

# Integration of Virtual Learning of Induction Machines for Undergraduates

Rajesh Kumar, Puneet Aggarwal

**Abstract**—In context of understanding problems faced by undergraduate students while carrying out laboratory experiments dealing with high voltages, it was found that most of the students are hesitant to work directly on machine. The reason is that error in the circuitry might lead to deterioration of machine and laboratory instruments. So, it has become inevitable to include modern pedagogic techniques for undergraduate students, which would help them to first carry out experiment in virtual system and then to work on live circuit. Further advantages include that students can try out their intuitive ideas and perform in virtual environment, hence leading to new research and innovations. In this paper, virtual environment used is of MATLAB/Simulink for three-phase induction machines. The performance analysis of three-phase induction machine is carried out using virtual environment which includes Direct Current (DC) Test, No-Load Test, and Block Rotor Test along with speed torque characteristics for different rotor resistances and input voltage, respectively. Further, this paper carries out computer aided teaching of basic Voltage Source Inverter (VSI) drive circuitry. Hence, this paper gave undergraduates a clearer view of experiments performed on virtual machine (No-Load test, Block Rotor test and DC test, respectively). After successful implementation of basic tests, VSI circuitry is implemented, and related harmonic distortion (THD) and Fast Fourier Transform (FFT) of current and voltage waveform are studied.

**Keywords**—Block rotor test, DC test, no-load test, virtual environment, VSI.

## I. INTRODUCTION

WITH the advent of modern technology, the use of induction motors has become quite common, and this increase in the application of induction motor may be credited to its rugged construction, reliable use, economic consideration, and low maintenance requirements [4]. Hence, it becomes need of an hour for an electrical engineer to carry out performance analysis of such kind of motors. The performance analyses of induction motors help us to understand torque-speed characteristics, and performing harmonic analysis. The harmonic analysis in turn serves as a tool to reduce noise and vibration losses of an induction motor. This means that selecting a proper topology of switching sequence and filters, harmonics can be mitigated, hence resulting in minimization of losses due to noise and vibration in induction machine. Keeping all these goals in mind, the following paper presents computer aided teaching of three-phase induction machines for undergraduate students

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using MATLAB/Simulink environment. The role of computer aided teaching is very crucial for teaching pedagogy, as it gives engineering students an intuitive insight about what is happening inside a machine [5], e.g. study of speed torque characteristics, calculation of stator and rotor resistance, performing no-load test and block rotor test. Computer aided teaching is a tool of virtual learning on one side and reduces human error and computation on the other side [2]. It may reduce the chances of system damage due to change in system dynamics. Virtual environment easily detects system dynamics and produces an error. Hence, a necessary check is provided before implementing on real time system [6].

## II. STATOR AND ROTOR RESISTANCE

The aid of circulating a suitable current and measuring the voltage drop across terminals resistance of all available circuits is examined. The test, if taken with motor cold (at room temperature), provides a check for calculated values or basis of estimation of efficiency. By feeding the stator and rotor windings successively under DC voltage [7], the voltammetric method of resistance calculations until the nominal intensity gave the following average values.  $R_1 = 4.3 \Omega$  and  $R_2 = 1.33 \Omega$ , respectively.

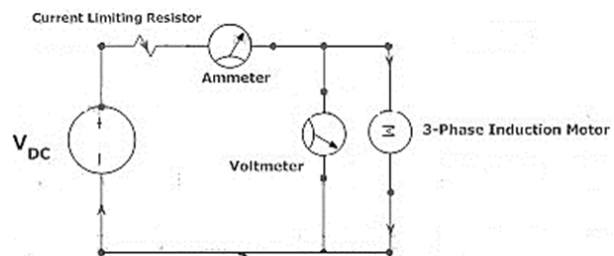


Fig. 1 Experimental setup for DC test

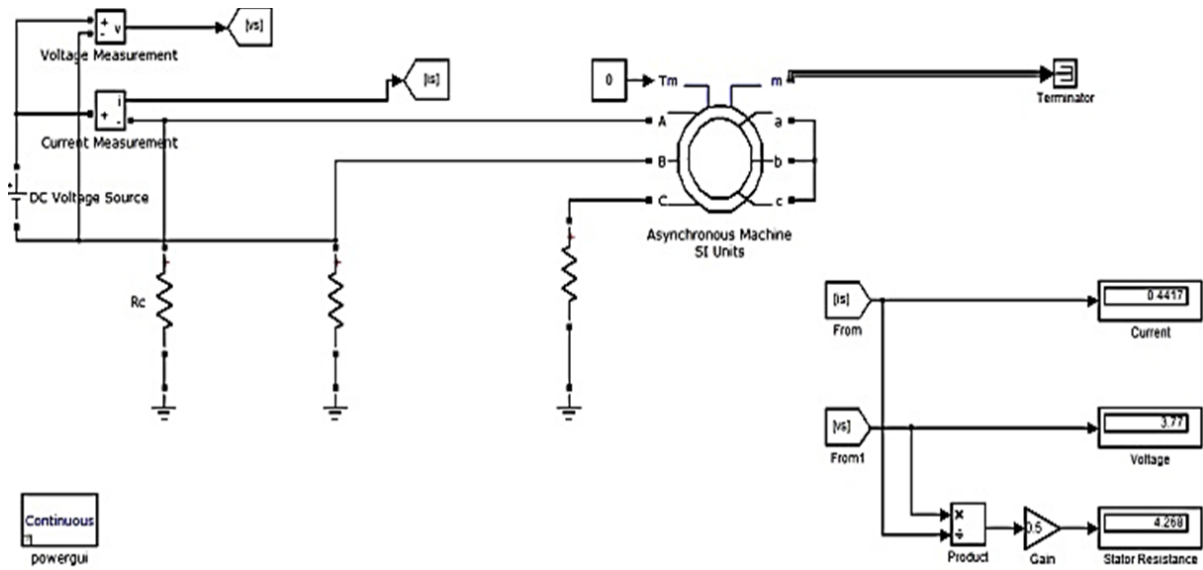
### A. Stator Resistance Using Simulink

Implementing the DC test for calculation of stator resistance can be done as shown in Fig. 2 [1]. The asynchronous motor block in Simulink diagram as shown in Fig. 2 can be modeled according to the values as shown in Table I.

Instead of voltmeter and ammeter shown in Fig. 1, current and voltage measurement blocks are used in the Simulink diagram shown in Fig. 2.

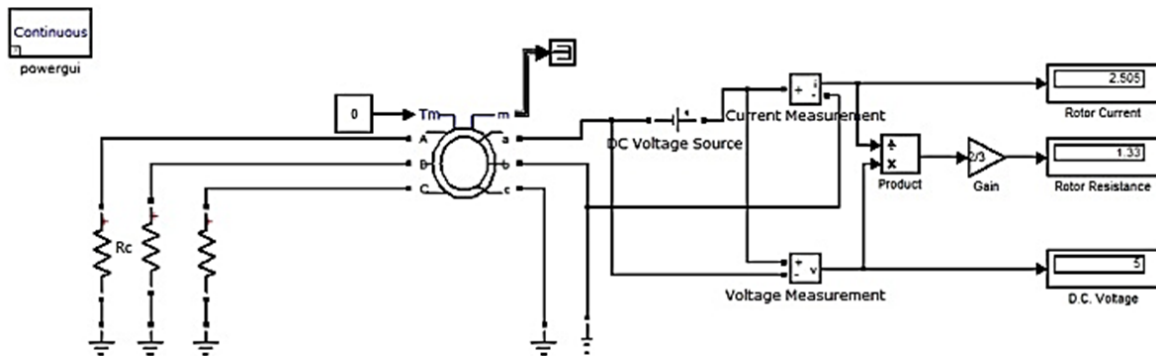
### B. Rotor Resistance Using SIMULINK

Using the parameters as shown in Table I, three-phase induction motor is modeled and following Simulink diagram is used for calculating rotor resistance of three phase induction motor.



**MEASUREMENT OF STATOR RESISTANCE USING DC-AMMETER METHOD**

Fig. 1 Stator resistance calculation using Simulink



**ROTOR RESISTANCE MEASUREMENT USING DC - AMMETER METHOD**

Fig. 2 Rotor resistance calculation using Simulink

TABLE I  
PARAMETER SPECIFICATIONS

PARAMETER	VALUES
Nominal Power(L-L), Voltage and Frequency	2588.2 VA, 415 V, 50 Hz
Stator( $R_1, L_1$ )	4.3 $\Omega$ , 0.028 H
Rotor( $R_2, L_2$ )	1.33 $\Omega$ , 0.072 H
Core Resistance $R_c$	562.98 $\Omega$
Mutual Inductance $L_m$	0.225 H
Inertia, Friction, and Pair of Poles	0.03124 $\text{kgm}^2$ , 0.00358 Nms, 4

III. NO-LOAD AND BLOCK ROTOR TEST

No-Load test is one of the most informative tests which give the core and pulsation losses, friction and windage loss,

magnetizing current, and no-load power factor. Any mechanical unbalance, noise, faulty connection etc. are revealed. The stator connection is made to supply normal frequency and variable voltage; instruments are included to measure the voltage, input power, and current. After the start, the motor is run in normal running condition, i.e. short circuited, with brush gear raised in case of slipping motors with this equipment. When the motor has run long enough for its bearing to show distress if faulty, applied voltage is raised to about 20% over normal voltage, input power and current are observed. The readings are lower values of voltage down to that at which the current starts again to rise [7].

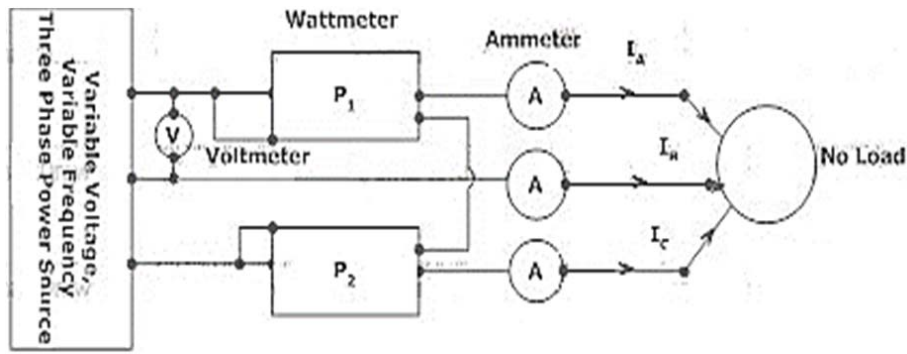


Fig. 3 Experimental setup for no-load test

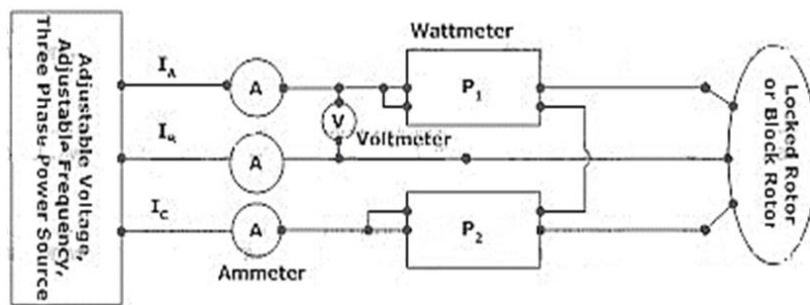


Fig. 4 Experimental setup for block rotor test

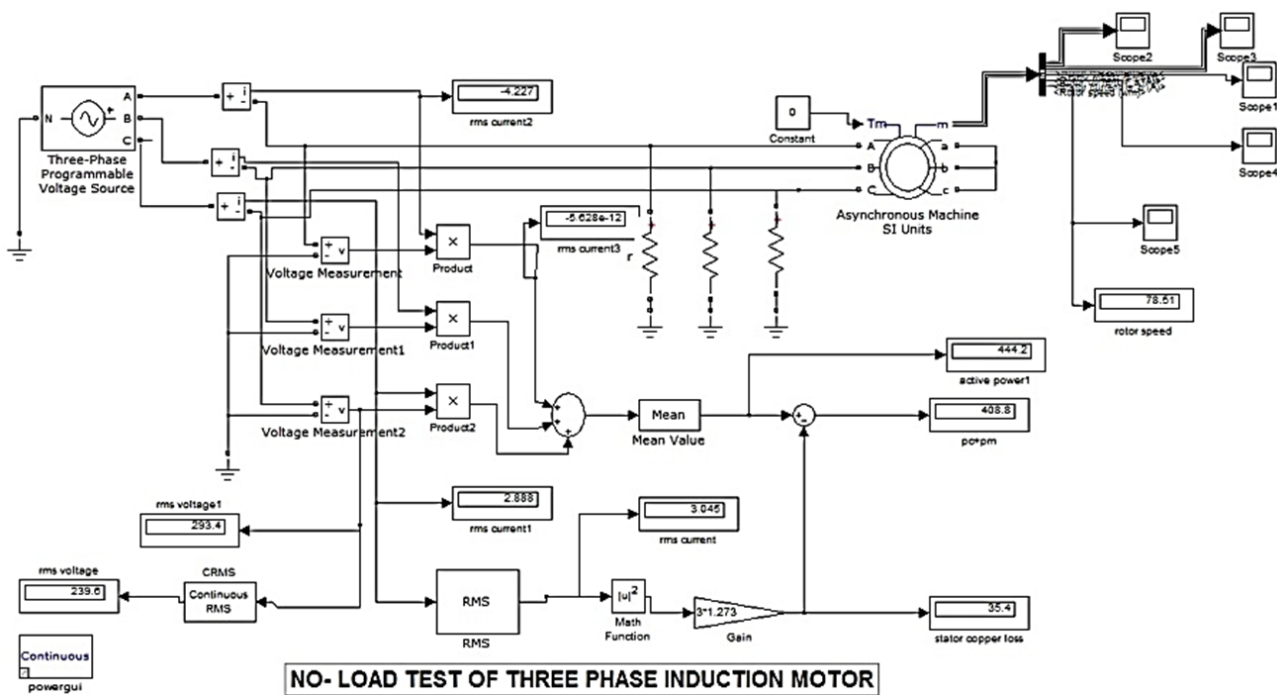


Fig. 5 No-load test using Simulink

Block Rotor test is analogous to short-circuit of a transformer. The rotor is held stationary and short circuited under its normal running conditions. The test consequently reveals no mechanical defects, but is of importance furnishing short circuit current and power factor, enables the current

diagram to be drawn.  $I^2R$  losses measured by the test are necessary for estimation of efficiency by loss summation. The stator is supplied with low voltage of normal frequency, to avoid excessive currents. The position at which the rotor is clamped may affect the current. If so, variations are noted

when the rotor is locked at various positions, and mean position is found. Alternatively, rotor may be allowed to rotate very slowly during the progress of test. The voltage is raised in steps with reading of current and power input, until the current reaches twice the normal. The readings are taken quickly to avoid overheating [7].

#### A. No- Load Test Using Simulink

For performing No-Load test using Simulink environment, authors have modeled asynchronous machine in SI units according to parameter values mentioned in Table I. The No-

Load test is performed using Simulink diagram as shown in Fig. 6 [2].

#### B. Block Rotor Test Using Simulink

The Block Rotor test using Simulink can be performed by modeling the asynchronous machine in SI units using the tabulation of Table I. The Block Rotor test of three-phase induction motor is carried out by making moment of inertia of rotor to infinity, i.e. by modifying the inertia and friction factor to 10,000 kgm<sup>2</sup> and 10,000 N-ms, respectively and using the following simulation diagram as shown in Fig. 7 [2].

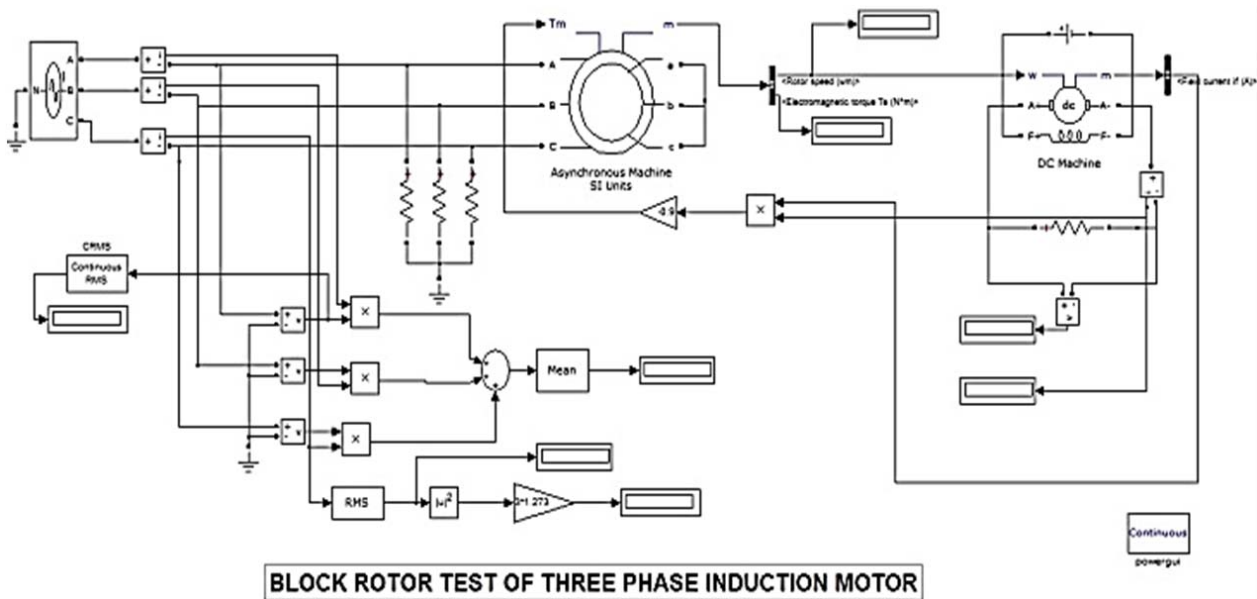


Fig. 6 Block rotor test using Simulink

In the Simulink diagram shown in Figs. 6 and 7 respectively, three-phase programmable source is fed with values of 415 V and 50 Hz, respectively. The motors are driving DC generators debiting on resistive load of 10  $\Omega$ . The DC generators shown in Fig. 7 are separately excited; along with armature and field circuit respectively represented by A+, A- and F+, F- and having an inductor and resistor in series having electromagnetic force [2].

#### IV. VSI CONTROLLED INDUCTION MOTOR DRIVE

In AC grid connected drives, a common diode bridge rectifier which would provide a pulsed DC voltage from the mains is required. Here, the basic circuit might look simple but problem of concern here is switching these devices accurately. PWM inverters make it possible to control both frequency and magnitude of voltage and current applied to a motor. These inverter-powered motor drives are more variable and offer in a wide range better efficiency and higher performance as compared to fixed frequency motor drives [8]. PWM inverter delivers energy to the AC motors and is controlled by applying PWM signals to the gates of power MOSFET switches at different times to produce desired output. Depending on the type of load and type of speed,

different methods are adopted for speed control of motors. To perform stepless control for above and below the rated speed with high torque and for eliminating harmonics, the most suitable control is PWM inverter fed induction motor control [8]. The block diagram of VSI fed Induction Motor is shown in Fig. 8 [3].

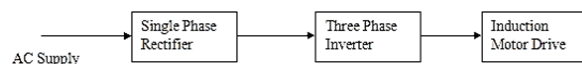
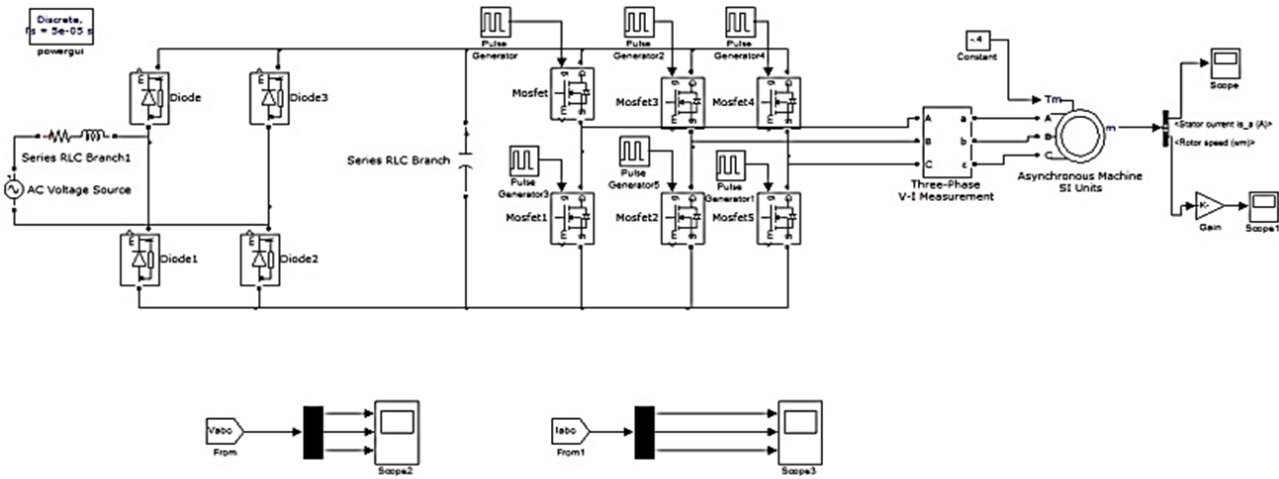


Fig. 7 Block diagram using Simulink

#### A. VSI Fed Induction Motor Using Simulink

The PWM inverter has to generate a nearly sinusoidal current, which can control the voltage and current with 120-degree phase difference in each phase. The circuit of six-switch three-phase inverter is shown in Fig. 9. In three-phase voltage source fed inverter drive system, an uncontrolled diode bridge rectifier is used to convert AC into DC. PWM inverter is used to convert DC into variable voltage variable frequency AC. And this is supplied to the motor gate pulses for three-phase inverter as shown in Fig. 10 [3].



**SPEED CONTROL OF THREE PHASE SLIP RING INDUCTION MOTOR**

Fig. 8 VSI fed induction motor drive

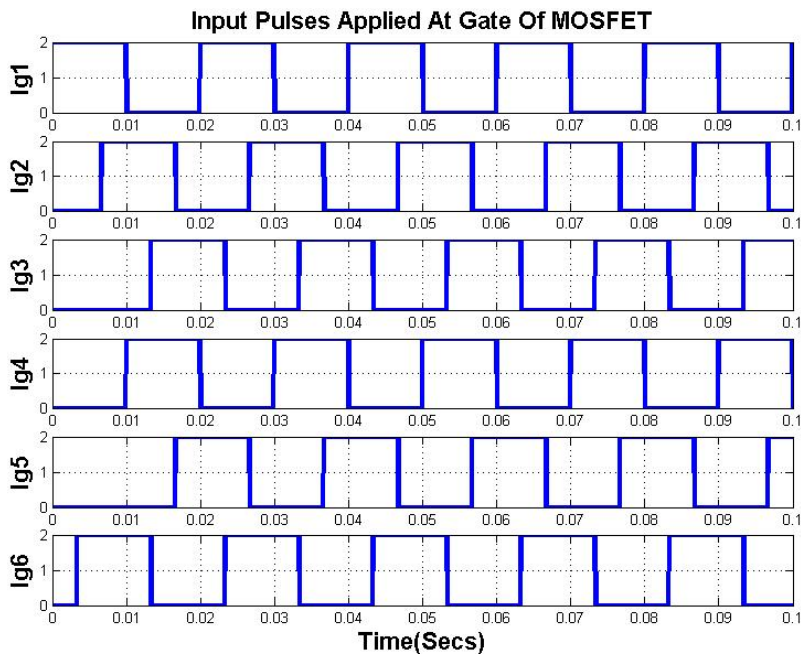


Fig. 9 Input pulses applied at gate

**V. RESULTS AND CONCLUSIONS**

**A. DC Test and No-Load Test**

After successful implementation of DC test using Simulink for calculation of stator and rotor resistances respectively, the following results are yielded: Stator Resistance ( $R_1$ ) = 1.33  $\Omega$  and Rotor Resistance ( $R_2$ ) = 4.26  $\Omega$ . Further, No-Load test was carried by varying the input voltage and then tabulating corresponding obtained parameters as shown in Table II.

The value of  $P_{core}$  is calculated by subtracting  $P_{mec}$  from  $P_{core} + P_{mec}$ ,  $P_{mec}$  can be obtained by using MATLAB commands Polyfit, Linspace, and Polyval. These commands are used to obtain the best line passing through maximum

number of points. The intersection of these curves with y-axis gives mechanical loss which is equal to 10.22 W [2]. This is shown in Fig. 11. For different values of voltage, variation of torque with respect to slip speed is observed as shown in Fig. 12.

TABLE II  
RESULTS OF VIRTUAL NO-LOAD TEST

$U_o(V)$	$I_o(A)$	$P_o(W)$	$P_{SLC}(W)$	$P_{core}+P_{mec}(W)$	$P_{core}(W)$
415	3.045	444.2	35.4	408.8	398.57
380	2.577	377.2	25.36	351.9	341.67
300	2.214	242.3	18.73	223.6	213.37
280	1.986	211.4	15.06	196.3	186.07
260	1.899	175.5	13.77	161.7	151.47

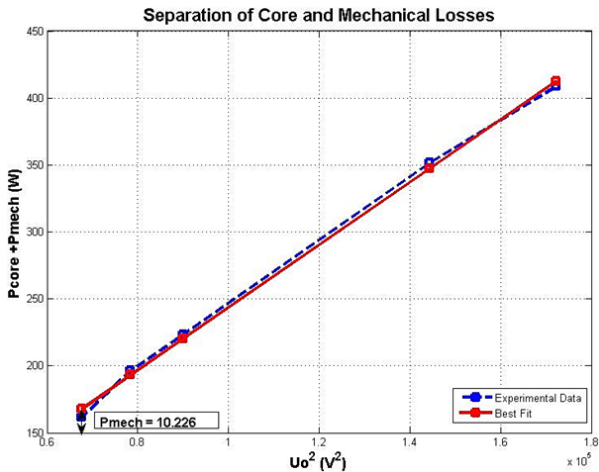


Fig. 10 Separation of core and mechanical loss

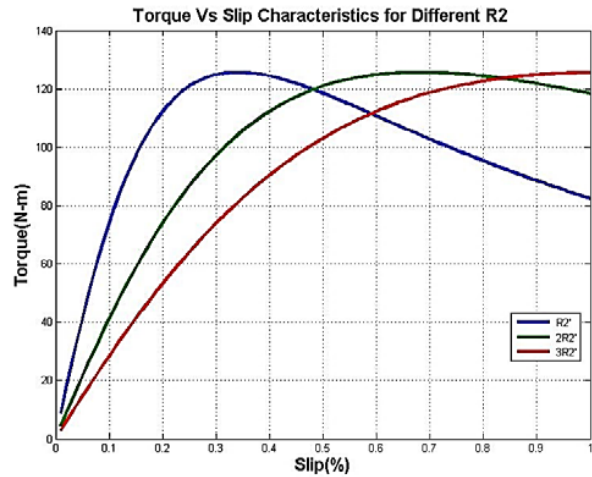


Fig. 12 Torque speed curves for different resistance

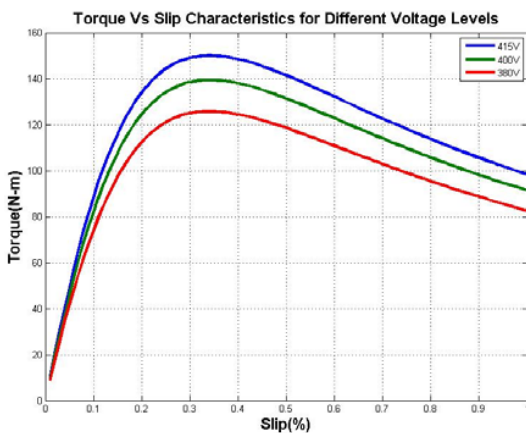


Fig. 11 Torque vs slip for different voltages

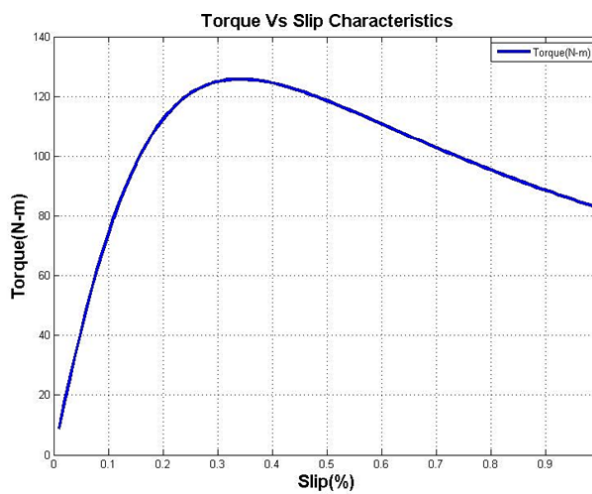


Fig. 13 Torque slip for operational voltage

As it can be observed from Fig. 12 torque is directly proportional to the voltage level, as the voltage levels fall down maximum torque also falls down. It can also be observed that, for certain increase in slip speed, the torque increases and then gradually starts decreasing, this is inevitable as slip operation of motoring, braking, and regeneration follows.

Now the variations of torque slip characteristics for different rotor resistances can be observed in Fig. 13. The torque speed characteristics for operational voltage and resistance can be shown in Fig. 14.

### B. VSI Fed Induction Motor Drive

After implementing the simulation of VSI fed induction motor drives, the following results are obtained. The phase current waveforms are shown in Fig. 15.

The output phase voltages so obtained are shown in Fig. 16.

The THD analysis of VSI fed induction motor drive was done for voltage and current waveforms respectively which are shown in Fig. 17 and Fig. 18, respectively.

From Figs. 17 and 18, it can be observed that THD for phase voltage was found to be about 34.38%, and that phase current was found to be about 8.75%.

### C. Conclusions

The simulation shown here is an attempt to make teaching more interactive by making students to learn virtual environment of machines and implementing them. The further advantages are virtual environment which serves as a best tool for students who are hesitant to work directly on machine, so simulation tool will provide a check for students whether their design is proper and they can proceed to carry out respective tests. As in electrical engineering we deal with high voltages a minor error in the live circuit may lead to chaos. Hence causing economical and functional damage. Virtual environment also boost up innovations as here we get an open source to try our institutions with proper logic and hence observe the relation with reality without much of financial stress on an individual. Hence authors here propose to include these simulation tests in to undergraduate courses to boost up their learning practices.

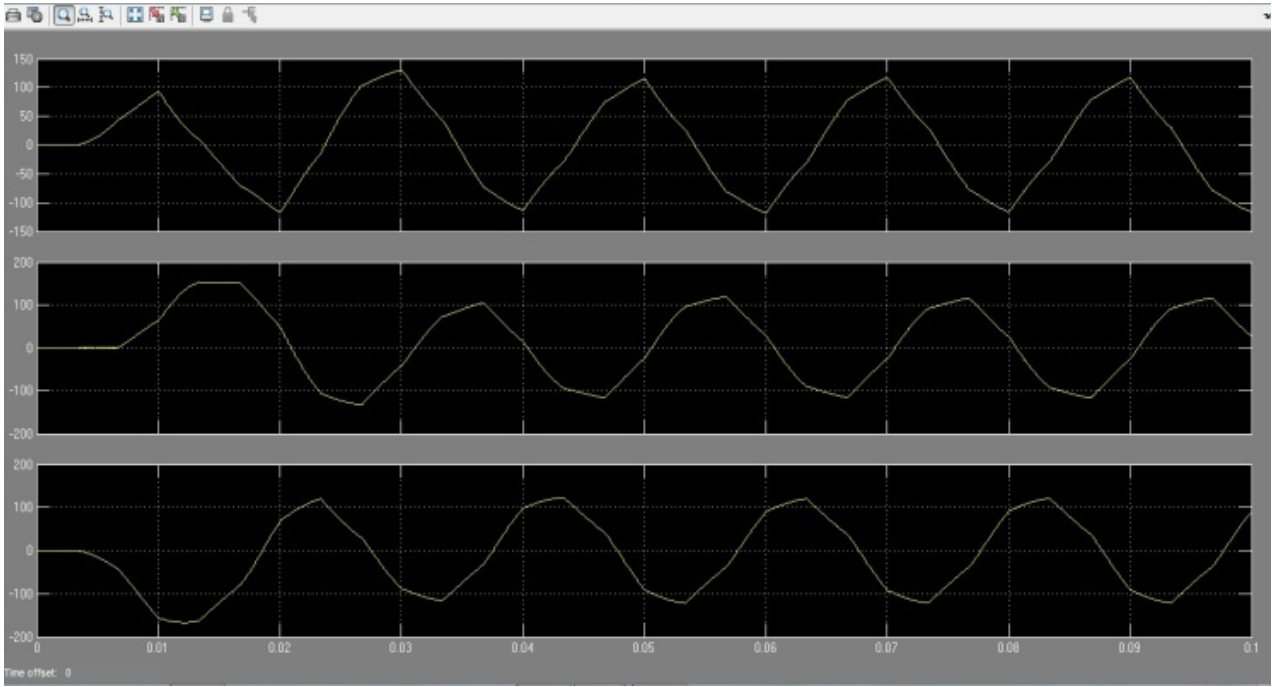


Fig. 14 Phase current waveforms of VSI

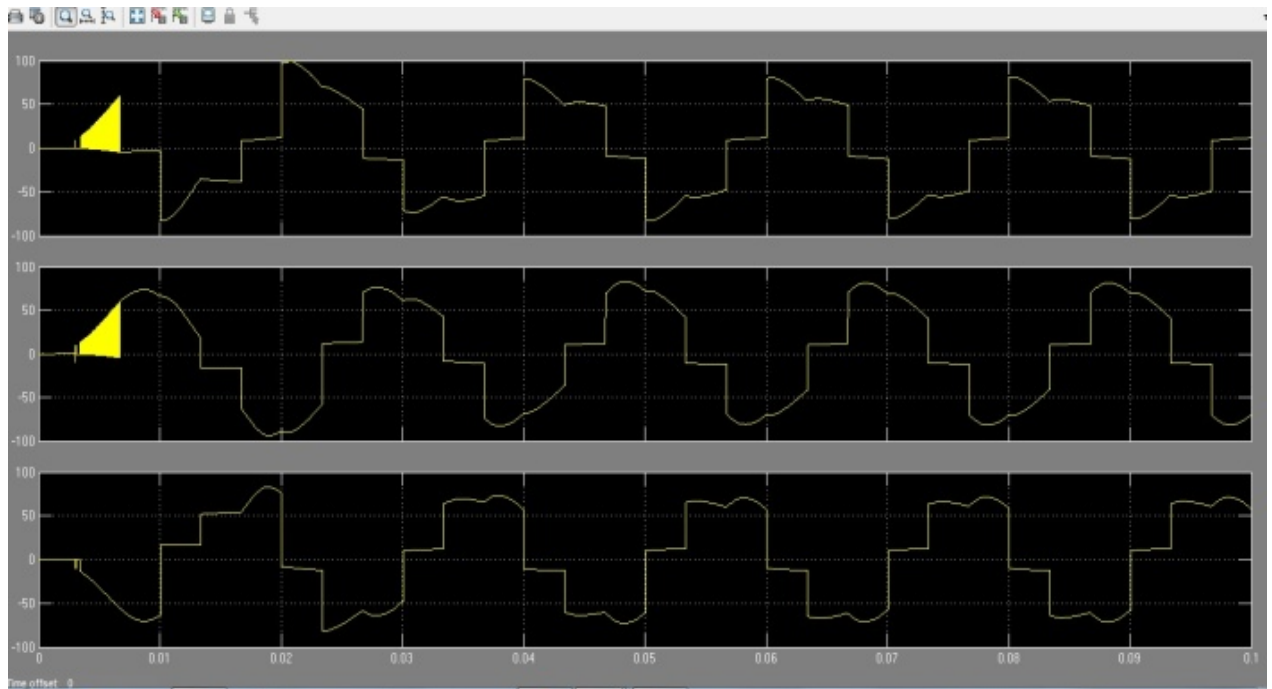


Fig. 15 Output phase voltages of VSI

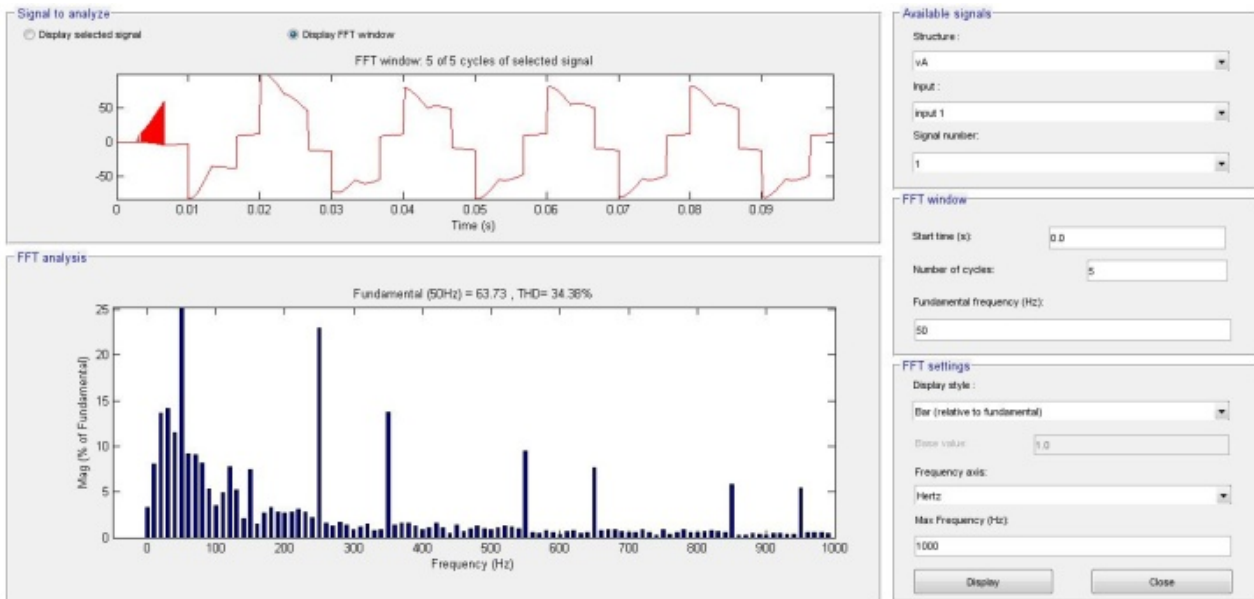


Fig. 16 FFT analysis of phase voltage

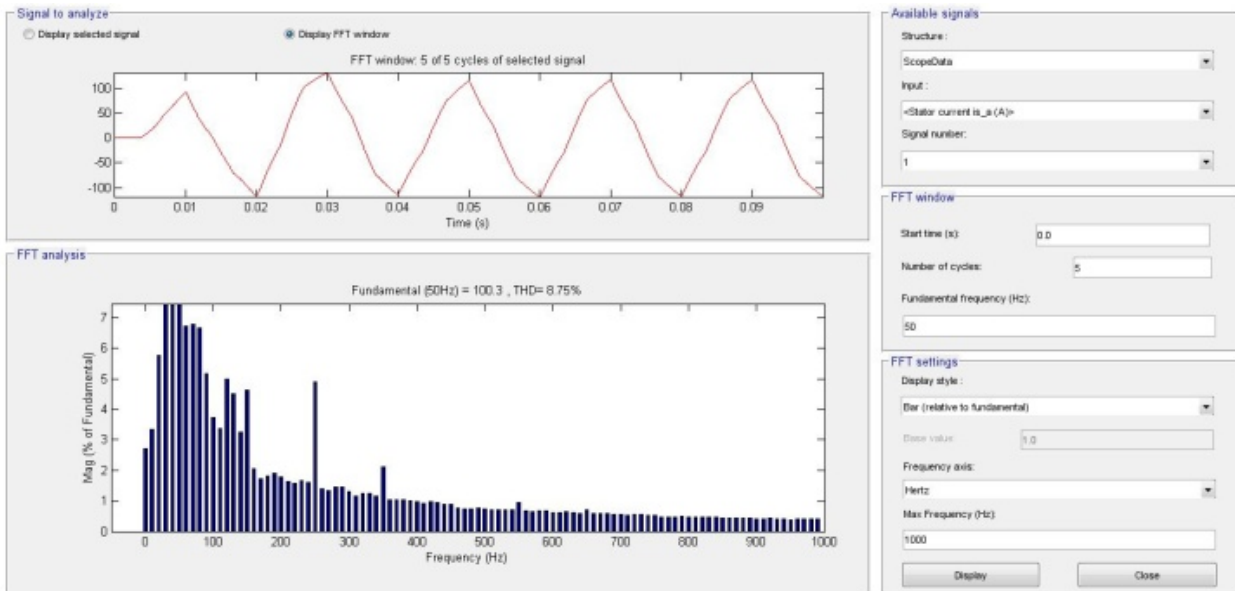


Fig. 17 FFT analysis of phase current

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