An S-Function-Based Dynamic Model of a Three-Phase Induction Motor for Improved Simulation Efficiency

***Haulatu Sidi Ahmad and **Yahaya Yusuf**
*Physics Department, Shehu Shagari University of Education, Sokoto
**Physics Department, Federal University, Gusau
Email: bazata70@gmail.com

https://doi.org/10.56201/rjpst.vol.9.no10.2026.pg77.89

Abstract
The numerous advantages of induction machines such as economy, efficiency and reliability have made it very popular in industrial and domestic applications. The advent of computer simulation platform has accelerated the development of models that represents induction machine's operation. In this paper, a model that represents a generalized induction machine using the S-Function of MATLAB/Simulink software was developed. To achieve this, a space-phasor notation was used to formulate a model. The 3-phase parameters of current, flux, voltage and inductance were first transformed into 2-axis d-q notation. These parameters were then used to implement the dynamic equations of the machine based on a single user defined S-Function block. This was to overcome the speed problem associated with normal Simulink library blocks. To test the accuracy of the model, a 3-phase ac voltage was applied through a direct-on-line startup. The effectiveness of the result obtained from simulation of the designed model was validated for loads with torques of 10 N.m and 40 N.m at t=1s. The results obtained at the different load torques showed that there was significant increase in simulation speed when compared with the conventional models. The paper then recommended that the proposed model may be used on its own or incorporated in advanced Electric Drive systems

Keywords: *asynchronous motor, modelling, S-Function, Simulink, Simulation speed*

Introduction

A three-phase asynchronous motor is an electromechanical energy converter that operates at speeds less than the synchronous speed with 120^0 phase difference between its three phase lines. Its operation is based on generation of a rotating magnetic field. With an advantage of efficiency that is well over 90%, relatively cheap, ruggedness coupled with the advent of computer programming and numeric computing platform, research into optimization of induction machines has been heightened through the development of appropriate models [1]–[7]. One major drawback of the machine is that its speed varies with the applied load. MATLAB numeric computing platform is a popular software that is helping scientists and engineers analyze data, develop algorithms to create algorithms. The platform contains professionally developed toolboxes with interactive applications that allow one to automatically generate programs that could be used to reproduce or to automate works. Due to the inherent integration of vectorised system representation in block diagram form and its graphical portrayal of time evolutions of signals and its Graphical User Interface (GUI) for building models which makes it easier and

user friendly than other software packages [4].

A lot of literature has shown that there are models developed for induction machines using Simulink blocks to represent the machine's dynamic equations [1]–[3], [6]. The drawback of this method is however its simulation speed [1]. This problem is more pertinent in applications like electric drives where simulation speed is critical [1], [8]. S-Function is however superior for applications requiring better speed of simulation. It has been suggested that complex nonlinear models such as induction machines will be more efficiently represented using equations in a Matlab-file instead of Simulink blocks. The Simulink can then assess the Matlab file from S-Function block. This procedure has the advantage of blending the advantages derived from running it directly on solvers like ODE45 with that graphically linked to other Simulink blocks. This method is envisaged could provide a more suitable technique for some industrial and domestic purposes. In this paper, a model that represents a generalized induction machine using the S-Function of MATLAB/Simulink software was developed. To achieve this, a space-phasor notation was used to formulate a model. The 3-phase parameters of current, flux, voltage and inductance were first transformed into 2-axis d-q (direct and quadrature axis), notation. These parameters were then used to implement the dynamic equations of the machine based on a single user defined S-Function block. This was to overcome the speed problem associated with normal Simulink library blocks. To test the accuracy of the model, a 3-phase ac voltage was applied through a direct-on-line startup.

The development of Induction Machine Model

The induction machine is more or less a generalized transformer with the difference being the dynamic rotor and shunted output. The stator winding is connected to a three-phase supply. The induction machine can be represented by the per phase approximate equivalent circuit shown in Figure 1. whenreferred to primary.

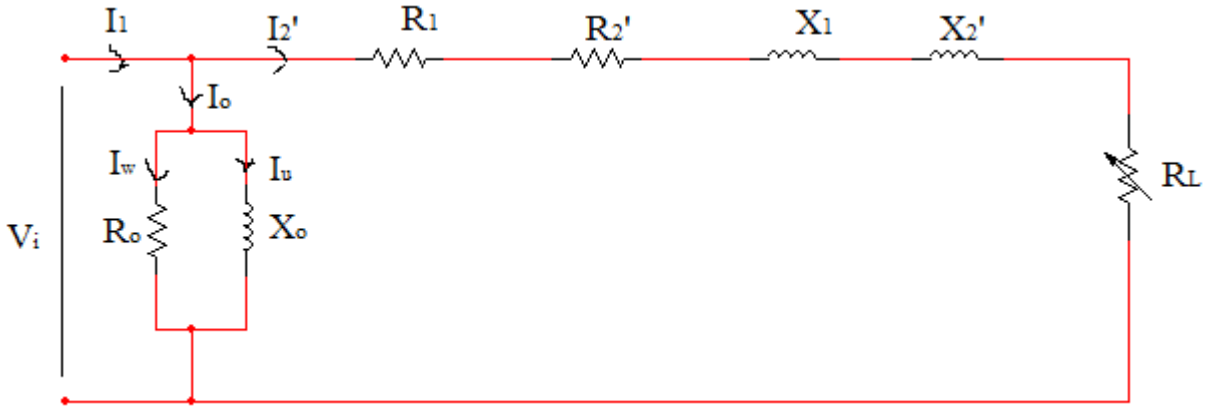


Figure 1: Per phase per phase approximate equivalent circuit of induction motor

Where I_1 is the stator current, I_2^1 the rotor current referred to primary, Rs + R_r^1 equivalent resistance referred to stator, , Ls + L_r^1 are the equivalent reactance referred to stator, $R_L$is the variable load.When the induction motor is in running mode the behavior is complex because of the coupling between the stator and rotor phases [9]. The 3-phase parameters of current, flux, voltage and inductance were first transformed into 2-axis d-q (direct and quadrature axis), notation. The space-phasor voltage equations of the stator and rotor was expressed in d-q components [1], [3], [10], [11]:

If R_s and R_r are the stator and rotor resistances, L_s and L_r are the stator and rotor self-inductance ω_s and ω_r are the stator and rotor speeds, L_m is the mutual inductance, ψ_s and ψ_r are the stator and rotor flux linkages respectively then the voltages andflux linkage equations can be represented as equation (1) and (2) respectively.

$$\begin{bmatrix} v_{ds} \\ v_{qs} \\ v_{dr} \\ v_{qr} \end{bmatrix} = \begin{bmatrix} R_s + sL_s & 0 & sL_m & 0 \\ 0 & R_s + sL_s & 0 & sL_m \\ L_m & \omega_r L_m & R_r + sL_r & \omega_r L_r \\ -\omega_r L_m & sL_m & -\omega_r L_r & R_s + sL_r \end{bmatrix} \cdot \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} \psi_{ds} \\ \psi_{qs} \\ \psi_{dr} \\ \psi_{qr} \end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_m & 0 & L_r \end{bmatrix} \cdot \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} \quad (2)$$

Equation (3) relates the mechanical speed of the induction machine to the torque:

$$T_e = T_L + \frac{2J}{p}\frac{d\omega_r}{dt} \quad (3)$$

Where T_e is the electrical Torque, T_L is the load torque, J is the combined rotor and load inertia, p represents the number of poles and ω_r is the rotor speed.

In terms of currents, the stator, rotor currents and the torque is written as;

$$T_e = \frac{3}{2}\frac{p}{2} L_m \left(i_{qs} i_{dr} - i_{ds} i_{qr} \right) \quad (4)$$

Realization of the S-Function

The S-Function makes it possible to represent the dynamic motor with mathematical sets of equations.[8]. The parameters specified in the S-Function Parameters field are passed to the corresponding S-Function. Equation 5 is the M-file S-function in a\ MATLAB function

$$[sys, xo, str, ts] = f(t, x, u, flag, p1, p2, ...) \quad (5)$$

Where*f* = S-function name, *t* = current time, *x* = state vector, *u* = the block's = inputs, *flag performed task while p1, p2*,... parameters of the block. The standard format for the flags in an S-Function is given in blocks diagram of Figure 2[12]. The Simulink simulation takes place by constantly calling the s-function name by the use of the flag. This process specifies the operation to be performed. After the completion of a task by a s-function the result is returned as indicated by the syntax.

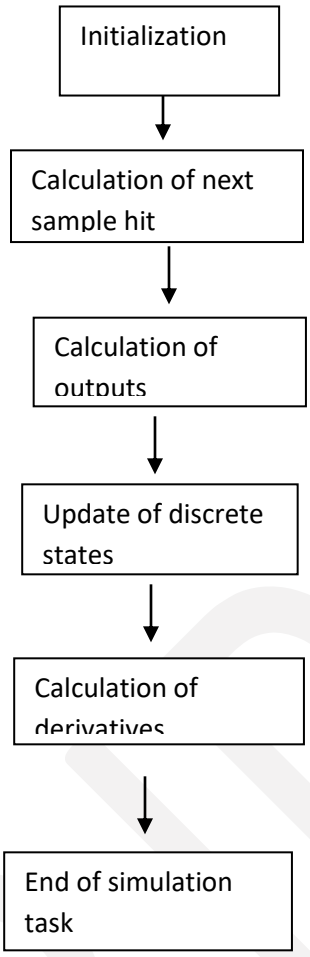


Figure 2: Blocks diagram representing the S-function flag routine

Simulink Implementation

The S-Function induction machine model is tested in Simulink as shown in Fig. 3. The three-phase ac voltages were converted to two-phase and vice-versa using the two matrix gain blocks 'ABC2ab' and 'ab2ABC' respectively. .

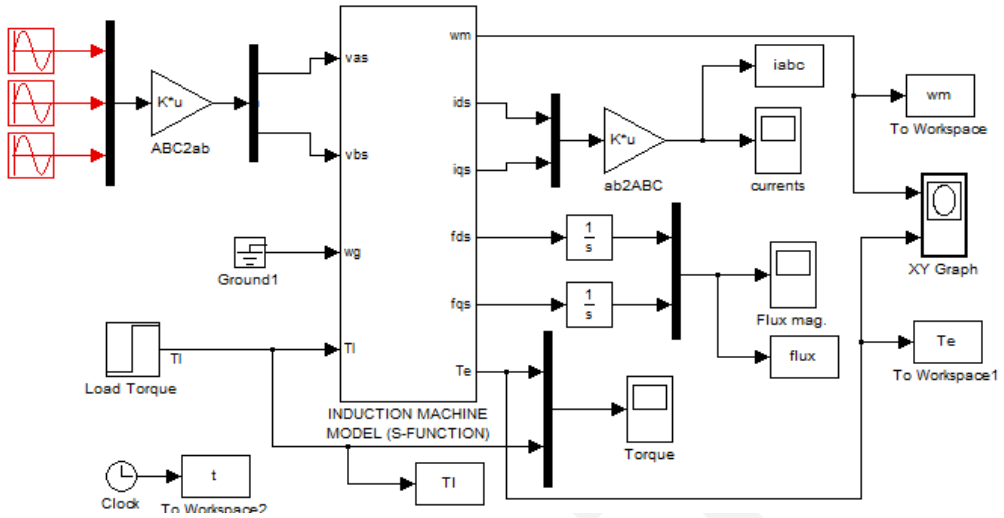


Fig. 3; Induction Machine test model

Equation 5 was used to transform the three-phase to two-axis

$$\begin{bmatrix} v_{as} \\ v_{bs} \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

We then chose an induction machine for the simulation studies. The parameters of the induction motor used is tabulated in Table 1

Table 1: Parameters of the induction motor

S/N	Parameter	Type/value
1	Phase	3-phase
2	Poles	4-poles
3	R_{si}	0.5310Ω
4	Rr	0.4081Ω
5	Lsi	0.0025H
6	Lm	0.0025H
7	Lri	0.0850H
8	Frequency (fo)	60Hz
9	J	0.1 Kg/m^2
10	Poles (p)	4
11	Induction motor	Squirrel cage

Simulation Results and Discussion

The results of the simulations are presented in figure 3 to 8. This set of first results are when the load torque $T_L = 10N.m$ and t = 1 second. Fig. 3 shows the result of the simulation of Relationship between Rotor Speed in rad/sec with time in seconds. It is seen that the rotor speed attains maximum speed at less than 0.5 seconds.

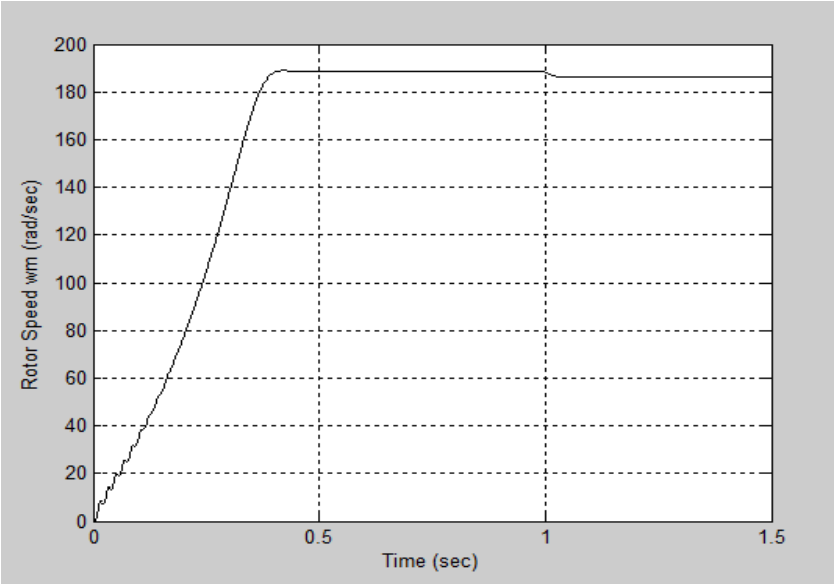


Fig. 3: Relationship between Rotor Speed (rad/sec) and time

Figure 4 is the simulated result showing the relationship between electrical (Te) and load torque (TL) in Nm on one hand against time in seconds. The two toques are noted to follow the same pattern after 0.5 seconds.

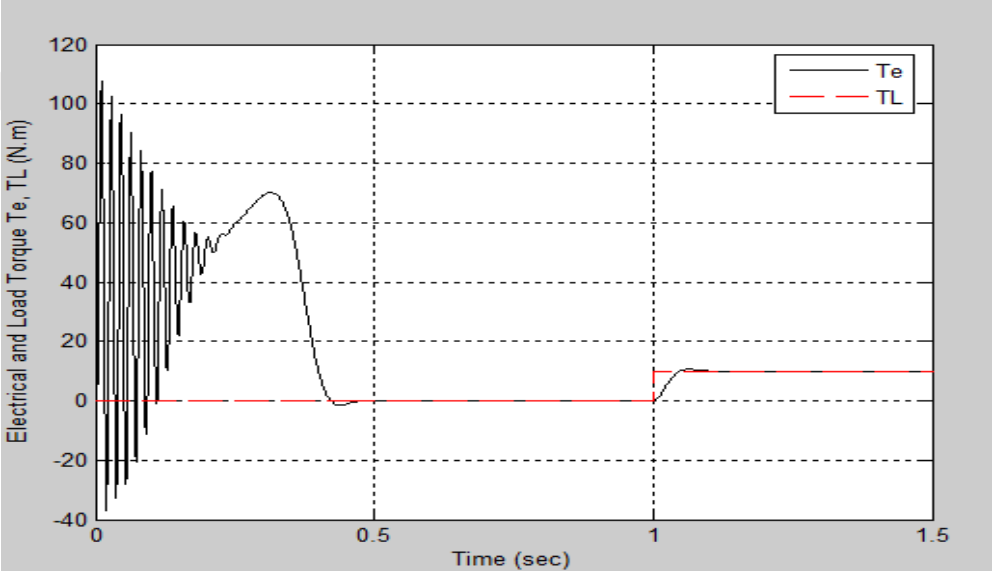


Fig. 4Motor Torque with Tl=10N.m

The behavior of the stator currents iaibic with respect to time is depicted in Figure 5. The stator currents are noted to stabilize just before 0.5 seconds.

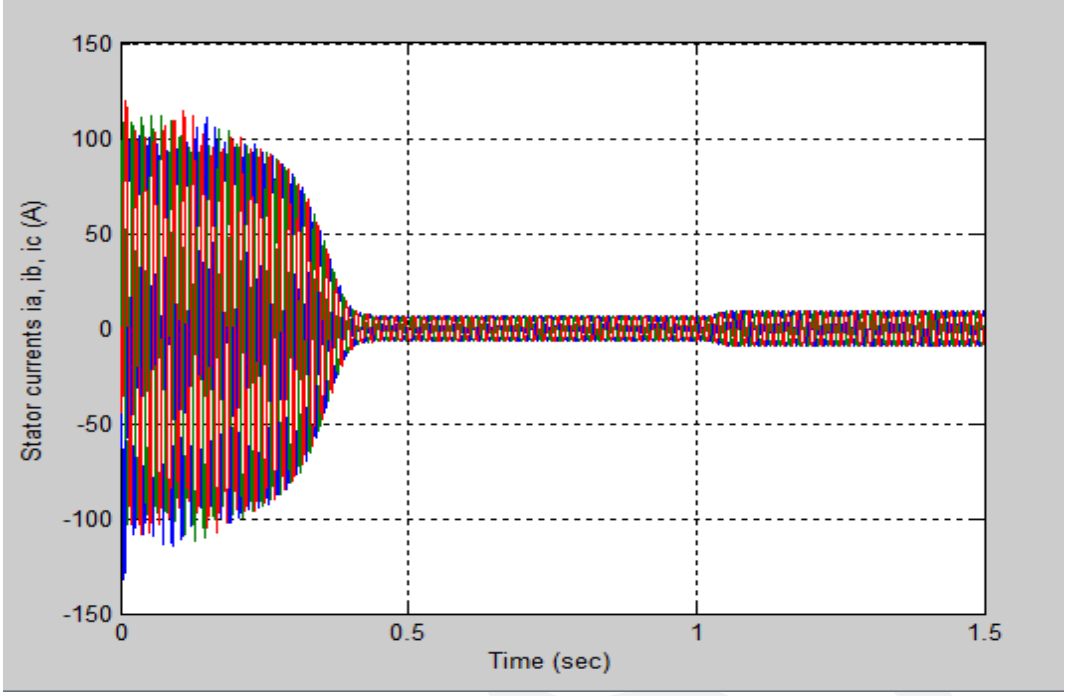


Fig 5 Stator currents ia, ib, ic (A)

The relationship of the stator currents relationship with time was then zoomed in to see the post transient and the result presented in Figure 6. The currents settled at a maximum value of 10A after one second.

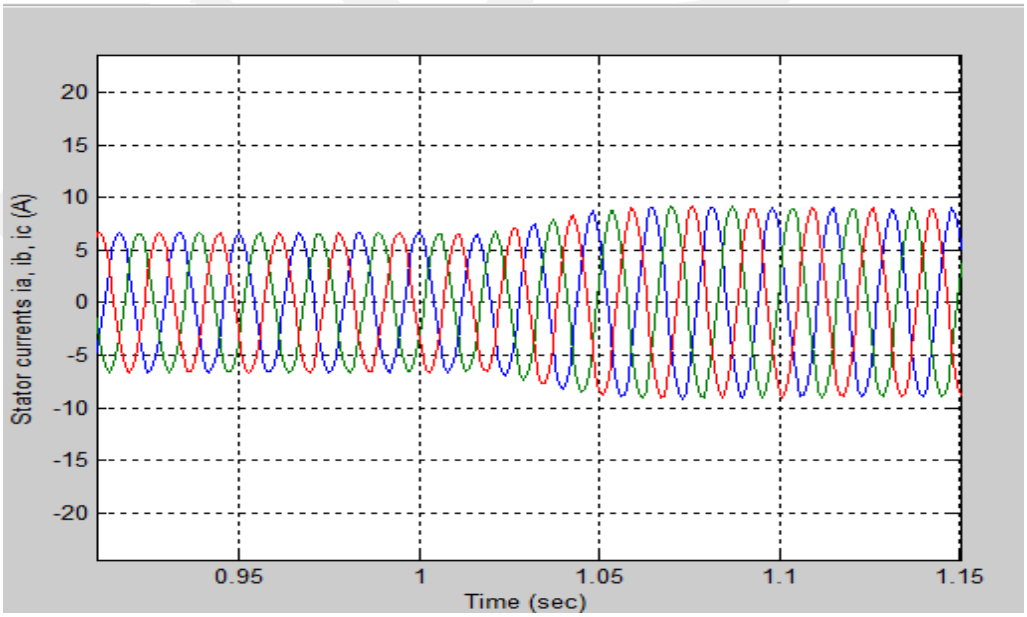
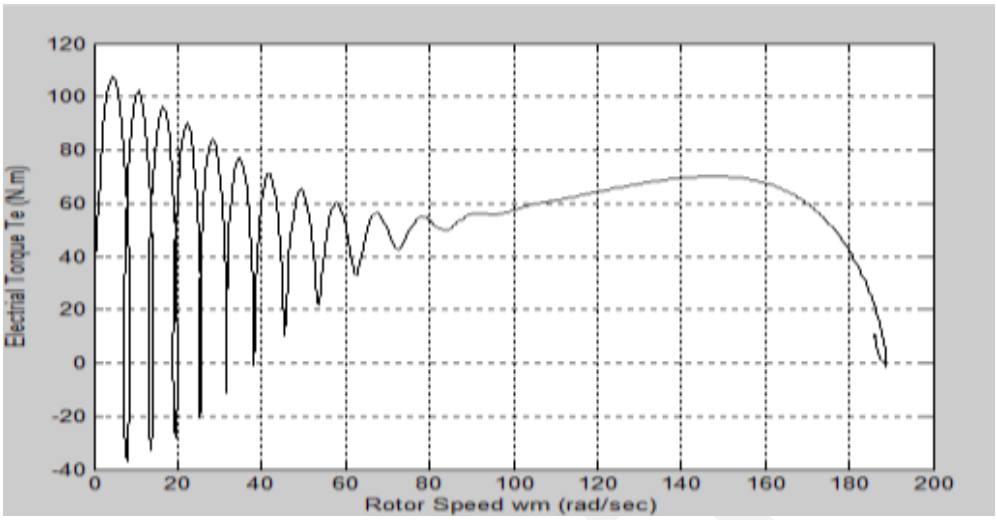


Fig. 6Zoomingof the stator the post transient of Fig. 5

Figure 7 is the presentation of the relationship between the electrical torque in Nm and that of the rotor speed in radians per second.



. 7 Torque Speed relationship

The simulated value of the variation of stator flux fds and fqs is shown in Fig. 8.

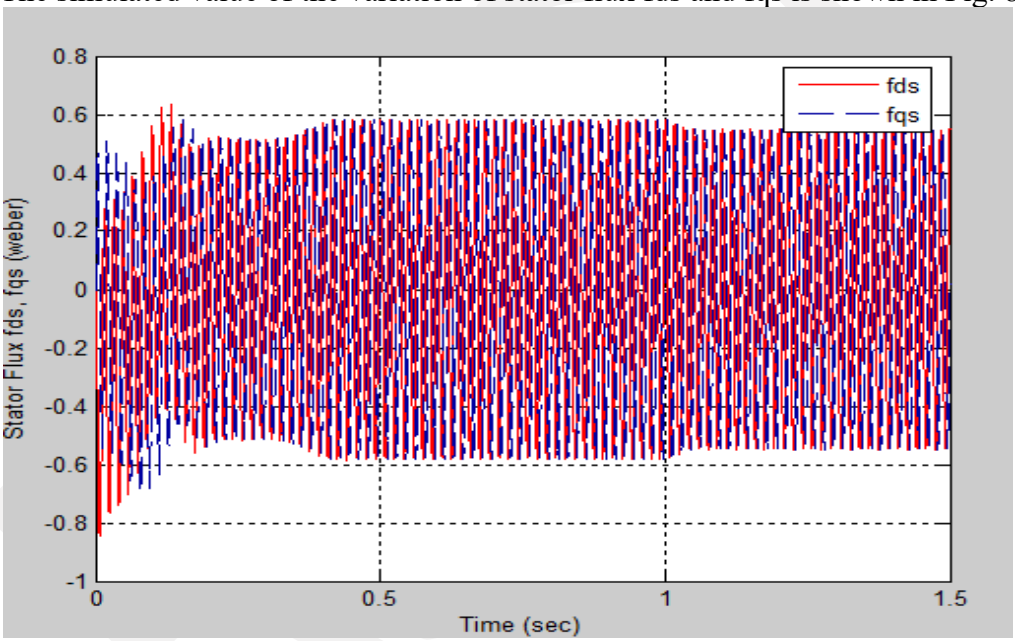


Fig 8Stator Flux f_{ds} f_{qs}

With load toque increased to 10 Nm and t=1 second the results obtained are presented in Fig 9 to Fig 14. Fig 9 shows the result of the simulation of Relationship between Rotor Speed in rad/sec with time in seconds. It is seen that the rotor speed attains maximum speed befor 0.5 seconds the rotor speed settles at around 187 rad/sec.

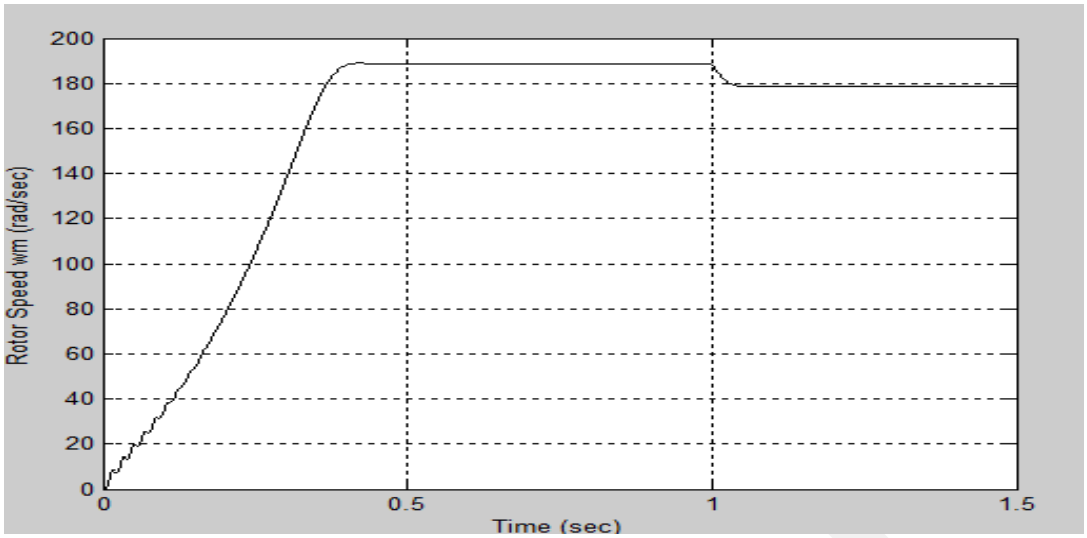


Fig. 9Rotor Speed (rad/sec)

The motor torque (electrical and load) exhibited the behavior when the load is 40 Nm is as shown in Fig. 10. The shape is very similar to that of 10 Nm.

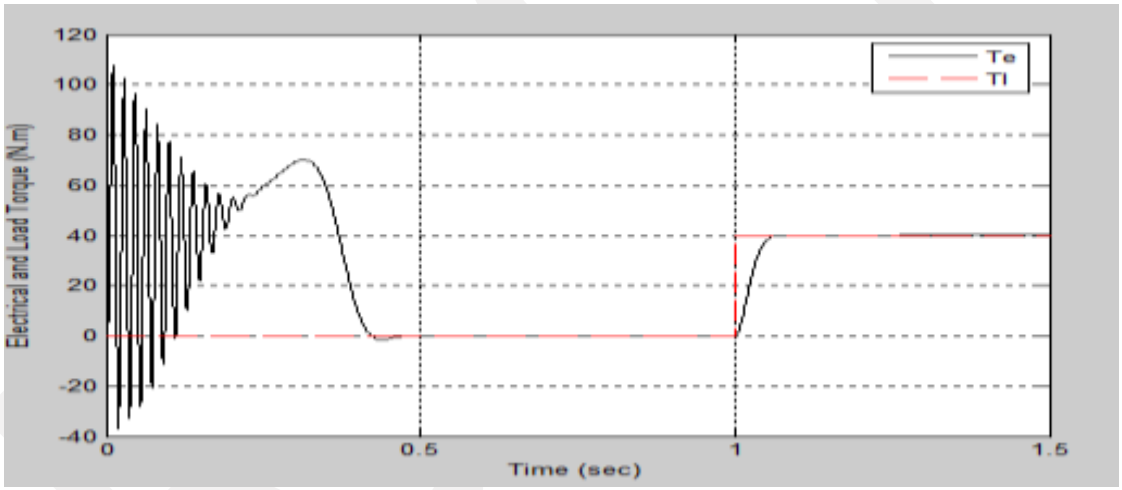


Fig. 10Motor Torque at $T_L = 40N.m$

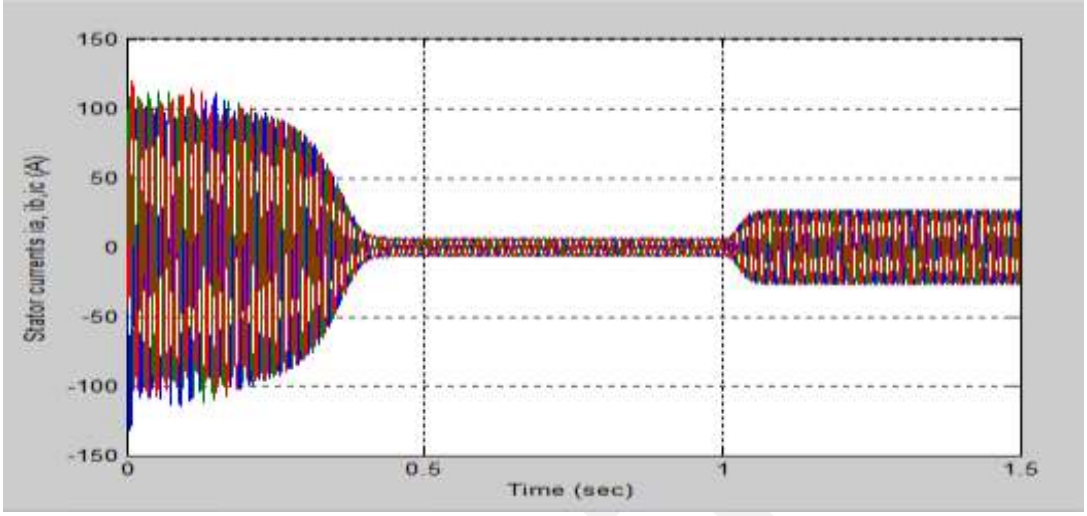


Fig. 11 Stator currents ia, ib, ic (A

The relationship of the stator currents relationship with time was then zoomed in to see the post transient and the result presented in Figure 6. The currents settled at maximum current of 10A after one second.

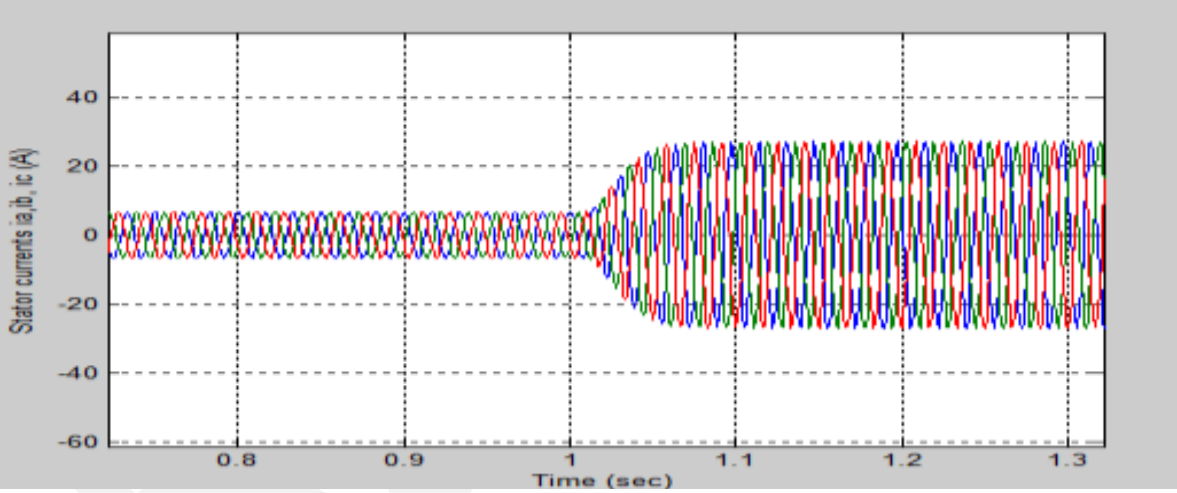


Fig. 12 Zooming the post transient of Fig. 13

Figure 13 is the presentation of the relationship between the electrical torque in Nm and that of the rotor speed in radians per second.

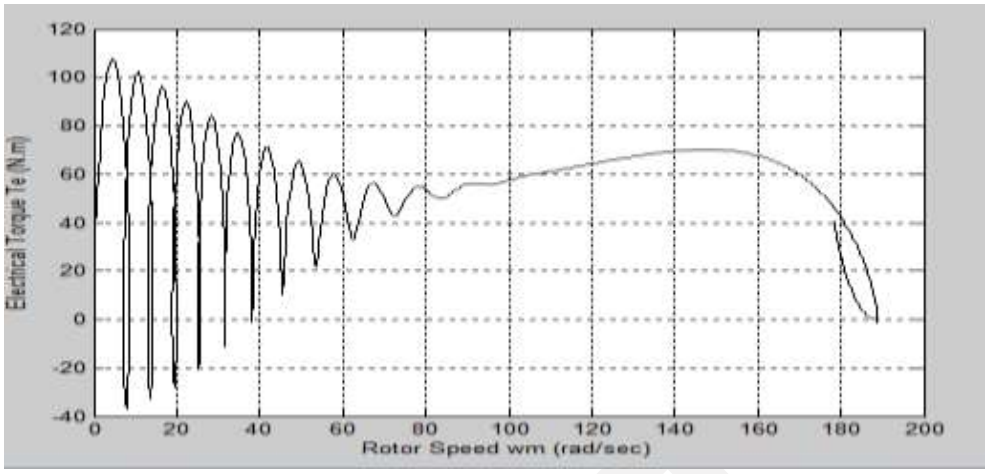


Fig. 13 Torque Speed relationship

The simulated value of the variation of stator flux fds and fqs is shown in Fig. 8.

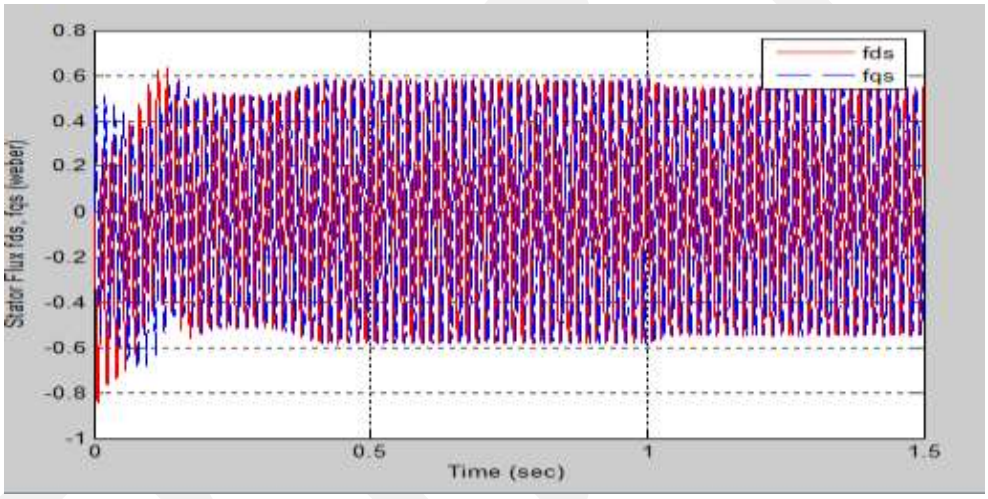


Fig 14Stator Flux f_{ds} f_{qs}

The the results of computer simulation using the SIMULINK model with $T_L = 10N.m$ and 40 Nm are similar to those obtained in the literatures [6, 1, 2]. In order to assess the improvement in simulation speed, the duration of simulation (t_{sim}) is compared with that of a conventional model developed by [2]. Both models are simulated under the same operating conditions and simulation parameters.The comparison of the simulation periods of s-function model to that of a conventional model at load toques of 10 Nm and 40 Nm are presented in Table 2. In both cases the s-function simulation periods was less than the conventional model [2].

Table 2: Comparison of simulation periods of s-function model to that of a conventional model

Load Toque Nm	S-Function Model Simulation period t_{sim} (s)	Conventional Model Simulation period t_{sim} (s)
10	2.26	4.10
40	2.65	4.78

Conclusion

In this paper, we have been able to model an asynchronous motor by the use of space-phasor notation. S-function was employed to completely model a three-phase induction machine with all the 3-phase quantities converted to two-axis d-q notation. The parameters of the motor were then used to implement the dynamic equations of the machine based on a single user defined S-Function block. This was to overcome the speed problem associated with normal Simulink library blocks. To test the accuracy of the model, a 3-phase ac voltage was applied through a direct-on-line startup. The effectiveness of the result obtained from simulation of the designed model was validated for loads with torques of 10 N.m and 40 N.m at t=1s. The results obtained at the different load torques showed that there was significant increase in simulation speed when compared with the conventional models. The paper then recommended that the proposed model may be used on its own or incorporated in advanced Electric Drive systems.

RJPST

References

[1] S. Cheng, C. Li, F. Chai, and H. Gong, "Research on induction motor for mini electric vehicles," Energy Procedia, vol. 17, pp. 249–257, 2012, doi: 10.1016/j.egypro.2012.02.091.
[2] S. Das, P. Purkait, and S. Chakravorti, "Space-vector characterization of induction motor operating conditions," in Proceedings of the Fifteenth National Power Systems Conference (NPSC), IIT Bombay, India, 2008, pp. 512–517.
[3] M. Çunkaş and R. Akkaya, "Design optimization of induction motor by genetic algorithm and comparison with existing motor," Mathematical and Computational Applications, vol. 11, no. 3, pp. 193–203, 2006, doi: 10.3390/mca11020193.
[4] F. Mansour, "Induction motors: Construction, principle of operation, power and torque calculations, characteristics and speed control," ResearchGate, June 2020, doi: 10.13140/RG.2.2.15490.71360.
[5] S. Nivasarkar, U. Meshram, A. Date, A. Dalvi, and G. Sarode, "Speed control of single phase induction motor using single MOSFET," in Proceedings of the 2018 International Conference on Smart Electric Drives and Power System (ICSEDPS), 2018, pp. 340–344.
[6] E. Idoko, E. S. Obe, and J. U. Agber, "Operation of single phase induction motor with two identical stator windings," American Journal of Engineering Research, vol. 5, no. 6,
[7] Z. Anthony, Erhaneli, and F. Ismail, "Single phase induction motor with 4 windings design and current control in auxiliary winding," in Proceedings of the International Conference of CELSciTech 2019: Science and Technology Track, Advances in Engineering Research, vol. 190, pp. 50–53, 2019, doi: 10.2991/iccelst-st-19.2019.10.
[8] C. Saravanan, A. Mohamed Azarudeen, and S. Selvakumar, "Performance of three phase induction motor using modified stator winding," Global Journal of Researches in Engineering: Electrical and Electronics Engineering, vol. 12, no. 5, pp. 1–5, 2012.
[9] H. F. Rashag, S. P. Koh, A. N. Abdalla, N. M. L. Tan, K. H. Chong, and S. K. Tiong, "DTC torque ripple minimization based on PSO-PID controller," Scientific Research and Essays, vol. 7, no. 15, pp. 1564–1572, 2012, doi: 10.5897/SRE11.2073.
[10] B. Masurkar, M. Isasare, B. Mandal, G. Fulzele, S. Ade, and S. Patle, "Implement direct torque and flux control (DTC) induction motor drive model: A review," Journal of Engineering Sciences, vol. 13, no. 10, 2022.
[11] N. El Ouanjli, S. Motahhir, A. Derouich, A. El Ghzizal, A. Chebabhi, and M. Taoussi, "Improved DTC strategy of doubly fed induction motor using fuzzy logic controller," Energy Reports, vol. 5, pp. 271–279, 2019, doi: 10.1016/j.egyr.2019.02.001.
[12] S. Potturi and R. S. P. Mandi, "Latest advances in DTC control of induction motors," International Journal of Recent Technology and Engineering, vol. 8, no. 6S, pp. 120–123, 2020, doi: 10.35940/ijrte.F1008.0386S20