

## VIRTUAL MEASUREMENT SYSTEM FOR DETERMINATION AND STUDY OF THE PER-PHASE EQUIVALENT CIRCUIT PARAMETERS

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**Abstract** – In the presented paper, using Lab View graphical programming environment are implemented the virtual instrumentation's concept, realizing a virtual measurement system which are been used in searching and testing laboratories of electrical machine and drives, in engineering education from universities, colleges and schools for upgraded their laboratories with the power of computer-based data acquisition and analysis. The virtual instrument developed permitted determination of the phase's stator resistance  $R_1$  from Direct and Indirect Measurement and the per-phase equivalent circuit parameters of an asynchronous motor. This parameters are determinate from Short Circuit Test (Blocked-Rotor) and No-Load Test, for simulation of monophas voltage and current or for real-time acquisition

**Keywords:** asynchronous motor's short-circuit and no-load testing, measurement's virtual instrument, parameters of the equivalent electrical circuit, real-time and simulation acquisition.

### 1. INTRODUCTION

The aim of this work is to realize a virtual measurement's system for identify and estimate the equivalent circuit parameters of a three-phase asynchronous machine. The parameters of the per-phase equivalent circuit are very important to compute various motor quantities, such as input (stator) current and power, developed torque, rotor current, power factor and efficiency [1].

For determination of equivalent circuit parameters, it is necessary performing three tests [1],[2]:

- determination of stator resistance  $R_1$  (direct or indirect measurement);
- Blocked-rotor test ( $X_1$ ,  $X_2'$ ,  $R_2'$ );
- no-load test ( $R_{Fe}$ ,  $X_m$ );

The proposed system consists of two functions: a function to generate the signals for simulation monophas voltage and current and a function to real time acquisition. Both functions are included in the designed virtual instrument. Otherwise, the system consists of a hardware component and the software programs. The paper is organization in some sections.

In section 2 it is presented a few theoretical aspects about the equivalent circuit parameters of asynchronous motors (defining equations, diagrams, etc.) in short circuit (Blocked-Rotor) and No-Load Test.

In section 3 it is presented the list of system equipments; the Frontal Panel and Block Diagram of virtual instrument and the experimental setup of the Blocked-Rotor Test and No-Load Test.

In section 4 it is presented step by step the manipulation of VI. Section 5 contain the conclusions

### 2. THEORETICAL ASPECTS OF THE MOTOR EQUIVALENT CIRCUIT PARAMETERS

In (Fig. 1) is display the per-phase equivalent circuit of an asynchronous motor:

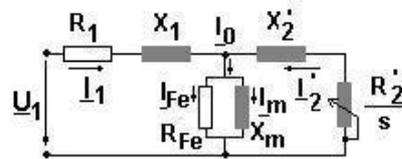


Figure 1: Per-phase equivalent circuit of an asynchronous motor.

In this circuit,  $R_1$  and  $X_1$  represent stator resistance and leakage reactance,  $R_2'$  and  $X_2'$  represent rotor resistance and leakage reactance referred to stator side and  $s$  denotes the slip.

The  $R_{Fe}$  and  $X_m$  represent the resistance stands for core losses and the magnetizing reactance.

#### 2.1. Determination of phase's resistance $R_1$

The value of the stator winding resistance  $R_1$  can be obtained from Direct Measurement ( $R_{ab}$ ,  $R_{ac}$  and  $R_{bc}$  are measured) or Indirect Measurement (measured a dc voltage  $U_{dc}$  applied to the two phases of Y-connected stator windings and  $I_{dc}$  current flowing through these windings).

For the first method (Direct Measurement), calculate the per-phase resistance  $R_1$  allowing for +5 % skin effect [2]:

$$R_1 = \frac{R_{average} \cdot (1 + 0.05)}{2} \quad (1)$$

Where:

$$R_{average} = \frac{R_{AB} + R_{BC} + R_{AC}}{3} \quad (2)$$

$R_{ab}$ ,  $R_{bc}$  and  $R_{ac}$  are resistances measured between bounds adding two by two from winding's stator star connected.

For Indirect Measurement  $R_1$  is calculated with formula:

$$R_1 = \frac{1}{2} \cdot \frac{U_{dc}}{I_{dc}} \quad (3)$$

Where  $U_{dc}$  and  $I_{dc}$  are the dc voltage and the dc current

## 2.2. Determination of stator leakage reactance $X_1$ , rotor resistance $X'_2$ and leakage reactance $R'_2$ referred to stator from Blocked-Rotor Test

With the rotor blocked and with a reduced voltage applied to the stator terminals ( $s=1$  and  $I_0 \approx 0$ ), the magnetizing branch current is negligibly, therefore the shunt branch ( $R_{Fe} || X_m$ ) (Fig. 1) in the equivalent circuit can be neglected (see Fig. 2).

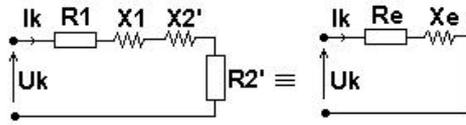


Figure 2: The equivalent circuit of the blocked-rotor asynchronous motor.

The per-phase active power is calculated from the rms values of the line current  $I_k$ , the phase voltage  $U_k$  and the phase  $\varphi$ :

$$P_k = U_k \cdot I_k \cdot \cos \varphi \quad (4)$$

The equivalent short circuit parameters can be calculated as:

- The per-phase equivalent impedance:

$$Z_{ek} = R_{ek} + jX_{ek} = \frac{U_k}{I_k} \quad (5)$$

- The per-phase equivalent resistance:

$$R_{ek} = \frac{P_{ek}}{I_{ek}^2} = R_1 + R'_2 \quad (6)$$

- The per-phase equivalent reactance:

$$X_{ek} = \sqrt{Z_{ek}^2 - R_{ek}^2} \quad (7)$$

When we know phase's stator resistance  $R_1$  (that was measured) and the per-phase equivalent resistance  $R_{ek}$  (that was calculated) has been determining rotor's resistance referred to stator side:

$$R'_2 = R_{ek} - R_1 \quad (8)$$

Similar to the transformers and supposing that the leakage reactance  $R_{ek}$  is divided equally between the primary and the secondary windings have been determining stator's reactance  $X_1$  and rotor's reactance referred to stator side  $X'_2$  [2]:

$$X_1 = X'_2 = \frac{X_{ek}}{2} \quad (9)$$

## 2.3. Determination of resistance for core losses $R_{Fe}$ and magnetizing reactance $X_m$ from No-Load Test

In no-load test, a rated, balanced ac voltage is applied to the stator while it is running at no load. See in (Fig. 3) the particularization of the per-phase equivalent circuit (Fig. 1) for this condition.

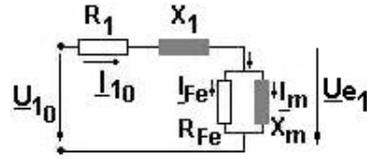


Figure 3: The equivalent circuit for no-load test of asynchronous motor.

Knowing active power:

$$P_{10} = U_{10} I_{10} \cos \varphi_{10} \quad (10)$$

the equivalent parameters in no-load test can easily be computed with formulas [1]:

- The resistance stands for core losses:

$$R_{Fe} = \frac{U_{e1}^2}{P_{Fe,n}} = \frac{U_{e1}^2}{P_{10} - P_{J10}} = \frac{U_{e1}^2}{U_{10} I_{10} \cos \varphi_{10} - I_{10}^2 R_1} \quad (11)$$

Where:

$$U_{e1} = U_{10} - I_{10}(R_1 + jX_1) \quad (12)$$

$$P_{10} - P_{J10} = P_{Fe,n} \quad (13)$$

- The magnetizing reactance:

$$X_m = \frac{U_{e1}}{I_m} \quad (14)$$

Where:

$$I_m = \sqrt{I_{10}^2 - I_{Fe}^2} \quad (15)$$

And:

$$I_{Fe} = \frac{P_{Fe,n}}{U_{e1}} = \frac{U_{10} I_{10} \cos \varphi_{10} - I_{10}^2 R_1}{U_{e1}^2} \quad (16)$$

### 3. STRUCTURE OF MEASUREMENT SYSTEM

The hardware and software composition for the proposed system is:

-for Simulation mode: Computer running Windows XP; LabVIEW Full Development System with designed virtual instrument; NI-DAQmx for USB Devices [3];

-for Real-Time mode: given simulation mode moreover NI-USB 6008 Data Acquisition Board with Cable and Connectors; Hall Transducers for voltage and current; Slip-ring Induction Machine; Rotor Clamp for the Blocked-Rotor Test; DC Generator for the No-Load Test; Power Supply 3-phase

#### 3.1. Software component of the system

The system is design for two-operation mode: simulation mode and real-time acquisition mode.

For Simulation Test the desired values of supply inputs (voltage, current-peak amplitudes, frequency and phase) are set with four numerical controls.

##### 3.1.1. Frontal Panel of the virtual instrument

Figure 4 shows the Frontal Panel of the system's virtual instrument.

In the left-up part of Frontal Panel, are placed the controls for setting acquisition's configuration (Real-Time Test): name of task/input channels, sample mode, sample to read/channel, rate or the controls for setting parameters of Simulation Test: the values of the phase voltage  $U_{1max}$ , the line current  $I_{1max}$ , frequency  $f_1$  and phase.

The choice between the Real-Time Test and Simulation it is made by switching a button; the LED is lighted.

The value of the stator winding resistance  $R_1$  obtained from Direct Measurement ( $R_{ab}$ ,  $R_{ac}$  and  $R_{bc}$  are measured with an precision ohmmeter and introducing in the three numerical control boxes) or Indirect Measurement ( $U_{dc}$ ,  $I_{dc}$  are measured with DAQ module and introducing in the two numerical control boxes).

The choice between the Direct Measurement and Indirect Measurement it's made by switching a button; a LED is lighted. For display, the value of  $R_1$  used the numerical control box.

In the right-up part of Front Panel, a scope display the waveforms of the phase voltage  $U_1$  and the line current  $I_1$ , in either International System of Units (S.I.)-absolute values or in per unit-relative values. The choice it's made by switching an horizontal button. With horizontal and vertical cursors helping, are determined with precession different instantaneous values of tension, current and phase angle (in degrees).

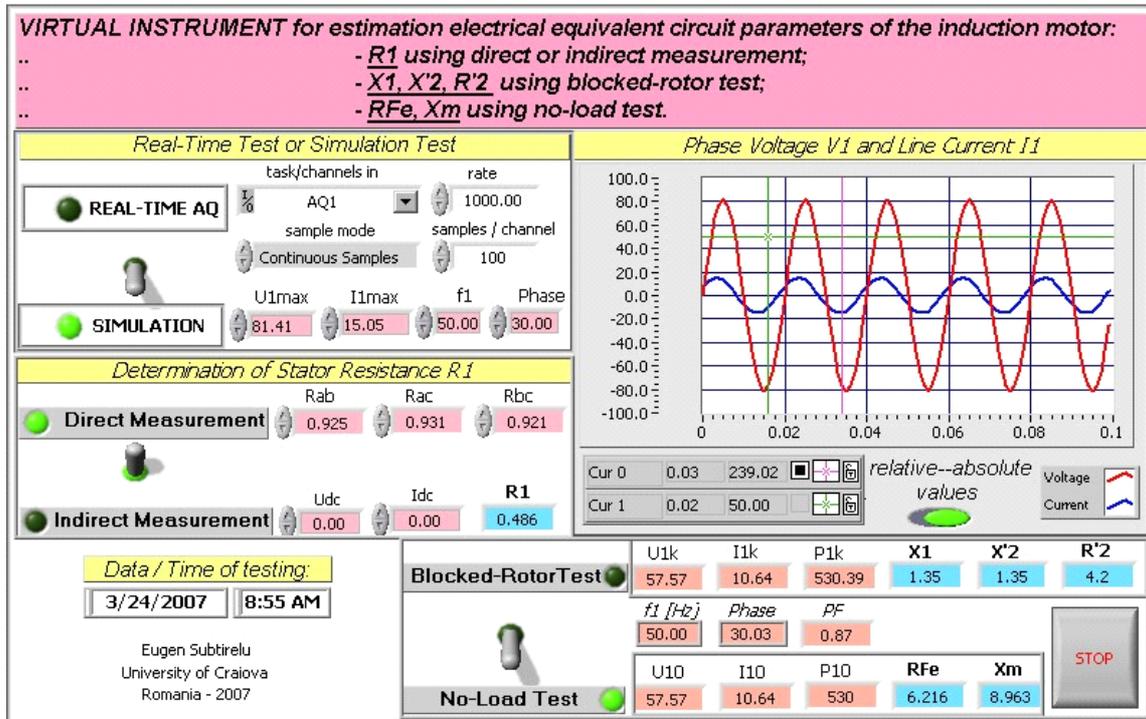


Figure 4: Frontal Panel of VI.

In the downside part of Frontal Panel are places the indicators with are displays the rms values of the phase voltage  $U_1$  and the line current  $I_1$ ; the active power  $P_1$  and the equivalent circuits parameters.

For the up position of switching button the up indicators displays the values for Blocked-Rotor Test:  $U_{1k}$ ,  $I_{1k}$ ,  $P_{1k}$  (corresponding to the loss in windings at short-circuit), the leakage reactance of the stator winding  $X_1$ , the leakage reactance of the rotor winding referred to stator side  $X'_2$ , rotor winding resistance referred to stator side  $R'_2$ .

For the down position of switching button the down indicators displays the values for No-Load Test:  $U_{10}$ ,  $I_{10}$ ,  $P_{10}$ , the resistance stands for core losses  $R_{Fe}$  and the magnetizing reactance  $X_m$ .

In addition, there are three indicators, which are display, the values of frequency  $f_1$ , phase and power factor PF.

The stop of virtual instrument's operation is made pushing STOP button.

### 3.1.2. Block Diagram of the virtual instrument

The block diagram contains the graphical source code for how the VI runs. Data flows from controls to functions and indicators through the wires.

Figure 5 shows the partial's Block Diagram of the system's virtual instrument with Blocked-Rotor Structure.

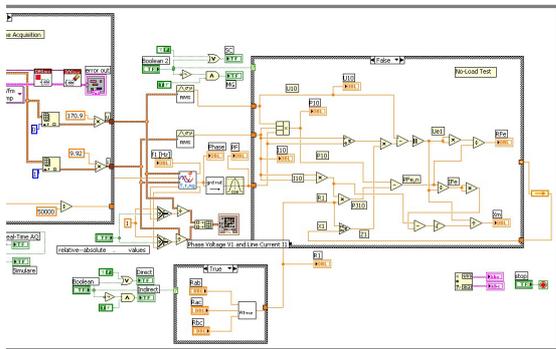


Figure 5: Block Diagram of VI with Blocked-Rotor structure.

As shown in figure the outputs of real-time or simulation input structure are connected to a root-mean-square blocks, named RMS to determine the rms value of each input signal (voltage  $u$  and current  $i$ ). Two display boxes read these rms values ( $U_1$  and  $I_1$ ).

The Feed back Node transfers in While Loop values ( $X_1=X'_2$  from Blocked-Rotor Test to No-Load Test) from one loop iteration to the next.

The phase angle between voltage and current is determinate with a subVI block in degree, over a running window of the one cycle of the fundamental frequency (50 Hz, 20 mS). This subVI is realized on

the principle of detected peaks / valley of the two input signals (Fig.6).

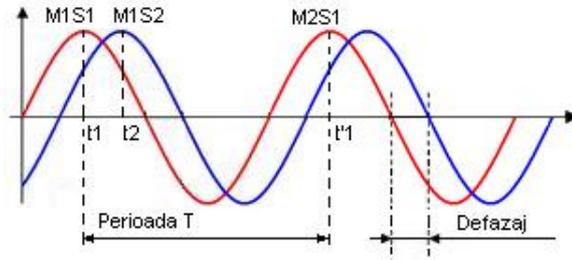


Figure 6: The phase between two sinusoidal signals  $S_1$  and  $S_2$

The phase result in degree is computed with formula:

$$Phase = \frac{t_2 - t_1}{T} \cdot 360^\circ \quad (17)$$

With subVI "degree  $\rightarrow$  rad" the phase is transform in radian units. These three values (rms of voltage, current and phase angle in radians) are connected to a power block that computes the active power. The output of this block is display on the power box  $P_1$ .

The different instantaneous values of tension and current are displayed on the waveform graph in (S.I.)-absolute values or in per unit-relative values.

In figure are three Boolean Case Structures (conditional structures): one structure for Real-Time (True) or Simulation Acquisition (False); one structure for Blocked-Rotor (True) or No-Load Test (False) and one structure for Direct Measurement of stator resistance  $R_1$  (True) or Indirect Measurement (False).

In each structure, wires connect controls and indicator terminals to the functions (Multiply, Subtract, Square Root, etc.) located on the Functions palette. Each structure executed one of the two frames (True/False), depend on Boolean evolution given from switch OFF/ON which represent the conditional instruction of the structure.

Figure 7 shows the partial's Block Diagram of the system's virtual instrument with Blocked-Rotor Structure.

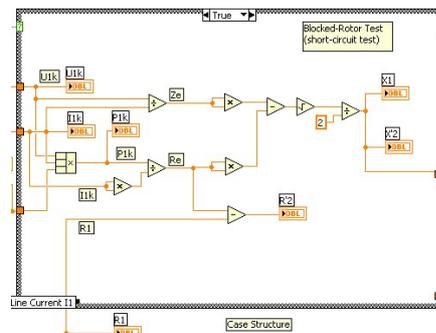


Figure 7: The No-Load part's of Block Diagram.

The structure's indicators are display the values of  $U_{10}$ ,  $I_{10}$ ,  $P_{10}$  and equivalent circuit parameters ( $R_{Fe}$ ,  $X_m$ ) for No-Load Test.

All of this presented elements from now (graphical blocks and structures) are included in a repetitive structure (type While), which executed them till now at the finishing terminal (right corner-downside, the "Stop if True" state) arrives logical values True.

To perform a real-time test the Case structure should be incorporated into the main VI, and the channels should be assigned as follows:

- Channel 0 to the Phase Voltage Measurement;
- Channel 1 to the Current Measurement;

Figure 8 shows the Real-Time part's Block Diagram of the system's virtual instrument.

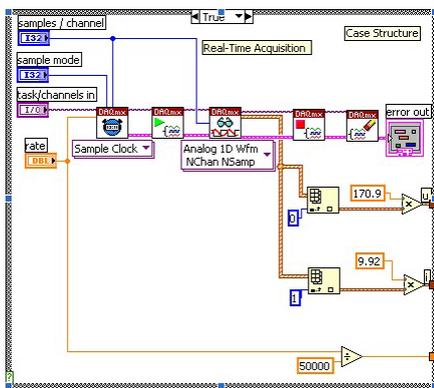


Figure 8: The Real-Time part's of Block Diagram.

In order to generate the signals for simulation monophase voltage and current are using a subVI having inputs:  $U_{1max}$ ,  $I_{1max}$ ,  $f_1$  and phase (degrees). This subVI is located in False sub diagram of first Case structure (Simulation Acquisition).

Besides operation systems for PC (Windows XP) and LabVIEW it is necessary NI-DAQmx Driver's software for DAQ controls ver.7.5 (acquisition's configuration: name of task/input channels, sample mode, sample to read/channel, rate-Hz, etc.) (See Fig. 9).

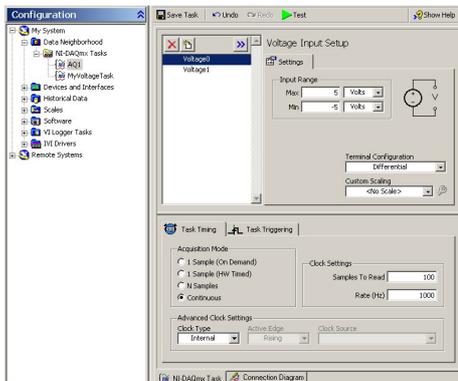


Figure 9: Set the name and the configuration for acquisition' task with NI-DAQmx.

### 3.2. Hardware component of the system

For Real-Time Test the phase supply voltage  $V_1$  and the line current  $I_1$  should be measured in real-time by the DAQ module, type NI-USB 6008. The features of DAQ module are: 8 analog inputs (8 SE, 4 DIF.), 12-bit resolution, 10 kS/s sampling frequency, 2 analog outputs (with 12-bit D/A conversion), 12 digital I/O and the transducers for U-I signal conditioning and isolation purposes with Hall effect (1000 V-50 A)-LEM.

#### 3.2.1. Blocked-Rotor Test

The short circuit test (Blocked-Rotor Test) on the asynchronous machine is similar to the short circuit test on the transformers and the wiring diagram is given in (Fig. 10).

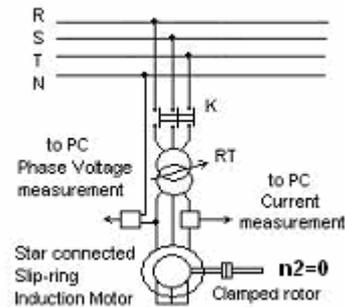


Figure 10: Experimental wiring diagram for Blocked-Rotor Test.

In the short circuit test, a reduction on the applied voltage is achieved by inserting an RT (Tension Regulation) in series with the stator terminals of the motor. With RT helping has been applicant a variant tension from 0 values to  $U_{1n}$  value, for who the line current is equal with motor's nominal current. Usually, the test are making at  $U_{1k} = (0.15 \div 0.25) U_{1n}$ . Starting resistors should be short circuited during the test.

The outputs of each LEM transducers (conditioned signals, dc voltage) are connected to a channel of DAQ module (Phase Voltage at channel0-voltage0 and Line Current at channel1-voltage1).

#### 3.2.2. No-Load Test

In this test, the stator of a slip-ring induction machine is supplied at a rated, balanced ac voltage at a rated frequency.

At this operation condition, the motor runs very close to the synchronous speed, which implies slip  $s$  is very small.

The wiring diagram for No-Load Test is given in (Fig. 11).

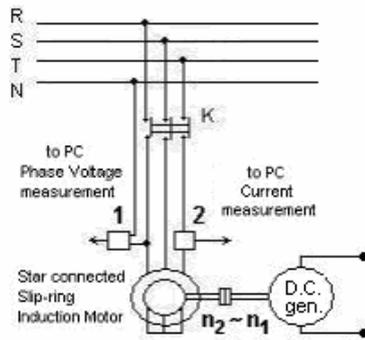


Figure 11: Experimental wiring diagram for No-Load Test.

As shown in figure, the three electrical connections of the rotor are short-circuited. In No-Load Test the mechanical torque at the machine's shaft is zero.

#### 4. PROCEDURE FOR EXPERIMENT'S SETUP AND WORK WITH SYSTEM

Follow the steps listed to prepare the system for this experiment.

Launch the LabVIEW and run the virtual instrument.

A) Determination of stator resistance  $R_1$ :

-Step1 - Choice from the switching button the direct or indirect measurement (LED lighting);

-Step2 - Enter on the respective controls the desired values  $R_{ab}$ ,  $R_{bc}$ ,  $R_{ac}$ ,  $U_{dc}$ ,  $I_{dc}$  (which were determinate previously); the value of  $R_1$  is calculated.

B) Simulation mode:

-Step1 - Choice the Simulation mode from the switching button (LED lighting);

-Step2 - Set the four controls on the desired values ( $U_{1max}$ ,  $I_{1max}$ ,  $f_1$  and phase);

-Step3 - On the display observe the waveforms of the phase voltage  $U_1$  and the line current  $I_1$ , in absolute or relative values;

-Step4 - Choice the Blocked-Rotor Test or No-Load Test from the switching button (LED lighting);

-Step5 - Read the numerical indicators with the values of circuit parameters; record all the data in a table.

C) Real-Time mode:

Due to the risk involved in working with high voltage the safety precautions are very important to followed. It must verify to achieve complete electrical isolation for current transducer (50 A and 100 A, DC to 100 kHz) for the current measurement and an isolation (1000 V rms, 50 kHz) for the voltage measurement.

-Step1 - Install NI-USB 6008 DAQ module to the PC desktop or Laptop;

-Step2 - Cable the module to the transducers bloc; cable the transducers block to the measurement motors circuit;

-Step3 - Configure the NI-DAQmx task; assigned the channels to the measurement signals;

-Step4 - Perform the wiring diagram for Blocked-Rotor Test or for No-Load Test; double check the setup and make sure no hazards exist for the operators;

-Step5 - Choice the Real-Time AQ mode from the switching button (LED lighting); set the parameters of acquisition;

-Step6 - Choice the Blocked-Rotor Test or No-Load Test from the switching button (LED lighting); read the numerical indicators with the values of circuit parameters; record all the data in a table.

-Step7 - Press STOP to stop the VI; close the VI and exit LabVIEW.

#### 5. CONCLUSIONS

With LabVIEW customized graphic environment the author provide an easy-to-use and interactive virtual instrument that is integrate in to the measurement system; this virtual instrument performed to obtain parameters of the per-phase equivalent circuit of the three-phase asynchronous motor.

This system can be used to enhance the students learning experience in both the theoretical and practical compute the equivalent circuit parameters of asynchronous motors. They understand how the equivalent circuit parameters of a three-phase induction motor are determined.

The approximations used in compute expressions (ex. for resistance  $R_1$ , the temperature effects are not taken into consideration, the expression of input power  $P_1$ , etc.) is reasonable enough for teaching purpose.

With the flexibility and the expandability of the programming interface, I will further increase the analysis capability and the functionality of the present system in the future.

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