# Transient Response Study of Induction Motor Using MATLAB/Simulink

Farhana Ahmad
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
Email : farhanaahmad87@gmail.com

*Abstract*: **This project investigates the nature of transient phenomena found in an induction motor. Electric machines play an important role in industry as well as our day-to-day life. They are used to generate electrical power in power plants and provide mechanical work in industries. The induction machine is considered to be basic electric machines. The present of transient phenomena is not acceptable. It covers the background review of induction motors and the type of induction motor modeled. Parameters are extracted from the selected induction motor by the means of experimental results while some are synthetic parameter values. The simulation by using MATLAB is used in order to understand on the effect of the transient response.**

***Keywords: Induction motor, transient phenomena, Matlab /Simulink***

## I. INTRODUCTION

The AC induction motor is well suited to applications requiring constant speed operation. In general, the induction motor is cheaper and easier to maintain compared to other alternatives [1].

In the world of machinery, induction machines are widely used as motor or sometimes as a generator supplying power to individual load or connected to an infinite bus through an appropriate electronic converter. Any sort of disturbance or short circuit between the lines to the ground, between line and line, or between all three lines will cause an electrical or mechanical transient [2]. As there is an absence of any field winding circuit in induction machine, the long transient period in the characteristic of a synchronous machine will be absent. Therefore the short-circuit current in the induction machine will be large but decay quickly. The induction machine also has a very high initial starting current in which could be three to eight times the rated value [3].

### *A. Equivalent Circuit of Induction Motor*

As we assume a turn ratio of 1:1 as seen in figure 1, the circuit parameter per phase is identified as follow:

$E_g$ = source voltage, line to neutral
$r_1$ = stator winding resistance
$x_1$ = stator leakage reactance
$x_2$ = rotor leakage reactance
$r_2$ = rotor winding resistance
$r_x$ = external resistance, effectively connected between one slip ring and the neutral of rotor
$X_m$ = magnetizing reactance
$R_m$ = resistance whose losses correspond to the iron losses and windage
T = ideal transformer having a turns ratio of 1:1

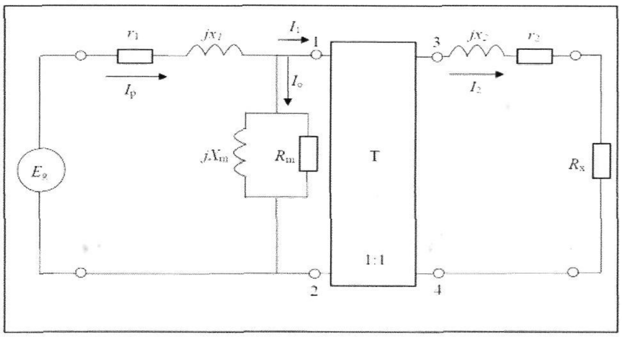


Figure 2. Equivalent circuit of a (wound rotor) induction motor at standstill

As slip is s, the actual voltage induced is:

$$E_2 = sE_2 \quad (1)$$

The secondary resistance $R_2$, is therefore given by

$$R_2 = r_2 + R_X \quad (2)$$

### *B. Losses and Gross Power*

From the equivalent circuit, the conditions per phase arising for the rotor [4]:

$$Rotor\ copper\ loss\ = (I_2)^2 R_2\ = P_2 \quad (3)$$

$$Mechanical\ output = (I_2)^2 R_2 \left(\frac{1}{s-1}\right) = P_m \quad (4)$$

In addition, the stator copper loss per phase is **[8]**:

$$Stator\ copper\ loss = R_1 (I_1)^2 = P_s \quad (5)$$

## C. *Torque, Power and Phase Current*

Toque may be express in many possible ways and at this point, the instantaneous torque is proportional to the product of rotor current and the field strength cutting the rotor at any instant. Torque can be described in terms of mechanical output, thus:

$$T_g = \frac{3P_m}{\omega}$$
$$= \frac{3P_g(1-s)}{2\pi N_s(1-s)}$$
$$3P_a(1-s) \qquad (6)$$

And air-gap power:

$$P_g = E_1 I_2 \cos \emptyset_2 \qquad (7)$$

By making the assumption that, the magnetizing current is negligible at all operating current as it is lagging on the main current and therefore is less important as a magnitude [4]. The equivalent circuit produces the phase current of the below:

$$I_2 = \frac{(I_2)^2}{[R_1+(R_2/S)]^2+(X_1+X_2)^2} \qquad (8)$$

And air-gap power per phase:

$$P_g = \frac{(I_2)^2 R_2}{s} \text{ per phase} \qquad (9)$$

## D. *Rotor Frequenct and its Effects*

When a rotor is at standstill, it behaves as a three-phase transformer with a short circuit in the secondary. The Electro Magnetic Flux (EMF) induced in the rotor bears a direct relationship to the supply EMF, numbers of turns, flux as well as frequency. Hence, at a given speed, the rotor EMF at speed is equal to rotor EMF at standstill multiply by slip, S. This on the other hand leads to other changes such that rotor leakage reactance at speed will differ from the leakage at standstill in the rotor [4].

Slip, s is given by:

$$s = \frac{\omega_s - \omega}{\omega_s}$$
$$= N_s - \frac{N}{N_s} \qquad (10)$$

Where:
$N_s$ = synchronous speed $(r/min)$
$N$ = rotor speed $(r/min)$

Rotor leakage reactance at standstill:

$$X_R = 2\pi f_s L \text{ in ohms } (\Omega) \qquad (11)$$

In Addition, the reactance at speed:

$$X'_R = SX_R \qquad (12)$$

## E. *Circuit Model of a Three-Phase Induction Motor*

For this project, the circuit block diagram for the MATLAB Simulink is created by the means of mathematical transfer functions. The circuit model is shown below

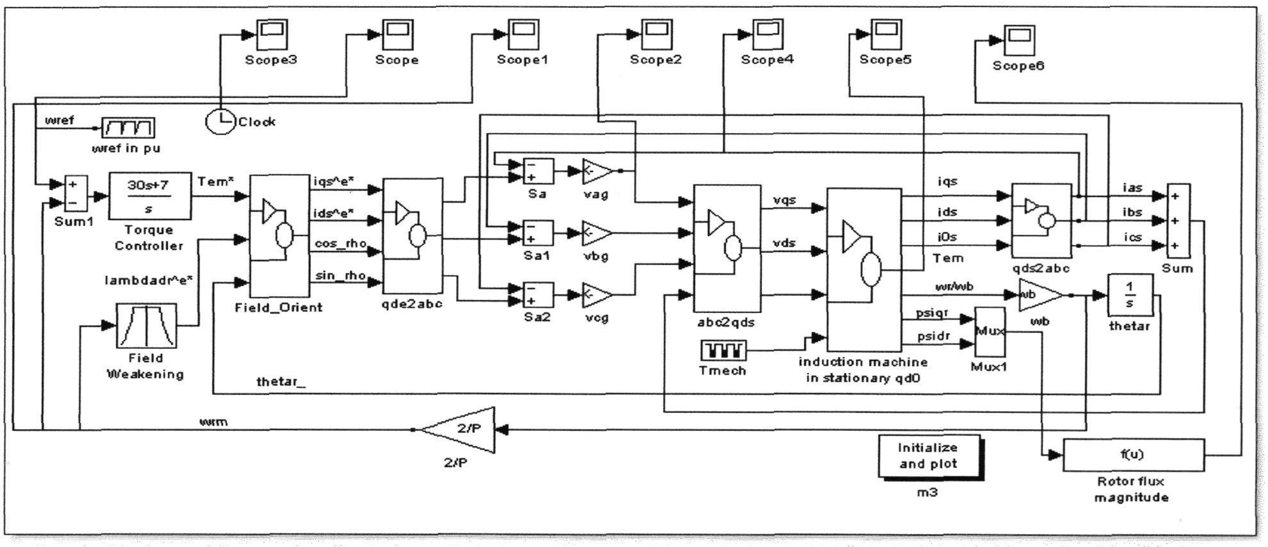


Figure 2. MATLAB Simulink Model of aThree-Phase Induction Machine

## II. METHODOLOGY

### *A. Flow Chart*

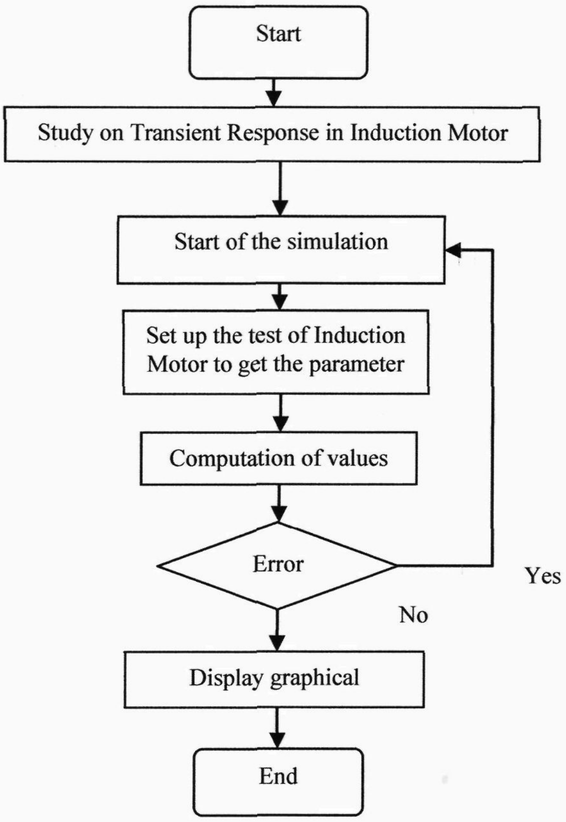


Figure 3. Flow chart for analysis of transient response of induction motor

### *B. Transient Behavior*

Transient response is used in induction motor so as to determine the characteristic and behavior of the motor when small faults are injected into the motor input. When small faults are injected into the system it is desirable to see how the motor will respond in terms of speed, output torque, current, voltage, etc. The eventual aim is to determine how fast the motor will regain its stability (normal operation condition). Transient response covers response to 3 types of faults (inputs):

1. Impulse response. This will determine how the motor will react to impulses such as surge.
2. Step response. This will determine how the motor will react to small injections of DC voltages/currents.
3. Ramp input response. This will determine how the motor will react to ramp kind of input fault.

In addition to the above, transient response is also used to determine the starting characteristics of the motor. In this way, we can determine the motor inrush, and other starting condition using Matlab/Simulink.In this project for start-up from standstill and load cycling at fixed frequency while for second simulation is for speed cycling at no-load

### *C. Experimentation*

In order to analyze the transient response in induction motor, first step is to get the approximation value of R1,R2,$X_m$, $R_m$ and X1 and X2.To get this value a serial of test need to be done such as:

1. No-load Test

The motor circuit is connected for on-load test according to the approved circuit .The induction motor is started as follows. The power supply is zeroes, then the power is switched on and the voltage is raised slowly, being careful not to exceed rated stator current. When full voltage has been applied; the average value of stator phase voltages and stator phase currents and three phase of power are calculated and recorded. These reading are used to calculate $R_C$ and $X_M$. The no-load speed is measured and the minimum slip of the motor is computed. After taken all the necessary data, power is turned off. [5].

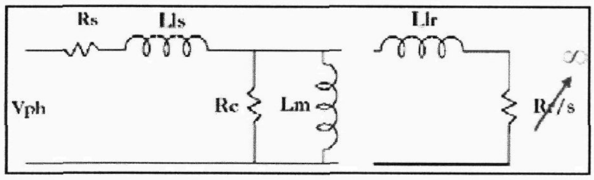


Figure 4. Equivalent circuit for No-Load test

2. Blocked Rotor Test

The blocked rotor test, like short circuit test on a transformer, provides the information about leakage impedances and rotor resistance. Rotor is at the stand still, while low voltage is applied to stator windings to circulate rated current. Measure the voltage and power to the phase [5]. Since there is no rotation slip, s=1 which gives us following equivalent circuit.

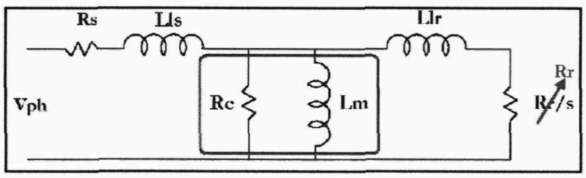


Figure 5. Equivalent circuit for Blocked Rotor Test

3. DC Resistance Test

The dc resistance of each of the stator windings is measured by using the voltmeter-ammeter method. The supply voltage is set to zero to start the experiment and turn up slowly and carefully so as not to exceed rated current in each case. The value of voltage and current (at approx. rated current) is recorded and an average resistance value is determined [7].

## III. RESULT AND DISCUSSION

### *A. Experimentation*

The following test results are obtained from three-phase, 2.24kW, and 415V, four-pole, and 50Hz slip ring induction motor. The parameter of the equivalent circuit is obtained by conducted a no-load test, blocked rotor test and dc resistance test.

TABLE I. NO-LOAD TEST

| No-Load Test | |
|---|---|
| $V_{NL(LL)}$ | 415.00V |
| $V_{NLø}$ | 239.60V |
| $I_{NL}$ | 3.00A |
| $P_{NL}$ | 450.00W |
| $P_{ø}$ | 150.00W |
| N | 1478.00rpm |

TABLE II. BLOCKED ROTOR TEST

| Blocked Rotor Test | |
|---|---|
| $V_{BR(LL)}$ | 80.00V |
| $V_{BRø}$ | 46.19V |
| $I_{BR}$ | 5.50A |
| $P_{BR}$ | 300.00W |
| $P_{ø}$ | 100.00W |
| N | 0.00rpm |

TABLE III. DC RESISTANCE TEST

| Phase Position | Rated Voltage (V) | Rated Current (I) | Resistance Value (Ω) |
|---|---|---|---|
| Phase A | 4.00 | 3.10 | 1.90 |
| Phase B | 4 .00 | 3.10 | 1.91 |
| Phase C | 4 .00 | 3.10 | 1.90 |

Therefore, with all experimental value as shown in table I table II, and table III the value of the parameters in the equivalent circuit, for the induction machine per phase was calculated in figure 6.

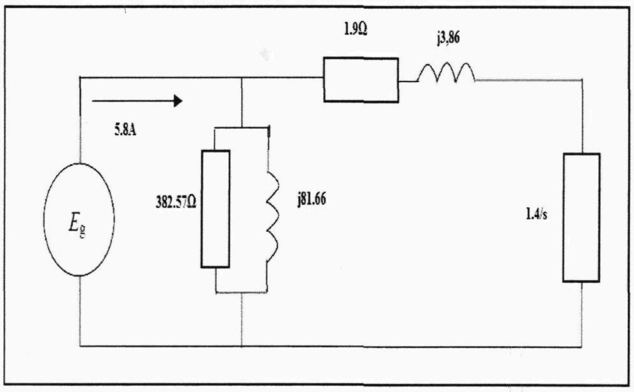


Figure 6. Approximate Equivalent Circuit

### *B. Simulation*

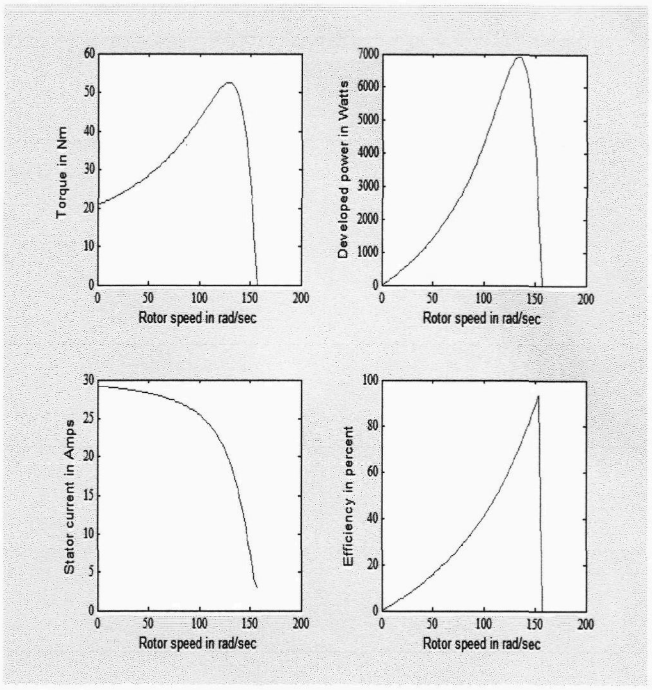


Figure 7. Steady-state characteristic of three-phase

MATLAB was used to model the three-phase induction machine and the steady-state characteristics is plotted to verify that the machinery parameters are similar to the actual three-phase induction machine. The machine parameters were setup and disturbances were simulated to display the characteristic in terms of torque, current, power and efficiency against the rotor speed. Operating from rated frequency and sinusoidal voltage supply, rated torque is 21.14Nm. The considerably lower starting torque for the constant current supply case is because the values of airgap voltage (or Flux) and rotor current are relatively lower than in the constant voltage supply at starting. During the initial starting current there is large current occur due to transient phenomena which is 29.2A.The efficiency for induction machine is 93.36% and for the develop power can be as high as 6.97kW.The steady-state characteristic of the three-phase induction motor is shown in figure 7.

Two cases of simulation are done in these projects which are start-up from standstill at fixed frequency and for speed cycling at no-load. Each case produces six graphical displays:

1. Stator current vs time (Ia vs t)
2. Electromagnetic torque vs time (Tem vs t)
3. Rotor flux vs time (ω vs t)
4. Synchronous speed vs time ($\omega_s$vs t)
5. Rotor speed vs time ($\omega_r$ vs t)
6. Phase voltage vs time ($V_{ag}$ vs t)

The time duration for the simulation is 2 seconds and values of the mechanical speed are generated by the Simulink m-files. In the Simulink, the externally applied mechanical torque for the time array is running at rated load torque during the 0.75s to 1.0s and from 1.25s to 1.5s. It is running at half rated load torque from 1.0s to 1.25s marking to demonstrate the transient behavior at fixed reference speed.

### *1) Start-up and Loading Transients with Field-Oriented Control*

The results for start-up from standstill at fixed frequency are shown in figure 8 and figure 9 below:

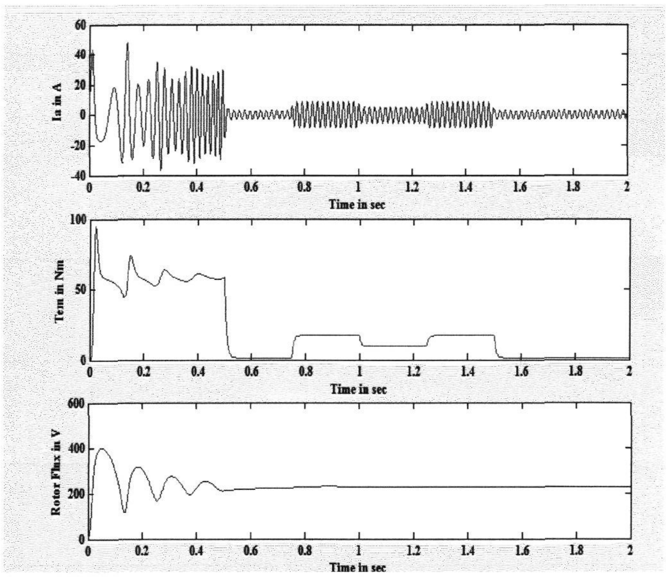


Figure 8. Transient Behavior of Stator Current, Torque and Rotor Flux for start-up and loading transients with field-oriented control

Based on the figure 8 above there is an increase and decrease of current while the loading is simulated. During the initial starting from stationery there is a large transient occur which is 43.24A. This transient starting current can be as high as three to eight times as the rated value which might cause a glitch in the power system that supplied the electrical power. Further, because of the absence of any field winding circuit in an induction machine, the long transient period of a synchronous machine will be absent. Therefore current in an induction machine will be large but will decay quickly.

The mechanical torque in the figure 8 showed a high transient increase due to the high start-up current from stationery position. The initial start up torque was 94.45Nm. The mechanical torque graph showed the increase and decrease of torque due to load disturbance at the specified timing.

The rotor flux is relatively stable except for the larger initial transient during start up of the rotor flux from standstill which is 400.2V.This increase in rotor flux transient behavior was mechanically undesirable.

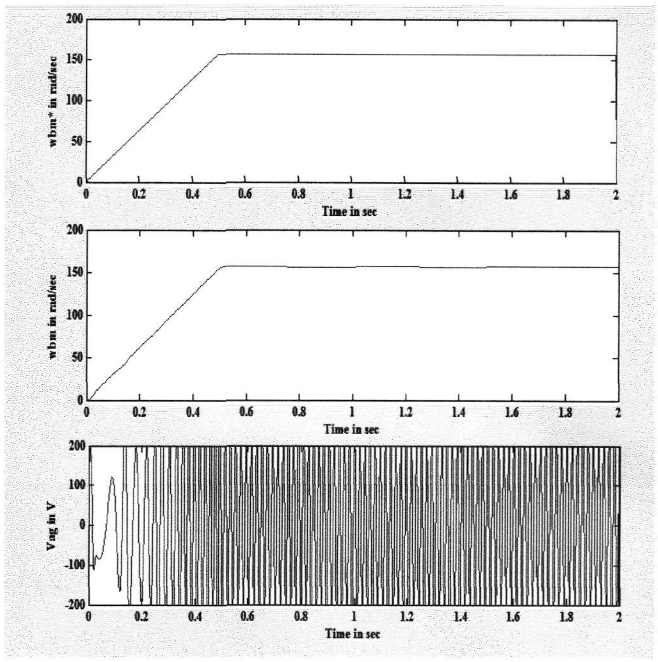


Figure 9. Transient Behavior of Mechanical Frequency, Base Mechanical Frequency and Phase Voltage in Stator for start-up and loading transients with field-oriented control

Figure 9 above showed the input reference speed in mechanical rad/sec (wbm$^*$) whereas wbm is the rotor speed in mechanical rad/sec. Figure 9 shows the response where wbm* was initially ramped up from zero to rated value at 0.5 s, thereafter wbm* was held fixed at the rated value and then a sequence of step changes in the applied mechanical torque (load) was made. The $V_{ag}$ represents the phase voltage in the stator and is largely inaccurate as it was rather high in voltage.

### *2) Response to Changes in Reference Speed with No-Load*

The result for speed cycling at no-load is shown below in figure 10 and figure 11. For this second simulation, the time duration was 2 seconds and values of the mechanical speed were generated by the Simulink m-files with a change in control settings. In the Simulink, the externally applied mechanical torque for the time array was running at rated load torque during start up to 1.0s and was running at half the rated torque from 1.0s to 1.5s. It ran at no-load torque from 1.5s to 2.0s marking to demonstrate the transient behavior at fixed reference speed.

The simulation for speed cycling at no-load, the estimated starting current is 43.53A for initial start up which is almost seven larger than rated current. This large transient starting current can cause damage to the induction machine.

The mechanical torque showed a large transient increase due to the high start up current from stationery position. The initial start up torque was 94.6Nm.The mechanical torque graph showed an increased and decreased of torque due to load disturbance.

The rotor flux showed a large initial transient during the start up of the rotor flux from standstill which is 400.8V. This transient behavior shows a harmonic and stabilizes at 0.8s.This increase in rotor flux transient behavior is undesirable mechanical.

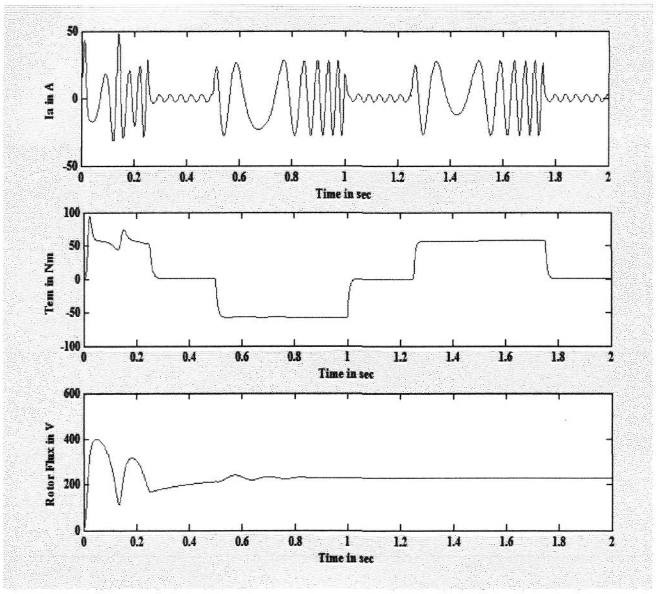


Figure 10. Transient Behavior of Stator Current, Torque and Rotor Flux for Response to Changes in Reference Speed with No-Load

Figure 11 shows the response for no-load (that is no applied mechanical torque).The input reference speed in mechanical rad/sec (wbm*) whereas wbm is the rotor speed in mechanical rad/sec when wbm* was being ramped up from zero to rated value in one direction and then ramped down to rated in the opposite direction. The $V_{ag}$ represented the phase voltage in the stator and was largely inaccurate as it was rather high in voltage.

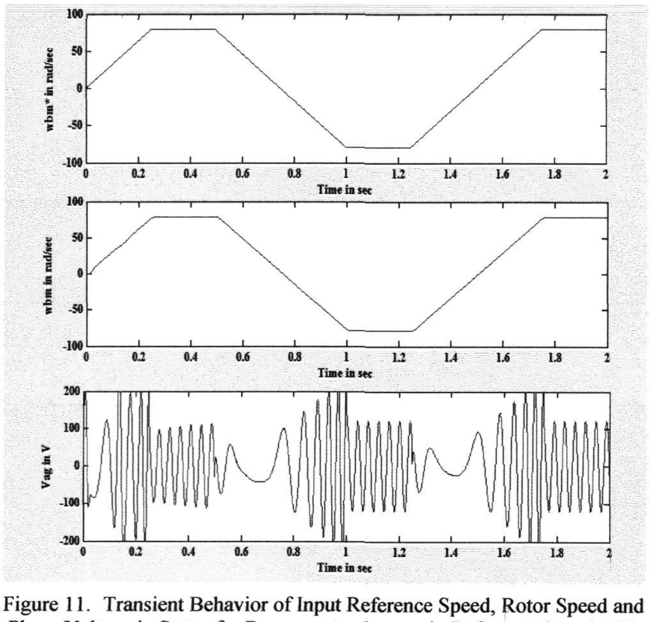


Figure 11. Transient Behavior of Input Reference Speed, Rotor Speed and Phase Voltage in Stator for Response to changes in Reference Speed with No-Load

## IV. CONCLUSION

In this project, implementation of modular simulink mode for induction motor simulation has been introduced. An increase or decrease in load will trigger a transient response from a three-phase induction machine. These *transient phenomena existed in all three-phase induction* machines, and had posted tremendous challenges to the power system engineers. From the first simulation, which for start-up and loading transients with field-oriented control start-up, transient can be observed in most graphical displays. As the simulation was not running at full load during the start up, the transient harmonics was only minimal. When response to changes in refence speed with no-load, the pulsation in Vag and Is, those pulsations are in response to changes in speed reference (1st trace of both case ) In , the speed reference was held constant after it was ramped up to 200 rad/s. It showed extremely high transient for the current in the stator and the rotor flux. Such abnormally high transient could only be observed in simulation. If it were in a real life situation, there would be mechanical damages to the machine or a trip in the main circuit breaker (MCB) of the electricity supply.

## V. FUTURE DEVELOPMENT

Although this thesis has provided significant study on the simulation of the a three-phase induction machine using MATLAB Simulink, the other areas to be explored for future studies can be:

1. Simulation on the "Real-Life" three-phase induction machine found in Power Machine Lab of Universiti Teknologi Mara. A comparison of the experimental and simulated result can subsequently be achieved.
2. Enhancing of the MATLAB Simulink program with a Graphical User Interface (GUI) to facilitate easy control for settings.
3. Further detailed analysis of the three-phase induction machine behaviour need to be found to create a more "Real-Like" model to increase the accuracy of the simulation.

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