Rotor Side Speed Control Methods Using MATLAB/Simulink for Wound Induction Motor

Rajesh Kumar, Roopali Dogra, Puneet Aggarwal

Abstract—In recent advancements in electric machine and drives, wound rotor motor is extensively used. The merit of using wound rotor induction motor is to control speed/torque characteristics by inserting external resistance. Wound rotor induction motor can be used in the cases such as (a) low inrush current, (b) load requiring high starting torque, (c) lower starting current is required, (d) loads having high inertia, and (e) gradual built up of torque. Examples include conveyers, cranes, pumps, elevators, and compressors. This paper includes speed control of wound induction motor using MATLAB/Simulink for rotor resistance and slip power recovery method. The characteristics of these speed control methods are hence analyzed.

Keywords—Wound rotor induction motor, MATLAB/Simulink, rotor resistance method, slip power recovery method.

I. INTRODUCTION

SPEED control of induction motor is achieved by adding resistance at the rotor side traditionally [2]. The rotor has three-phase winding connected in star [2]. Separate slip rings are connected to the three terminals of the rotor winding. Due to these slip rings, external resistance can be connected, which helps in speed control of wound rotor induction motor. Speed, at which maximum torque occurs for the motor, changes by adding resistance to the rotor circuit [1]. Hence, at low speeds, high torques can be produced. This is helpful for starting loads with high breakaway torque requirements. For an ordinary wound rotor induction motor, the closed loop control system thyristors are used in secondary side. Slip frequency voltage at the rotor side is rectified and is fed to a thyristor; a variable on time results in variable speed [1]. Torque varies widely with on time depending upon the following conditions: (a) when thyristor is parallel with the source and external resistance and (b) when the thyristor is in series with source and external resistance. Speed control of induction motor can be done majorly by two schemes:

1. Stator side control
2. Rotor side control

Where rotor side control includes slip power recovery mechanism and non-slip power recovery mechanism, respectively. The speed of induction motor can also be varied from the stator side and methods of speed control from the stator side includes (a) V/f control or frequency control (b) varying number of stator poles (c) Steering the supply voltage and varying the resistance using the rheostat on the stator side. Speed control methods from the stator side have many limitations considering the constructional aspects of machine hence rotor speed control method is a better alternative for speed control. The authors have used MATLAB/Simulink as a tool to understand characteristics of speed control of wound rotor induction motor. The characteristics studied here are of rotor side control using single thyristor, external resistance, and slip power recovery scheme, respectively. These methods of speed control are analyzed in the following sections.

II. ROTOR SIDE CONTROL USING SINGLE THYRISTOR

The circuit used for the implementation of rotor side control of wound rotor induction motor using single thyristor is shown in Fig. 1 [1].

The addition of external resistance to the rotor of wound rotor induction motor makes the rotor resistance high during the starting, hence the rotor current is low, and starting torque is at maximum [6].Also, rotor resistance is directly proportional to slip necessary to generate maximum torque. In wound rotor motors, the rotor resistance is increased by adding an external resistance [1]. It is possible to achieve pull-out torque even at low speeds, since slip is more due to increase in rotor resistance [7].

A. Rotor Resistance Control (Single Thyristor Control) Using Simulink

The Simulink diagram for the implementation of rotor resistance control (single thyristor control) using Simulink is shown in Fig. 2. The asynchronous motor block in Simulink diagram as shown in Fig. 2 can be modeled according to the values as shown in Table I.

TABLE I
PARAMETER SPECIFICATIONS

PARAMETER	VALUES
Nominal Power(L-L), Voltage and Frequency	2250*746 VA, 2400V, 60Hz
Stator(R_1,L_1)	0.029Ω, 0.226/377H
Rotor(R_2,L_2)	0.022Ω, 0.226/377H
Mutual Inductance L_m	13.04/377H
Inertia, Friction, and Pair of Poles	63.87kgm^2, 0 Nms, 2

The circuit basically consists of three-phase AC supply fed asynchronous machine. The output of the machine is fed to bus selector, which helps us to plot the characteristics of machine. A simple resistive load is used for the analysis of output of wound rotor induction machine. To establish desired speed, control of a thyristor of considerable value is

Rajesh Kumar is with the Maharishi Markandeshwar University, Mullana, 133203, Haryana, India (corresponding author, phone: +918398069447, e-mail: rjesh10391@gmail.com).

Roopali Dogra is with the Maharishi Markandeshwar University (phone: +919622731576, e-mail: roopalidogra5@gmail.com).

PuneetAggrawal is with the Maharishi Markandeshwar University (phone: +918059931096, e-mail: puneet241@gmail.com).

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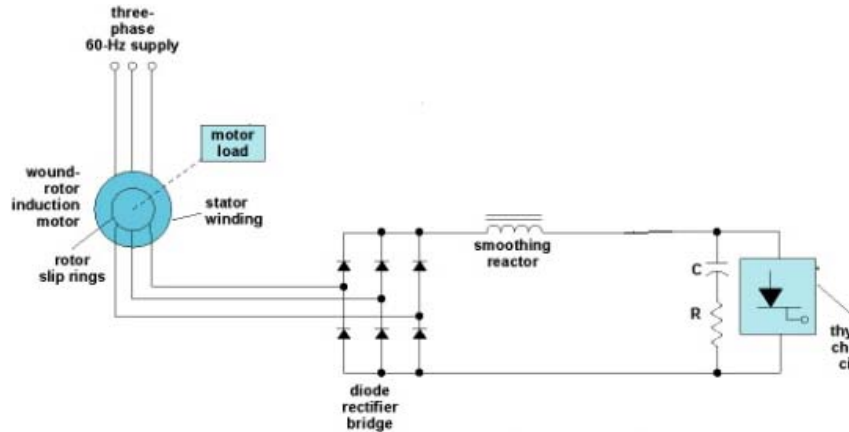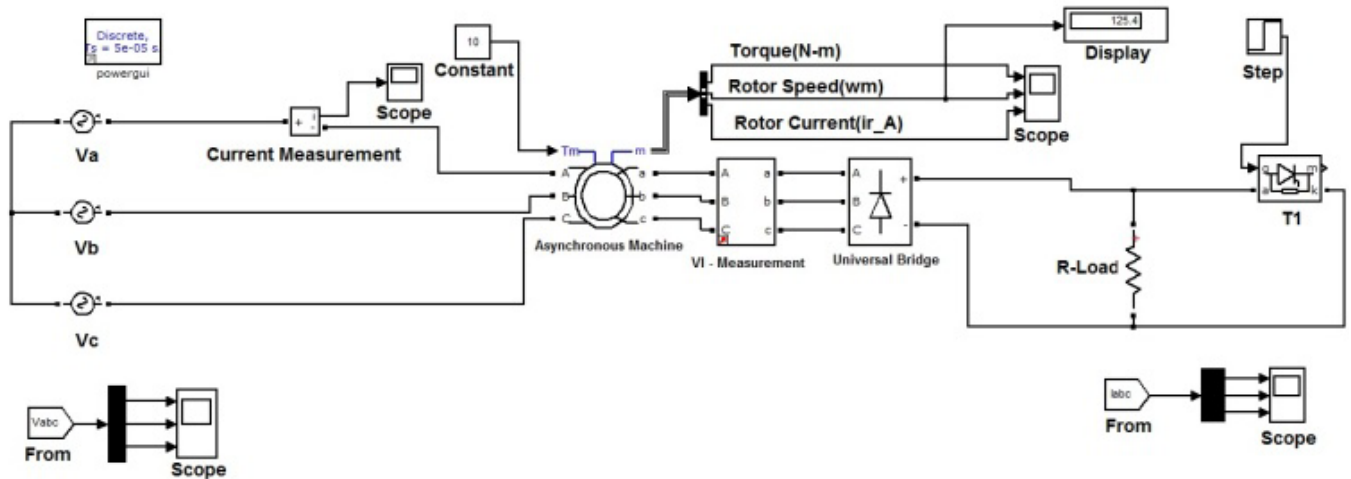established in parallel acting as load manipulator

Fig. 1 Experimental setup rotor resistance control using Simulink

Rotor Side Control of SRIM using Single Thyristor

Fig. 2 Control (single thyristor control) using Simulink

III. ROTOR RESISTANCE METHOD

In the following method, a resistor bank is attached to the rotor side of wound rotor machine along with breaker. The breaker helps in changing resistances in different intervals of time. The variation in speed is hence observed with change in resistance at different intervals of time. The Simulink diagram for the following method is shown in Fig. 3 [2].

The asynchronous machine block can be modeled according to the parameters as tabulated in Table II.

IV. SLIP POWER RECOVERY SCHEME

The most common example of slip power recovery scheme is Scherbius drive system. It provides control of slip ring induction motor below synchronous speed [2]. Here, the rotor AC power is converted using diode rectifier to DC. Further, it is converted back to AC and feedback to source of power supply using controlled rectifier [2]. The power supply can be controlled by varying inverter counter EMF, (V2) which is controlled by controlling firing angle [2]. To reduce ripple in DC link current (Id), DC link inductor is provided. The schematic of slip power recovery scheme is shown in Fig. 3 [2].

TABLE II
PARAMETER SPECIFICATIONS

PARAMETER	VALUES
Nominal Power(L-L), Voltage and Frequency	2250*746VA, 6300, 50
Stator(R_1,L_1)	0.0859Ω, 0.0051228H
Rotor(R_2,L_2)	0.0826Ω, 0.003714H
Mutual Inductance L_m	0.23984H
Inertia, Friction, and Pair of Poles	50kgm^2, 0 Nms, 4

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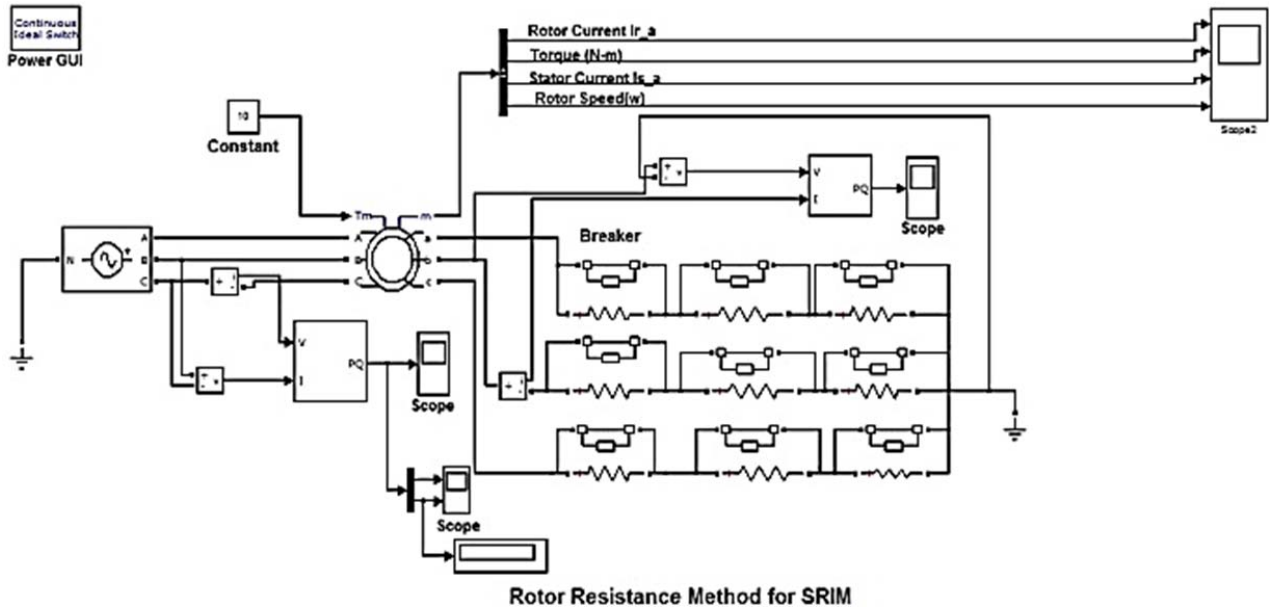Vol:11, No:7, 2017

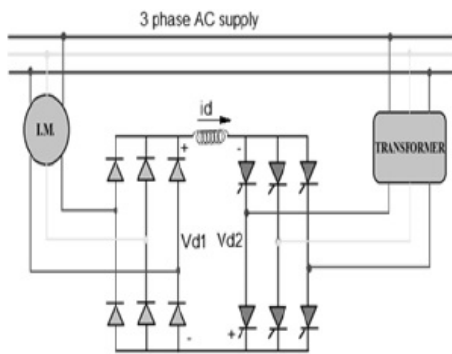Fig. 3 Experimental setup for rotor resistance method

Fig. 4 Schematic diagram of slip-power recovery scheme

Neglecting stator and rotor resistance voltage drops we have [5],

$$V_1 = \frac{3*\sqrt{6}}{\pi} * \frac{sV}{n} \qquad (1)$$

and

$$V_2 = \frac{3*\sqrt{6}}{\pi} * \frac{V}{m} \cos \alpha \qquad (2)$$

$$m = \frac{V_2}{V_1 + V_2} \qquad (3)$$

where, V_1 = stator voltage, V_2 = rotor voltage where α is the firing angle of the inverter, n and m are respectively the stator to rotor turns ratio of motor and source side to converter side ratio of the transformer. The drop across the inverter is neglected.

$$V_1 + V_2 = 0 \qquad (4)$$

$$s = -\frac{n}{m} \cos \alpha = -\alpha \cos \alpha \qquad (5)$$

Maximum value of α is restricted to 150 for safe commutation [2].

To match the voltages V_1 and V_2, transformer is used. At lowest speed required from the drive, V_1 will have the maximum value V_{1m} given by

$$V_{1m} = nVs_{max} \qquad (6)$$

where s_{max} is the value of slip at lowest speed if α is restricted to 150, m is chosen such that the inverter voltage has a value V_{1m}, when α is 150 [8].

$$mV \cos 150 + nVs_{max} \qquad (7)$$

$$m = -\frac{ns_{max}}{\cos 150} \qquad (8)$$

If rotor copper loss is neglected

$$sP_g = |V_2| * I_d \qquad (9)$$

A. Slip Power Recovery Scheme Using SIMULINK

The Simulink diagram for the implementation of slip power recovery scheme is shown in Fig. 5 [2].

The asynchronous machine block is modeled according to the parameters as shown in Table II [2]. The transformer in the Simulink diagram shown in Fig. 5 is modeled according to the parameters shown in Table III [2].

TABLE III
PARAMETER SPECIFICATIONS

PARAMETER	VALUES
Nominal Power	0.055 MVA
Frequency	50 Hz
V1 for winding 1	440 V
V2 for winding 2	6300 V
Magnetizing Resistance Rm	1 Ω
Magnetizing Inductance Lm	1 H

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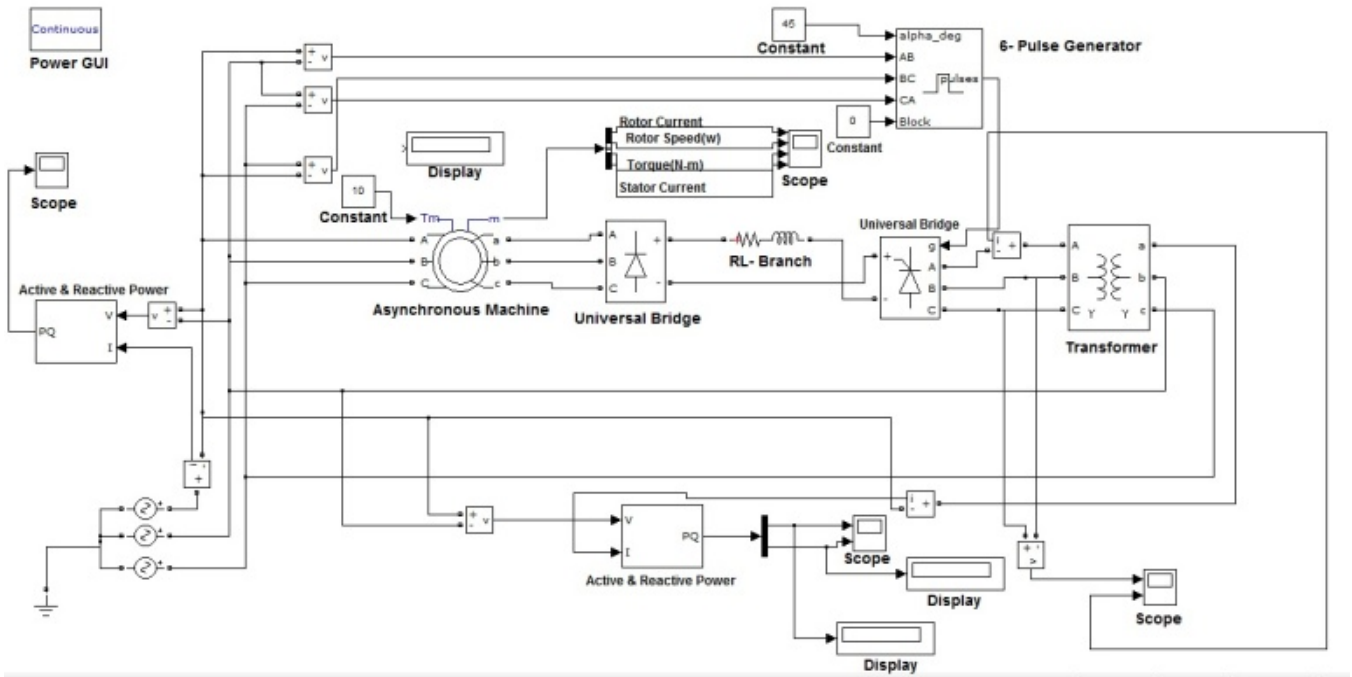The slip power in the Simulink is feedback to the supply [4].

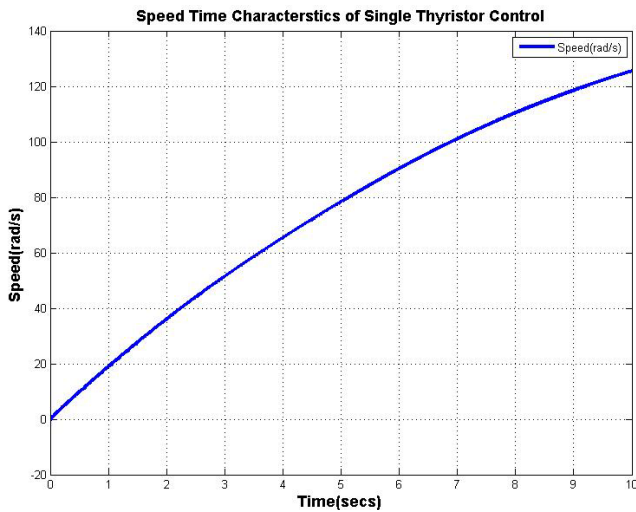Fig. 5 Slip power recovery scheme using Simulink

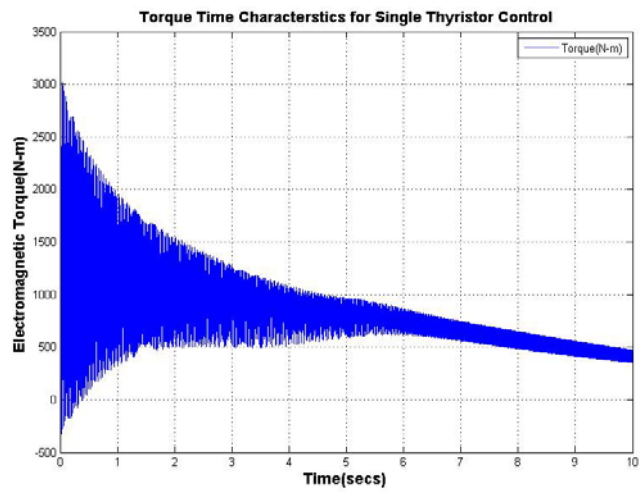Fig. 6 Speed-time characteristics of single thyristor control

Fig. 7 Torque-time characteristics for single thyristor control

V. RESULTS AND CONCLUSIONS

After successful implementation of rotor resistance method using SIMULINK diagram as shown in Fig. 2, the following characteristics are yielded as shown in Figs. 6, 7, and 8, respectively [3].

With the change in resistance the speed variation can be observed as in Fig. 9.

The Total Harmonic Distortion (THD) of the rotor resistance method using single thyristor control can be analyzed as in Figs. 10-12 for current waveform and voltage waveform in Figs. 13, 14, and 15, respectively.

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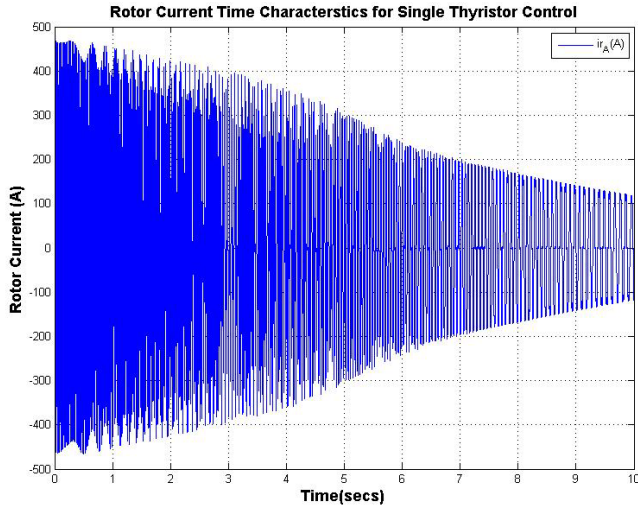Vol:11, No:7, 2017

Fig. 8 Rotor current time characteristics for single thyristor control
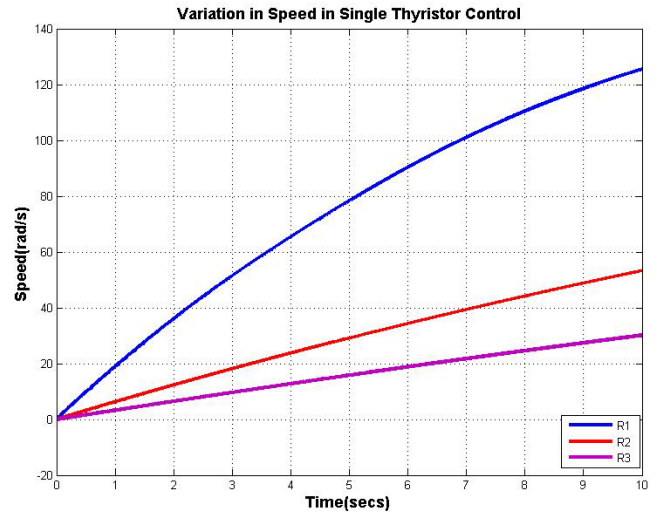
Fig. 9 Variation in speed in single thyristor control

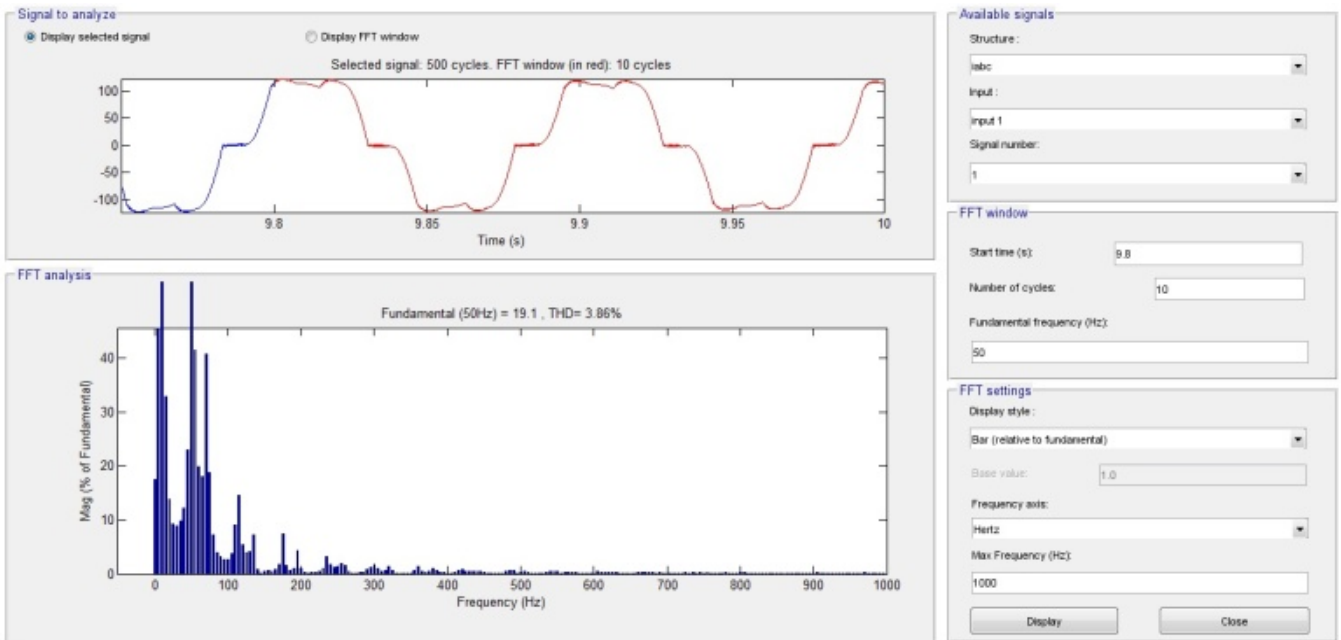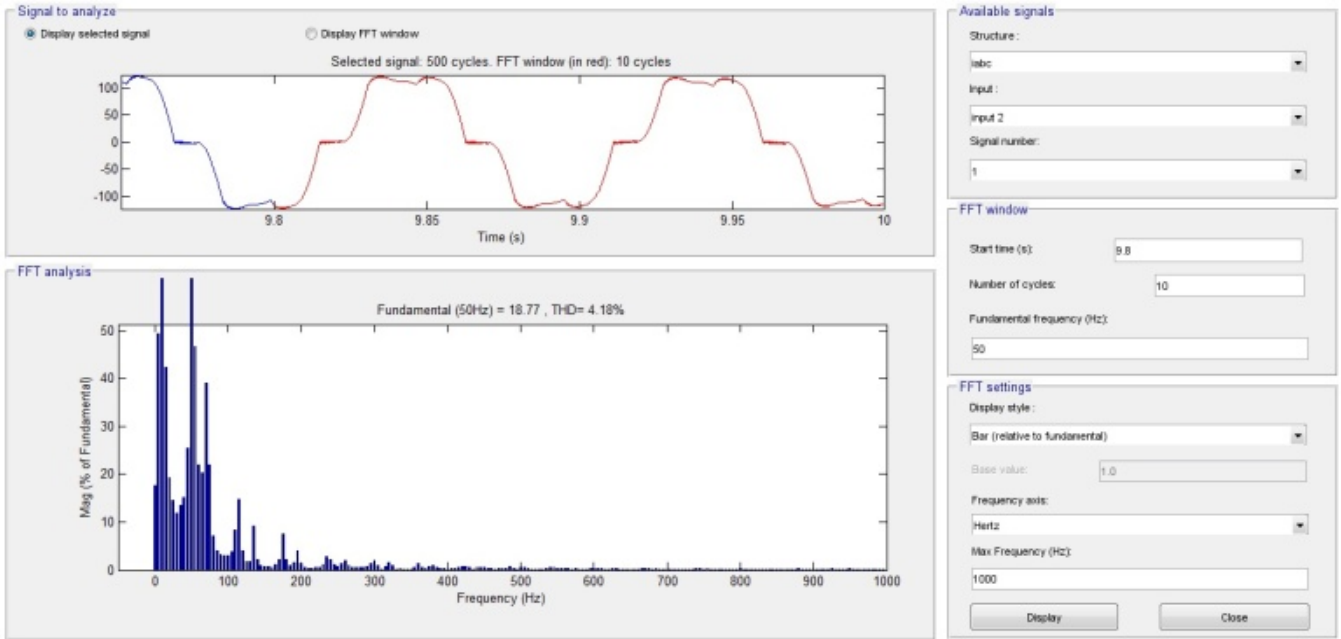Fig. 10 THD analysis for phase (a) of rotor current

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Fig. 11 THD analysis for phase (b) of rotor current
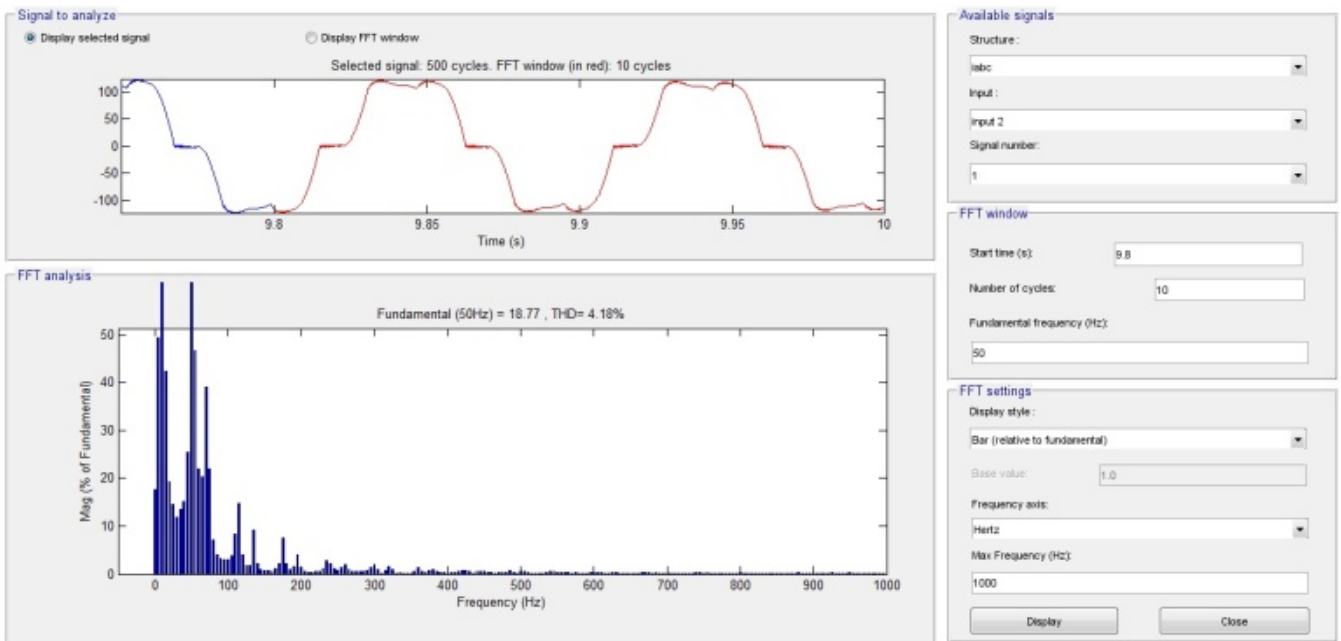
Fig. 12 THD analysis for phase (c) of rotor current

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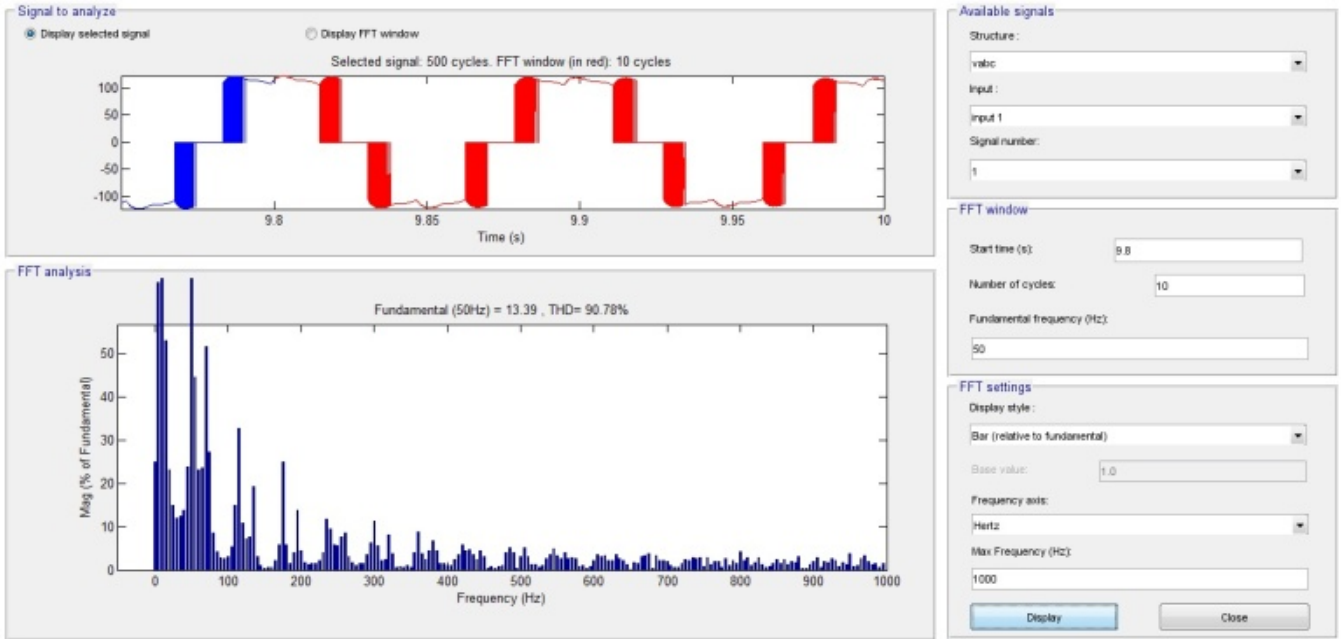
Fig. 13- THD analysis for phase (a) of rotor voltage
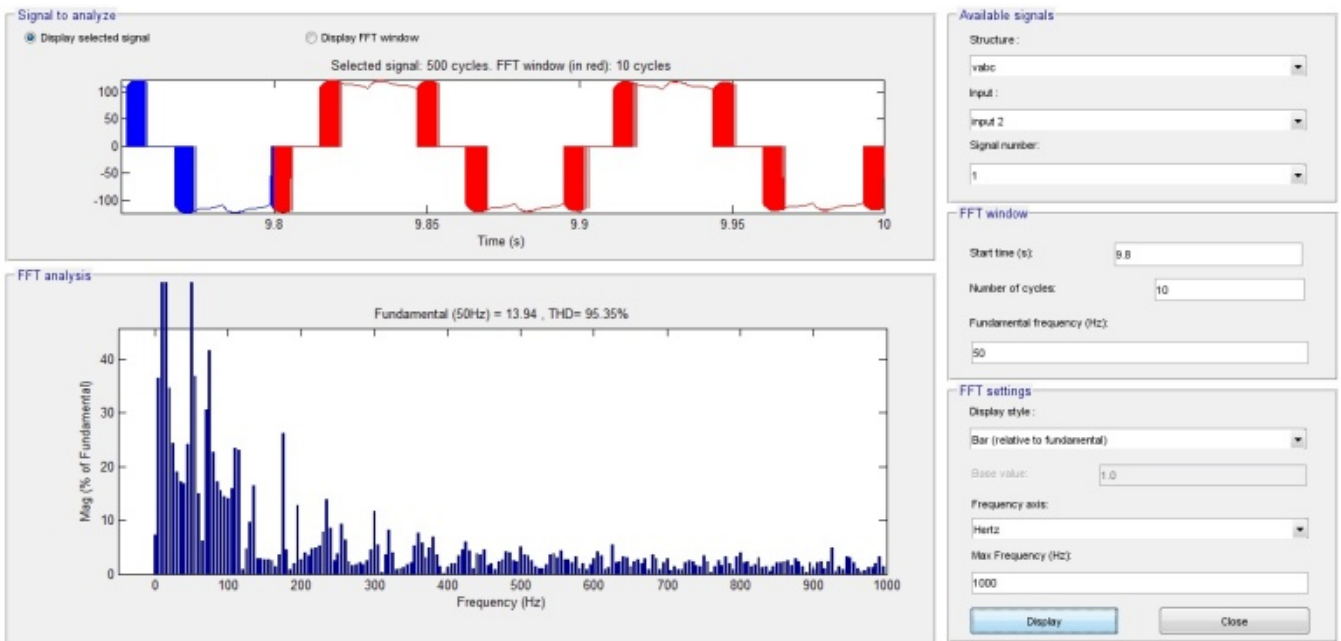
Fig. 14 THD analysis for phase (b) of rotor voltage

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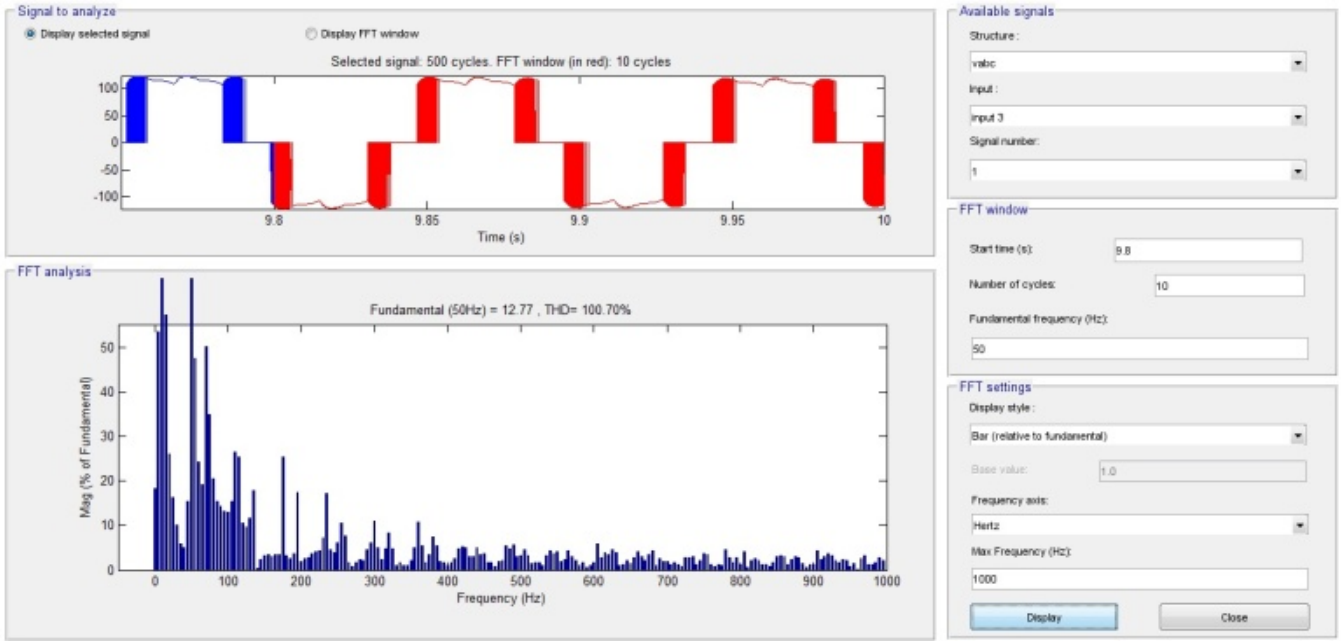International Journal of Mechanical and Mechatronics Engineering
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Fig. 15 THD analysis for phase (c) rotor voltage

The similar characteristics are observed while implementing Simulink diagram of Fig. 3 as shown in Figs. 15, 16, and 17, respectively.
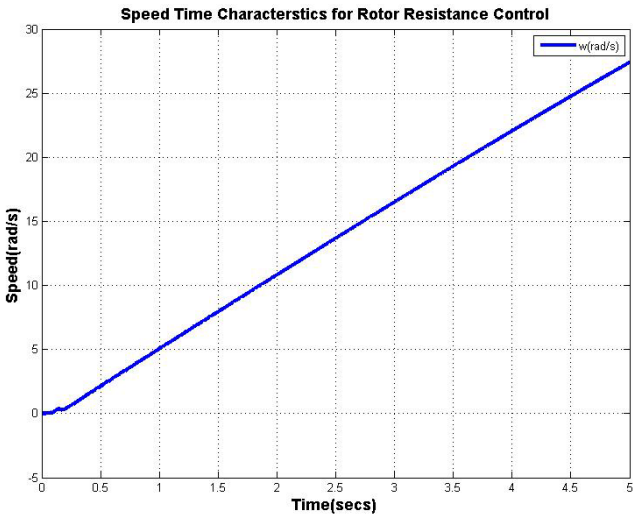

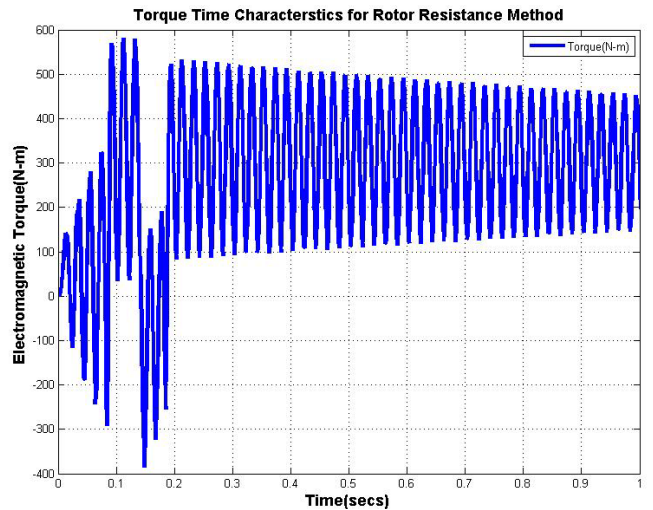Fig. 16 Speed-time characteristics for rotor resistance control

Fig. 17 Torque-time characteristics for rotor resistance method

VI. CONCLUSIONS

The control of speed of wound rotor induction motor can be performed using rotor resistance control. Increase in rotor resistance causes decrease in current, hence increase in speed. Due to the use of power electronics, switches in rotor resistance method using single thyristor control THD in current and voltage waveform at the rotor side of IM can be observed. From the method of rotor side control using resistance, we can control the speed of the rotor, but due to this method, losses of the system will increase due to resistance losses.
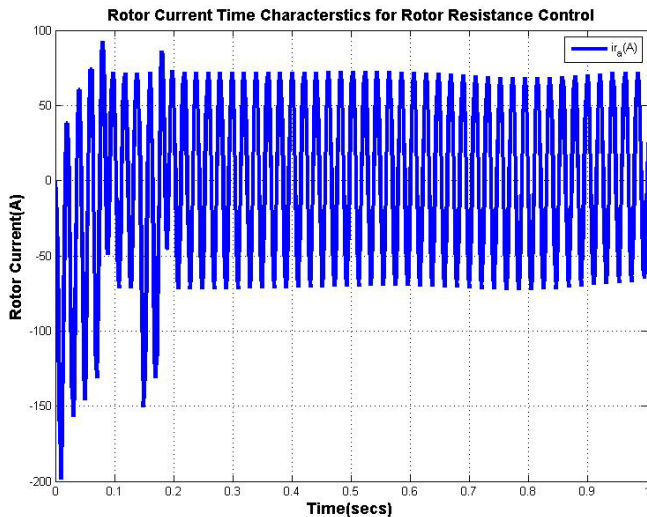
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Fig. 18 Rotor current-time characteristics for rotor resistance control

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Rajesh Kumar born in Kural, Bhiwani, Haryana, India on 10th March 1992. He is currently pursuing Masters in Technology on Electrical Engineering, MaharishiMarkandeshwar University, Mullana, Haryana, India He completed his B.Tech on 2014 from National Institute of Technology Goa, Ponda, Goa, India.

He did training on "Embedded Systems" from International Institute of Information Technology, Pune. Mr. Kumar was a student Member of IEEE.Mr. Kumar was Editor-In-Chief of The Electrical Student Luminous Association (TESLA), National Institute of Technology Goa. He was Campus Ambassador of Innovians Technology Greater Noida and organized National Level Workshop on "Industrial Automation". His areas of interest include Control System, Power systems, Renewable energy, Power Electronics and Drives.

Roopali Dogra born in Jammu, India on 6th May 1988. She completed her Bachelor of Technology and Masters (M.Tech) in the years 2013 and 2015 respectively. Her area of interests includes Machines, Control System and Power Systems.

PuneetAggrawalborn in Ambala Cantt., Haryana, India on 24th November 1981. He is currently working as an A.P. in Electrical Department, Maharishi Markandeshwar Engineering College, Mullana, India. He completed his Bachelor of Technology and Masters (M.Tech) in the years 2003 and 2010 respectively. Hisarea of interest includes Power Electronics and Drives, Networks, Operation Research, and Application to Power Electronics and Power Systems.