Simulation of Single Phase AC Induction Motor (Capacitor Start) By Using Matlab Simulink

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Abstract – **This technical report will discuss the basic operation of an AC single phase induction motor and the capacitor start single phase AC induction motor. Besides that, this report also will discuss about the characteristic of single phase induction motor for the capacitor start type including the torque, speed and current. For this project, Matlab Simulink will be used as a simulator.**

Keywords-component; Capacitor Start; Single Phase AC Induction Motors; Matlab Simulink

I. INTRODUCTION

The AC induction motor is often referred to as the workhorse of the industry because it offers user simple, rugged construction, easy maintenance and cost-effective pricing. These factors have promoted standardize and development of a manufacturing infrastructure that has led to a vast installed base of motors: more than 90% of all motors used in worldwide industry are AC induction motors. They run at essentially constant speed from zero to full load.

AC induction motors have for many years been reliable workhorses in converting electricity into rotating power. The last 20 years has seen increasing usage of these motor with adjustable frequency controls to add variable speed capability to AC motors. While AC motors were initially applied to relatively simple variable speed applications (such as varying the flow rate of a fan or pump), advances in AC motors and control technology have allowed their use in higher performance applications.

There are several types of AC induction motors available in the market. Different motors are suitable for different application. Although AC induction motors are easier to design than DC motors, the speed and the torque control in various types of AC induction motor require a greater understanding of the design and the characteristics of these motors [6].

Single phase induction motors are used very widely in many equipment's in houses, offices and factories. They are used only in small sizes, less than 2 horse power and mostly in the fractional horse power range. They are relatively simple in construction but considerably more difficult to analyse than 3-phase induction motors. Single phase induction motors in the 1/8 to 3/4 horse power range are very widely used for fans, washing machines, refrigerators, blowers, centrifugal pumps and etc. Single phase induction motors operate at low power factors and are less efficient than 3-phase induction motors [2].
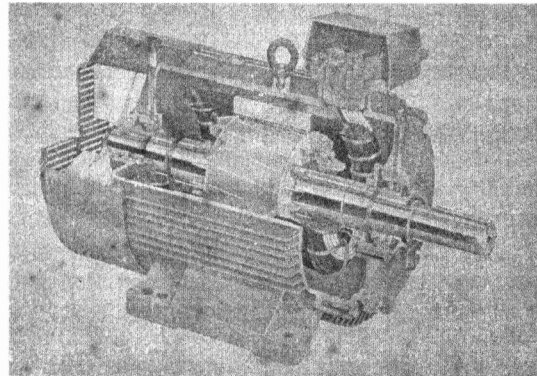

Figure 1. AC Induction Motor

Generally, induction motor is categorized based on the number of stator winding. There are:-

- Single-Phase Induction Motor.
- Three-Phase Induction Motor.

Single phase induction motor can be divided into 5 types. The type of single phase induction motor are Split Phase AC Induction Motor, Capacitor Start AC Induction Motor, Permanent Split Capacitor (Capacitor Run) Induction Motor, Capacitor Start/Capacitor Run AC Induction Motor and the last one is Shaded-Pole AC Induction Motor. However, this technical report will discuss about the Capacitor Start AC Induction Motor only.

For this project, the Matlab Simulink software is used. Matlab is becoming increasingly popular among students, technicians, researchers and engineers because of its features such as interactive work mode, immediate graphing facilities, built-in functions and the possibility of adding user written functions and simple programming. For the new version of Matlab, it's become with new features which are calling Simulink. This feature is very easy to use and can save the time to get the result very fast.

A. Basic Operation of Single Phase Induction Motor Capacitor Start Type

The single-phase AC induction motor best fits this description. The single-phase induction motor is not self-starting. In order to make the motor start rotating, some arrangement is required so that the motor produces a starting torque [6].

As the name suggests, this type of motor has only one stator winding (main winding) and operates with a single-phase power supply. In all single-phase induction motors, the rotor is the squirrel cage type. When the motor is connected to a single-phase power supply, the main winding carries an alternating current. This current produces a pulsating magnetic field [6].

Due to induction, the rotor is energized. As the main magnetic field is pulsating, the torque necessary for the motor rotation is not generated. This will cause the rotor to vibrate, but not to rotate. Hence, the single-phase induction motor is required to have a starting mechanism that can provide the starting kick for the motor to rotate [6].
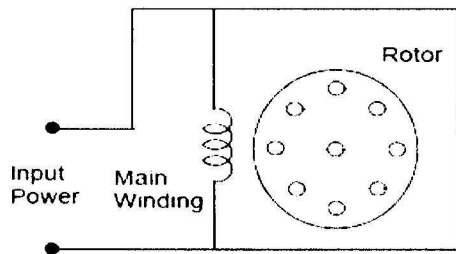
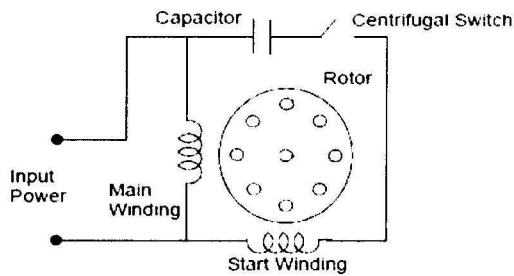Figure 2. Single Phase AC Induction Motor without Start Mechanism

Figure 3. Single Phase AC Induction Motor with Start Mechanism

The starting mechanism of the single-phase induction motor is mainly an additional stator winding (start/auxiliary winding) as shown in Figure 3. The start winding can have a series capacitor and/or a centrifugal switch.

When the supply voltage is applied, current in the main winding lags the supply voltage due to the main winding impedance. At the same time, current in the start winding leads/lags the supply voltage depending on the starting mechanism impedance. Interaction between magnetic fields generated by the main winding and the starting mechanism generates a resultant magnetic field rotating in one direction. The motor starts rotating in the direction of the resultant magnetic field [6].

Once the motor reaches about 75% of its rated speed, a centrifugal switch disconnects the start winding. From this point on, the single-phase motor can maintain sufficient torque to operate on its own [6].
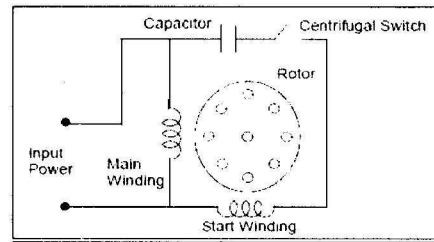

Figure 4. Capacitor Start AC Induction Motor

Capacitor Start Induction Motor is a modified split-phase motor with a capacitor in series with the start winding to provide a start "boost". Like the split-phase motor, the capacitor start motor also has a centrifugal switch which disconnects the start winding and the capacitor when the motor reaches about 75% of the rated speed. Since the capacitor is in series with the start circuit, it creates more starting torque, typically 200% to 400% of the rated torque. And the starting current, usually 450% to 575% of the rated current, is much lower than the split-phase due to the larger wire in the start circuit [6].

A modified version of the capacitor start motor is the resistance start motor. In this motor type, the starting capacitor is replaced by a resistor. The resistance start motor is used in applications where the starting torque requirement is less than that provided by the capacitor start motor. Apart from the cost, this motor does not offer any major advantage over the capacitor start motor. They are used in a wide range of belt-drive applications like small conveyers, large blowers and pumps, as well as many direct-drive or geared applications [6].

II. SCOPE OF STUDY

Several scope of works involved in this project as follows:

- Study the concept of induction motor, basic operation and the characteristic.
- Learn to use Matlab Simulink software in order to develop the design of the project.
- Run the simulation and observed the results.
- Detected any problems and overcome it.
- Analysed the result and make discussion.

III. METHODOLOGY

A. Matlab Simulink software

Matlab R2008a version 7.6.0 has been selected as the software used in the simulation process involved in this project in order to determine the performance of single phase induction motor for capacitor start. Matlab Simulink is software package for modelling, simulating and analysing dynamic systems facilitated by the graphical interface and the library of templates or function blocks that are commonly used in mathematical descriptions of dynamic systems. The step of using Matlab Simulink is defining a model or mathematical representation and the parameters of your system, picking a suitable integration method, and setting up the run condition which is run-time and initial conditions.

2

In creating a Simulink process, the important part is block of the system which it can be combining together to form a simulation. So then construction of simulation can be made by follow the rearranged block of the model.

Before start and running the simulation, the start time and stop time of simulation must be specified. The all parameter also must be set. To start the simulation, the button start located under the main menu heading simulation of either the main Simulink screen or the model screen must be pushed. Prior to the simulation, the scope must be placed and open up the clock template to monitor the progress of the simulation.

Figure 5. Matlab Simulink Display Interface
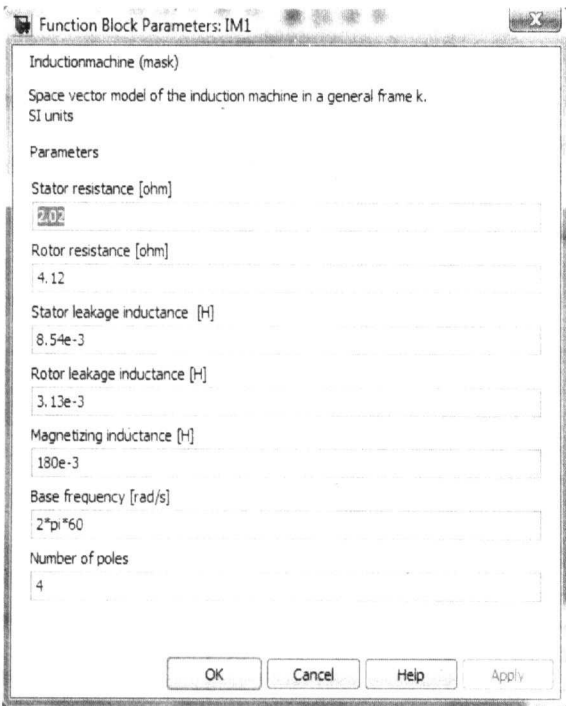
Figure 6. Initial Value for Starting the Simulation

B. Flow chart for the simulation.
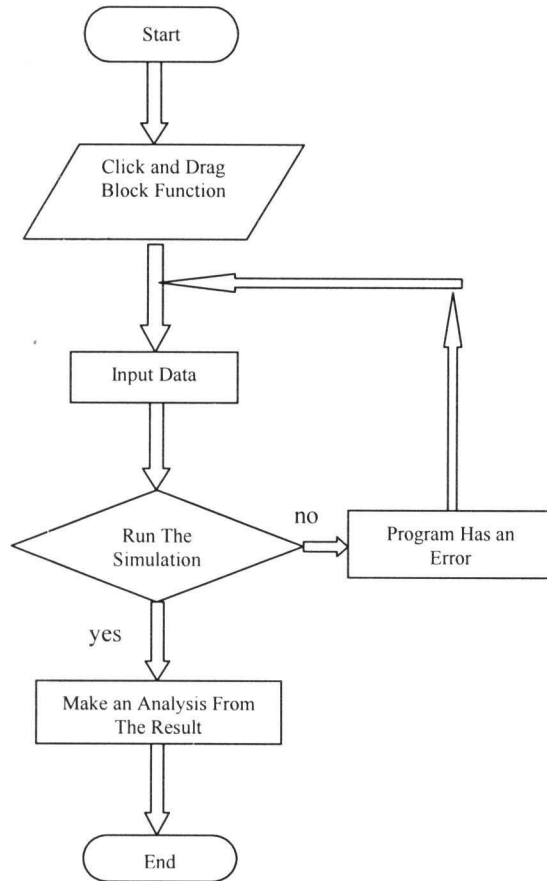
Figure 7. Flow Chart for the Simulation

IV. RESULT AND DISCUSSION

Figure 4 show the simulator of capacitor start single phase induction motor. Several block diagrams involved when making this simulator such as Induction Machine, Integrator, Gain, Scope, Sum, Out Port, Subsystem, XY Graph and etc.
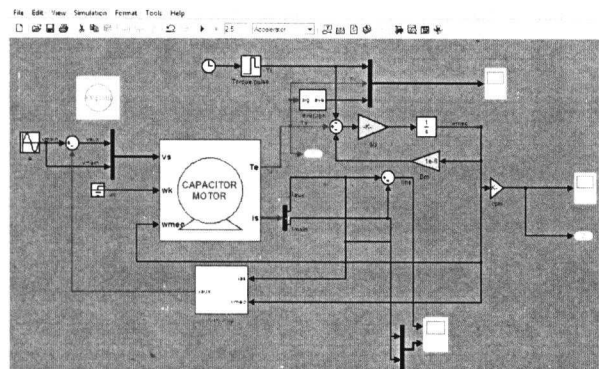

Figure 8. Simulator of Capacitor Start Single Phase Induction Motor

Before running this simulator, the initial setting for the several parameters is set. The setting of the parameter as the following table:

3

TABLE I.   TABLE OF INITIAL VALUE

Parameter	Value (Unit)
Stator Resistance, Rs	2.02 Ω
Rotor Resistance, Rr	4.12 Ω
Stator Leakage Inductance, Ls	8.54e-3 H
Rotor Leakage Inductance, Lr	3.13e-3 H
Magnetizing Inductance, Lm	180e-3 H
Base Frequency, Fb	2π60 rad/s
Number of Pole	4
Start Capacitance	183e-6 F
Speed When Switch Disconnects	3/4 pu

For the mechanical system, the equation as below:

$$Te = Jd\omega/dt + B\omega + TL \tag{1}$$

$$(Te - TL - B\omega) \times 1/J \times 1/s = \omega \tag{2}$$

Assume: K=1/J as a gain and 1/s is an integrator.

Where: TL= applied load (in the form of steps)

Before running this simulator, we also set the value for the parameter of gain and other parameter as below:

TABLE II.   TABLE OF INITIAL VALUE FOR GAIN

Parameter	Value
K(1/J)	1/0.0147
B	1e-6
K(rpm)	30/π

For this project, the time for running the simulation is set to 2.5 second.

A.   *Speed versus Time Graph*
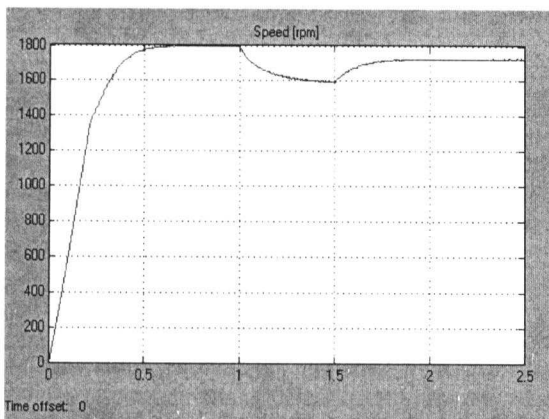
Figure 9. Speed versus Time

From the graph, the result show the speed initially increase rapidly. At the time of 0.5 second the graph show the speed start to constant before start to decrease slowly after 1 second. When times reach 1.5 second the speed show the increase slowly before start to constant around 1.8 second.
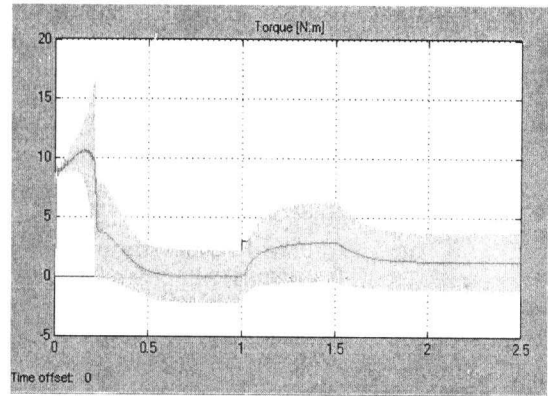
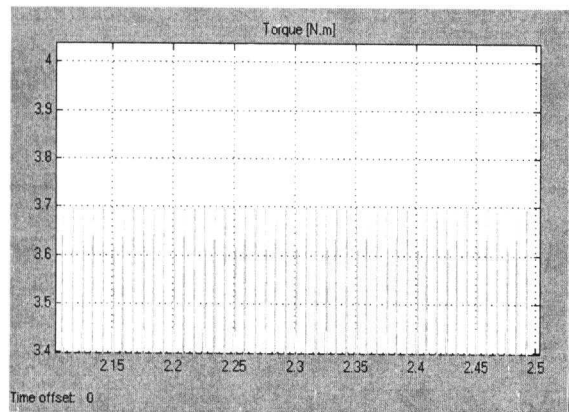B.   *Torque versus Time Graph*

Figure 10. Torque versus Time

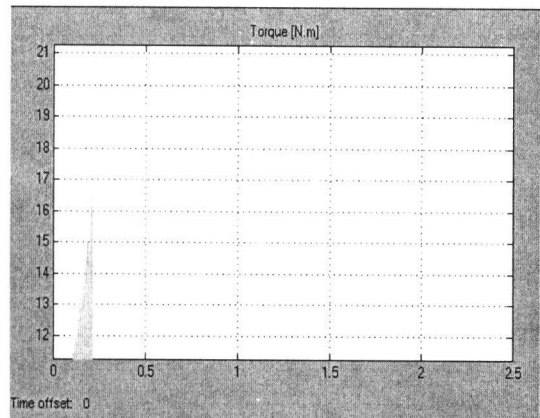Figure 11. Torque versus Time at Rated

Figure 12. Torque versus Time at Starting

After running the simulation, the graph shows the high starting torque at the starting before start to decrease around 0.25 second. The torque still declining until no torque when time reaches 0.5 second to 1 second. After 1 second, the torque shows the increasing until 3 Nm at 1.5 second before start to decline until 2.5 second. For the graph in figure 11, the graph show the torque versus time at the rated with the maximum rated value is 3.7 N.m while the graph in figure 12 show the torque versus time at the starting with the maximum rated value is 16.5 N.m. From these both graph, it

4

show that the high torque at the starting with approximately 400% increasing from the torque rated.

% of starting torque = (16.5 × 100) / 3.7
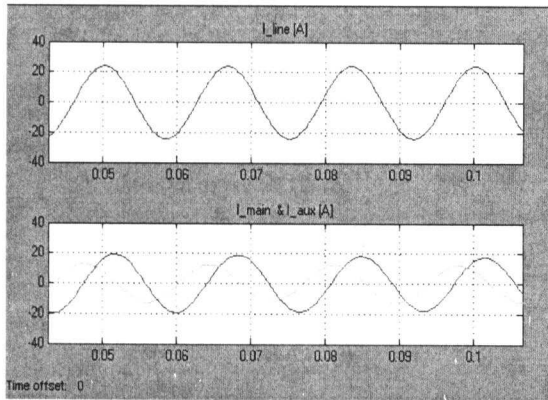= 445%

C. Current versus Time Graph

Figure 13. Line Current, Main Current and Auxiliary Current Versus Time
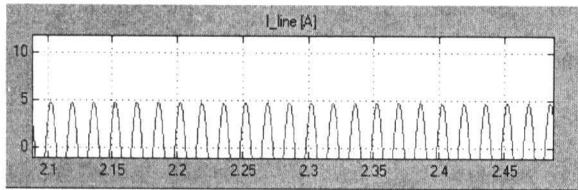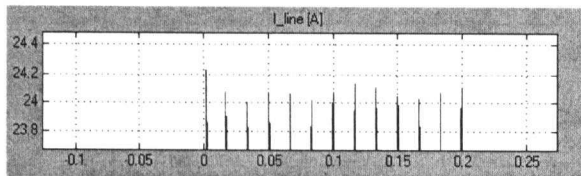

Figure 14. Line Current versus Time at Rated

Figure 15. Line Current versus Time at Starting

The graphs above show the line current, auxiliary current and main current versus time. For the line current versus time, the result show the constant sinusoidal wave from starting until time reach 2.5 seconds with the current amplitude approximately of 20 Ampere.

For the graph of main current versus time and auxiliary current, the result show the different phase for both. The difference phase between start winding current and main winding current is between 80 degrees. When the motor reaches about 75% of the full load speed, the centrifugal switch opens and thus disconnecting the stator winding and the capacitor from the main winding. It is important to point out from the phases diagram that the phase difference between main winding and start winding is almost 80 degrees as against 30 degrees in a split-phase induction motor. It is evident from the phase's diagram that the current through the start winding current Is through the main winding current Im lags the applied voltage. It is to be appreciated that the resultant current I, is small and is almost in phase with the applied voltage V [3].

For the graph in figure 14, the graph show the line current versus time at the rated with the maximum rated value is 5A while the graph in figure 15 show the line current versus time at the starting with the maximum rated value is 24A. From these both graph, it show that the high current at the starting with approximately 480% increasing from the current rated.

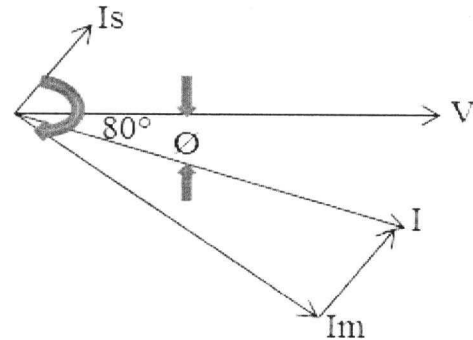% of starting current = (24 × 100) / 5
= 480%

Figure 16. Phasor Diagram for Current and Voltage
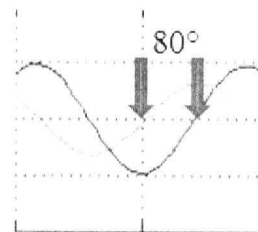

Figure 17. Difference Phase for Starting Current and Main Current
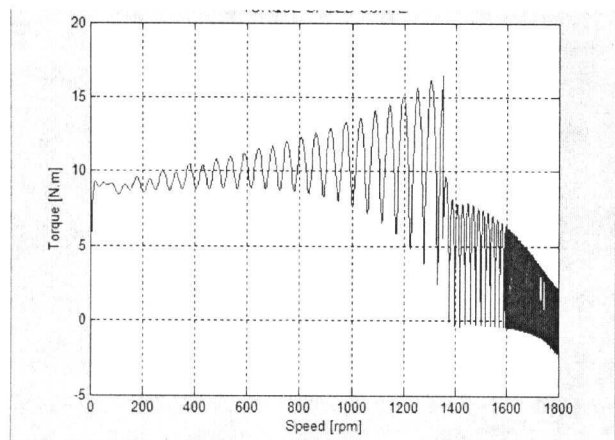
D. Torque versus Speed Graph

Figure 18. Torque versus Speed Graph

The graph shows the result of torque versus speed. From the observation, the result shows the torque increases due to speed increase. At the 75% rated, which is approximate of 1350 rpm, torque drops to 8 Nm due to

5

centrifugal switch that are disconnect from the start winding at 75% rated.

V. Conclusion

After doing this design on simulation of single phase AC induction motor for the capacitor type by using Matlab Simulink, the conclusion from the research can be drawn as the followings:

- The result of the characteristic from the simulation is approximately same with the theoretical result.
- Knowing the basic operation of the single phase AC induction motor and the other type of single phase AC induction motor.
- Understanding the process of simulation by using Matlab Simulink from the creating process until running the simulation and get the result from the simulation.
- By the used of mathematical model, it will assist in the understanding of dynamic modelling of the single phase AC induction motor for capacitor start type.
- By using Matlab Simulink, it will help the engineers in providing a faster solution to the problems in the new product design of machine with minimum errors.

VI. Future Development

In the study conducted, it was capacitor start AC induction motor simulation by using Matlab Simulink. For the future development, further works could be extended to Split Phase AC Induction Motor, Permanent Split Capacitor (Capacitor Run) Induction Motor, Capacitor Start/Capacitor Run AC Induction Motor and Shaded-Pole AC Induction Motor in the same context.

Acknowledgement

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