American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-5, Issue-6, pp-13-19
www.ajer.org
Research Paper Open Access

Operation of Single Phase Induction Motor with two Identical Stator Windings

E.Idoko[1], E.S.Obe[2], J.U.Agber[3].
[1,3](Electrical and Electronics Engineering department,University of Agriculture,Makurdi,Nigeria)
[2](Electrical Engineering department,University of Nsukka,Nigeria)

ABSTRACT : *Single phase induction motors (SPIMs) are widely used motor due to the availability of single phase supply in virtually every home. They are reliable, robust, and cheap, applied in the production line of industries, and are also used in homes, offices etc. They are associated with some problems like, not self starting, low starting torque, high starting current, inability to carry heavy loads etc. This paper on SPIM with two identical stator windings is aimed at analyzing the machine with two equal stator windings in order to solve some of these problems with SPIM in order to enhance its performance. The machine equations are established, modeled using direct-phase variable model. The equations are simulated using embedded MATLAB function block simulink to verify its performance in terms of stator currents, electromagnetic torque and rotor speed. The dynamic performance of the machine was further verified as load torques was applied. The simulation results demonstrated the feasibility of the proposed scheme and also show some level of improvement.*

Keywords: *SPIM with two identical stator windings, MMF harmonics, Total Harmonic Distortion (THD), MATLAB Simulink block, in-rush (IR) current.*

I. INTRODUCTION

SPIMs are small motors, mostly built in the fractional horsepower range. These motors are widely employed for low power applications. In these applications, the machine runs at constant frequency and is fed directly from the alternating current (A.C) grid with any type of control strategy. SPIMs are used in a wide variety of commercial and industrial applications [1]. These motors are widely used due to their energy availability characteristics [2]. They are commonly used in small rating where three phase supply is not usually available [3]. It has no inherent starting mechanism since it is normally operated with only one stator winding and therefore some special arrangements, such as providing an auxiliary winding in the stator, has to be made for making it self-starting. It requires just one power phase for its operation [4]. They are reliable, robust, and cheap, and are also used in homes and offices for air conditioners, refrigerators, washing machines, furnace fans, and garbage disposals. The auxiliary winding is disconnected from the circuit by a centrifugal switch as the rotor attains close to maximum speed. This motor is associated with some problems like, not self-starting, cannot accommodate heavy loads due to low power factor, it has low starting torque, high starting current, low efficiency, which makes for great energy wastage [5]. The increasing concern for energy provision is causing more demand for the efficiencies of electric motors and appliances which use them. A motor with two identical windings in the stator is conceived to improve the conventional motor. The conventional capacitor run SPIM is manufactured either with single or double capacitor with the aim of improving the starting and running torque of the motor [6]. Mera and Câmpeanu [7] investigated the maximum efficiency for a given torque measurements made with large number of fixed value capacitors. It was concluded that the value of the starting torque increases with the capacitor. Also, for a high starting torque, the capacitor must have a high value. Mohd and Gurmeet [8] further investigated the electromagnetic field analysis of the execution of single phase capacitor run induction motor using composite rotor conductor and confirmed that, rotor geometry and rotor winding are the real components that assume an essential part in streamlining the performance of the machine.

A lot of methods have been employed in modeling induction motor, some of these models are: the D-Q axis model [9, 10, 11], 2D finite element model [12], Generic Algorithm [13] in order to investigate machine performance.

It is obvious from the findings that, all the papers reviewed worked with a conventional SPIM with non-identical windings on their stator frame. The purpose of this paper is to investigate and improve the conventional SPIM performance by making the two windings in the stator identical. This work shall provide a drive with lower torque ripples and a drive with lower current per watts, etc.

II. MODE OF OPERATION

This paper is to employ direct-phase variable model in analyzing the proposed machine with two identical windings in the stator. The two windings in the stator occupy 50% each, having identical number of pole, and are interwoven such that they occupy the same slot space. Both windings in the stator are sinusoidally distributed, and, therefore unlike conventional SPIM, the net flux in the stator core is a rotating sine wave. So there is no need for capacitor, however, the voltage can be two phase or with the use of two phase power electronic drive [14]. The rotor is a squirrel cage type. The two identical windings in the stator frame are displaced by 90 electrical degrees. The flux due to the current flowing in each phase winding is sinusoidal with a positive direction. The instantaneous values of these two fluxes set up by the two windings produce a resultant flux, whose value is a vector sum of these two fluxes at any time. It is obvious that the resultant flux is constant in magnitude, which implies that, it is equal to the maximum flux due to either phase and is making one revolution per cycle, meaning that the resultant flux rotates synchronously. Due to the fact that both windings in the stator are symmetrical, the circulating harmonic currents originated from mutual leakage coupling between the stator windings. This machine can be applied in all areas where SPIMs find applications.

III. ANALYSIS OF THE MACHINE

In analyzing this machine, the following assumptions are made, they are:

- The stator windings are portrayed by orthogonal sinusoidal distributed windings.
- The rotor windings *ar* and *br* are sinusoidally distributed.
- The rotor winding of the machine is short-circuited ($v_{ar} = v_{br} = 0$).
- Saturation, slotting effect, eddy current and temperature effects are neglected.
- The airgap distance between the stator and rotor is uniform.

3.1 Stator Design Layout

The stator windings layout configuration is designed for the SPIM with two identical stator windings as shown in Fig 1.0. The windings of this motor are configured to be identical after careful studying an identical conventional motor configuration whose stator layouts are non-identical. The waveform acquired gives the desired MMF sinusoidal waveform. This four-pole motor stator has 24 slots; it implies that the motor has 6 slots per pole with the auxiliary and the main windings distributed along the slots in the stator.

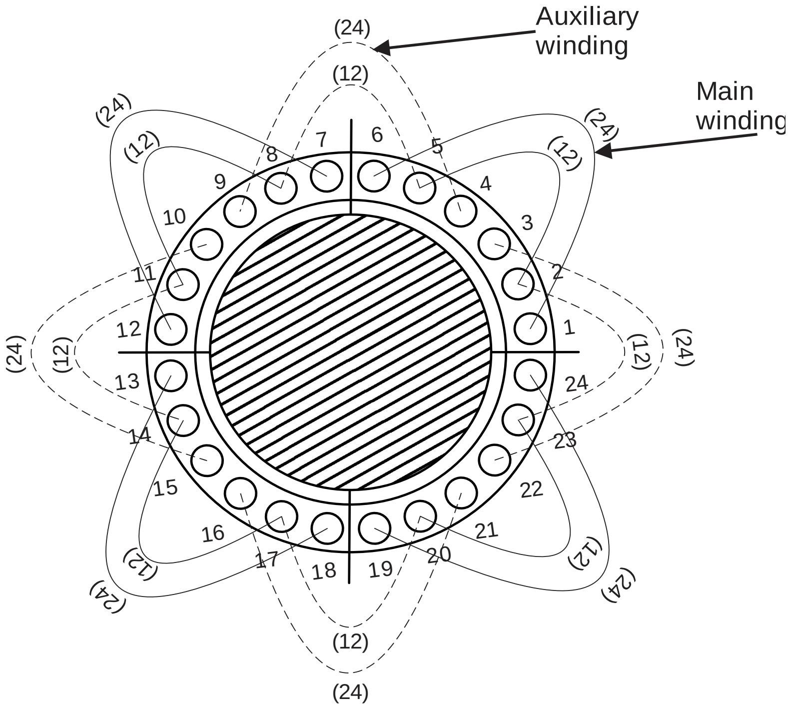


Figure 1.0: SPIM with two identical stator windings layout

3.2 Mathematical Model

Fig. 2.0 is a four pole SPIM with two identical stator windings, portrayed by orthogonal sinusoidal distributed windings with equal windings on the stator, which implies that both windings in the stator are symmetrical. The angular displacement about the stator is denoted θ_s and its axis is *as*-axis. The angular velocity of the rotor is w_r and θ_r is its angular displacement. Since the axes of the main and auxiliary stator windings are already orthogonal, for simplicity in analysis, the stationary *a*-*b* axes may be aligned with the orthogonal axes of the physical winding as shown in Fig. 2.0.

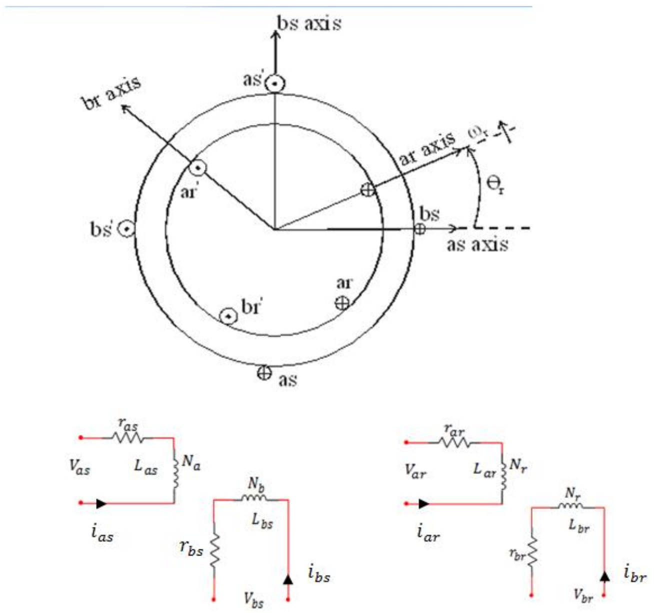


Figure 2.0: Cross section of SPIM with two identical stator windings

3.2.1 Derivation of Stator and rotor voltage equations

The voltage equations for both the stator and rotor are derived with respect to their self and mutual inductances from Fig 2.0 as presented:

$$V_{as} = r_{as} i_{as} + p\lambda_{as} \quad (1)$$
$$V_{bs} = r_{bs} i_{bs} + p\lambda_{bs} \quad (2)$$
$$V_{ar} = r_{ar} i_{ar} + p\lambda_{ar} \quad (3)$$
$$V_{br} = r_{br} i_{br} + p\lambda_{br} \quad (4)$$

The p denotes differentiation with respect to time $\left(\frac{d}{dt}\right)$

Equation 1-4 can be summarized as shown in equation 5

$$V = IR + \frac{d}{dt}[LI] \text{ ; where, } \lambda = [LI] \quad (5)$$

Expanding $\frac{d}{dt}[LI]$ in equation 5 and making $\frac{dI}{dt}$ the subject, yields

$$\frac{dI}{dt} = \frac{1}{L}\left[V - I\left(R + w_r \frac{dL(\theta)}{d\theta}\right)\right] \text{, where } w_r = \frac{d\theta}{dt} \text{ ; } R = \text{diag}[r_{as} \;\; r_{bs} \;\; r_{ar} \;\; r_{br}];$$

$$V = \begin{bmatrix} V_{as} \\ V_{bs} \\ 0 \\ 0 \end{bmatrix}; I = \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{ar} \\ i_{br} \end{bmatrix}; L = \begin{bmatrix} (L_{asas} + L_{ls}) & L_{asbs} & L_{asar} & L_{asbr} \\ L_{bsas} & (L_{bsbs} + L_{lS}) & L_{bsar} & L_{bsbr} \\ L_{aras} & L_{arbs} & (L_{arar} + L_{lr}) & L_{arbr} \\ L_{bras} & L_{brbs} & L_{brar} & (L_{brbr} + L_{lR}) \end{bmatrix}$$

let, $L_{ij} = \frac{\mu_o rl}{g}\int_0^{2\pi}(N_i \cos\theta\, N_j sin\theta)\, d\theta$, where, $L_{ij} = L_{asas}, L_{asbs}, L_{bsas}$ etc.

Leakage inductances of phase-a and phase-b stator windings are L_{ls} and L_{lS} respectively, while those of the rotor windings are $L_{lr}\,(L_{lR})$. The self and mutual inductances values were obtained from the inductance calculation embedded in the MMF waveform code.

3.2.2 Torque Equation

The torque equation for the machine is presented as:

$$T_e = \left({}^{P}/_{2}\right)(i_{abs})^T \frac{\delta}{\delta\theta_r} \begin{bmatrix} L_{sr}\cos(\theta_r) & -L_{sr}\sin(\theta_r) \\ L_{Sr}\sin(\theta_r) & L_{Sr}\cos(\theta_r) \end{bmatrix} i_{abr} \qquad (6)$$

Expanding equation 6 yields equation 7:

$$T_e = \left({}^{P}/_{2}\right) L_{sr} i_{as}\left(-i_{ar}\sin(\theta_r) - i_{br}\cos(\theta_r)\right) + L_{Sr} i_{bs}\left(i_{ar}\cos(\theta_r) - i_{br}\sin(\theta_r)\right) \quad (7)$$

The inductance L_{sr} is the amplitude of the mutual inductances between stator and rotor windings.
The torque and rotor speed are related by

$$T_e = J\left(\frac{2}{P}\right) P\omega_r + T_L \qquad (8)$$

IV. MODELING USING MATLAB/SIMULINK

Matlab/Simulink models were developed to examine the SPIM with two identical stator windings. The equations from (1)-(5) and (8) are modeled using direct-phase variable model and implemented in an embedded MATLAB Simulink block with the oscilloscope displaying the results as presented in Figure 3.0. The parameters used for this simulation were obtained from the open and short circuit tests performed on an identical conventional SPIM as presented in Table 1.0

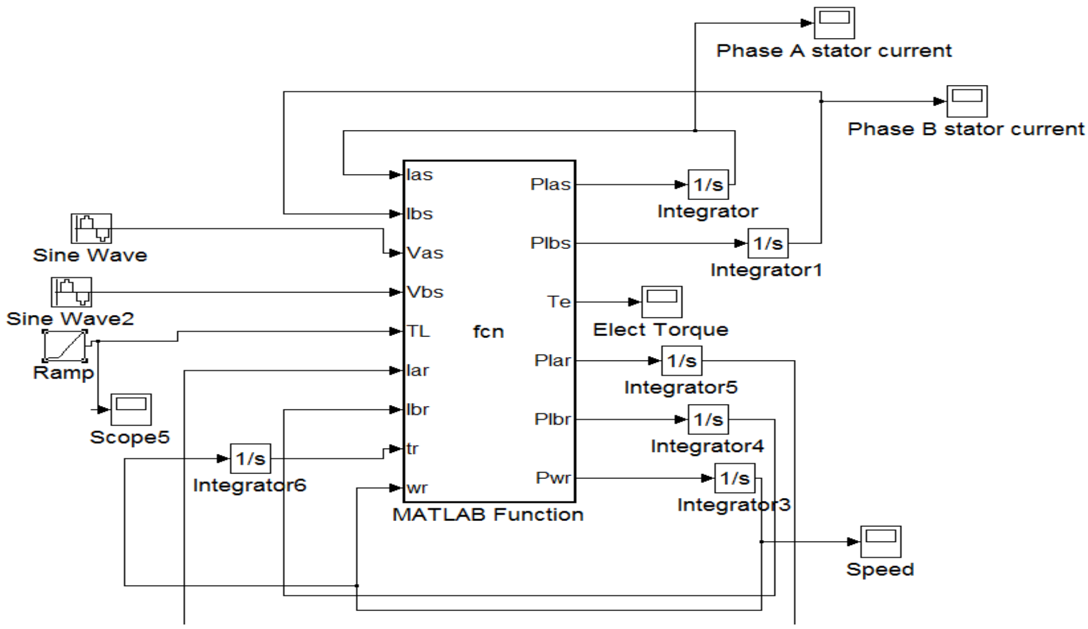


Figure 3.0: Simulink model of the SPIM with two identical stator windings

Table 1.0: Machine Data for SPIM

L_{ls}=0.002H;	Moment of inertia, J=0.015;
L_{lS}=0.002H;	Number of main windings, N_a=24;
L_{lr}=0.0015H;	Number of auxiliary windings, N_b=24;
L_{lR}=0.0012H;	Turn windings on rotor, N_r=33;
r_{as} =2.3Ohms;	Number of pole, p=4;
r_{bs} =2.3Ohms;	Effective stack length, l =0.15
r_{ar} =1.6Ohms;	Airgap radius, R=0.099
r_{br} =2.1Ohms;	mu=4*pi*10^-7

V. RESULTS AND DISCUSSION

The simulation results are obtained from the simulink model in Fig 3.0, the results are presented in Fig. 5.0 to 9.0. The objective of this paper is to investigate the performance of the induction motor with two identical windings in the stator. The results are discussed as shown in different sections.

5.1 MMF Distribution in the Air Gap

Fig. 4 is a result obtained from MATLAB code written using the number of windings designed on each slot of the stator with respect to Fig.1.0, the aim is to investigate if the motor waveforms for the two windings (Main and Auxiliary) are sinusoidal and identical. This is because the MMF distribution in the air gap is determined by the number of slots and the coil in each slot. It is obvious from the result that, they are. They contain harmonic components with one fundamental component which are identical with a THD of 0.2073 for both windings as seen in Fig. 5.0. This implies that the motor can be powered by an A.C. voltage.

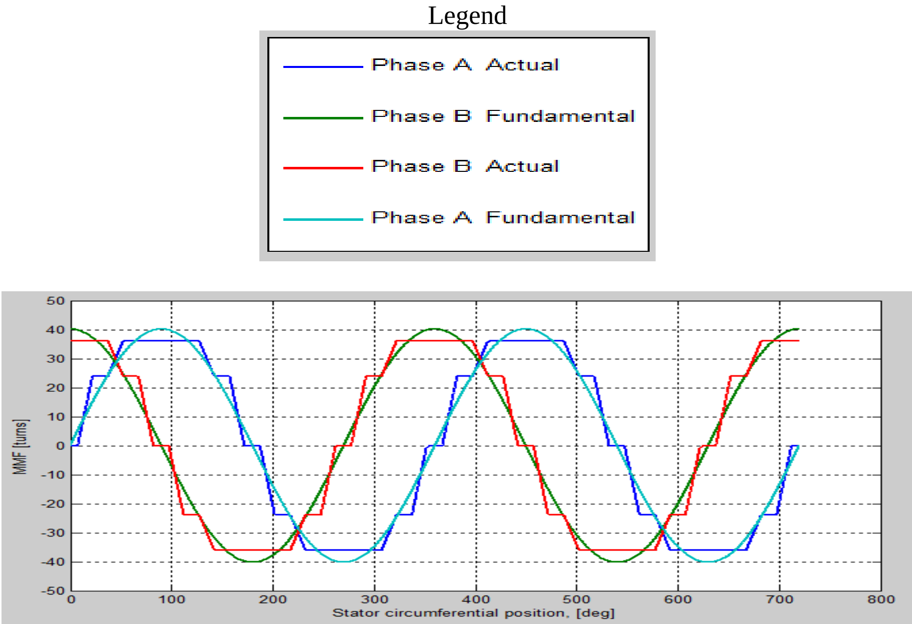
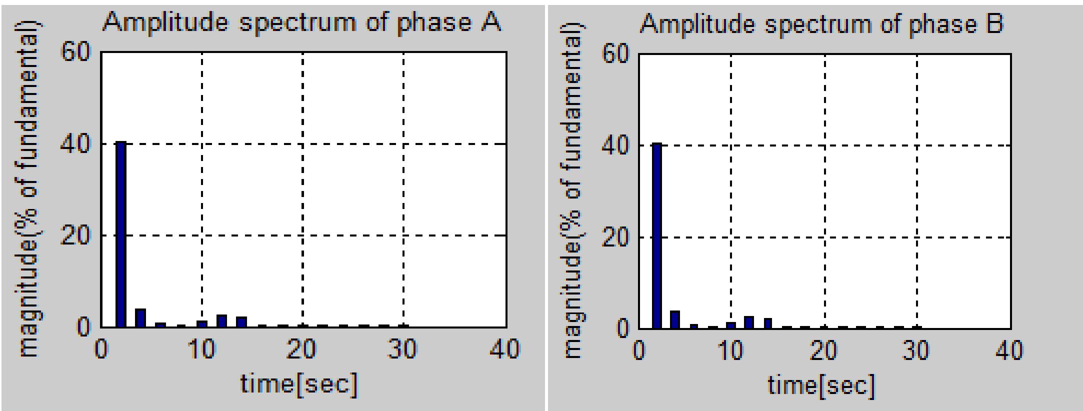


Figure 4.0: MMF distribution of the main and auxiliary winding for the SPIM with two identical stator windings



(a) (b)

Figure 5.0 (a) and (b): identical winding harmonics components for the main and auxiliary windings in the stator of the SPIM with two identical stator windings, with THD of 0.2073.

5.2 Stator Current

The machine result in Fig. 6 and Fig. 7 show the waveforms and envelops of the stator currents. Fig 6.0 is the main winding stator current plotted against time while Fig 7.0 is the auxiliary winding stator current plotted against time. Fig. 6.0 shows that when voltage is supplied to the machine, it starts with the main winding IR current of 43.0 A and drops to 8.00A at no-load, at time 1.5s when load torque was applied and as the load appreciates; the machine maintained that value of current for a long time before obtaining the full-load current of 11.00A. This result is related in Fig. 7.0 which proves the configuration of the windings is identical.

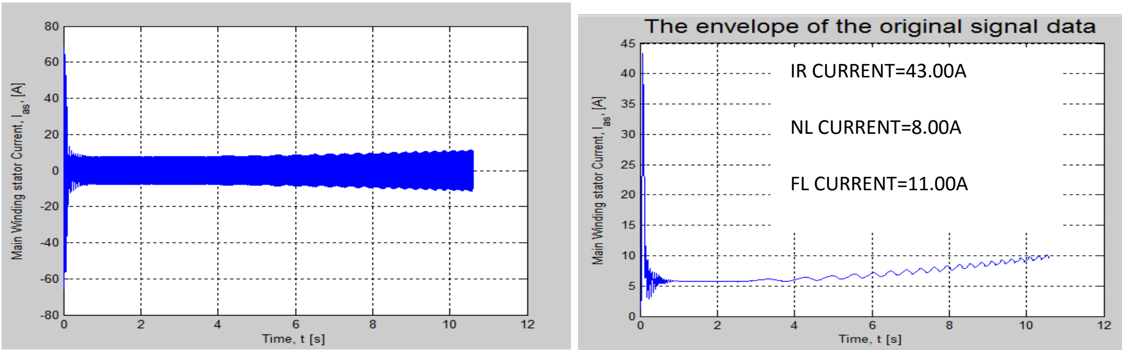
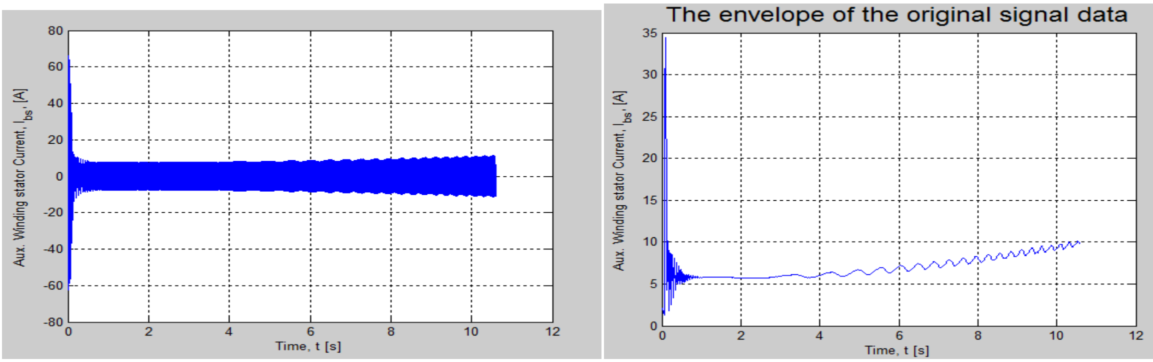


Figure 6.0: Main winding stator currents for SPIM with two identical windings (a) waveform (b) Envelope of current



(a) (b)

Figure 7.0: Auxiliary winding stator currents for SPIM with two identical windings (a) waveform (b) Envelope of current

5.3 Electromagnetic Torque

Fig. 8.0 is the result obtained for plotting electromagnetic torque against time. It is obvious from the figure that the motor starts with a high starting torque, at time 1.5s when load was applied and as it kept increasing, the electromagnetic torque kept appreciating in order to accommodate the load torque until it acquires a full-load torque of 9.8Nm.

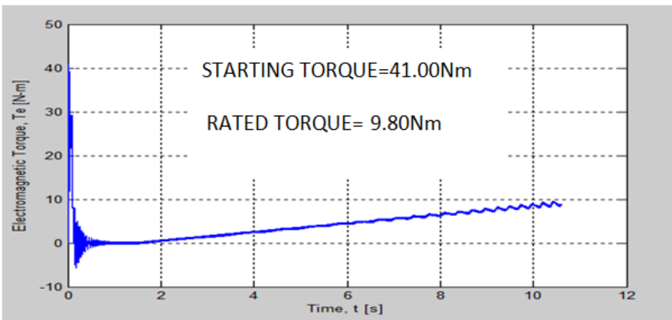


Figure 8.0: Electromagnetic torque SPIM with two identical windings

5.4 Rotor Speed

Fig 9.0 shows the rotor speed plotted against time. On application of the voltage, the motor starts smoothly and the speed increased before the attainment of full nominal speed of 377 rad/sec at no load. This is the expected speed of a 4-pole 60Hz induction motor. At 1.5 seconds when the load torques was applied and as the load kept appreciating, the speed was maintained for a considerable time before it starts subsiding to a full load speed of 358 rad/sec at allowable slip of 0.05.

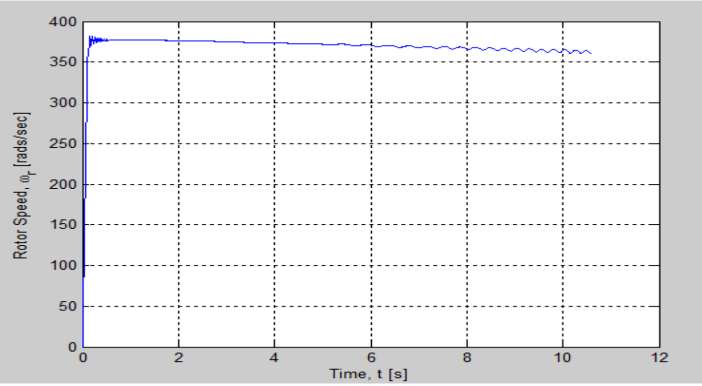


Figure 9.0: Rotor speed during starting and its response to load torque for the SPIM with two identical windings

VI. CONCLUSIONS

The SPIM with two identical windings circuit was designed; the machine equations were generated from the circuit in Fig. 2.0 and resolved using embedded MATLAB function block. The simulation results show the feasibility of the proposed motor in terms of machine characteristics such as the stator currents, the torque and speed. It has been established that; this motor operates with low IR current; high starting torque with a rotor speed that support heavy loads. Apart from that, although the machine will have slightly more conductors in the stator; however, the increased output per current will entail a significant reduction of running cost in terms of low volt-ampere, entailing a lower Watts per ampere.

REFERENCES

[1]. Manuel Guerreiro, D. F. and Armando C. (2008). A Phasor Spped Control of a Single or Two Phase Induction Motor,*Proceedingof the 2008 International Conference on Electrical Machines, 1,2008.*

[2]. Vinamra K. G. and Yogesh C, Modeling & Simulation of PWM Controlled Cycloconverter FED Split Phase Induction Motor, *International Journal of Advanced Research in Electrical,Electronics and Instrumentation Engineering*,1(3), 2012.

[3]. Mohamed M.B, Jemli M. Boussak M and Gossa M. Speed Sensorless Vector control of Single phase Induction Motor. 1,2008.

[4]. Mohd A. I. and Gurmeet S, A Review on Influence of Rotor Geometry on the Performance of Single-Phase Capacitor-Run Induction Motor, *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 3(6), 2007, 10216-10224.

[5]. Hui Z., Xiuhe W., Xuemei L. and Dauhan W, A New Type Single Phase Induction Motor with a Negative Sequence Compensatory Winding, *Second IEEE Conference on Industrial Electronics and Applications*, 2007, 82-85.

[6]. Sedat S. Mehmet O., Bilal and Gumus, Modeling and Simulation of A Single Phase Induction Motor with Adjustable Switched Capacitor. *9 International Conference on Power electronics and Motion Control- EPEPEMC, Poland, 2000.*

[7]. Mera R., and Câmpeanu R, Optimal Performance of Capacitor-Run Single Phase Induction Motor. *IEEE Tranction*, 2012, 718-723.

[8]. Mohd A. I. and Gurmeet S., A Review on Influence of Rotor Geometry on the Performance of Single-Phase Capacitor-Run Induction Motor. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering* (An ISO 3297: 2007 Certified Organization). 3(6), 2014, 10216-10224.

[9]. Sujay S., Subhro P., Pradip K. S. and Gautam K. P., Non Linear Modeling of Split Phase Type Single Phase Induction Motor. *International Journal of Science and Research* (IJSR), *2(1)*, 2013, 398-402.

[10]. Sunita K. J., Fanibhushan S. and Mukesh K. B, Modeling and Simulation of an Induction Motor. *International Journal of Engineering Research and Development 10(4)*, 2014, 57-61

[11]. Animesh K., Nihar R. R., Pradip K.S., Rajarshi M. and Gautam K. P, Dynamic Modelling Of Single-Phase Permanent Capacitor Induction Motor and Study of Non-Linear Phenomenon**,** *International Journal Of Computational Engineering Research (ijceronline.com). 2(5)*, 2012, 1690-1694.

[12]. Zhou D., Rajanathan C.B. and Sapeluk A.T. and Ozveren C.S, Finite-element-aided design optimization of a shaded-pole induction motor for maximum starting torque, *IEEE Transactions on Magnetics*, *36*, 2000, 3551-3554.

[13]. Sarac V., Petkovska L., Cundev M. and Cvetkovski G, Comparison Between Two Target Functions for Optimization of Single Phase Shaded Pole Motor Using Method of Generic Algorithms, *Journals of Material Processing Technology. 161,2005,89-95.*

[14]. Branislav Dobrucky, Michal Frivaldsky, Michal Prazenica, Pavol Spanik, Valeria Hrabovcova, Peter Sekerak, Lukas Kalamen and Pavol Rafajdus, Two-Phase Power Electronic Drive with Split -Single- Phase Induction Motor, University of Zilina, Dept. of Mechatronics and Electronics, 010 26 Zilina, Slovakia 2010 IEEE, 1683-1688.