Computer Simulation of Two-leg ac Voltage Controller-fed Induction Motor under Starting Condition

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ABSTRACT
Computer simulation of two-leg ac voltage controller-fed three phase induction motor is attempted to find out an optimum firing angle combination of the voltage controller for better starting performance. Optimum firing angle combination is the firing angle at which the negative torque pulsations is zero with minimum acceleration time and other electrical characteristics like peak positive electromagnetic torque pulsations, peak starting current are having satisfactory values. The effect of variation of motor parameters on different performance characteristics are investigated to select a better motor parameter combination for a particular machine, which gives improved starting performance. Results show that, based on the computer simulation, slight modifications can be done for the motor parameters in the design stage itself, which may account for the approximations taken during the design stage.

Keywords
AC voltage control, Computer simulation, Induction motor starting.

List of symbols

r_s - Stator resistance in ohms

r_r - Rotor resistance in ohms

ω_r - Rotor speed in rps

L_m - Magnetizing inductance in henry

L_s - Stator inductance in henry

L_r - Rotor inductance in henry

i_{ds} - Direct axis stator current in A

i_{qs} - Quadrature axis stator current in A

i_{dr} - Direct axis rotor current in A

i_{qr} - Quadrature axis rotor current inA

TL - Load torque in Nm

P - Number of poles

V_{ds} - d-axis stator voltage in V

V_{qs} - q-axis stator voltage in V, V_{ds} and V_{qs} are functions of α.

1. INTRODUCTION
Computer application is widely used in the field of electrical engineering for design, testing, modeling etc. Many researchers use various computer simulations to find out the performance of different electrical equipments, before actually erecting the equipments in the industry. Three phase induction motors have been the workhorse in various industrial, manufacturing and propulsion applications [1]. Hence its performance improvement both at starting and running are important area of research as far as industries are concerned.

Direct On Line (DOL) starting is the simplest and economic method of starting a three phase induction motor, which is used unless there is either an electrical or mechanical constraint which makes this option unsuitable [2]. But it offers absolutely no control capability. It is characterized by high starting inrush currents and torque pulsations, leading to voltage dip and brown out conditions and create problems to the connected electrical system and in some cases it may damage the mechanical system itself [3]. An alternative technique to the conventional solution of direct-on-line starting problem is the use of a static switch consisting of back-to-back connected thyristor pairs [4]-[9]. Since the initial triggering instants of thyristor switches are under the guidance of control circuitry in contrary to the closing instants of conventional circuit breaker poles, the starting current and torque transients can be minimized by a careful design work. Examination of the works reported [10]-[12] shows that the proposed control strategies are derived to obtain optimum firing angle. Earlier works reported in [13]-[16] shows dependence of optimum firing angle on the motor parameters.

This paper analyses the performance of two-leg ac voltage controller-fed induction motors and investigates the effect of variation of each motor parameters on different performance indices like peak negative torque pulsation, peak positive torque pulsations, peak current transient and acceleration time. Optimum firing angle combination(αβ) is taken as the firing angle at which negative torque pulsation is zero with minimum value of acceleration time and at the same time all other performance indices are giving satisfactory values. Initially optimum α with measured motor parameters are obtained and the variation of the performance indices are analyzed by continuous variation of each motor parameters. Simulations are carried out to find out the parameter dependence and hence to select a best parameter combination. To substantiate this concept, three motors having 2.2kW, 3.7kW and 7.4kW were selected for the study.

2. Proposed controller

Computer simulation of the proposed set up is done in MATHLAB simulink. Firing pulses to the six thyristors are produced by MATLAB programming. Flow chart for the control action is given in Figure 1. The schematic diagram of the two-leg ac voltage controller-fed induction motor is given in Figure 2. It consists of two pairs of back-to-back connected thyristors in series with R and B phases, forming R and B phase group of thyristors respectively. α is the firing angle to phase R and β to phase B and Y phase is directly connected to the motor, hence the name two-leg control. Firing pulses to negative thyristors, T_{bR} and T_{bB} are given at (π+α) and (π+β) respectively. Firing pulses are suitably adjusted to achieve smooth starting of the motor.

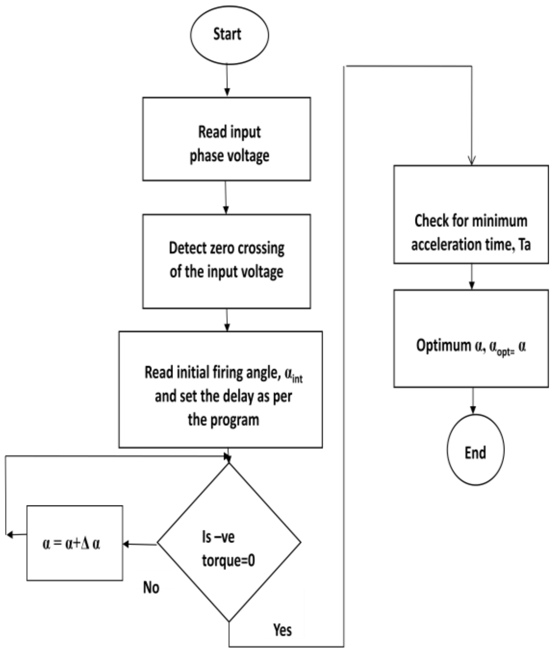


Fig 1: Flowchart for the control action

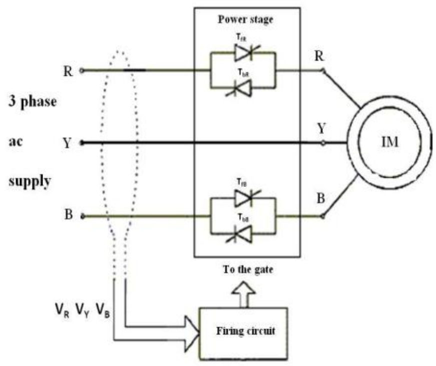


Fig 2: Schematic diagram of two-leg ac voltage controller-fed induction motor

The matrix differential equation of the induction motor described in stator reference frame [17] is given in equation (1)

$$\begin{bmatrix} \frac{di_{ds}}{dt} \\ \frac{di_{qs}}{dt} \\ \frac{di_{dr}}{dt} \\ \frac{di_{qr}}{dt} \end{bmatrix} = \frac{1}{\sigma} \begin{bmatrix} \frac{-r_s}{L_s} & \frac{\omega_r L_m^2}{L_s L_r} & \frac{r_r L_m}{L_s L_r} & \frac{\omega_r L_m}{L_s} \\ \frac{-\omega_r L_m^2}{L_s L_r} & \frac{-r_s}{L_s} & \frac{-\omega_r L_m}{L_s} & \frac{r_r L_m}{L_s L_r} \\ \frac{r_s L_m}{L_s L_r} & \frac{-\omega_r L_m}{L_r} & \frac{-r_r}{L_r} & \frac{-\omega_r L_m}{L_r} \\ \frac{\omega_r L_m}{L_r} & \frac{r_s L_m}{L_s L_r} & \frac{\omega_r L_m}{L_r} & \frac{-r_r}{L_r} \end{bmatrix} \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix} +$$

$$\frac{1}{\sigma} \begin{bmatrix} \frac{1}{L_s} & 0 & \frac{-L_m}{L_s L_r} & 0 \\ 0 & \frac{1}{L_s} & 0 & \frac{-L_m}{L_s L_r} \\ \frac{-L_m}{L_s L_r} & 0 & \frac{1}{L_r} & 0 \\ 0 & \frac{-L_m}{L_s L_r} & 0 & \frac{1}{L_r} \end{bmatrix} \begin{bmatrix} v_{ds} \\ v_{qs} \\ 0 \\ 0 \end{bmatrix} \qquad (1)$$

Where

$$\sigma = 1 - \frac{L_m^2}{L_s L_r}$$

The electromagnetic torque is governed by the equation

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

The speed is given by

$$\frac{d\omega_r}{dt} = \frac{T_e - T_L}{J} \qquad (3)$$

Equations (1), (2), and (3) are used to develop the motor model in Matlab/Simulink for analyzing the starting transients of the motor drive system. The machine parameters of the selected motors were obtained from the experimental tests. These values are given in appendix and are used for simulation work. Three machines with rating 2.2kW labeled as machine A, 3.7kW labeled as machine B and 7.4kW labeled as machine C are used for the work. Initially optimum firing angle combination for each machine is obtained based on the simulation. By keeping the firing angle constant at its optimum value, currents, voltages, speed and electrodynamic torque waveforms of the motor are analyzed by varying each motor parameters in a specified range. Positive electrodynamic torque peak, negative electrodynamic torque peak, acceleration time, current ripple, and peak current are tabulated in perunit values and these are plotted against different motor parameters. From these plots, modified motor parameter values are obtained and optimum αβ combination based on the modified motor parameters is arrived for each machine.

3. RESULTS AND DISCUSSION

Computer simulation has been done on three different rated machines labeled machine A, B and C to analyze the starting performance.

3.1 Performance optimization

In order to find out the optimum firing angle combination, various electrical characteristics under considerations are observed and are plotted against α with fixed value of β. This fixed value of β is the optimum firing angle obtained with three-leg control [13]. Optimum α is taken from these plots and keeping this α constant, firing angle to phase B ie β is varied. Various electrical characteristics are observed and tabulated. These are plotted against β to obtain the optimum β. The plots of performance parameters against firing angle α for machine A is shown in Figure 3 as an example and the value of α obtained is 55.2^0 for machine A. Similarly plots for finding the optimum β is shown in Figure 4. The value of β is observed as 62.4^o. Thus the optimum α,β combination is 55.2^0 and 62.4^0 for machine A. Similarly optimum α,β combination for other machine are also obtained and are shown in Table I.

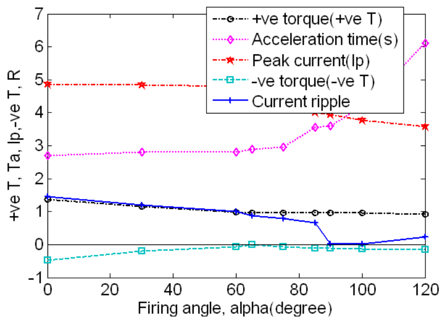


Fig 3: Plots to find optimum α with β = 62.2^0 for machine A

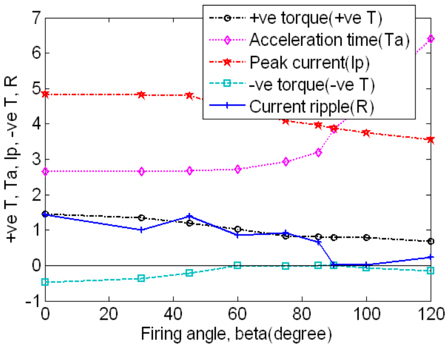


Fig 4: Plots to find optimum β with α = 55.2^0 for machine A

3.2 Effect of variation of machine parameters on motor performance

Machines are simulated by varying different motor parameters. Various electrical characteristics under consideration are observed. These are plotted against different motor parameters and are shown in Figures 5-8 for machine A. It is observed that peak positive torque pulsation increases and peak current decreases with increase in rotor resistance. Acceleration time first decreases and reaches to a minimum value and then increases with increase in rotor resistance. Peak negative torque pulsation reaches to zero when the rotor resistance is 2.0Ω and above. Peak positive torque pulsation and peak current decreases with increase in stator and rotor inductances, but the acceleration time increases with increase in inductance.

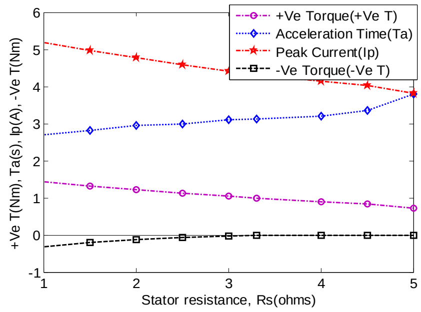


Fig 5: Variation of electrical characteristics with stator resistance for Machine A

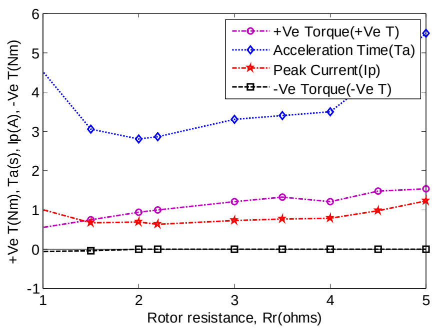


Fig 6: Variation of electrical characteristics with rotor resistance for Machine A

There exists a negative torque pulsation when the inductance is 20.0mH and above. Peak positive torque pulsation increases, peak current and acceleration time decreases with increase in mutual inductance and peak negative torque pulsation does not depend on mutual inductance. Based on the computer simulation, modified motor parameter combination that gives improved starting performance is obtained. For example for 2.2kW machine, rotor resistance is selected as 2.0Ω at which the acceleration time has minimum value with zero negative torque pulsations and all other performance characteristics are having satisfactory values compared to the performance values with measured motor parameters. Stator resistance is taken as 4.2Ω at which negative torque pulsation is zero and also the positive torque pulsation and peak current are having reduced values. Similarly all other motor parameters are also obtained and are selected as Lm=250.0mH and Ls/Lr=18.0mH.

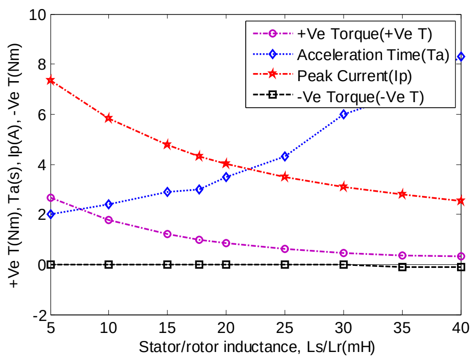


Fig 7: Variation of electrical characteristics with stator/rotor inductance for Machine A

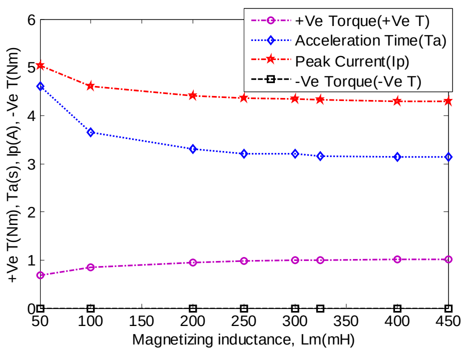


Fig 8: Variation of electrical characteristics with magnetizing inductance for Machine A

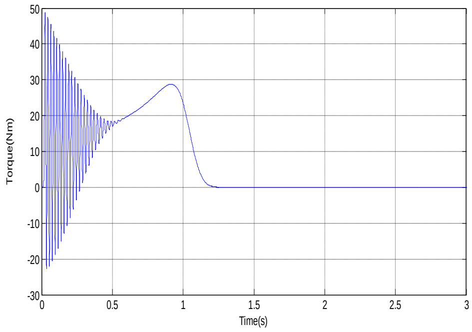
Motors are simulated with the modified motor parameters and the performance characteristics are noted. Positive torque pulsation is reduced from 24.5Nm to 22.3Nm with modified motor parameters. Peak starting current is reduced to 22.6A from 24.4A and acceleration time is reduced to 1.4s from 1.6s with modified motor parameter values. Optimum firing angle combination is changed with the modified motor parameters and the new optimum αβ combination for machine A is modified to 54.8^0 and 61.3^0 from 55.2^O and 62.4^O. The performance values for all the machines are given in Table I. Electromagnetic torque pulsation at DOL starting, torque, transient current and speed, and steady state current waveforms at optimum αβ combination with modified motor parameters for machine A are shown in Figure 9. Results show that there is a significant improvement in the starting performance compared to the actual parameter values and also under steady state conditions the motor currents are sinusoidal in nature. Actual and modified motor parameter values are shown in Table II. Performance values for DOL starting are given in Table III for comparison.

Table 1. Performance comparison with actual and modified motor parameters

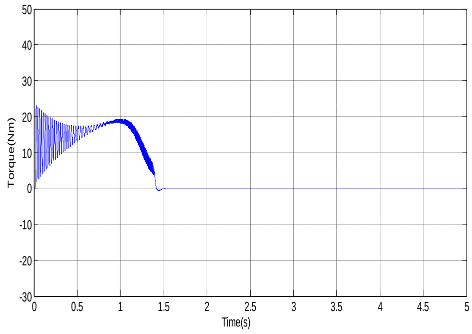
Machine	Values with actual motor parameters					Values with modified motor parameters				
	Optimum αβ combination (Degrees)	Peak +ve Torque (Nm)	Peak -ve Torque (Nm)	Acceler-ation Time (S)	Peak Current (A)	Optimum αβ combination (Degrees)	Peak +ve Torque (Nm)	Peak -ve Torque (Nm)	Accele-ration time (S)	Peak Current (A)
A	55.2, 62.4	24.5	0	1.6	24.4	54.8, 61.3	22.3	0	1.4	22.6
B	56.1, 56.8	23.8	0	0.8	15.95	55.4, 56.2	21.4	0	0.56	13.8
C	64.2, 66.5	30.7	0	1.9	20.18	61.3, 65.4	27.8	0	1.57	18.6

Table I2. Actual and modified motor parameters

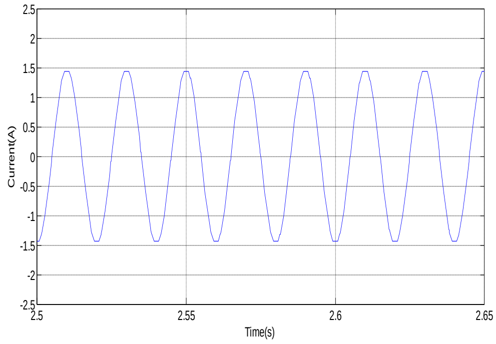
Machine	Actual motor parameters				Modified motor parameters			
	Stator resistance Rs(Ω)	Rotor resistance Rr(Ω)	Magnetizing inductance Lm(mH)	Stator/rotor inductance Ls/Lr(mH)	Stator resistance Rs(Ω)	Rotor resistance Rr(Ω)	Magnetizing inductance Lm(mH)	Stator/rotor inductance Ls/Lr(mH)
2.2kW,415V, 50Hz,4.5A	3.3	2.2	324.5	17.7	4.2	2.0	250.0	18.0
3.7kW,400V, 50Hz,7A	6.2	5.23	692.73	30.42	6.7	5.0	655.0	31.40
7.4kW,400V, 50Hz,15A	2.06	2.05	356.25	17.6	2.5	2.0	340	17.8



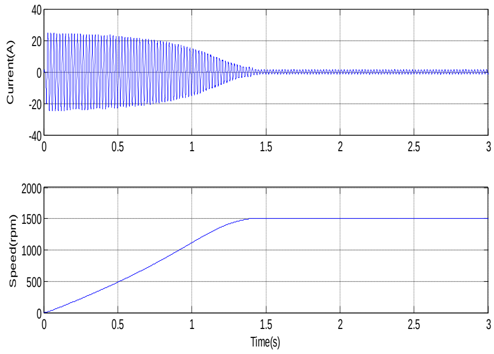
(a)



(b)



(c)



(d)

Fig 9: (a) Transient electromagnetic torque vs time for DOL starting, (b),(c) and (d) Transient electromagnetic torque vs time, Steady state current vs time and Transient current and speed vs time for optimum αβ combination with modified motor parameters for machine A

Table II3. Performance values for DOL starting

Machine	**Peak +ve Torque (Nm)**	**Peak –ve Torque (Nm)**	**Acceler-ation Time (S)**	**Peak Current (A)**
A	48.74	22.75	1.2	39.45
B	39.4	13.7	0.6	25.5
C	32.54	18.82	1.7	26.31

4. CONCLUSION

Computer simulation of two-leg ac voltage controller-fed three phase induction motor is carried out to analyze the starting performance. Various factors like peak positive torque pulsation, peak negative torque pulsation, peak starting current, and acceleration time are selected for analyzing the performance. In order to study the dependence of motor parameters, motors are simulated by varying different motor parameters. Three different rated motors are used for the work. A modified motor parameter combination is arrived from the simulation results, which gives better starting performance. Results show that the performance of the motors with modified motor parameter values is improved significantly compared to the performance with actual motor parameters. It also shows that based on the computer simulation results, slight modifications can be done to the motor parameters in the design stage itself, which gives better starting performance and may account for the approximations taken during the design process.

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