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Comparative analysis in the performance of the FH 90 squirrel cage motor using MP1015 variable frequency inverter drive and normal frequency supply

By

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Abstract:

Three-phase electric motors are very rugged machines that have to withstand almost endless abuse from end users and still continue to perform to specification. There are several variables of which end user is often unaware. Many have significant effect on the general performance of the motor like the terminal voltage and the application of various torques. In this study, the researchers will conduct experiments in determining the performance of the FH 90 Squirrel Cage Motor first by using the normal frequency supply, second with the use MP1015 Variable Frequency Inverter Drive in the input terminals and third with the aid of a thermistor in the rotor windings. In the third experiment, the researchers analyzed the effect of the temperature in the performance of the FH 90 motor by inserting a thermistor in the rotor windings. The performance of the FH 90 motor can be determined by plotting the performance curves in each experiment. These are the curves of the speed, torque, ampere, temperature and voltage. Based from the results, when running in a normal supply frequency, the speed of the FH 90 is constant and the torque is varied to obtain the desired results. Therefore, the output power, current and efficiency is in proportion to the speed and tends to drop off when the motor stalls. In the second experiment, when driven using MP1015 VFID, the torque is constant and the frequency is varied to obtain the required results. It is observe that when using the MP1015, the torque is constant when the supply frequency is varied from 48-90 Hz this is because the ratio of the voltage and frequency is constant throughout the experiment. In the third procedure, it is observed that when using MP 1015 VFID in the FH 90 motor , the torque of the load is constant and the temperature rises only from 20-30 Hz and from 80 to 90 Hz. Beyond these values, the motor experiences a rise in temperature and thus more power losses has been developed. But when the motor is expected to run in normal frequency supply, the FH 90 motor experiences constant rise in temperature from 0.1 N-m to 0.5 N-m. Thus, the motor must be provided with a cooling fan to prevent it from harmful effects of overheating.

Keywords:

FH 90, MP1015 Variable Frequency Inverter

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1. Introduction:

Inherently, alternating current (AC) motors are not as well as suited to variable-speed applications as are dc motors, because their speed cannot be satisfactorily controlled by simple voltage variation. Reducing the supply voltage to a 60-Hz three-phase induction motor will reduce its speed-regulating ability. That is, an ac induction motor operating at reduced voltage is unable to maintain a reasonably steady shaft speed in the face of slight changes in torque demand imposed by the mechanical load [1]. The AC motor that will be used by the researchers is the FH90 Squirrel Cage Induction Motor. This three-phase Cage Rotor Induction Motor is probably the most frequently used of all electrical drives, especially in industrial applications at higher power levels. The popularity of this machine is due to a combination of its relatively low cost, robust construction, compact size, reliability and minimal servicing/maintenance requirement [2].

In the Electrical Engineering Laboratory of Mapua Institute of Technology there is equipment called the MP1015 Variable Frequency Inverter Drive (VFID). This Variable Frequency Inverter Drive was developed to provide with the equipment and facilities, which are necessary to investigate and understand the principles involved with practical frequency inverter drives. One of the equipment, which is compatible with the MP1015 VFID is the THQ MK1V Electrical Machines Test Bed that serves as the main supply of voltage and torque for the FH 90 AC motor. The MP1015 VFID can be substituted for the three phase input to control the speed of the AC induction motor at constant torque. The major problem of the AC induction motor is its limitation to many applications. One of them is that the speed of rotation is dependent upon the mains supply frequency. Since the mains supply frequency is fixed, normally 50 to 60 Hz, the speed of rotation is considered to be constant. Another important consideration to be made when operating an induction motor is the cooling of the windings and bearings when there is a sudden increase of loading. As the load of the motor increases, the (I 2 R) losses will be taken into account and will greatly affect the motors efficiency [3]. Thus, a cooling fan must be designed within the machine casing to decrease these losses and maintain the temperature versus load conditions. Because of these problems, the researchers will make various experiments using the MP1015 VFID and other available resources in determining the performance of the ac induction motor.

The researchers will generate the performance curves of the FHJ90 ac motor using the normal voltage supply (220V, 60Hz) and by varying the frequency (from 5 to 100 Hz) using the MP1015 VFID. Another goal is to conduct an experiment regarding the possible effect of the MP1015 VFID in the Temperature vs. Torque performance of the FH90. Thus, these experiments are essential in determining the performance curves of the AC induction motor. The results of these graphs will show the advantages of installing VFD’s in ac induction motors for possible energy savings, easy process controls and for less maintenance cost.

2. Methodology

The first part of this research is to study the basic principles, operation and safety of the equipments to be used in this research. The equipments used are the THQ MK1V Electrical Machines Trainer, Data Management System 2 (DMS 2), FH 90 Squirrel Cage Motor, MP1015 VFID and Yokogawa Oscilloscope. After studying the operation of the different equipments that will be used in this research, the researchers will conduct series of experiments in determining the performance of the AC induction motor. The three experiments for the performance of the AC induction motor are: a.) with input supply of 220 V, 60 Hz b.) with varying frequency of 10 Hz – 100Hz c.) with thermistor in the body of the AC motor in determining the temperature vs. torque curves.

I. With input supply of 220 V, 60 Hz

The set-up of this experiment was shown in figure 1. The induction motor is connected to the THQ MK1V Trainer and to the three phase line. The three phase input (220, 60Hz) in the AC motor comes from the main panel supply of the THQ MK1V. The dashed lines represent the DMS 2 equipment that will be used for the readings of amperes, voltage and watts of the motor. The DMS 2 will be connected to the trainer and will be interfaced to the computer. The computer will simulate the readings using DMS 2 software in digital form. After setting up the experiment, the torque must be adjusted 0.05 N-m at a time for smoother plotting of the graphs. The researchers will take the readings of the amperes, speed, voltage, and torque and power factor from the DMS 2 software. If analog devices were taken into consideration, the other parameters like efficiency, power input, power output and power factor (pf) can be computed as follows:

Calculations:

Po = (2 * л * speed * torque) / 60 (1)
VA = √3 * voltage input * current input (2)
Pin = Wa + Wb (3)
Efficiency = (Po / Pin) * 100% (4)
pf = (Po / VA) * 100% (5)

After computing all of the required values, the researchers will graph the Po, efficiency, power factor (pf), torque and current versus speed. Since the speed in this experiment is the independent variable, thus the speed is the x-coordinate or abscissa. An analysis of the results will be discussed after these performance graphs were obtained.

II. With varying frequency of 5 – 90 Hz.

This experiment is also similar to experiment number 1, but the difference is the input supply was varied by the MP 1015 VFID. Torque was not adjusted in this experiment instead the frequency must be varied every 5 Hz while the torque is primarily constant with a value of 0.3 N-m. The output waveforms of each result will be simulated using the Yokogawa Oscilloscope. This state of the art device has an internal floppy disk drive to save the files in either in bitmap, jpeg or gif format. The Yokogawa Oscilloscope is connected across the output supply of the TQ Test bed via a 5 pin cord connector. Similar to experiment no.1 the performance graphs of this experiment will be explained. These are the graphs of Pin, efficiency, speed, current and power factor vs. torque was obtained. The torque in this experiment was regarded as the abscissa of this experiment because the torque is held constant. An analysis of the results will be discussed after these performance graphs were obtained.

III. With the aid of thermistor in determining the behavior of stator windings due to extreme temperature

In this experiment, the researchers will insert a thermistor inside the FH 90 motor windings. The purpose of this method is to measure the temperature of the windings when it is operated during the normal supply and with the aid of MP1015. This experiment is subdivided into two and they are experiment 3.A and experiment 3.B.

A. Normal frequency supply

In this procedure, the researchers will do the same set-up with procedure I and II but the difference is a thermistor is inserted in the windings of the AC squirrel cage motor. The FH90 will be running at a constant speed while applying 0.1 N-m torque. While the motor is still running at 60 Hz, the initial temperature will be measured with a value of 26.5 degree Celsius and a torque value of 0.1 Nm. When the initial value of the temperature is reached, the value of the torque must be adjusted to 0.1 N-m per trial up to the point where the motor will stall. After every trial, the final temperature must be measured and must be cooled of for 5 minutes for every trial. The purpose of this procedure is to maintain the temperature up to 26.5 degree Celsius and to cool off the heat produce during the last trial. Again, the measured values of the voltage, speed torque and current can be determined using the DMS 2 software. After determining the values from the DMS 2 software, the graph of the torque vs. the speed will be determined to analyzed the behavior of the windings every 0.1 N-m torque. After finishing every trial in the experiment the researchers will measure the final temperature and will compute for the temperature difference, using the formula:

Tdiff = Tinitial – Tfinal (6)

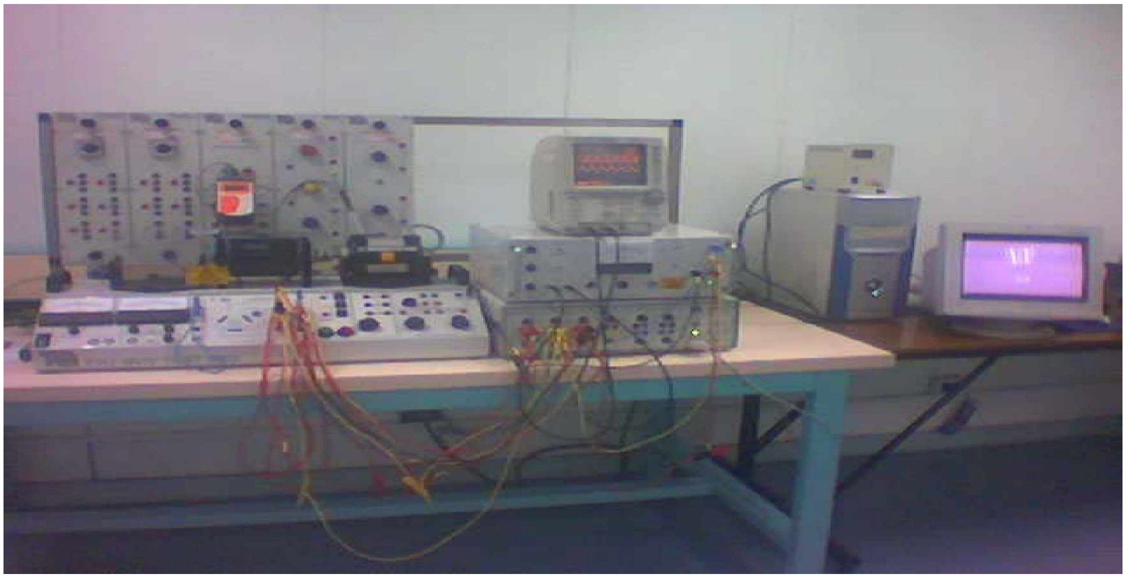


Figure (1): *Complete set-up of the experiment*

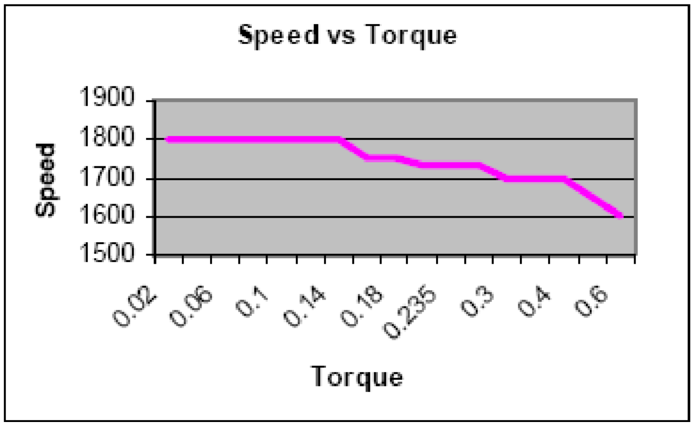
B. With varying frequency of (5-90 Hz)

Similar to the procedures of 3.a, the researchers will apply 5 to 90 Hz frequency in the FH 90 motor. The initial temperature will also be 26.5 degree Celsius and the initial torque during the normal frequency supply is 0.3 N-m. At the instant of starting the motor must first reached the 60 Hz, 0.3 N-m value and 26.5 Celsius temperature before applying the desired frequency. The purpose of this procedure is to maintain the efficiency of the motor and to have accurate results. For every five minutes, the values of the torque, current, speed and voltage will be measured by the help of the DMS 2 software. Afterwards, the graph of the speed vs. the temperature can be analyzed and compared to the previous results of procedure 3.A.

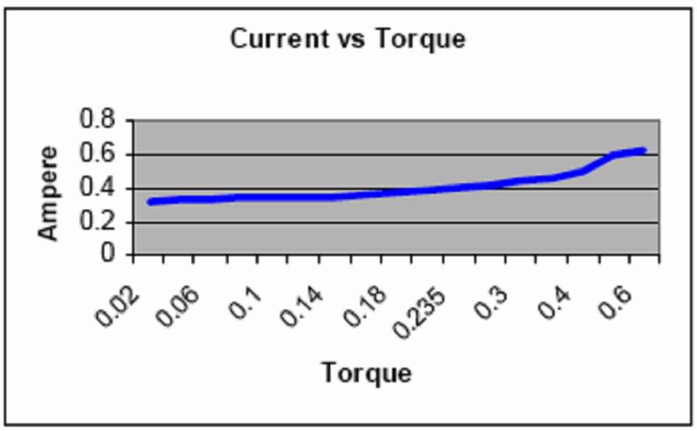
3. Results and Discussion

I. With input supply of 220 V, 60 Hz

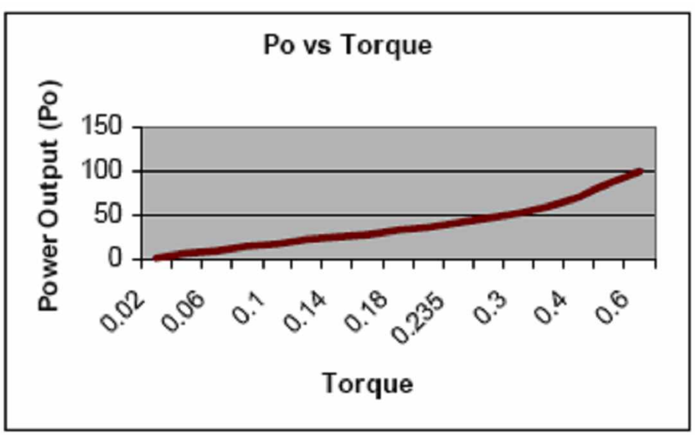
The corresponding performance curves were shown in graphs 1 to graphs 6. The adjustment of the torque is 0.02 N-m for the first 12 trial and 0.1 N-m for the last 4 trials. The full load torque or the stall torque of the FH90 AC motor is 0.6 N-m. Based from the graphical result of graph no.1, the speed is held constant after the first 7 trials because the windings is unsaturated and will drop off because the current in the rotor windings was saturated (*saturated* means that the voltage increases in proportion to the speed or flux in the field windings of the motor until it reaches a limit point or *unsaturated* which there is a certain level that the flow of current will become constant in the field windings, because the resistance cannot oppose anymore the flow of current because it reaches it limit. Thus, the opposition will depend upon the type of material used in the windings so that when the limit is reached the voltage tends to drop off to a certain value). Therefore, the graph of speed vs. torque will tend to fall. Based form graph no. 2, the current tends to have a concave upward curve, since the torque is proportional to the flow of current the value of the current tends to increase and tends to become constant at a certain level because of the saturation of windings. Based from graph no. 3, the Po is proportional to the flow of current and the torque of the load and thus the expected curve is in proportion to the load torque. The maximum efficiency of the motor is only 68% this is because during the time that this experiment was conducted the researchers did not use the DMS 2 software. Thus, a slight error can occur in the A3 and V3 meters because these equipments were not calibrated properly. Based from graphs 4 and 5, the pf vs. torque graph was a concave downward graph and the pf of the motor is expected to be 67% only while in the efficiency vs. torque graph, the graph is in proportion to the torque and tends to drop off. This is because the when the torque was increase, the losses in the motor will also increase or the I2R losses. Thus, the higher the voltage drops, the higher the Power losses and therefore it lowers the efficiency.



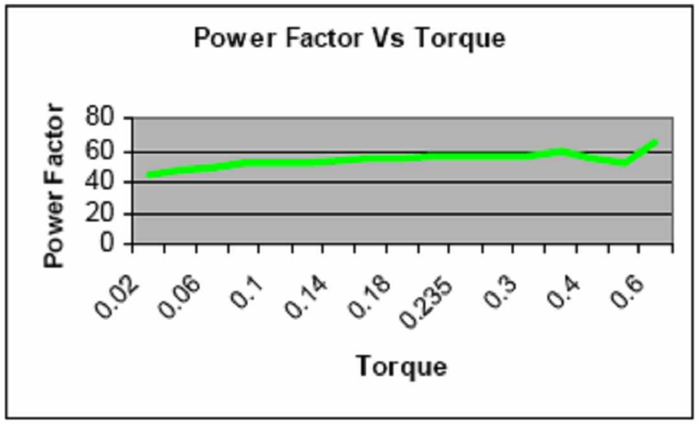
Graph (1). Speed Vs. Torque



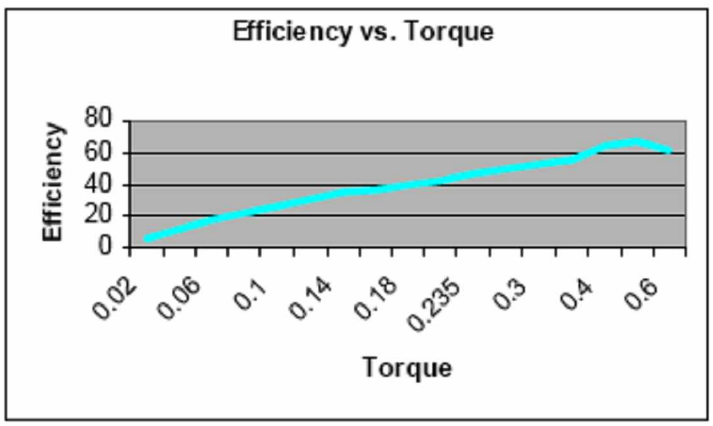
Graph (2). Ampere Vs. Torque



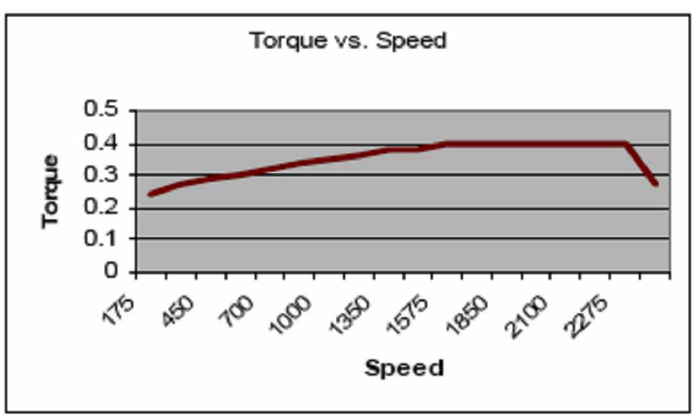
Graph (3). Pout Vs. Torque



Graph (4). pf Vs. Torque



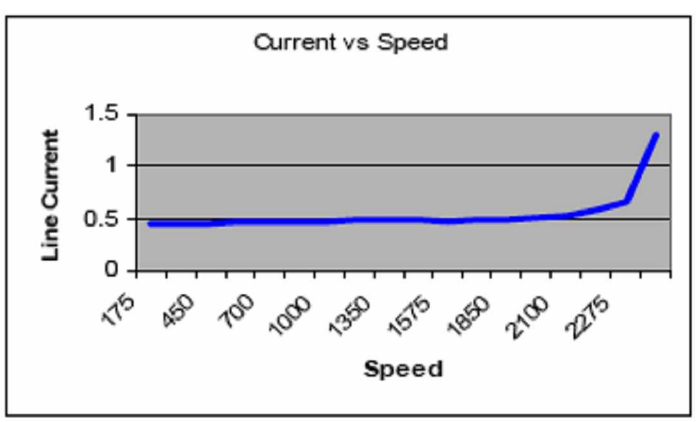
Graph (5). efficiency Vs. Torque



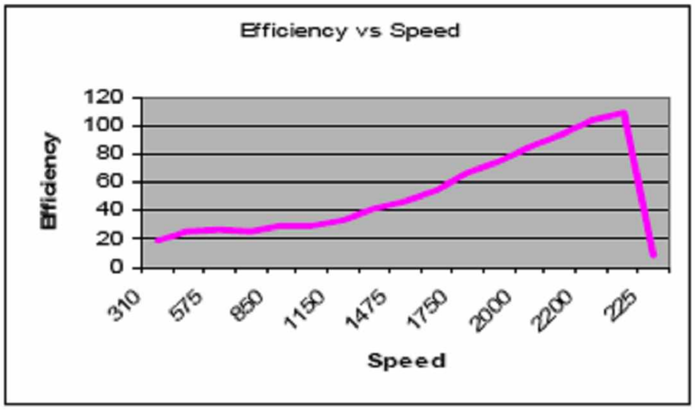
Graph (6). Torque Vs. Speed

II. With varying frequency of 5 – 90 Hz

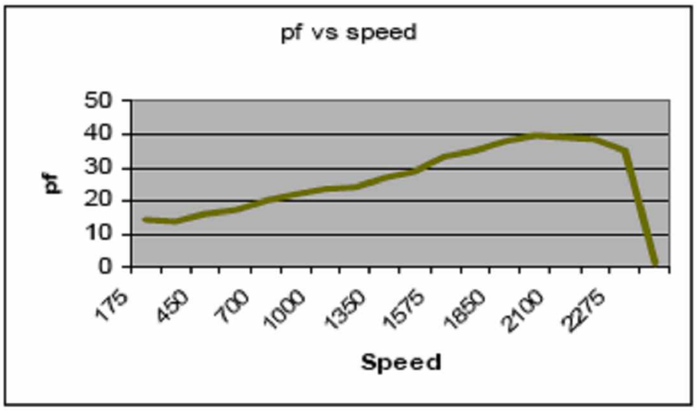
The performance graphs were shown in graphs 6 to 10. The torque is held constant at 0.4 N-m and the frequency is varied from 5 to 90 Hz and the MP1015 is inserted in the three phase supply lines. Based form the results of graphs 6 to 11, the torque is constant at every change in speed. A practical application for these is for elevators, saw mills and exhaust fans. For instance, in elevators it uses VFD's to ensure a smooth control in the speed although the load is heavy. Saw mills uses VFD's for controlling the speed by using a control knob which control the frequency instead of the voltage.
If the torque is constant for every change in speed, obviously, the current is also constant since the torque is proportional to the current. If torque is constant, the power losses (I^2R) will also be constant and therefore, the graph of the Po Vs Speed is in proportion to each other. It tends to fall down because it reaches the saturation point of the windings which makes the losses in the rotor windings to be high. Hence, if the losses was controlled by the VFD, the efficiency of the FH 90 will also increase and thus, the efficiency vs. speed graph is in proportion to each other and tends to fall. Based form the results, the maximum efficiency experience by the motor in this experiment is almost 93%, but the power factor becomes lesser with a maximum value of 35%. The speed is proportional to the voltage and thus the frequency vs. speed graph is also in proportion to each other. Based from the specification of the MP1015, from frequency values of 48 to 90 Hz, a constant torque will be experience by the FH 90 motor if the frequency to voltage ratio is constant. According to the results, the constant frequency to voltage was experience from 25 to 50 Hz value and thus, this assumption is not true in this experiment.



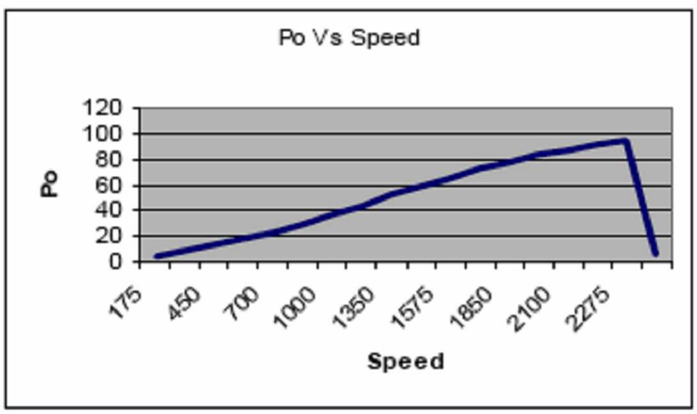
Graph (7). Line current Vs. Speed



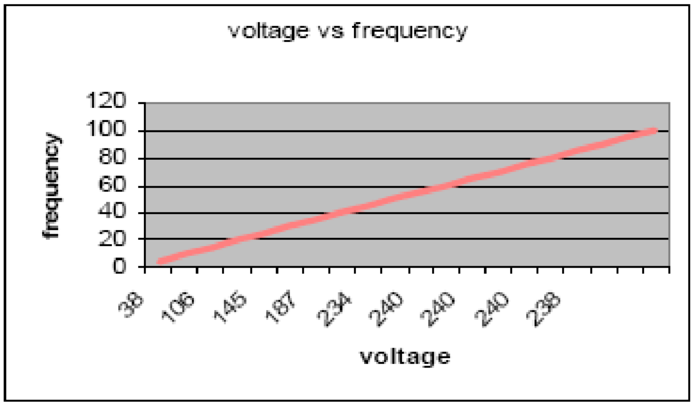
Graph (8). Efficiency Vs. Speed



Graph (9). pf Vs. Speed



Graph (10). Po Vs. Speed



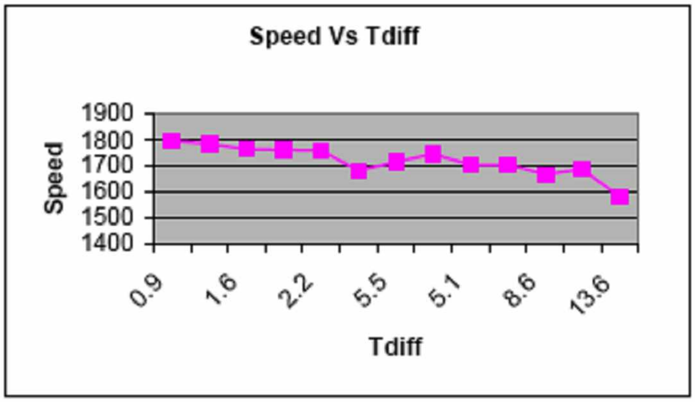
Graph (11). frequency Vs. voltage

Based form the results of graphs 6 to 11, the torque is constant at every change in speed. A practical application for these is for elevators, saw mills and exhaust fans. For instance, in elevators it uses VFD's to ensure a smooth control in the speed although the load is heavy. Saw mills uses VFD's for controlling the speed by using a control knob which control the frequency instead of the voltage. If the torque is constant for every change in speed, obviously, the current is also constant since the torque is proportional to the current. If torque is constant, the power losses (I^2R) will also be constant and therefore, the graph of the Po Vs Speed is in proportion to each other. It tends to fall down because it reaches the saturation point of the windings which makes the losses in the rotor windings to be high. Hence, if the losses was controlled by the VFD, the efficiency of the FH 90 will also increase and thus, the efficiency vs. speed graph is in proportion to each other and tends to fall. Based form the results, the maximum efficiency experience by the motor in this experiment is almost 93%, but the power factor becomes lesser with a maximum value of 35%. The speed is proportional to the voltage and thus the frequency vs. speed graph is also in proportion to each other. Based from the specification of the MP1015, from frequency values of 48 to 90 Hz, a constant torque will be experience by the FH 90 motor if the frequency to voltage ratio is constant. According to the results, the constant frequency to voltage was experience from 25 to 50 Hz value and thus, this assumption is not true in this experiment.

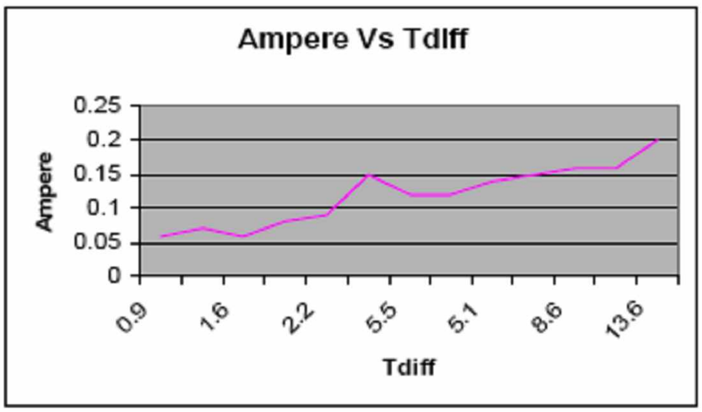
III. With the aid of thermistor in determining the behavior of stator windings due to extreme temperature

A. Normal frequency supply

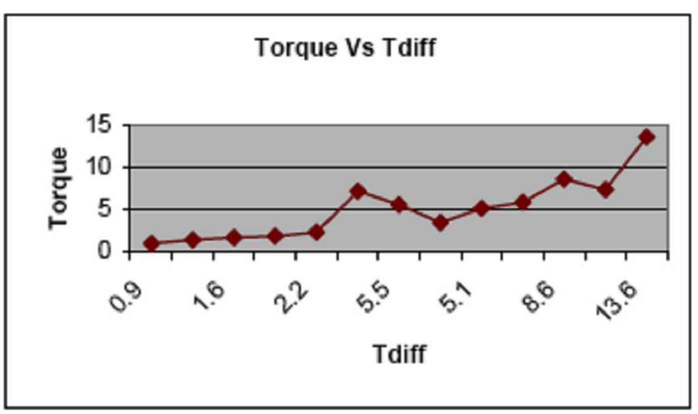
In this procedure, the frequency is held constant while the torque increases 0.05 N-m at every trial. The results were shown in the graphs 12 to graphs 14 of the Torque Vs. Tdiff, Speed Vs Tdiff and current Vs Tdiff. Tdiff was compute using equation no. (6), which is the difference of the initial temperature and the final temperature.



Graph (12). Speed Vs. Tdiff



Graph (13). Current Vs. Tdiff

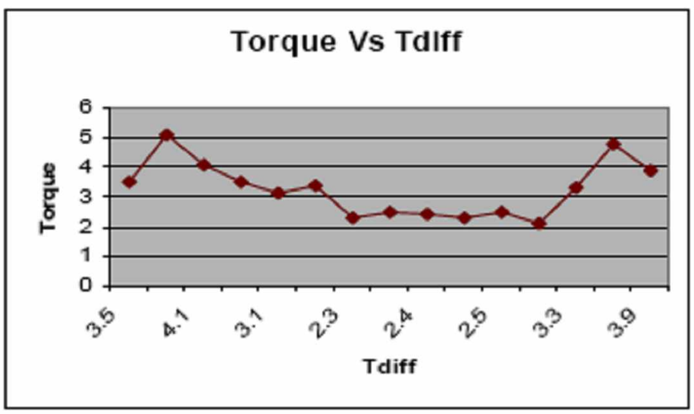


Graph (14). Torque Vs. Tdiff

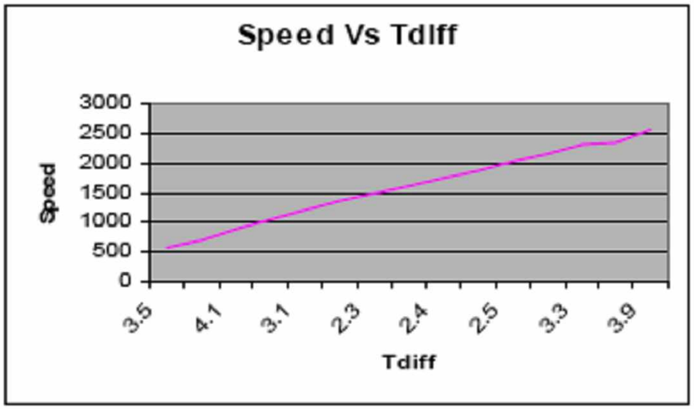
Based from the graphical results, the speed is in proportion with the increase of temperature while the torque and ampere is also in proportion with temperature. When the torque increases, a large amount of losses will occur since the voltage drops are in proportion with the loss of the windings and it has a major effect in the power output and efficiency. It is observed that a constant rise in temperature occurs from 0.1 to 0.3 N-m and tends to drop then go upwards from 0.35 to 0.65 N-m. The effect of the temperature of the windings will decrease the speed since the flux is in proportion to the voltage but inversely to the speed, this flux was also controlled by the current that passes to the field windings of the FH 90 motor and therefore, decreases the speed.

B. With varying frequency of (5-90 Hz)

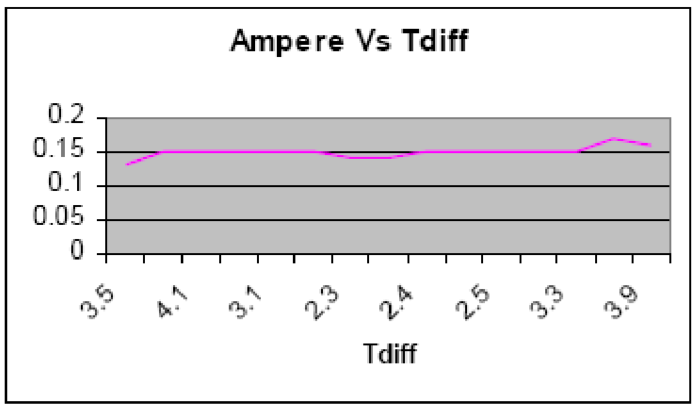
In this experiment, the speed is varied from 5 to 90 Hz and the temperature was measured with a thermistor in the rotor windings. The experiment was divided into 16 trials and every trial there was a 5 minute period for the determination of the final temperature. Afterwards, the difference of the temperature was determined by using equation (6). The performance curves were shown from graphs 15 to 17.



Graph (15). Torque Vs. Tdiff



Graph (16). Speed Vs. Tdiff



Graph (17). Current Vs. Tdiff

In this experiment, graph 15, 16 and 17 it represents the Torque vs. Tdiff, speed vs. tdiff and ampere vs. tdiff respectively. Based from graph 15, the torque is almost in proportion with the difference in temperature. A constant temperature was experienced from 50 to 75 Hz, and it follows the 48 to 90 Hz constant values based from the specification of the MP1015 equipment. Also a constant torque was experience by the FH90 motor from 30 to 90 Hz values but the voltage to frequency ratio was not constant from these values. Thus, the voltage to frequency ratio is not satisfied from 48 to 90 Hz. When the torque is constant, the current is also constant and based from the graph it follows a straight line and it is a good characteristic that when the motor has this condition the losses or the temperature is controlled or limited to a specified value. From experiment 1, the highest temperature value is 13.6 degrees but from experiment 2 the highest temperature is 5.1 and thus, the researchers can conclude that the motor was much more efficient when controlled by VFD. The life also of the motor can be longer because the losses of the windings can be controlled and also the temperature. Unlike experiment 1, when the torque or speed was increased, the temperature will rise and thus a rise in temperature will also tends to increase the voltage drops (I^2R). This condition will increase the power losses and therefore the motor will be less efficient and shorter life span.

Experiment 1. sample waveforms (Constant supply)

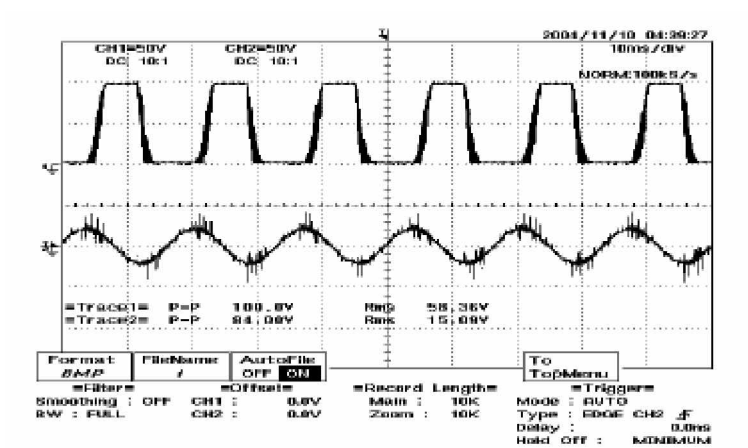


Figure (2): Torque of 0.01 N-m

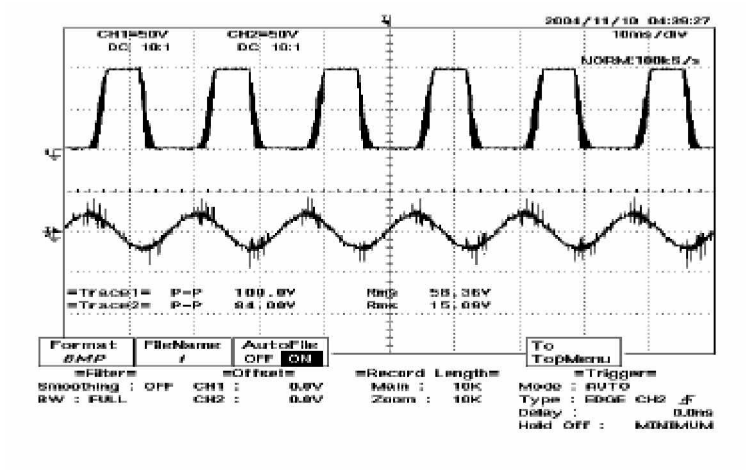


Figure (3): Torque of 0.15 N-m

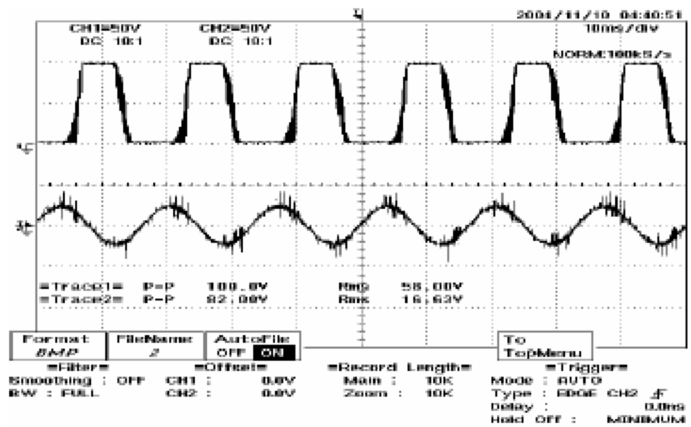


Figure (4): Torque of 0.2 N-m

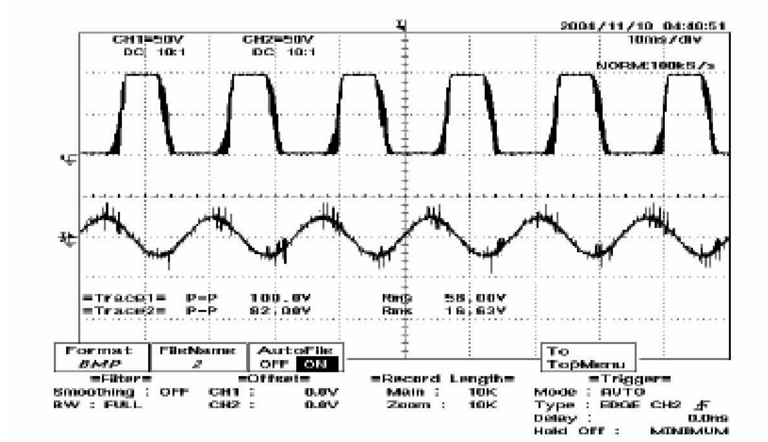


Figure (5): Torque of 0.25 N-m

Experiment 2. sample waveforms (varying frequency of 5-90Hz)

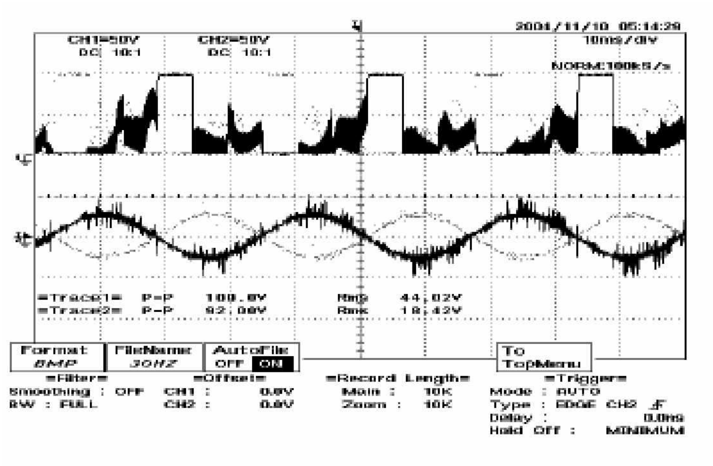


Figure (6): frequency of 30 Hz

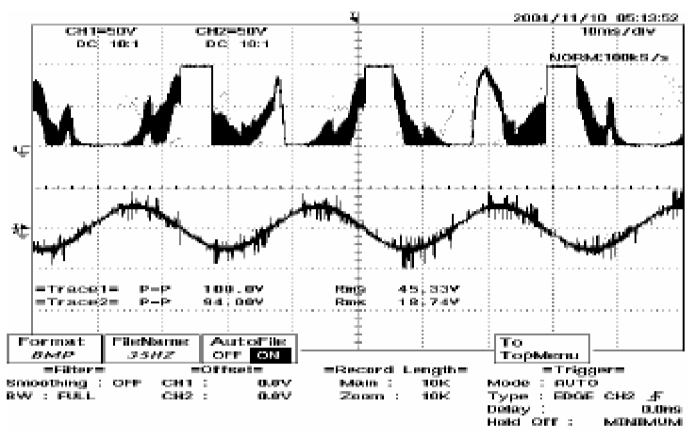


Figure (7): frequency of 35 Hz

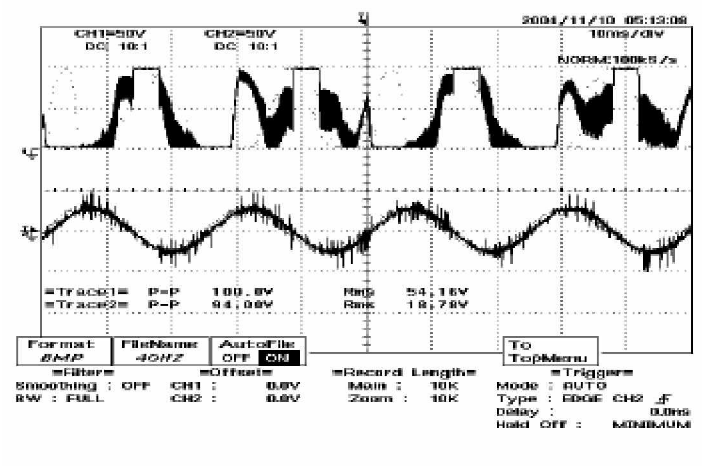


Figure (8): frequency of 40 Hz

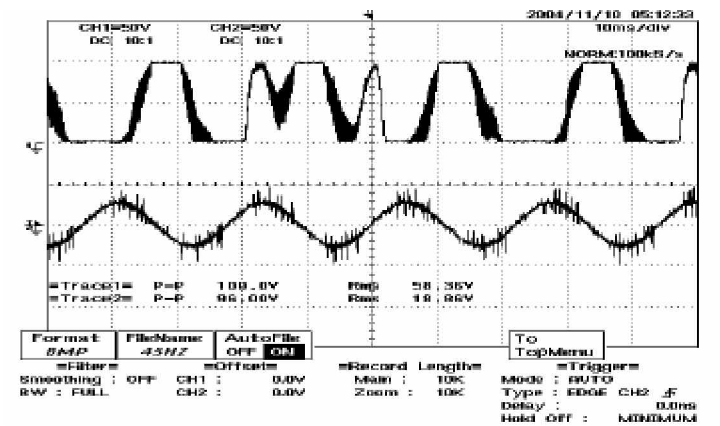


Figure (9): frequency of 45 Hz

4. Conclusion

Based from experiment no.1, it is observed that the efficiency as well as the power output is lower because of the increase in the power losses. On the other hand, based from experiment no.2, if the motor was driven by MP1015 VFID, the torque was held constant with a value of 0.3 N-m. Thus, it can have a large effect in the efficiency and power output. From this experiment, the maximum efficiency obtained was 93% unlike from the first experiment which was 64%. Also, it does not follow the specification of the MP1015 machine that from 48 to 90 Hz which is the voltage and frequency ratio must be constant to have a constant torque. Based from experiment 3A and 3B, the life span of the motor will be shorter if it is running in a normal supply because the voltage drops are high and the windings of the rotor will be easily saturated. The maximum temperature was 13.6 degree Celsius and experience a constant rise in temperature from 0.1 N-m to 0.5 N-m On the other hand, if the motor was running with MP1015 VFID, the motor will experience a temperature difference of 5.5 degree Celsius the temperature rises only from 20-30 Hz and from 80 to 90 Hz.

5. Recommendations

Based from the results gathered by the researchers, the following were highly recommended:
1. To analyze further the life span of the FH90 motor, the efficiency versus the temperature graph must be evaluated and experimented.
2. To get accurate results, the experiments must be done by one FH90 motor, since the other FH90 motors have different characteristics and efficiency rating.
3. To have smoother graphs and curves the machines like TQ MK1V and measuring instruments must be properly calibrated.

6. References

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[2] TQ Machines Training Modules , *MP 1015 Variable Frequency Drive User's Manual*: 2000

[3] Yamatake Honeywell, *Variable Frequency Drive User Guide*: 1999