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Analysis of Inverter Drive Working System as 3-Phase AC Motor Rotation Speed Regulator

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Abstract: *The use of induction motors in industry and factories is more profitable than DC or synchronous motors, one of the advantages is easy maintenance and high efficiency. On machines in the industry speed regulation is necessary. Along with the development of power electronics, this has become very easy to do, namely by supplying the motor with a variable speed drive (VSD) inverter. With a variable speed drive inverter supply, it is possible to adjust the motor speed by adjusting the voltage frequency. This study was conducted to determine the effect of variable frequency by using a variable speed drive inverter on the performance of a three-phase induction motor. Tests were conducted at frequencies of 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 Hz (inverter frequency) and the motor was loaded with 0.5Nm. From the study, it was concluded that, among other things, the use of a variable speed drive inverter resulted in greater motor losses and the motor produced a louder sound. At the same frequency (50 Hz) the motor efficiency is better when supplied directly from the power grid.*
Keywords: *inverter; inverter variable speed drive; three phase induction motor*

I. Introduction

The use of AC motors requires a star-triangle circuit for voltage and current stability during normal starting and starting. But now there is a control device that can control the speed of a 3-phase AC motor with Variable V / F and Inverter Drive which has advantages as soft starting, 3-phase AC motor rotation speed regulator, 3-phase AC motor braking system, and a 3-phase AC motor rotation reverse system.

Since, the voltage and frequency vary, it is also called VVVF (Variable Voltage Variable Frequency). The advantage of using Inverter Drive as a control device becomes more varied if it is known that an appropriate parameter setting is used to run the motor according to the desired purpose. Inverter Drives have been used in ventilation systems for large buildings. Such as for energy-saving fan motors and as well used in conveyors.

II. Review of Literature

2.1 Induction Motor

Induction motors are the most used motors in various industrial plants. They are simple in design, cheap and readily available and can be connected directly to the power source AC.

Induction motors have two main electrical components, namely:

1. Stator

The stator is the stationary part. The stator is made from several stampings with slots to carry three-phase windings. These windings are looped for a few poles. The windings are geometrically spaced at 120 degrees.

2. Rotor

The rotor is a moving or rotating part made of the iron core. The rotor of a 3-phase induction motor is divided into 2 types, namely a squirrel cage rotor and a wound rotor.

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2.2 Working Principle of 3-Phase Induction Motor

The working principle of a three-phase induction motor is based on Faraday's Law (changes in magnetic induction will cause induced voltage in a winding). Faraday's law is based on equation (2.1) as follows:

$$\varepsilon = \mathbf{B} \times \mathbf{l} \times \mathbf{v} \qquad \textbf{(2.1)}$$

Where:
ε = Induced voltage (v)
B = Magnetic field (T)
l = Conductor length (m)
v = Magnetic field speed induces conductor (m/s)

Another law that underlies the working principle of an induction motor is Lorentz's Law (If a conductor that is electrified is in a magnetic field, a force will arise called the electromagnetic force or Lorentz force). Lorentz's law is based on equation (2.2) as follows:

$$\mathbf{F = B \; x \; i \; x \; l} \qquad \textbf{(2.2)}$$

Where:
F = Lorentz force (N)
B = Magnetic field (T)
I = Current flowing in the conductor (A)
l = Conductor length (m)

Induction motors work depending on the rotating magnetic field generated in the motor air gap caused by the stator winding current. The three-phase stator winding is wound with a distance between the windings of 120 ° electrically. If the winding is given a three-phase voltage, a current will flow and cause a magnetic field. It will flow current and cause a magnetic field. The magnetic field in a winding area will cause a flux in each phase. The three fluxes combine to form a vector flux that moves around the stator surface at a constant speed called the rotary magnetic field. At a constant speed called a rotating magnetic field. The rotating magnetic field will cause the rotor to rotate in the same direction as the rotating flux.

2.3 Three Phase Induction Motor Power

Power Problems of Three-Phase Induction Motor In an induction motor, there is no power source directly connected to the rotor, so that the power passing through the air gap is equal to the input power to the rotor. The motor input power to the stator is formulated in equation (2.3) as follows:

$$\mathbf{Pin} = \sqrt{\mathbf{3}} \times \mathbf{VL} \times \mathbf{IL} \times \mathbf{cos}\ \varphi \qquad \textbf{(2.3)}$$

Where:
Pin = Input power (w)
VL = Input Line to Line Voltage (V)
IL = Input Current per Phase (A)
Cos φ = Power factor

The electrical power flowing at the stator terminal is then converted into mechanical power on the rotor shaft and produces torque. Torque is the ability of a motor to rotate a load. The amount of torque on the motor is formulated in the equation (2.4) as follows:

$$\tau = 9,55 \times \frac{Pout}{nr} = 9,55 \times \frac{Pin}{ns} \qquad \textbf{(2.4)}$$

Where:

τ = Motor Torque (Nm)
P_{out} = Output Power or Mechanical Power (W)
P_{in} = Input Power or Electrical Power (W)

2.3 Three-Phase Inverter

Inverters are power electronic devices that function to convert DC input voltage into AC output voltage with adjustable size and frequency. A three-phase inverter is an inverter device that has a three-phase AC output voltage. In general, the three-phase inverter circuit comprises 6 transistor switches shown in Figure 2.1, as follows

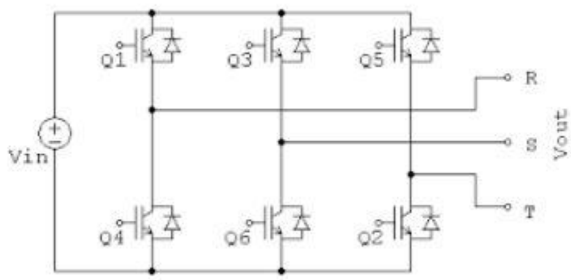

Figure 1. *On Line Starter Direct Diagram*

Each transistor works for 180°. Three transistors always remain on. When transistor Q1 is turned on, the phase of a terminal is brought to the positive side of the DC voltage source. When transistor Q4 is turned on, the phase of a terminal is brought to the negative side of the DC voltage source. There are six operating modes in one cycle (one cycle equals 360°) and the duration of each mode is 60°. The triggering signals shown in figure 2.8 are shifted from each other by 60° to get a three-phase voltage. The switches of any of the inverter legs (S1 and S4, S3 and S6, or S5 and S2) cannot be turned on and off simultaneously as this will cause a short circuit in the DC source.

2.4 Variable Speed Drive

A variable speed drive is a device that controls the speed of a motor as required. For three-phase induction motors, the speed depends on the value of the voltage frequency according to equation (2.5). The device for speed control is called a variable voltage drive, where the input is a three-phase voltage (with a mains voltage of 380 V and a frequency of 50 Hz) and the output is a three-phase voltage whose voltage and frequency values can be adjusted as required. The basic circuit of a variable voltage drive is shown in Figure 2.2 as follows:

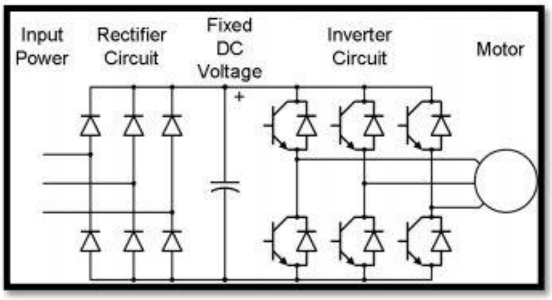

Figure 2. *The Base Circuit of Variable Voltage Frequency Drive*

In Figure 2, a three-phase voltage source that has a line-to-line voltage of 380 V and a frequency of 50 Hz is flowed into the rectifier and converted to DC. Basically, the AC voltage that is converted into DC cannot turn into pure DC pure because there is still a ripple voltage and the value is still changing, for that a filter is needed to reduce the ripple voltage. The output voltage from the DC filter has flowed into a three-phase inverter and converted into a three-phase voltage whose voltage and frequency can be changed. The voltage and frequency can be changed according to the needs.

2.5 VLT® Automation Drive FC 30

This module uses a frequency converter type VLT® Automation Drive FC 30 with a power capacity of 0.25-75 kW. This converter uses a voltage source (input) of 380 V and an output voltage (output) of 380 V (3 phase), to control the load using PWM settings. controlling the load using PWM settings. The advantages of this converter have advantages such as Modbus RTU Communication, PID Control, Sensor less Vector Control, and Motor Parameter Auto Tunning. Modbus RTU communication has the function of controlling the converter through a PLC or through other devices. PID control is used to fix the speed on the motor quickly and is usually used as a control for pressure, temperature, flow, and others. Auto Tunning is used to automatically set the motor at low speed with a variable load. As for Sensor less Vector Control to control torque characteristics and can stabilize the speed in various conditions according to load variations.

a. Product Description

Frequency converters are electronic motor controls for the purpose of:

1. Regulating motor speed in response to system feedback or remote commands from an external controller. The power converter system consists of a frequency converter, a motor, and the equipment driven by the motor.
2. Monitoring system and motor status.

The frequency converter can also be used for motor overload protection. Depending on the configuration, the variable frequency drive can be used in stand-alone applications or as part of a larger system or plant. Frequency converters can be used in industrial and commercial environments according to local regulations and standards.

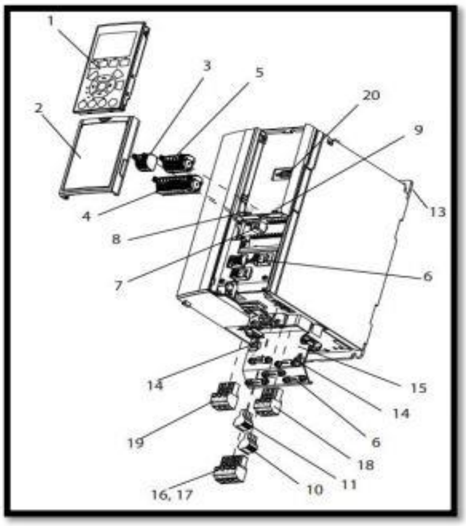

Figure 3. *VLT® Automation Drive FC 301/302 Breakdown Drawing*

Table 1. VLT® Automation Drive FC 301/302 Description

1	Local control panel (LCP)	**11**	Relay 2 (04, 05, 06)
2	Cover	**12**	Lifting ring
3	Fildbus-connector RS485	**13**	Mounting slots
4	Digital input/output connectors	**14**	Earth connection (PE)
5	Digital input/output connectors	**15**	Cable shield connector
6	Grounding and disconnection take cover	**16**	Brake terminals (-81, +82)
7	USB connector	**17**	Load sharing terminal (-88, +89)
8	RS485 terminal switch	**18**	Motor terminals 96 (U), 97 (V), 98 (W)
9	DIP switch for A53 and A54	**19**	Mains input terminal 91 (L1), 92 (L2), 93 (L3)
10	Relay 1 (01, 02, 03)	**20**	LCP Connector

b. Cable Schematic

A schematic shows the connections in a circuit in a clear and standardized way. It is a way of communicating to other engineers exactly what components are involved in a circuit and how they are connected. A good schematic will show the names and values of the components, and the parts or components will be labeled to indicate their intended use. A schematic is defined as a drawing that simply shows something using symbols. A schematic is a drawing that represents the components of a process, device, or other object using abstract, often standardized symbols and lines. Schematic diagrams represent only the essential components of a system, although some details in the diagram may be exaggerated or introduced to facilitate understanding of the system.

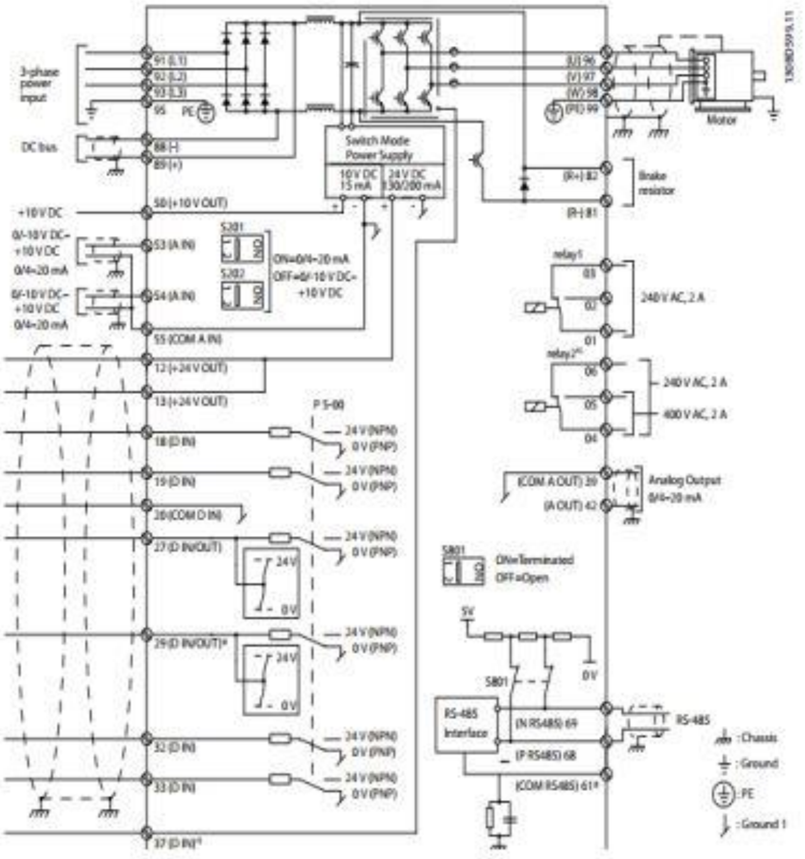

Figure 4. *Basic Wiring Scheme*

c. Motor Connection

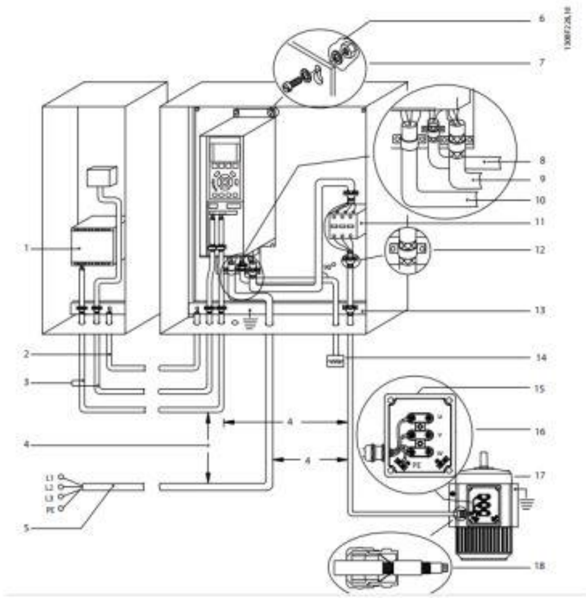

Figure 5. *Illustration of an Example of the Correct Way to Install EMMC*

Table 2. VLT® AutomationDrive FC 301/302 Description

1	PLC	**10**	Power supply cable (without shield).
2	Minimum balancing cable 16 mm2 (6 AWG)	**11**	Output contactors, and so on.

3	Control cable	**12**	The insulation cable is peeled off.
4	Minimum 200 mm (7.9 in) between control cable, motor cable and mains cable	**13**	Common ground busbar. Obey local and national regulations regarding cabinet earthing.
5	Power supply.	**14**	Brake resistor.
6	Plain surface (no paint).	**15**	metal box
7	Star ring.	**16**	Connection to motor
8	Brake cable (shielded)	**17**	Motor.
9	Motor cable (shielded).	**18**	EMC cable connector

III. Research Methods

3.1 Materials and Equipment

1. 3-Phase Induction Motor

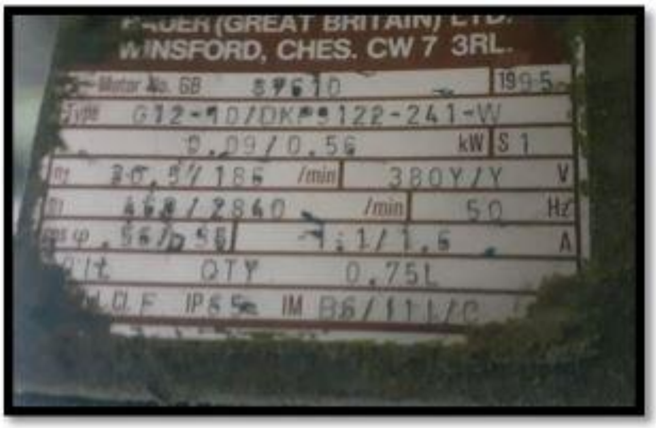

Figure 6. *Nameplate of 3-phase Induction Motor*

Specifications:

a. Nominal voltage (VL-L) = 380 V
b. Nominal current = 1.6 A
c. Power = 0.56 kW
d. Cos phi = 0.56
e. Frequency = 50 Hz
f. Number of poles = 4 Pole
g. Insulation class = F
h. Connection = Star (Y)

2. Ampere meter (Ampere pliers)
3. Volt meter
4. Variable Speed Drive (VSD)

Specifications:
a. VLT Automation Drive
b. Danfoss 1.1 kW

Figure 7. *VLT Automation Drive 1,1 KW*

3.2 Observed Variables

The variables observed in this final project include:

a. Frequency of
b. Load Torque
c. Voltage
d. Current
e. Motor Speed

3.3 Research Procedure

Based on the flowchart diagram, the calculation and processing techniques can be seen in Figure 8 below:

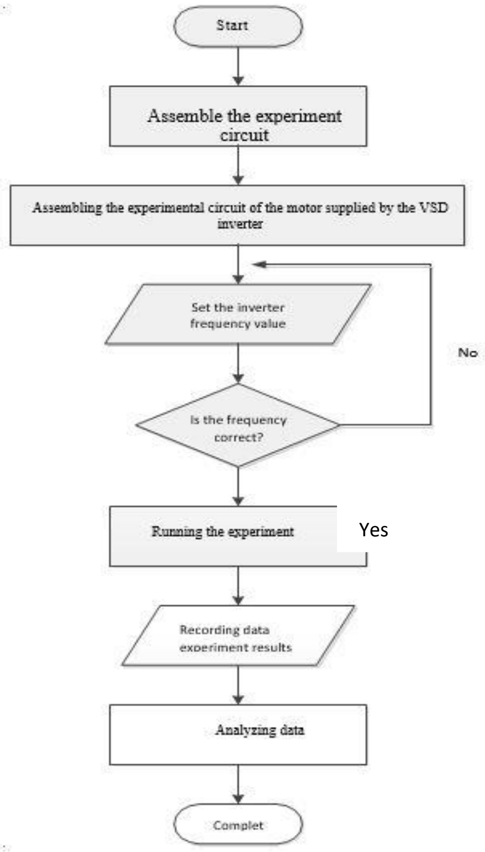

Figure 8. *Flowchart of Research*

Description:
1. Build the experimental circuit with a supply from the mains.
2. Build the experimental circuit with the supply from the variable speed drive (VSD) inverter.
3. Start the three-phase induction motor by pressing the start button according to the rated voltage of the motor in a balanced voltage condition with the supply by the variable speed drive (VSD).
4. Set the frequency value on the frequency inverter in the range of 0-50 Hz.
5. Measure the voltage, current and speed of the three-phase induction motor at a frequency of 0-50 Hz.
6. Press the stop button until the motor stops rotating.
7. The experiment is finished.

IV. Discussion

4.1 Three Phase Induction Motor Experiment Supplied from Variable Speed Drive Inverter (VSD)

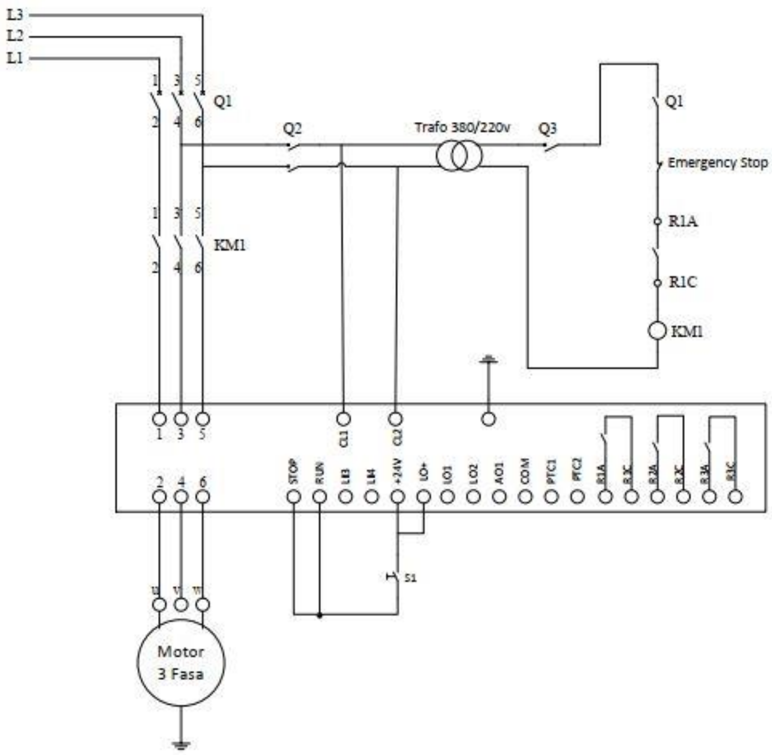

Figure 9. *Experimental Circuit of Three Phase Induction Motor Supplied from Inverter Variable Speed Drive*

Procedure of the experiment:
1. Set up the experiment as shown in Figure 4.1.
2. Increase the 380 volt three-phase voltage applied to the asynchronous motor.
3. Press the start button (S1) to start the motor and the inverter.
4. Set the output frequency of the frequency inverter by turning the selector switch on the frequency inverter. In this experiment, the selected frequency is in the range of 5 to 50 Hz.
5. Record the current (I), the input voltage (V) and the motor speed (rpm).

6. Press the stop button to stop the motor and the inverter.
7. Experiment completed

4.2 Experiment Result Data

The test data of the 3-phase induction motor is supplied from the Variable Speed Drive (VSD) Inverter for frequencies of 5 to 50 Hz. Speed Drive (VSD) Inverter for frequencies of 5 to 50 Hz.

Table 3. Test Results Data at Frequencies 5 to 50 Hz

No	Frequency (Hz)	Voltage (Vac)	Current (A)	Nr (Rpm)
1	5	57,2	1,29	149
2	10	86,9	1,26	300
3	15	135	1,35	450
4	20	170	1,44	599
5	25	215	1,45	748
6	30	247	1,51	897
7	35	296	1,54	1048
8	40	330	1,66	1198
9	45	372	1,69	1347
10	50	405	1,62	1496

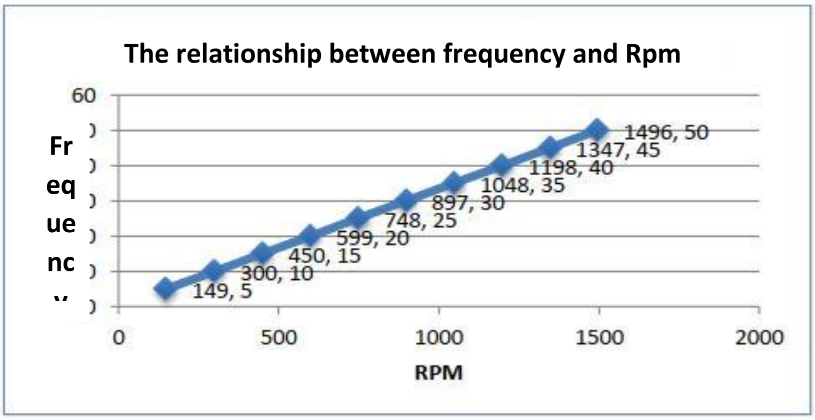

Figure 9. *Graph of Frequency (5-50 Hz) Vs Speed of Induction Motor*

4.3 Data Analysis of Experimental Results

a. Frequency 5 Hz

From the experiment, when the motor is supplied from a variable speed drive inverter with a frequency of frequency of 5 Hz and given a load of 0.5 Nm, the following data is obtained:

V	: 57.2 volts	Cos θ	: 0,56
^{I}Load	: 1.29 amperes	R stator	: 21,28 Ω
^{I}UnLoad	: 0.9 amperes	Pole: 4	

Nr: 149 rpm

Figure 10. *Motor Testing with 5 Hz Frequency Setting*

Stator rotating field speed (ns)

$n_s = \frac{120 \times f}{p}$

$= \frac{120 \times 5}{4}$

= 150 rpm

a. Slip

S $= \frac{ns - nr}{ns}$

$= \frac{150-149}{150}$

=0,006

b. Incoming power at motor (PIn) (P_{In})

$P_{In} = \sqrt{3} \times V \times I \times cos\ \theta$

$= \sqrt{3} \times 57{,}2 \times 1{,}29 \times 0{,}56$

= 71,570 watt

c. Core power loss at no load (P_0)

$P_{nl} = \sqrt{3} \times V \times I \times cos\ \theta$

$= \sqrt{3} \times 57{,}2 \times 0{,}9 \times 0{,}56$

= 49,932 watt

PoSCL $= I^2 R_s = (0{,}9)^2 \times 21{,}28 = 17{,}24$-

watt $P_0 = P_{nl} - P_0SCL$

= 49,932 watt - 17,24 watt

= 32,692 watt

Where:

P_{nl} = incoming power at zero load

P_0SCL = power loss in the stator winding when the load is zero

d. Stator winding power loss

($P_{rCu\ 1}$) $P_{rCu\ 1} = I^2 \times R$

$= (1{,}29)^2 \times 21{,}28 = 35{,}41$ watt

e. Stator exit power (P_{0S}) = Power into the rotor (P_{in}

$_{R)}$ $P_{0S} = P_{in\ R} = P_{in} - (P_0 + P_{rCu\ 1})$

= 71,570 – (32,692 + 35,41)

= 3,468 watt

f. Power into the rotor (P_{Out})

P_{Out} = (1-slip) x $P_{in\ R}$
= (1- 0,006) x 3,468
= 3,447 watt

g. Losses caused by friction and wind P_t = 2% x P_{in}
= 2% x 71,570
= 1,431 watt

h. Output power (net)

$P_{Out\ B}$ = P_{Out} - P_t
= 3,447 - 1,431
= 2,016 watt

i. Induction motor efficiency (η)

$$\eta = \frac{Pout}{Pin} \times 100\%$$

$$= \frac{2,016}{71,570} \times 100\%$$

= 2,81 %

V. Conclusion

5.1 Conclusions

From the research and analysis results regarding the analysis of the inverter drive system as a three-phase AC motor speed controller, the author will conclude to get the essence and answer the purpose of this research. Some conclusions that can be drawn are:

1) Based on the tests and analysis done by the author, the higher the frequency value, the higher the motor speed. For a frequency setting of 50 Hz, the motor speed is 1496 rpm. With a frequency value of 5 Hz, the motor speed is lower, namely 149 rpm.
2) The frequency setting of a three-phase induction motor when using a frequency inverter on an induction motor affects the output of the induction motor. The current increases when the frequency decreases, while the voltage, power factor and motor speed decrease when the frequency decreases. In addition, the use of a frequency inverter affects the load that the induction motor can carry.

5.2 Suggestions

The author's suggestions for further research development in the future are:

1. In further research, it is recommended to determine the load that an induction motor with a variable speed inverter can carry by varying the torque value.
2. In further research, it is advisable to make a comparison when the motor is supplied by a 380-volt grid and by a variable speed inverter to obtain comparative data on the efficient use of variable speed inverters.

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