ripple reduction for induction motors drive – a Matlab/Simulink model," *IEEE International Electric Machines and Drives Conference, 2001*, pp. 884 -890.

[6] Bimal K. Bose, *Modern Power Electronics and AC Drives*, Prentice Hall, 2002.

[7] B. Ozpineci, B.K. Bose, "A soft-switched performance enhanced high frequency non-resonant link phase-controlled converter for ac motor drive," *The 24th Annual Conference of the IEEE Industrial Electronics Society (IECON'98)*, Aachen/Germany, 1998, vol. 2, pp 733-749.

[8] H. Li, B.Ozpineci and B.K.Bose, "A soft-switched high frequency non-resonant link integral pulse modulated dc-dc converter for ac motor drive," *The 24th Annual Conference of the IEEE Industrial Electronics Society (IECON'98)*, Aachen/Germany, 1998, vol. 2, pp 726-732.

[9] Burak Ozpineci, Leon M. Tolbert, Syed K. Islam, Md. Hasanuzzaman, "Effects of silicon carbide (SiC) power devices on pwm inverter losses," *The 27th Annual Conference of the IEEE Industrial Electronics Society (IECON'01)*, Denver/Colorado, 2001,pp. 1187-1192.

[10] J. O. P. Pinto, B. K. Bose, L. E. B. Silva, M. P. Kazmierkowski, "A neural-network-based space-vector PWM controller for voltage-fed inverter induction motor drive," *IEEE Transactions on Industry Applications*, vol. 36, no. 6, Nov./Dec. 2000, pp. 1628-1636.

[11] J. O. P. Pinto, B. K. Bose, L. E. B. Silva, "A stator flux oriented vector-controlled induction motor drive with space vector PWM and flux vector synthesis by neural networks," *IEEE Industry Applications Society Annual Meeting*, Rome/Italy, 2000, pp. 1605-1612.

[12] J. O. P. Pinto, B. K. Bose, L. E. Borges, M. P. Kazmierkowski, "A neural-network-based space-vector PWM controller for voltage-fed inverter induction motor drive," *IEEE Industry Applications Society Annual Meeting*, Phoenix/Arizona, 1999, pp. 2614-2622.

[13] P. C. Krause, *Analysis of Electric Machinery*, McGraw-Hill Book Company, 1986.