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Siti zaliha mohammad noor
Universiti Teknologi MARA

Mustafar Kamal Hamzah
Universiti Teknologi MARA

Three Phase Induction Motor Analysis using MATLAB/GUIDE

S.Z.Mohammad Noor, M.K.Hamzah, P.N.A. Megat Yunus
Faculty of Electrical Enginnering
University Technology Mara (UiTM),
40450 Shah Alam, Selangor

Abstract- **This paper illustrates the development of MATLAB/GUIDE (Graphical User Interface Development Environment) software program to simulate the performance of three phase induction machines complete with graphical analysis display on a computer. The selected simulation results used 1 horse power (hp) and 20 hp three phase induction machines. Analysis includes Transient response, Starting method: (a) Rotor resistance starting (b) Direct on-line starting, Linearized Analysis and Some none zero Vsg conditions. Stationary reference frame is used in modelling of MATLAB/Simulink to standardize the variable used in simulation.**

Keywords:-**Graphical User Interface Development Environment (GUIDE), Graphical User Interface (GUI), Induction motor**

I. INTRODUCTION

The Induction machine is the most rugged and the most widely use machine in the industry. They are simple, reliable, low-priced, robust and easy to maintain. Furthermore, they are comparatively less expensive to equivalent size synchronous or DC machines and range in size from a few watts to 10000hp [1]. There are two different types of induction motor rotors, one is called a squirrel-cage rotor while the other is called wound rotor [5-6]. The induction machine can operate both as a motor and as a generator. The induction machine is extensively used as a motor in many applications [1-2].In the induction machine both stator winding and rotor winding carry alternating current. The Alternating Current (AC) is supplied to the stator winding directly and to the rotor winding by induction, therefore the machine called induction machine [3] [5].

There are a few published papers on Matlab GUI for induction machine analysis, Rajesh Kr. Ahuja et. al. [7] have proposed the analysis of a normal three phase induction motor as a Self-Excited Induction Generator (SEIG) to feed single phase loads especially for energizing isolated locations using locally available renewable energy. The simulation results are compared with the experimental results. S.Ranjith Kumar et. al. [8] presented educational software tool using Matlab GUI enables the teachers in teaching induction generator concepts, its operation and performance in different configurations like SEIG and Grid Connected Induction Generator (GCID). S.S. Murthy et. al. [9] presents the steady state analysis of SEIG under different operating conditions. Furthermore, Zhenxing Liu et.al. [10] has proposed GUI for static and dynamic characteristics for DC motor and Balogh Tibor et. al [11] has proposed GUI to compare various type of Brushless DC motor (BLDC) models with the trapezoidal and sinusoidal back-EMF waveforms. In this work, for induction motor simulation, stationary reference frame are used, which has the advantage of eliminating some terms from the voltage equations. To eliminate the time-varying inductances, the equations are frequently transformed to q-d-0 variables in the arbitrary reference frame.

II. THREE PHASE INDUCTION MOTOR

A three-phase induction motor contains three-phase distributed windings that are housed in slots on the stationary part of the motor, usually called the stator. The stator is composed of laminations of high-grade sheet steel. The rotating part of the machine, or rotor, also contains either a distributed three-phase winding or a cage of interconnected copper bars that serve as rotor winding conductors. Unlike dc machines, induction machines have a uniform air gap [2].

A. Operating Characteristic

The induction machine can be operated in three modes: motoring, generating, and plugging. If the stator terminals are connected to a three-phase supply, the rotor will rotate in the direction of the stator rotating magnetic field. This is the motoring mode of operation of the induction machine. The steady-state speed n is less than the synchronous speed n_s. If the speed of the system is higher than the synchronous speed and the system rotates in the same direction as the stator rotating field, the induction machine will produce generating torque acting opposite to the rotation of the rotor. The generating mode of operation is utilized in some drive applications to provide generative braking.

If the system rotates in a direction opposite to the stator rotating magnetic field, the torque will be in the direction of the rotating field but will oppose the motion of the rotor. This is called a braking torque. This mode of operation is utilized in drive applications where the drive system is required to stop very quickly. Expression for the average value of electromagnetic torque developed by the P-pole machine with constant voltage supply is

$$T_{em} = \frac{3p}{2\omega_e} \frac{V^2 th(\frac{r'_r}{s})}{(r_{th} + \frac{r'_r}{s})^2 + (X_{th} + X'_{lr})^2} \tag{1}$$

Maximum torque is developed when the variable resistor $\frac{r'_r}{s}$, draws maximum power from source that is when

$$\frac{r'_r}{s_{max}} = \sqrt{{r_{th}}^2 + (x_{th} + x'_{lr})^2} \tag{2}$$

Therefore the maximum torque developed with constant voltage supply is

$$T_{max_{em}} = \frac{3p}{4\omega_e} \frac{{V_{th}}^2}{r_{th} + \sqrt{{r_{th}}^2 + (X_{th} + X'_{lr})^2}} \tag{3}$$

B. *Starting Methods*

Starting a motor from the standstill with the rated stator voltage applied can result in large starting current, typically as much as six to eight times the rated current of the motor. The starting current of a large induction motor could result in excessive voltage drop along the feeder that is disruptive or objectionable to other load in same feeder.

Various methods can be used to reduce the current drawn by the motor during starting. One popular method is to reduce the voltage applied to the stator windings during starting, using an autotransformer or star-delta contactor. In some application, such as in compressor drives, the requirement of large starting torque may necessitate the use of another method of reducing the starting current that of using external rotor resistance starting of a wound-rotor machine [4].

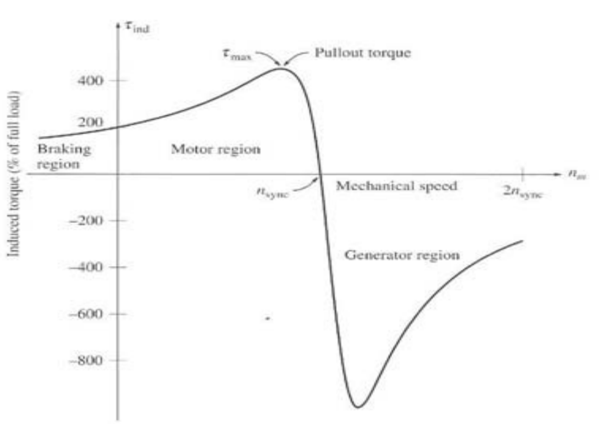

Fig.1. Average Torque vs. slip with constant voltage supply.

The torque-speed characteristic for a wound-rotor induction motor is shown in Figure 1. Recall that it is possible to insert resistance into the rotor circuit of a wound rotor because the rotor circuit is brought out to the stator through slip rings.

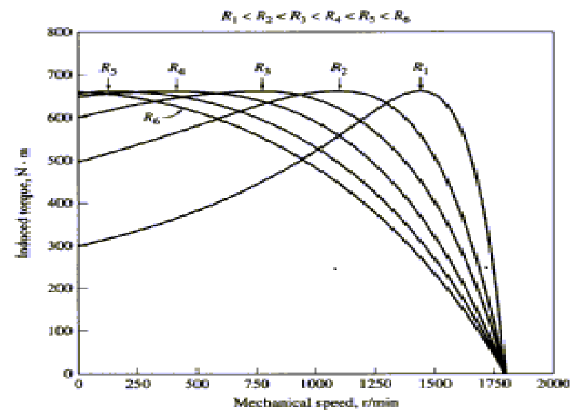

Fig. 2. The effect of varying rotor resistance on the torque speed characteristics of a wound-motor induction motor

Notice on the figure 2 that as the rotor resistance is increased, the pullout speed of the motor decreases, but the maximum torque remains constant [5].

C. *Simulation of Induction Machine in Stationary Reference Frame*

Stationary reference frame model are used in the simulation to simulate a three phase, P-pole, symmetrical induction machine. Winding connections of stationary reference frame are shown in figure 3 below.

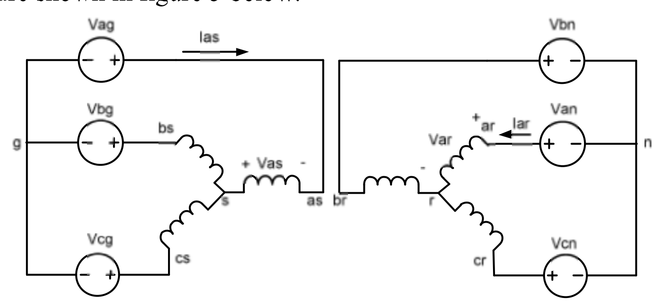

Fig.3. Stator and rotor connections

Consider first the input voltages for the given neutral connections of the stator and rotor windings shown.

The three applied voltages to the stator terminals vag, vbg, and vcg need not be balanced or sinusoidal. In general, the three stator phase voltages are:

$$v_{as} = v_{ag} - v_{sg}$$
$$v_{bs} = v_{bg} - v_{sg}$$
$$v_{cs} = v_{cg} - v_{sg}$$

Therefore,

$$3v_{sg} = (v_{as} + v_{bs} + v_{cs}) - (v_{ag} + v_{bg} + v_{cg})$$

In simulation, the voltage vsg can be determined from the flow of phase currents into the neutral connection by:

$$v_{sg} = R_{sg}(i_{as} + i_{bs} + i_{cs}) + L_{sg}\frac{d}{dt}(i_{as} + i_{bs} + i_{cs}) = 3\left(R_{sg} + L_{sg}\frac{d}{dt}\right)i_{0s}$$

where Rsg and Lsg are the resistance and inductance between the two neutral points. Of course, if s and g are shorted, vsg=0.

III. MATLAB/GUIDE

A graphical user interface (**GUI**) is a user interface built with graphical objects -- the components of the GUI -- such as buttons, text fields, sliders, and menus. If the GUI is well-designed, it should be intuitively obvious to the user how its components function. For example, when you move a slider, value changes; when you click an OK button, your settings are applied and the dialog box is closed.

Fortunately, most computer users are already familiar with GUIs and know how to use standard GUI components. By providing an interface between the user and the application's underlying code, GUIs enable the user to operate the application without knowing the commands would be required by a command line interface. For this reason, applications that provide GUIs are easier to learn and use than those that are run from the command line.

IV. MODELING AND SIMULATION IN MATLAB/GUIDE

Stationary reference frame model are used in the simulation to simulate a three phase, P-pole, symmetrical induction machine. Four type of analysis of Induction Motor implemented in GUIDE is shown in Figure 4. The flow chart of the GUI simulation is shown in Figure 5.

GUIDE stores GUIs in two files, which are generated the first time you save or run the GUI:

FIG-file - a file with extension .fig that contains a complete description of the GUI figure layout and the components of the GUI: push buttons, menus, axes, and so on. When you make changes to the GUI layout in the Layout Editor, your changes are saved in the FIG-file.

M-file - a file with extension .m that contains the code that controls the GUI, including the callbacks for its components. This file is referred to as the GUI M-file. When you first run or save a GUI from the Layout Editor, GUIDE generates the GUI M-file with blank stubs for each of the callbacks. You can than program the callbacks using the M-file editor.GUI main layout of the induction motor analysis shown in Figure 6.

The user can choose type of analysis of induction motor and used the standard parameters of the induction motor given in the simulation. In addition, the user can do the variation in the parameter of the induction motor and obtain the results in just few seconds. Figure 7 shows the simple example on Transient Response for operating characteristics of three phase induction motor. The simulation step is shown in figure 5.

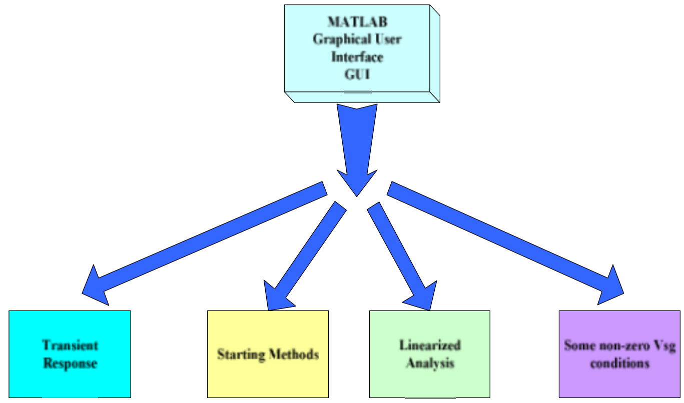

Fig.4. Four types of analysis in GUI

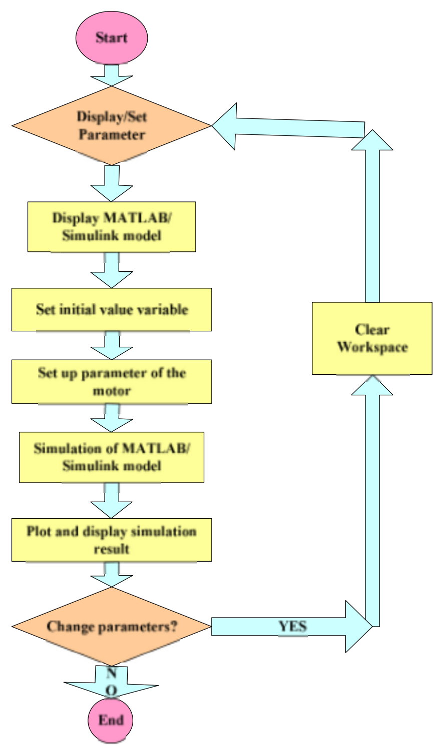

Fig.5. Flowchart of MATLAB/Guide simulation

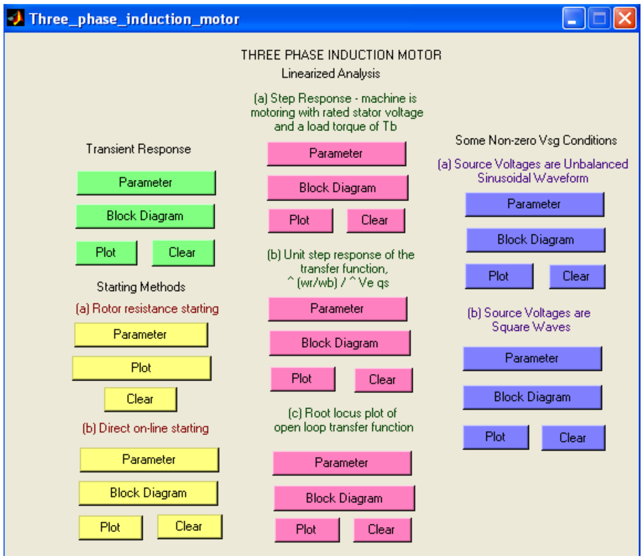

Fig.6. GUI Main Layout

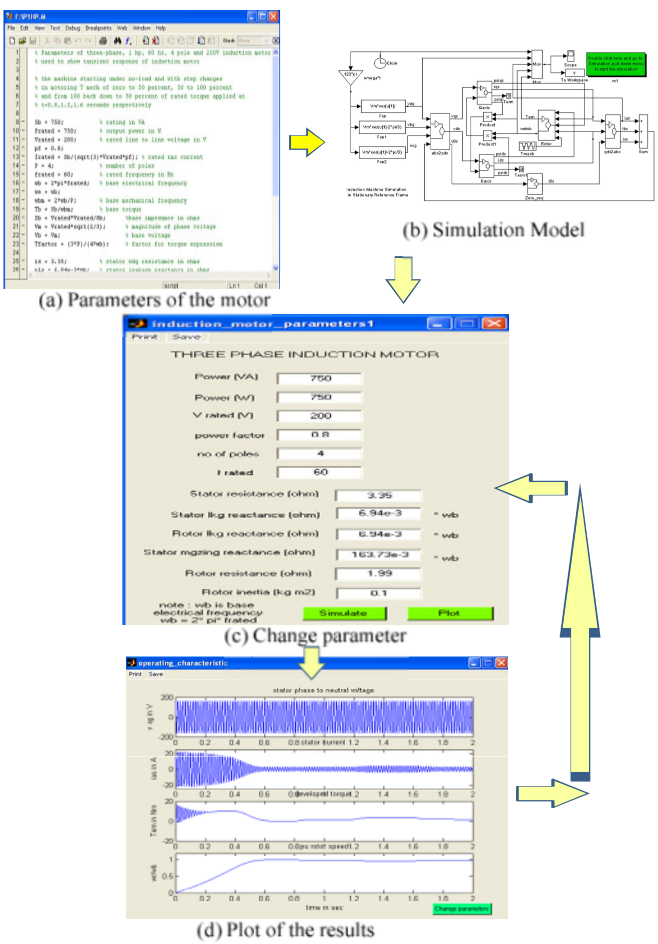

Fig.7. Transients Response for operating characteristics of three phase induction motor.

V. Results And Discussion

Results obtained from MATLAB/Simulink and applied to MATLAB/Guide. The results displayed by using MATLAB/Guide.

A. *Transient Response*

Transient Response of ias, Tem and wr when motor starting under no-load condition with step changes in motoring a T mech of 0% to 50%, 50% to 100% and from 100% back to 50% of rated torque applied at t=0.8, 1.2 and 1.6 seconds respectively.

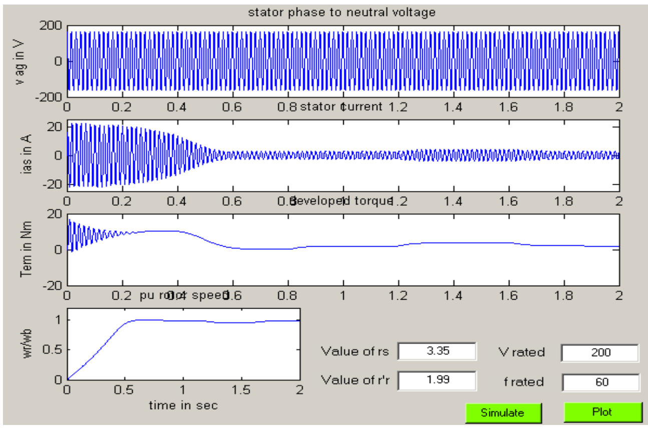

Fig.8. Transient response for no-load startup and step load response of a single exited, three-phase, 1-hp, 60Hz, 4-pole and 200-V induction motor.

Figure 8 showed the transient response for no-load startup and step load response of a single exited, three-phase, 1-hp, 60Hz, 4-pole and 200-V induction motor.

The motor starting under no-load condition with step changes in motoring a T mech of 0% to 50%, 50% to 100% and from 100% back to 50% of rated torque applied at t = 0.8, 1.2 and 1.6 seconds, respectively. About 0.7 seconds, the steady state is reached.

B. *Starting Method*

a. Rotor Resistance Starting

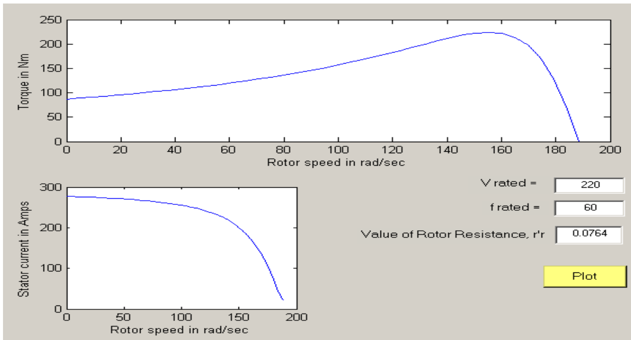

Fig. 9.Torque and stator current curves of three-phase, 20-hp, 60Hz, 4-pole and 220-V wound rotor induction motor for 0.0764 Ω rotor resistance.

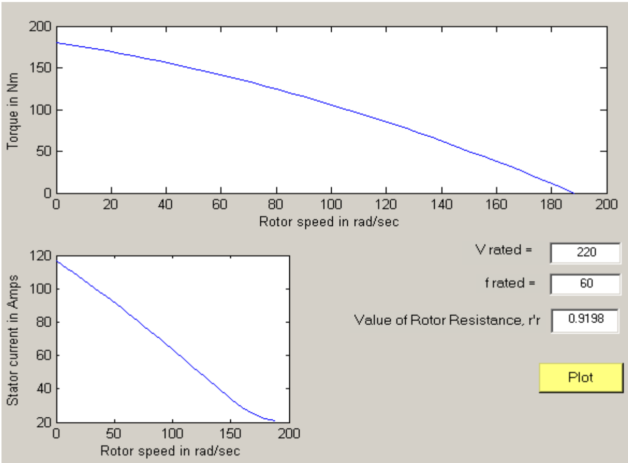

Fig.10. Torque and stator current curves of three-phase, 20-hp, 60Hz, 4-pole and 220-V wound rotor induction motor for 0.9198 Ω rotor resistances.

For starting method of three-phase, 20-hp, 60Hz, 4-pole and 220-V wound rotor induction motor. On Rotor Resistance Starting, Figure 9 and 10 showed the torque and stator current curves for 0.0764Ω rotor circuit resistance at rated slip 0.0287 and 0.9198 Ω at slip 0.4 which maximum torque is developed. From these figure, as the rotor resistor is increased, the graph shift to the left and the pull-out speed of the motor decreases, but the maximum torque remain constant. Values of torque and stator current can be proved by calculation for each value of rotor resistance.

b. Direct On-line Starting

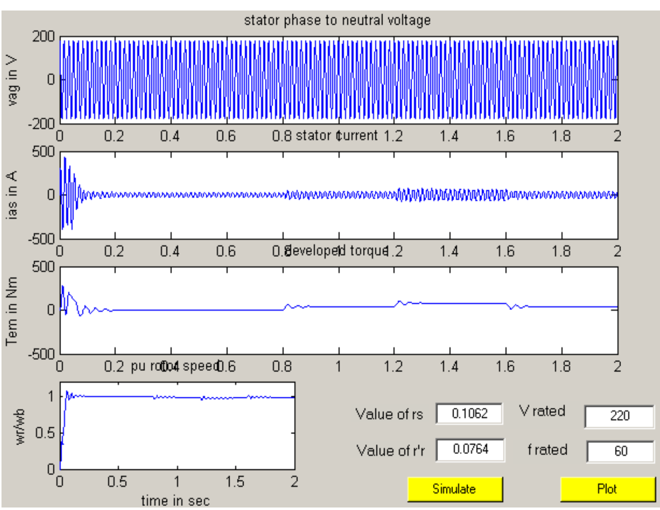

Fig.11. Simulation on direct on-line starting of three-phase, 20-hp, 60Hz, 4-pole and 220-V wound rotor induction motor.

On Direct on-line starting, in Figure 11, motor start from standstill with full-rated supply voltage and a load torque of Tb (base torque of machine). About 0.2 seconds, the steady state is reached.

C. Some Non-zero Vsg Condition

Some Non-zero Vsg Condition using single exited, three-phase, 1-hp, 60Hz, 4-pole and 200-V induction motor shown below.

From Figure 12 (a) and (b) the source voltages are unbalanced in a manner that Vag+Vbg+Vcg is not equal to zero, the value of Vsg will not be zero. With extreme unbalanced condition, the motor may not develop sufficient torque to run up with the value of mechanical torque, Tmech , that is set at - Tb/2. About 0.7 seconds, the steady state is reached.

From Figure 13 (a) and (b) the sources voltages are square waves, each phase being displaced 120° apart from others and of magnitude such that rms value is the same as that of the three-phase sine voltage. The motor is startup with a constant load torque of T_{mech} = -T_b. However the torque is unbalanced.

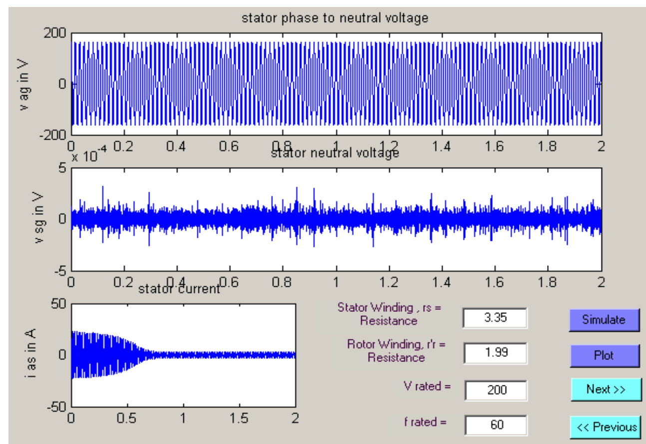

Figure 12 (a)

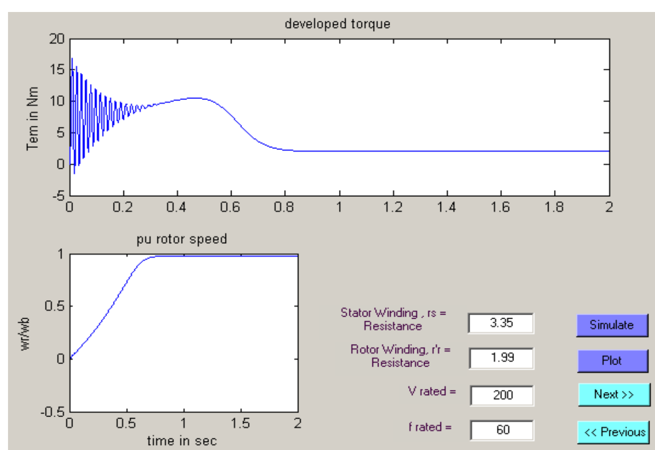

Figure 12 (b)

Fig.12. (a) and (b): simulation of source voltage are unbalanced sinusoidal waveforms of a single exited, three-phase, 1-hp, 60Hz, 4-pole and 200-V induction motor.

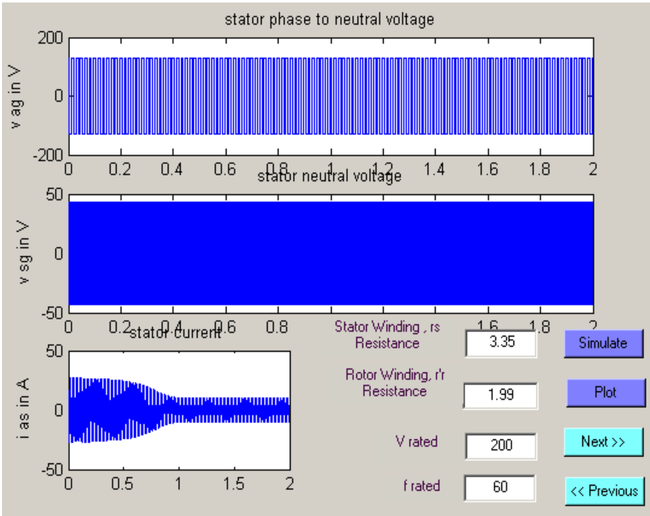

Figure 13 (a)

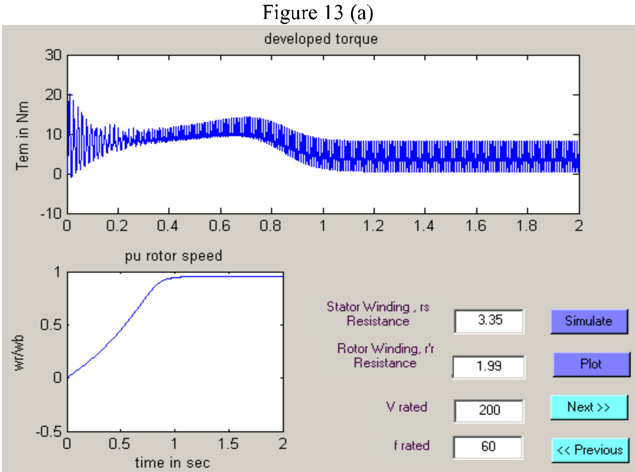

Figure 13 (b)

Fig.13. (a) and (b): Simulation of source voltage are square waves of a single exited, three-phase, 1-hp, 60Hz, 4-pole and 200-V induction motor.

VI. CONCLUSION

As a conclusion, this paper can be useful to manufacturer or student to study the behaviours of induction machines. Using the MATLAB/GUIDE, this project can be used as to investigate the behaviours of induction machines. Also, the parameter of the motor can be changed by modifying the m-file of motor parameter. The test on this machine, such as methods for reducing the starting voltage, is useful to safe energy used by the consumer neither in industrial nor individuals. The problem that normally exist in this machines such as high starting torque, high starting current and others can be eliminated or reduced so as to make sure the machines is in good condition and safe to be used by consumers.

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