

Induction Motor Testing Using MATLAB/Simulink

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Abstract - The proposed paper describes MATLAB/Simulink implementation of three different tests of induction motor, namely dc-test, no-load test, and blocked-rotor tests performed to identify equivalent circuit parameters. An induction motor works on the induction phenomenon. Simulink is utilized to build the model of the test. In order to investigate the proposed testing method, experimental studies are performed & comparative result is shown and the equivalent circuit has been drawn.

Key Words: MATLAB/SIMULINK, Induction Motor, Equivalent circuit parameters, Modelling, Simulation.

1.INTRODUCTION

Computer-aided teaching tools have become an integral element of both classroom lectures and laboratory activities in electrical machinery education with the introduction of low-cost personal computers and numerous easily available software packages. Induction motor computer models and simulations are useful teaching aids because they allow the instructor to quickly illustrate steady-state performance of the motor under varied loading situations using computer-generated graphics[1].

The use of computational tools in laboratory investigations improves the learning experience and allows students to evaluate the findings of laboratory experiments and compare them to those generated through computer simulations[2]. This type of comparison helps students understand the limitations of hardware experiments and, on the other hand, recognize that computer models cannot replace physical hardware experiments, which may or may not accurately reflect the functioning of induction motors due to various modelling assumptions. Furthermore, an undergraduate electric machinery course that incorporates current computer hardware and software tools in both lecture and laboratory sections meets the expectations of today's students who want to use computers and simulation tools in all aspects of a course, potentially attracting more students[3]. Undergraduate electrical machinery courses generally include both classroom and laboratory components. The steady-state

functioning of the induction motor is covered in the classroom part, where the per-phase equivalent circuit is utilised to compute different motor characteristics such as input current and power, power factor, generated torque, and efficiency. Equivalent circuit parameters are required for the computations related with steady-state functioning. In a typical laboratory experiment, these characteristics are acquired by running the motor through three tests: dc, no-load, and blocked-rotor. These tests, and also a load experiment, are included in the laboratory portion, allowing students to obtain significant hardware and measurement experience while learning about induction motor operation. In comparison to previous laboratories they have visited, students are unaccustomed with a laboratory setting that comprises huge machinery and rather sophisticated measuring methods and instruments. The laboratory exercise's time restrictions are likewise a tough adjustment. Students are needed to set up and execute three induction motor experiments, obtain the appropriate measurements, and analyse steady-state performance of the motor under various loading circumstances in a typical two-hour laboratory period. Due to time constraints, students frequently hurry through experiments in order to complete them on time, preventing them from gaining a genuine understanding of motor operation and comprehending what has been gained during laboratory practise.

As a result, simulation tools for induction motor investigations must be created to serve as effective warm-up activities before students enter the laboratory[4] This paper's goal is to offer simulation models of these induction motor tests in order to create a computational laboratory. The dc, no-load, and blocked-rotor simulation models are created using MATLAB/Simulink as stand-alone solutions.

Students' programming abilities increase as a result of this exercise, which will be beneficial in other courses as well. The dc, no-load, and blocked-rotor experiments are described in the entire exercise. To be precise, the experimental setup for each test is presented first, along with a brief description of how these tests are carried out and how the associated measurements are utilised to compute the comparable circuit parameters.[5] The appropriate Simulink model for each test is then shown and compared to the actual experimental setup. In addition, it compares the corresponding circuit parameters calculated from simulation data with data collected from tests.

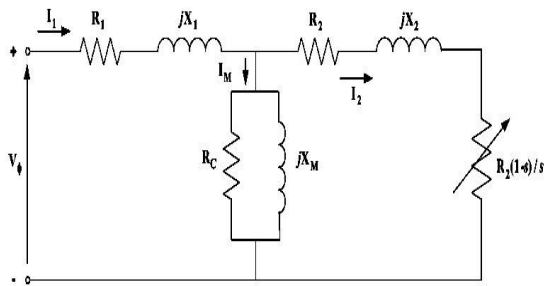


Fig -1: Per-phase equivalent circuit of an induction motor.

2. EXPERIMENTAL SETUPS AND SIMULINK MODELS

The steady-state operating characteristics of a three-phase induction motor are often investigated using a per-phase equivalent circuit as shown in Fig. 1. In this circuit, R_1 & X_1 represent stator resistance and leakage reactance, respectively; R_2 and X_2 denote the rotor resistance and leakage reactance referred to the stator, respectively; R_c resistance stands for core losses; X_m represents magnetizing reactance; and s denotes the slip. The equivalent circuit is used to facilitate the computation of various operating quantities, such as stator current, input power, losses, induced torque, and efficiency. When power aspects of the operation need to be emphasized, the shunt resistance is usually neglected; the core losses can be included in efficiency calculations along with the friction, windage, and stray losses. The parameters of the equivalent circuit can be obtained from the dc, no-load, and blocked-rotor tests. In the following, both experimental setup and Simulink models of each test are described.

2.1 DC Test

The dc test is performed to compute the stator winding resistance. A dc voltage is applied to the stator windings of an induction motor. The resulting current flowing through the stator windings is a dc current; thus, no voltage is induced in the rotor circuit, and the motor reactance is zero. The stator resistance is the only circuit parameter limiting current flow.

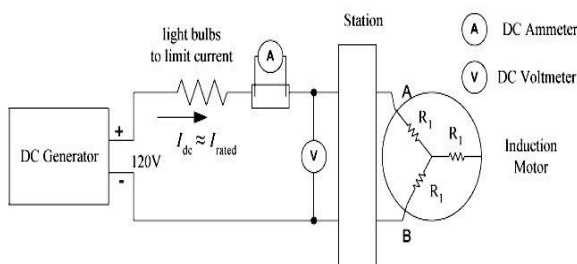


Fig. 2. Experimental setup of the dc test

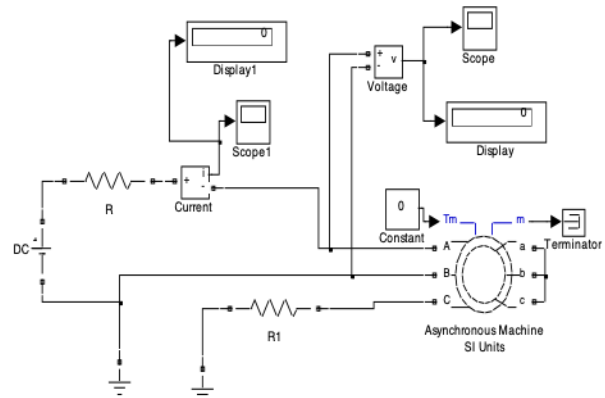


Fig. 3. Simulink implementation of the dc test.

A 120-V dc power source is applied to the two phases of a Y-connected induction motor. A group of light bulbs are installed in the circuit as a resistive load in order to adjust dc current to the rated value. The current in the stator windings and voltage across the two phases of the motor are measured. Fig. 3 depicts the Simulink implementation of the dc test. From the PSB machine library, an induction motor block is used whose electrical parameters (such as nominal voltage and equivalent circuit parameters) and mechanical parameters (such as inertia and number of poles) can be specified in either International System of Units (S.I.) or in per unit. Similar to the experimental setup, a 120-V dc source is applied to the two phases (phases A and B) of the induction motor through a series resistance, while the phase C is grounded through a resistance branch in order to have a complete electrical connection. The purpose of the series resistance between the dc source and the induction motor is to limit the current flowing through the two windings of the motor to its rated value, which is similar to the lighting bulbs used in the hardware setup of Fig. 2. Voltage and current measurement blocks measure the instantaneous voltage across two phases and the current flowing through the windings, respectively. Two scopes display the waveforms of the voltage and current, while two display boxes are used to obtain the steady-state values of the dc voltage, and current. With these two measurements, the stator resistance can easily be computed.

2.2. No-Load Test

The no-load test on an induction motor is conducted to measure the rotational losses of the motor and to determine some of its equivalent circuit parameters. In this test, a rated, balanced ac voltage at a rated frequency is applied to the stator while it is running at no load, and input power, voltage, and phase currents are measured at the no-load condition. Fig. 4 illustrates

the experimental setup of the no-load test conducted at C.C.E&T, BHILAI.

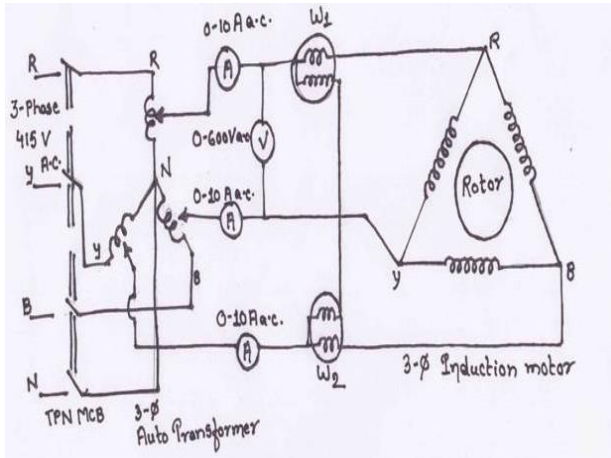


Fig.4: Experimental setup of the no-load test.

The procedure of no load test is given below:-

- Make connection as shown in figure- 4.
- Set the variac to zero and switch on the mains.
- Apply the voltage gradually and start the motor & note the reading in the wattmeter, voltmeter & ammeter.
- Compute the shunt branch parameters R_o & X_m using formula

$$\text{Power factor} = \frac{P_i}{VI_o}$$

$$R_o = \frac{V^2}{P_i}$$

$$X_m = \frac{V}{\sqrt{I_o(1 - pf^2)}}$$

Where, Power factor is the no-load power factor of the motor.

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Model in fig.5 shows the Simulink realization of the no-load test, where a three-phase balanced Y-connected ac source whose per-phase voltage is 240 V/50

Hz is applied to the stator terminal of the induction motor. The electrical inputs of the induction motor block are the three electrical connections of the stator (terminals A-B-C), while the electrical outputs (terminals a-b-c) are the three electrical connections of the rotor, which is short-circuited.

The input block (*terminal Tm*) is the mechanical torque at the machine's shaft. This torque is set to be zero to simulate the no-load condition. The equivalent circuit parameters obtained from experimental data and the numbers of poles are specified using the induction motor-block dialogue box. Three current measurement blocks are used to measure the instantaneous current of each phase. The outputs of the voltage measurement block and the current measurement block of phases are connected to a power measurement block, called the active and reactive power measurement, that computes the active power and reactive power. The output of this block is connected to a scope and to a display block to obtain the waveforms. One can see that there are some differences between the hardware setup and Simulink model. For example, the per-phase-based real and reactive input power is measured in the simulation model, while in the experiment the total three-phase real input power is measured. However, this difference is not significant since under the three-phase balanced operation; computations are usually completed using the per-phase quantities.

Similarly, the per-phase voltage is measured in the simulation, as opposed to the line-to-line voltages measured in the hardware experiment. These measurements enable the approximate computation of the sum of the magnetizing reactance and the stator leakage reactance.

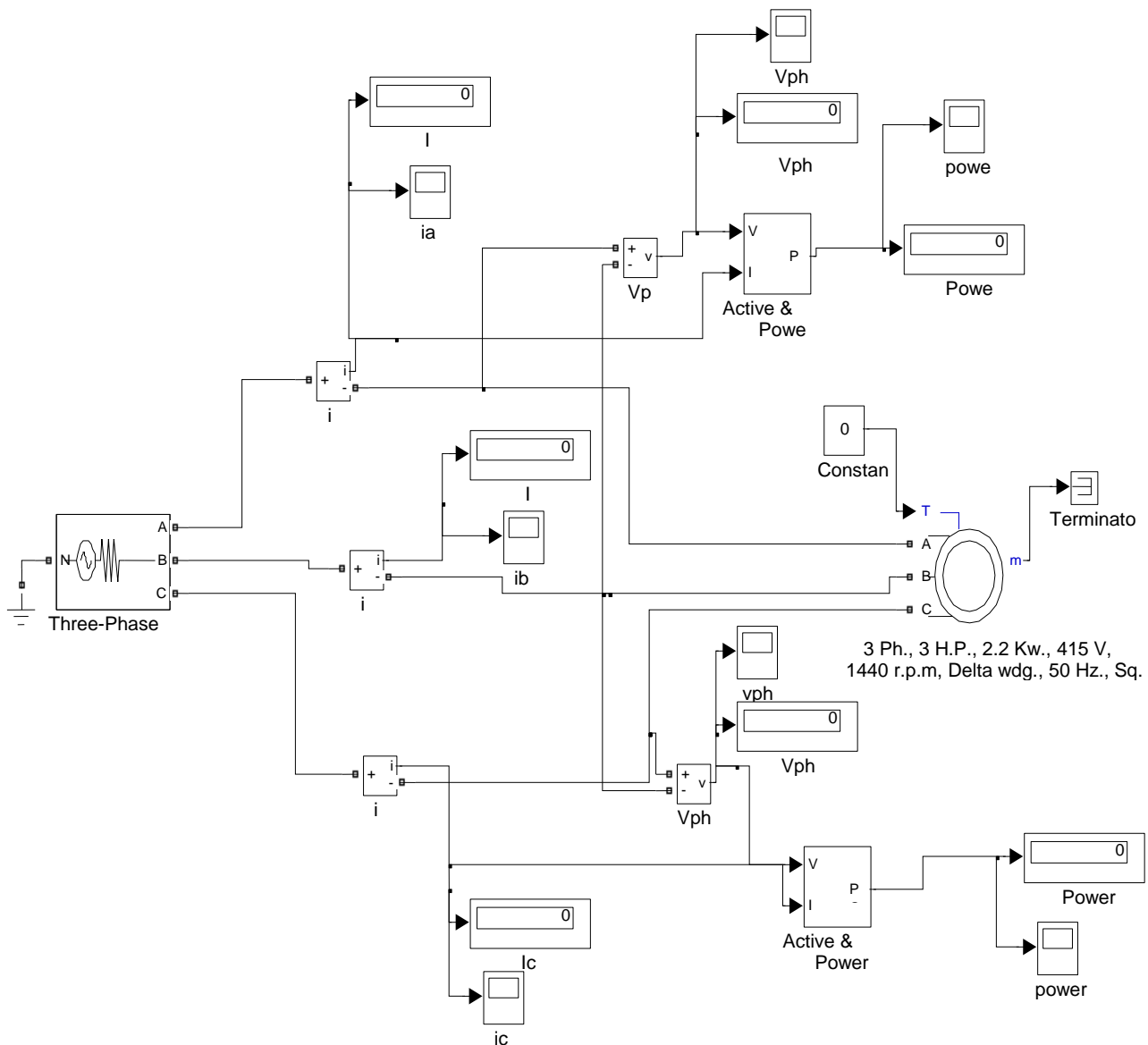


Fig. 5 The Simulink implementation of the no-load test.

2.3 Blocked-Rotor Test

The blocked-rotor test on an induction motor is performed to determine some of its equivalent circuit parameters. In this test, the rotor of the induction motor is blocked, and a reduced voltage is applied to the stator terminals so that the rated current flows through the stator windings. The input power, voltage, and current are measured. For some design-class induction motors, this test is conducted under a test frequency, usually less than the normal operating frequency so as to evaluate the rotor

resistance appropriately. The experimental setup of the blocked-rotor test is not shown here since it is similar to that of the no-load test shown in Fig. 4. The only difference is that a synchronous generator coupled with a dc motor and auto transformer were installed in the circuit in order to perform the blocked-rotor test at various frequencies and to control input voltage to the stator. Fig. 6 shows the Simulink model of the blocked-rotor test. This model is almost the same as that of the no-load test shown in Fig. 5. However, there is a slight difference between the two models. In the blocked-rotor model, the inertia of the induction motor is set to infinity in order to simulate the blocked-rotor condition. Several measurements blocks are used to measure the current,

voltage, and active/reactive powers. The mechanical torque to the rotor is set to an arbitrary nonzero value [in this case, 5 Newton-meter (N-m)], which will not affect the blocked-rotor condition since the inertia is infinite. Because of the infinite inertia, rotor speed remains at zero during the blocked-rotor simulation. Various test frequencies for blocked-rotor simulation can be easily achieved by changing the frequencies of the connected voltage sources rather than using a synchronous

$$Z_{br} = [V_{br}/I_{br}] \Omega/Phase$$

$$X_{br} = (Z_{br}^2 - R_{br}^2) \Omega/Phase$$

$$R_2 = (R_{br} - R_1) [(X_2 + X_m)/X_m]^2$$

Using the above formulas the various parameters are calculated and tabled in Table-I. Performing these tests at computer using MATLAB/SIMULINK is might easy task. Students at undergraduate level can easily do it in very fast and regular manner.

3. COMPARISON OF EQUIVALENT CIRCUIT

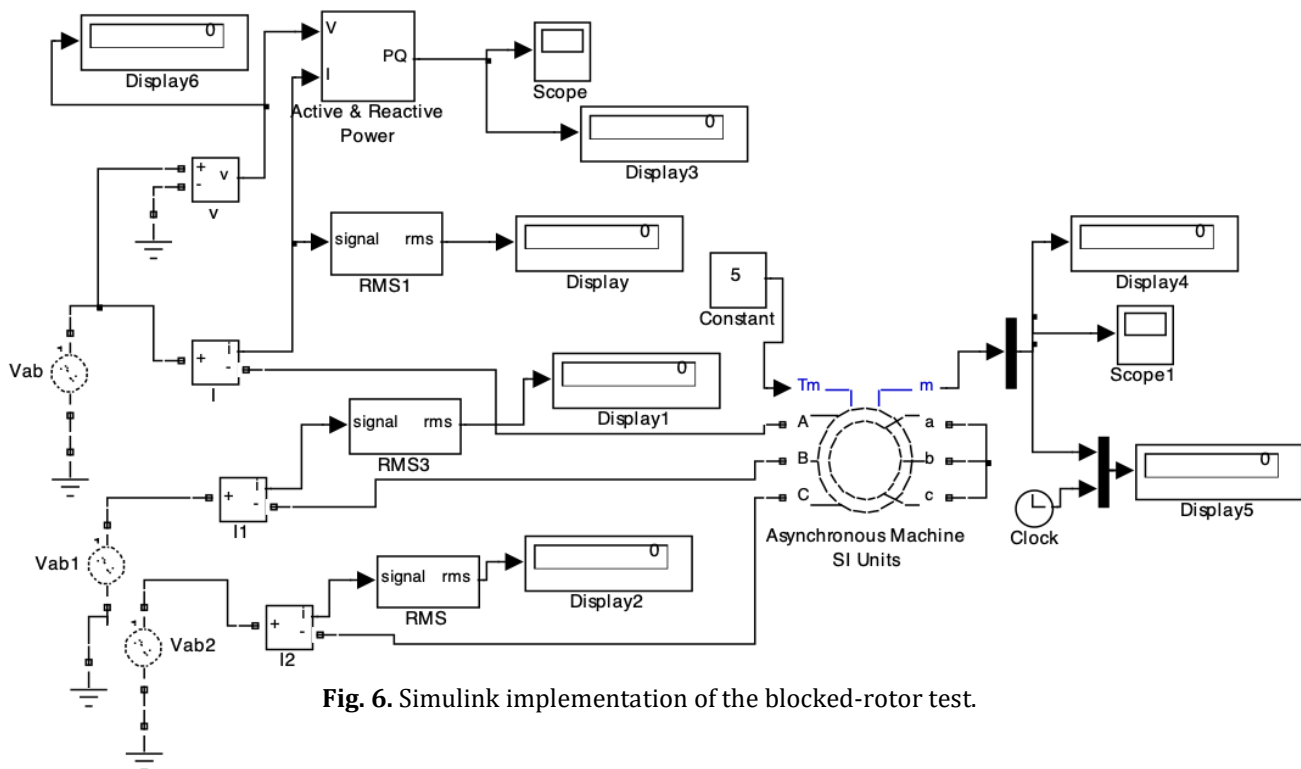


Fig. 6. Simulink implementation of the blocked-rotor test.

generator coupled with a dc motor. The measurement data from the blocked rotor test enables one to determine approximately the blocked-rotor resistance and reactance at the test frequency.

The result of the Blocked rotor test is than taken and the calculation is done in order to obtain the equivalent circuit parameter of the motor. As for the rotor resistance, a better approximation is required since it has a more significant effect on the motor performance when compared with the other circuit parameters.

Then perform the calculation using formula:

$$R_{br} = [P_{br}/3(I_{br})^2] \Omega/Phase$$

PARAMETERS

When the three tests are completed, equivalent circuit parameters can easily be computed.

- 1) The stator resistance is directly computed from the dc test using the formula: $R_1 = 0.5V_{dc}/I_{dc}$.
- 2) The no-load test gives the sum of the magnetizing reactance and the stator leakage reactance.
- 3) The blocked-rotor test gives that of the stator and rotor leakage reactance.

To illustrate the effectiveness of the proposed simulation models, one compares the equivalent circuit parameters determined by simulations with those obtained by hardware experiments. The motor used for this purpose is the three-phase 50 Hz Δ -connected and 3 H.P. induction motor of 415V, 1440 rpm located at Electrical Machine Lab, CCE&T Bhilai.

A set of hardware experiments are first performed (i.e., dc, no-load, and blocked-rotor tests) on the induction motor to obtain appropriate equivalent circuit. For the induction motor models of the dc, no-load, and blocked-rotor tests were run. The simulation data of no-load and blocked-rotor tests for motor is shown in below Table-1.

Table -1: EQUIVALENT CIRCUIT PARAMETERS DETERMINED BY SIMULATION AND THE CORRESPONDING ERRORS

Parameter	Test result from experiment	Test result from simulation	Percentage error
R_o	617.36 Ω	572.02 Ω	7.3%
X_m	122.23 Ω	104.92 Ω	8.5%
Power factor	0.19	0.18	5.2%
R_1	1.64 Ω	1.6 Ω	2.43%
$X_1=X_2$	2.15 Ω	2.11 Ω	1.86%
R_2	0.86 Ω	0.92 Ω	6.9%

Using the simulation data and the corresponding errors relative to those obtained experimentally. The error computations assume that equivalent circuit parameters determined experimentally are accurate. The results indicate that relative errors are negligible, and the proposed simulation models accurately predict the equivalent circuit parameters. The largest error occurs in the stator and rotor leakage reactances, since one assumes that two reactances have equal contributions to the blocked-rotor reactance, which might not be the real case

4. CONCLUSION AND FUTURE WORK

In this paper, simulation models of induction motor tests performed to obtain parameters of the per-phase equivalent circuit of three-phase induction motors is shown and circuit parameters obtained from simulation results are compared with those obtained from hardware experiments. The error studies show that MATLAB paired

with Simulink is a good simulation tool to model induction motor tests and to evaluate steady-state characteristics of the induction motor. Furthermore, a successful integration of simulation models is described in a software laboratory in an electric machines course, which complements classroom lecture and laboratory practice. A logical extension to the software laboratory would be to include Simulink models of experiments of transformers, dc machines, and synchronous machines so that a complete computational laboratory is available to support electric machinery education.

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BIOGRAPHIES

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