AN AC DRIVE SYSTEM TO REPLACE AN EXISTING DC DRIVE SYSTEM

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degree of Master of Science

by
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Abstract

DC commutator motor is the oldest motor but still the best performance motor. It has control simplicity and control accuracy although commutator motor has some inherent drawbacks due to its mechanical commutator. Normally, the older the motor, the higher the effects of some drawbacks.

This dissertation is based on "Replacing an old DC drive system with a new AC drive system" in order to eliminate prevailing practical problems arisen due to aging of the drive system. The DC drive system being less reliable, that results high down time of the relevant machine effecting loss in production. .

Briefing on new AC drive system, other than the existing control functions, some functional improvements are also adopted assuring far better running performance of the machine than present. Minimum maintenance, quick failure restore, minimizing down time and hence improved reliability are the key motivations of the project.

It is considered the maximum running speed of the machine for capacity selection of the motor and the AC drive. The required modifications in power and control wiring are introduced keeping operational part of the machine in such a way that, machine operator does not feel any difference while in operation. Same switches, selectors, pushbuttons are utilized as in the existing system.

Economic consideration of the proposed system against the existing system is discussed followed by the design. Improved power factor, reduced total harmonic distortion, improved efficiency and enhanced reliability of the machine contributes positive impact on the proposed system.

It is important to say that, this is much oriented at reliability improvement of the particular machine than the other sayings.

DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

UOM Verified Signature

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25th January. 2010

I/We endorse the declaration by the candidate.

UOM Verified Signature

Dr.J.P.Karunadasa

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Acknowledgement

My first sincere gratitude goes to my supervisor, Dr. J. P. Karunadasa, head, Department of Electrical Engineering, University of Moratuwa, for his great and kind guidance, insights, attention extended towards me for successful flow of the dissertation.

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Chapter 1

Introduction

1.1 Overview of the dissertation

This project is focused on a machine which prints permanent labels on glass bottles. All the movements of the machine are activated through mechanical systems by means of one rotating machine which is a separately excited DC motor coupled through a belt drive.

DC motor is driven by a AC/DC converter which composed with armature supply, field coil supply, tacho generator feed back and speed adjustment facilities.

DC commutator motor is the oldest and still one of the best performing motor. Control simplicity and control accuracy are the assets of DC motors. No other motor can match these two aspects simultaneously.

But DC motors have some inherent drawbacks, most of these due to its mechanical commutator. They are namely,

- Need of frequent maintenance
- Occurrence of sparking of brushes
- Need of replacing brushes frequently
- Gradual wearing commutator surface requiring reshaping after sometimes
- Noise due to sliding parts
- Generation of EMI
- Existence of somewhat lower speed limits
- Difficulties of operating at standstill condition

But subjected to above limitations, user can all the time expect better performances. These are application dependant and there are so many applications that can accept these limitations [8].

In this application, motor being an old DC motor, it is now experienced less reliability arisen due to

Winding burning

Wearing of brushes and commutator problems

Speed fluctuations

More maintenance time

If the motor is undergone rewinding, it is normally required minimum of three days, resulting unavailability of machine with considerable amount of production loss.
This situation is turned out to provide a solution to improve reliability of operation by replacing the existing DC drive system with a new AC drive system.

AC drive system comprises of a cage induction motor, variable frequency drive and feed back control.
It is simple, low cost and involves less maintenance. Parts are available at door step and easy replacement at a failure. In case of a winding failure in-house rewinding is also possible. All these ensure reliability improvement of the machine. Figure 1.1 shows the proposed system.

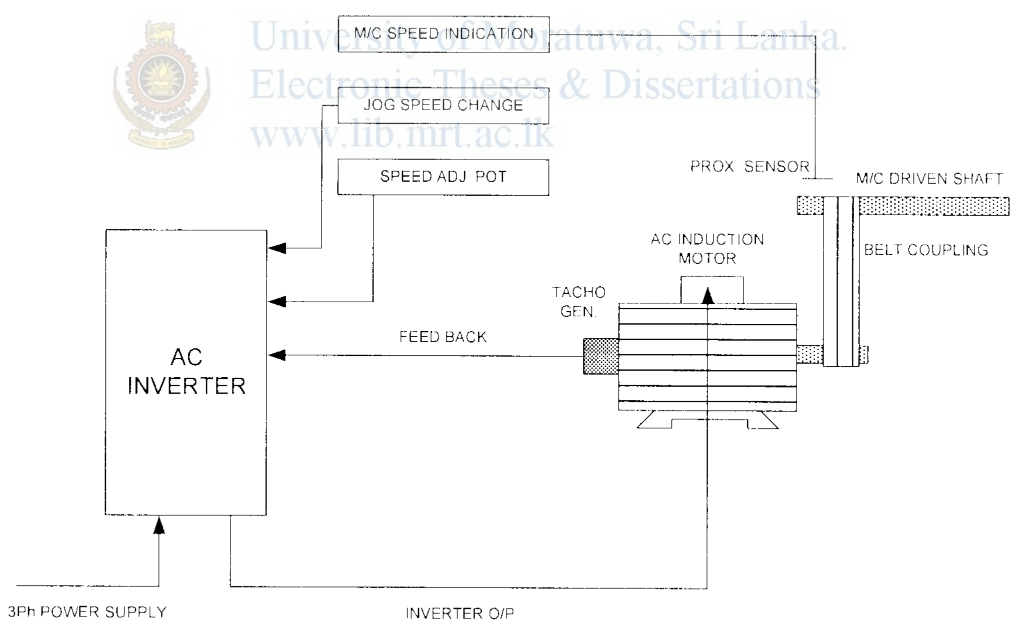


Figure 1.1- Proposed system

1.2 Objective of the project

Replace an existing old DC drive system with an AC drive system.

Principle motivations

- To improve reliability
- Eliminate brush replacements
- Solution for speed fluctuations caused by ware of brushes and minor damage of commutator segments.
- Eliminate substantially high rewinding time
- Reduce down time and hence reduce financial loss by expediting failure restore.
- Timely delivery of products

1.3 Existing system

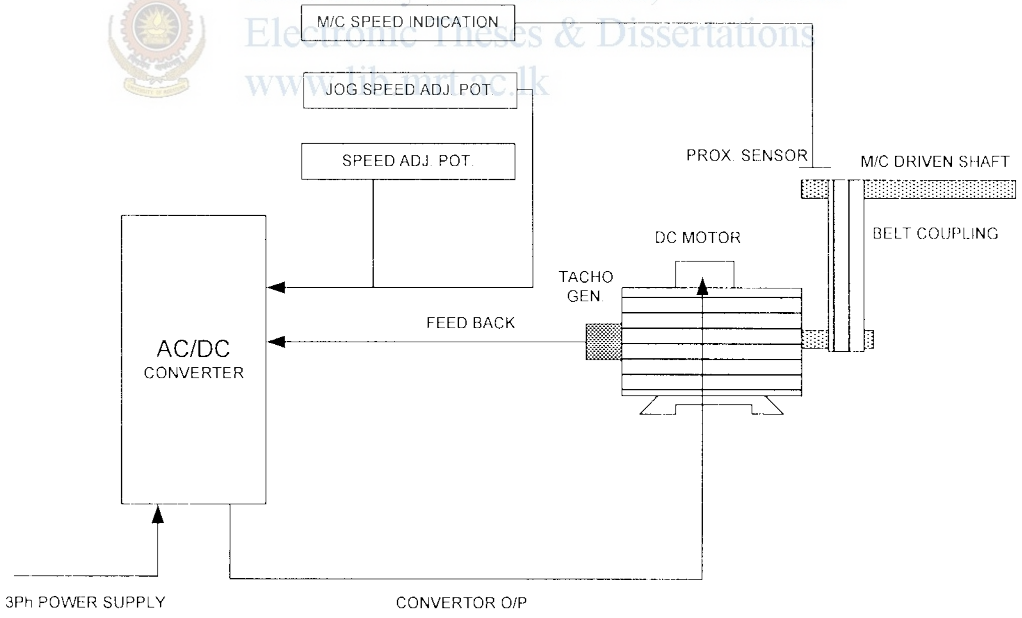


Figure 1.2- Existing system

1.3.1 Specification

Motor and DC drive specifications (Name plate data) as follows.

Motor GG5132-OGH40-6SU7-Z Make :SEIMENS			DC Drive Make : SEIMENS, D460/57
Voltage	42-460 V	460 V	Power input 380VAC 47A, 50/60Hz
Speed	50-2550rpm	2550rpm	Power output 460VDC 57A
Current	46-46.5 A	46.5 A	
Power	0.375-19 kW	19 kW	
Tacho-generator is fitted			

1.3.2 Speed Controlling

Running speed can be adjusted by means of a potentiometer provided. It also facilitates with another potentiometer connected with the same terminals in order to operate the machine in JOG mode. Jogging operation is important to operate the machine as desired when machine (or product) adjustment is required and also at maintenance. Operation is continuous duty.

As measured, machine running parameters as follows

Running	MIN	200	rpm
	MAX	740	rpm
Jogging	MIN	200	rpm
	MAX	740	rpm

1.3.3 Connection diagram of the DC Converter

Connection diagram of the DC converter is shown in Figure 1.3 [9]. Figure 1.4 [9] shows all inputs to the Converter. This is a Thyristor controlled unit.

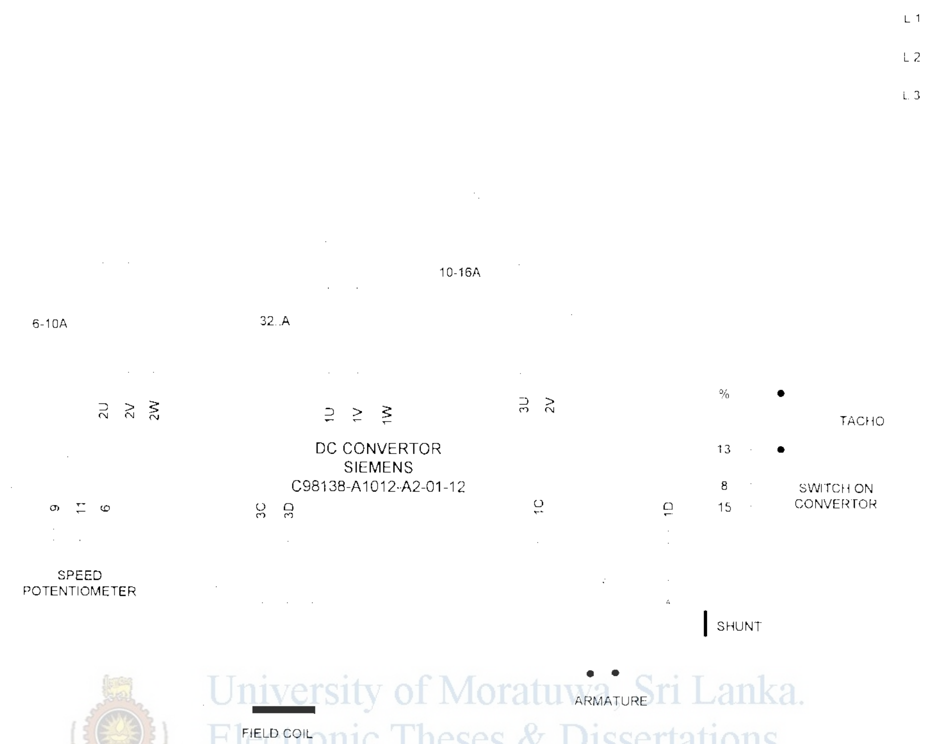


Figure 1.3 – Connections in DC Converter

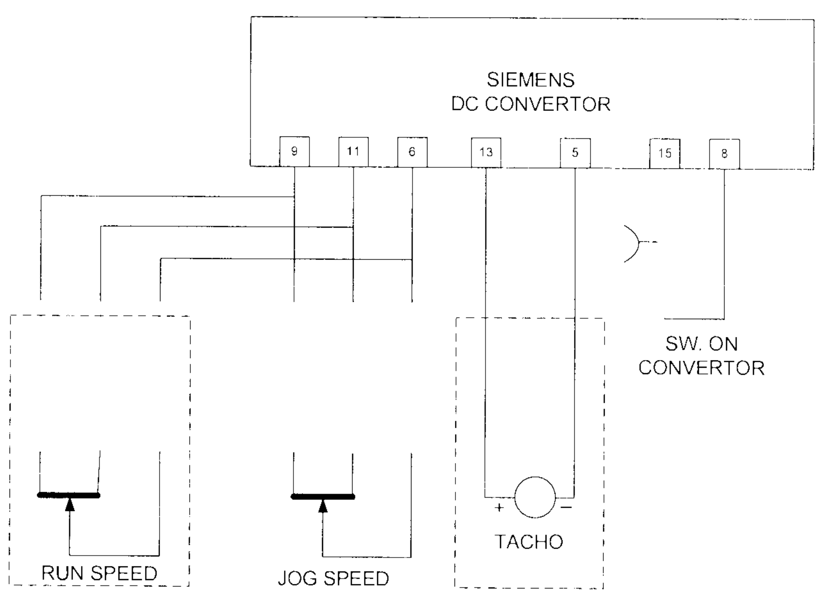


Figure 1.4 – Converter Inputs

1.3.4 Speed Indicator

Speed indicator at the machine shows the machine running speed by means of a separately connected proximity sensor which picks signals from rotating metal sections of the machine. It gives an indication on number of bottles moving in a minute. Figure 1.5 [9] below shows the connections.

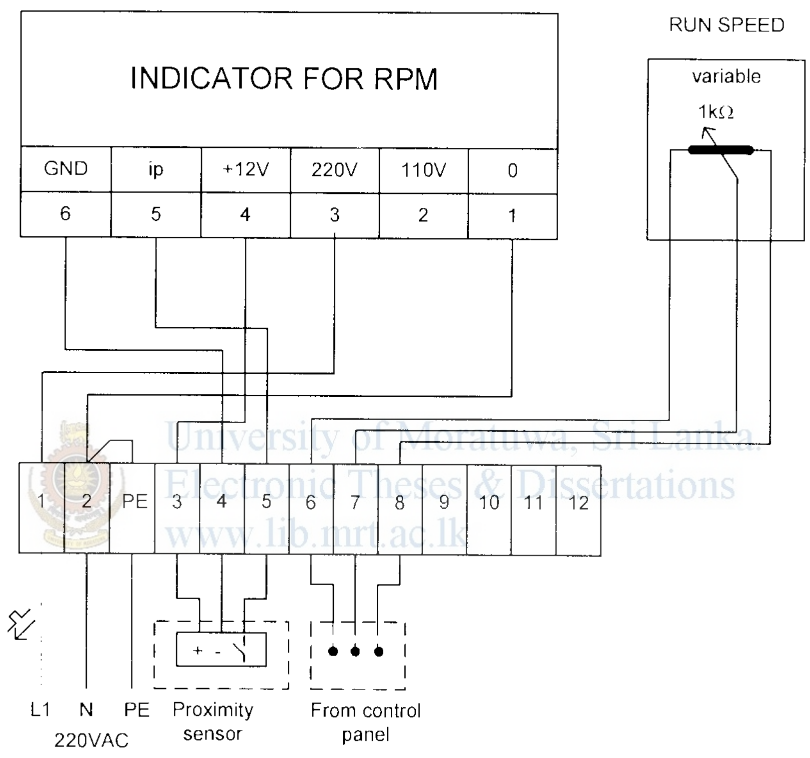


Figure 1.5 – Speed Indicator

Chapter 2

Selection of an AC Motor

2.1 Methodology of selecting an AC motor

Selection methodology of an AC motor for a particular application is described in this chapter. A three phase AC squirrel cage induction motor is preferred for the application.

2.2 Three Phase AC Induction Motors

Three-phase AC induction motors [5] are widely used in industrial and commercial applications. They are classified either as squirrel cage or wound-rotor motors.
These motors are self-starting and use no capacitors, start winding, centrifugal switch or other starting device.

They provide medium to high degrees of starting torque. The power capabilities and efficiency in these motors range from medium to high compared to their single phase counterparts. Induction motors are simple and rugged design, low-cost, low maintenance and direct connection to an AC power source are the main advantages of AC induction motors.

2.3 Cage Motors

Almost 90% of the three-phase AC induction motors are of this type [5]. Here, the rotor is of the squirrel cage type. The power ratings are from one-third to several hundred horsepower in the three-phase motors. Motors of this type, rated one horsepower or larger, cost less and can start heavier loads than their single-phase counterparts.

2.4 Voltage

The motor nameplate voltage [2] is determined by the available power supply which must be known in order to properly select a motor for a given application. The nameplate voltage will normally be less than the nominal distribution voltage.

The distribution voltage is the same as the supply transformer voltage rating. The utilization voltage is set at a slightly lower level to allow for a voltage drop in the system between the transformer and the motor leads.

The following table 2.1 for 50Hz standard shows the motor nameplate voltages which provide the best match to distribution system voltage and meet current motor design practices.

Motor Name plate voltage	
Polyphase Motors	
Below 125 HP	125HP and Up
200	-
220	-
380	380
415	415
440	440
550	550
3000	3000
Single phase motors	
110	-
200	-
220	-

Table 2.1 – Motor voltages and Power

Effects to low voltage induction motors due to unbalanced voltage supply is discussed in IEC60034-26 [12]

2.5 Frequency

Frequency [2] can be defined as the number of complete alterations per-second of an alternating current. The predominant frequency in the United state is 60Hz and 50Hz systems are common in other countries. Other systems, such as 40 and 25 hertz are isolated and relatively few in number.

2.6 Voltage and Frequency variation

All motors are designed to operate successfully with limited voltage and frequency variations [2]. However, voltage variation with rated frequency must be limited to ±10% and frequency variations with rated voltage must be limited to ±5%. The combination variation of voltage and frequency must be limited to the arithmetic sum of 10%.

The following conditions are likely to occur with variations in voltage.

A. An increase or decrease in voltage may result in increased heating at rated horsepower load. Under extended operation this may accelerate insulation deterioration and shorten motor insulation life.

B. An increase in voltage will usually result in a noticeable decrease in power factor. Conversely, a decrease in voltage will result in an increase in power factor.

C. Locked rotor and breakdown torque will be proportional to the square of the voltage. Therefore, a decrease in voltage will result in a decrease in available torque.

D. An increase of 10% in voltage will result in a reduction of slip of approximately 17%. A voltage reduction of 10% would increase slip by about 21%.

The following conditions are likely to occur with variations in frequency.

A. Frequency greater than rated frequency normally improves power factor but decrease locked-rotor and maximum torque. This condition also increases speed and therefore friction and windage losses.
B. Conversely, a decrease in frequency will usually lower power factor and speed while increasing locked-rotor maximum torque and locked-rotor current.

2.7 Motor output rating

2.7.1 Speed

The speed [2] at which an induction motor operates is dependent upon the input power frequency and the number of electrical magnetic poles for which the motor is wound. The higher the frequency, the faster the motor runs. The more poles the motor has, the slower it runs. The speed of the rotating magnetic field in the stator is called synchronous speed. To determine the synchronous speed of an induction motor, the following equation is used.

$$\text{Synchronous speed (rpm)} = \frac{120 \times \text{Frequency}}{\text{no of poles}} \tag{2.1}$$

Actual full-load speed (the speed at which an induction motor will operate at nameplate rated load) will be less than synchronous speed. The difference between synchronous-speed and full-load speed is called slip. Percent slip is defined as follows.

$$\text{Percent Slip at Full load} = \frac{(\text{Synchronous speed - Rotor speed})}{\text{Synchronous speed}} \times 100 \tag{2.2}$$

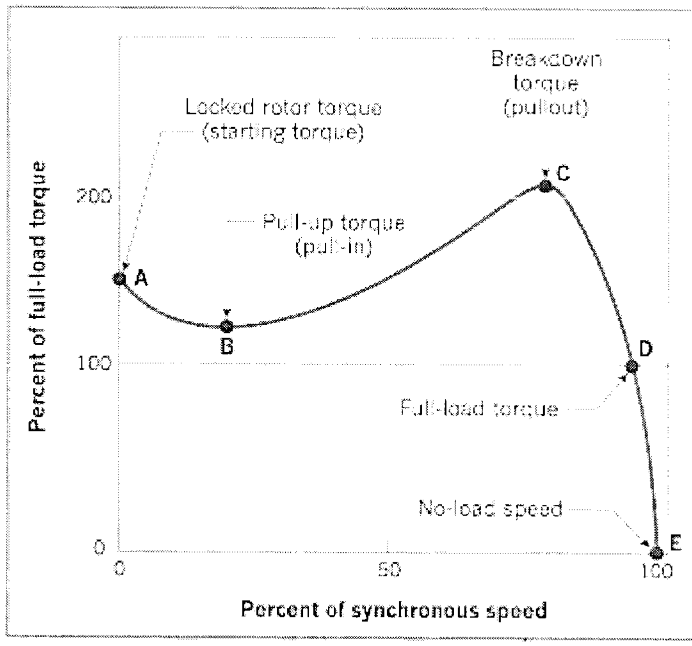


Figure 2.1 – Torque-Speed characteristic of an Induction motor

2.7.2 Torque and Power

Torque and Power [2] are two key characteristics that determine size of motor for an application.

The torque is merely a turning effort or force acting through a radius. Power is, how fast the shaft is turned. Turning the shaft rapidly requires more power than turning it slowly. Thus, power is a measure of the rate at which work is done.

2.7.3 Locked Rotor torque

Locked Rotor torque [2] is the torque which the motor will develop at rest (for all angular position of the rotor) with rated voltage at rated frequency applied. It is sometimes known as "starting torque" and is usually expressed as a percentage of full load torque. See Figure 2.1

2.7.4 Pull-up torque

Pull-up torque [2] is the minimum torque developed during the period of acceleration from locked rotor to the speed at which breakdown torque occurs. For motors which do not have a definite breakdown torque (such as NEMA design D) pull-up torque is the minimum torque developed up to rated full-load speed. It is usually expressed as a percentage of full-load torque. See Figure 2.1

2.7.5 Breakdown torque

Breakdown torque [2] is the maximum torque the motor will develop with rated voltage applied at rated frequency without an abrupt drop in speed. Breakdown torque is usually expressed as a percentage of full-load torque [2]. See Figure 2.1

2.7.6 Full-Load torque

Full load torque [2] is the torque necessary to produce rated horsepower at full-speed. See Figure 2.1

2.7.7 Motor Current

In addition to the relationship between speed and torque, the relationship of motor current [2] to these two values is an important application consideration. The speed-torque curve with the current curve added demonstrates a typical relationship in Figure 2.2.

There are two important points on this current curve are discussed below.

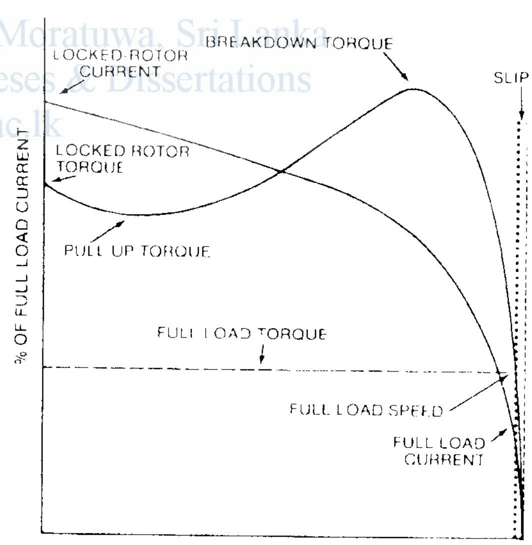


Figure 2.2 – Speed-Torque, Current curve

2.7.8 Full-Load current

The full load current [2] of an induction motor is the steady state current taken from the power line when the motor is operating at full-load torque with rated voltage and rated frequency applied.

2.7.9 Locked-Rotor current

Locked-Rotor current [2] is the steady-state current of a motor with the rotor locked and with rated voltage applied at rated frequency.

2.8 Motor Standards

Worldwide, various standards exist which specify various operating and constructional parameters of a motor. The two most widely used parameters are the National Electrical Manufactures Association (NEMA) and International Electromechanical Commission (IEC)

2.8.1 NEMA

NEMA [5] sets standards for a wide range of electrical products, including motors. NEMA is primarily associated with motors used in North America. The standards developed represent the general industry practices and are supported by manufactures of electrical equipment. These standards can be found in the NEMA Standard Publication No. MG1. Some large AC motors may not fall under NEMA standards. They are built to meet the requirements of a specific application. They are referred to as above NEMA motors.

The NEMA standards mainly specify four design types for AC induction motors-Design A, B, C and D. Their typical load speed curves are shown in Figure 2.3

Design A [5] has normal starting torque (typically 150-170% of rated) and relatively high starting current. The breakdown torque is the highest of all the NEMA types. It can handle heavy loads for a short duration. The slip is <= 5%. A typical application is the powering of injection molding machines.

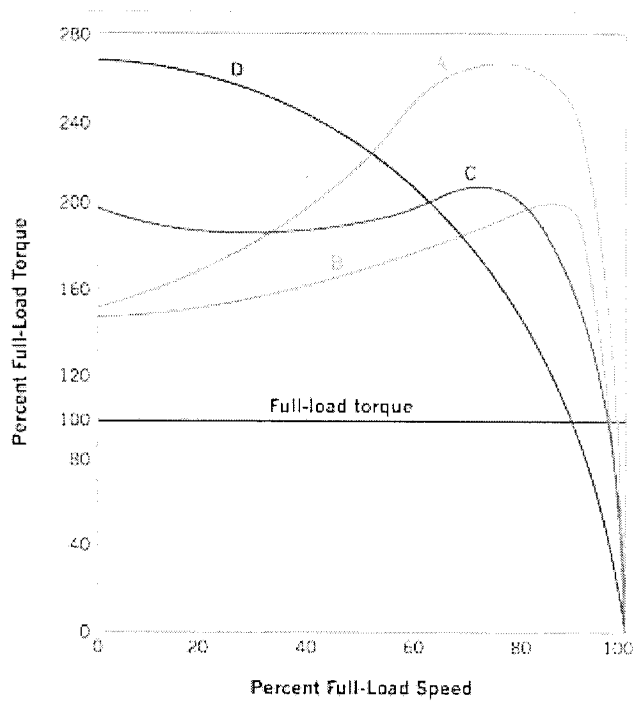


Figure 2.3 – Torque-Speed curves, NEMA design A, B, C, D

Design B [5] is the most common type of AC induction motor sold. It has a normal starting torque, similar to Design A, but offer low starting current. The locked rotor torque is good enough to start many loads encountered in the industrial application. The slip is <=5%. The motor efficiency and full-load PF are comparatively high, contributing to the popularity of the design. The typical applications include pumps, fans and machine tools.

Design C [5] has high stating torque (greater than two previous designs, say 200%), useful for driving heavy breakaway loads like conveyors, crushers, stirring machines, agitators, reciprocating pumps, compressors etc. These motors are intended for operation near full speed without great overloads. The starting current is low. The slip is <=5%.

Design D [5] has high starting torque (higher than all the NEMA motor types). The starting current and full-load speed are low. The high slip values (5-13%) make this motor suitable for applications with changing loads and subsequent sharp changes in the motor speed, such as in machinery with energy storage flywheels, punch presses, shears, elevators, extractors, winches, hoists, oil-well pumping ....etc. The speed regulation is poor, making the design suitable only for punch presses, cranes, elevators and oil well pumps. This motor type is usually considered a "special order" item.

Recently, NEMA has added one more design, i.e. Design E, in its standard for the induction motor. Design E is similar to Design B, but has a high efficiency, high starting currents and lower Full-load running currents.

The following Table 2.2 compares NEMA polyphase designs for several performance criteria.

NEMA Design	Starting current	Locked Rotor Torque	Breakdown Torque	% slip	Application
A	High to Medium	Normal	Normal	Max 5%	Broad applications including fans, blowers, pumps, machine tools
B	Low	Normal	Normal	Max 5%	Normal starting torque for fans, blowers, rotary pumps, unloaded compressors, some conveyors, metal cutting machine tools, misc. machinery. Constant load speed
C	Low	High	Normal	Max 5%	High inertia starts such large centrifugal blowers, fly wheels and crusher drums. Loaded starts such as piston pumps, compressors and conveyors. Constant load speed.

D	Low	Very High	-	-	Very high inertia and loaded starts. Choice of slip to match load.
				5-8%	1) Punch presses, shears and forming machine tools.
				8-13%	2) Cranes, hoists, elevators and oil well pumping jacks.

Table 2.2 – Comparison in NEMA Design

2.8.2 IEC

IEC [5] is the European-based organization that publishes and promotes worldwide, the mechanical and electrical standards for motors, among other things. In simple terms, It can be said that the IEC is the international counterpart of the NEMA. The IEC standards are associated with motors used in many countries. These standards can be found in IEC 34-1-16. The motors which meet or exceed these standards are referred to as IEC motors.

2.9 Duty Cycle

Continuous steady-running loads over long periods are demonstrated by fans and blowers. On the other hand, electric motors installed in machines with flywheels may have wide variations in running loads. Often, electric motors use flywheels to supply the energy to do the work, and the electric motor does nothing but restore lost energy to the flywheel. Therefore, choosing the proper electric motor also depends on whether the load is steady, varies, follows a repetitive cycle of variation, or has pulsating torque or shocks.

For example, electric motors that run continuously in fans and blowers for hours or days may be selected on the basis of continuous load. But electric motors located in devices like automatically controlled compressors and pumps start a number of times per hour. And electric motors in some machine tools start and stop many times per minute.

Duty cycle [6] is a fixed repetitive load pattern over a given period of time which is expressed as the ratio of on-time to cycle period. When operating cycle is such that electric motors operate at idle or a reduced load for more than 25% of the time, duty cycle becomes a factor in sizing electric motors. Also, energy required to start electric motors (that is, accelerating the inertia of the electric motor as well as the driven load) is much higher than for steady-state operation, so frequent starting could overheat the electric motor.

For most electric motors (except squirrel-cage electric motors during acceleration and plugging) current is almost directly proportional to developed torque. At constant speed, torque is proportional to horsepower. For accelerating loads and overloads on electric motors that have considerable droop, an equivalent horsepower is used as the load factor. The next step in sizing the electric motor is to examine the electric motor's performance curves to see if the electric motor has enough starting torque to overcome machine static friction, to accelerate the load to full running speed, and to handle maximum overload. Table 2.3 shows the motor duty cycle types [5] as per IEC standards

and discussed in IEC60034-1,4 [12].

No	Ref.	Duty cycle type	Description
1	S1	Continuous duty	Operation at constant load of sufficient duration to reach the thermal equilibrium
2	S2	Short time duty	Operation at constant load during a given time, less than required to reach the thermal equilibrium, followed by a rest enabling the machine to reach a temperature similar to that of the coolant (2 Kelvin tolerance)
3	S3	Intermittent periodic duty	A sequence of identical duty cycles, each including a period of operation at

			constant load and a rest (without connection to the mains). For this type of duty, the starting current does not significantly affect the temperature rise.
4	S4	Intermittent periodic duty with starting	A sequence of identical duty cycles, each consisting of a significant period of starting, a period under constant load and a rest period.
5	S5	Intermittent periodic duty with electric breaking	A sequence of identical duty cycles, each consisting of a period of starting, a period of operation at constant load, followed by rapid electric breaking and a rest period.
6	S6	Continuous operation periodic duty	A sequence of identical duty cycles, each consisting of a period of operation at constant load and a period of operation at no-load. There is no rest period.
7	S7	Continuous operation periodic duty with electric breaking	A sequence of identical duty cycles, each consisting of a period of starting, a period of operation at constant load, followed by an electric breaking. There is no rest period.
8	S8	Continuous operation periodic duty with related load and speed changes.	A sequence of identical duty cycles, each consisting of a period of operation at constant load Corresponding to a predetermined speed of rotation, followed by one or more periods of operation at another constant load corresponding to the different speeds of rotation (e.g. duty). There is no rest period. The period of duty is too short to reach the thermal equilibrium.

9	S9	Duty with non-periodic load and speed variations	Duty in which, generally, the load and the speed vary non-periodically within the permissible range. This duty includes frequent overloads that may exceed the full loads.

Table 2.3 - Motor duty cycle types as per IEC standards

2.10 Starting load inertia

In any type of duty cycle operations, it is necessary to determine not only the power requirements but the number of times the motor will be started, the inertia [2] of the driven machine, the type of load (constant or variable torque) and the method of stopping the motor.

The inertia of the rotating parts of the driven equipment affects the acceleration time and motor heating during acceleration. The heating of the motor rotor and stator during frequent starting, stopping, and /or reversals can become a design limitation.

2.11 Service Factor

Service factor [2] is defined as the permissible amount of overload a motor will handle within defined temperature limits. When voltage and frequency are maintained at name plate rated values, the motor may be overloaded up to the horsepower obtained by multiplying the rated horsepower by the service factor shown on the nameplate. However locked-rotor torque, locked-rotor current and breakdown torque are unchanged. NEMA has defined service factor values for standard polyphase dripproof, 60Hz motors are as shown in the following table. Table 2.4

Hp	Synchronous Speed, rpm						
	3600	1800	1200	900	720	600	514
1	1.25*	1.15*	1.15*	1.15*	1.0	1.0	1.0

1.5-125	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*
150	1.15*	1.15*	1.15*	1.15*	1.15*	1.15*	1.0
200	1.15*	1.15*	1.15*	1.15*	1.15*	1.0	1.0
Over 200	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Table 2.4 – Service Factors

* These service factors apply only to NEMA design A,B and C motors.

2.12 Temperature and Altitude

A major consideration in both motor design and application is heat. Excessive heat will accelerate motor insulation deterioration and cause premature insulation failure. Excessive heat may also cause a breakdown of bearing grease, thus damaging the bearing system of a motor.

The total temperature a motor must withstand is the result of two factors; external or ambient temperature, and internal or motor temperature rise. An understanding of how these components are measured and expressed is important for proper motor application.

For a given application, the maximum sustained ambient temperature, measured in degrees Celsius, should be determined. Most motors are designed to operate in a maximum ambient temperature of 40^0C at 1000m above sea level. If the ambient temperature or altitude differ the standard, motor may need to be modified to compensate for the increase in total temperature. As a sequence of differed ambient temperature and altitude from the standard, effective motor power must be found accordingly. Following tables show degrading factors for ambient temperature and altitude.

Ambient temperature	Temperature factor
30^0C	1.06
35^0C	1.03

Altitude above sea level	Altitude factor
1000 m	1.00
1500 m	0.98

40^0C	1.00
45^0C	0.97
50^0C	0.93
55^0C	0.88
60^0C	0.82

Table 2.5 a - Temperature factor

2000 m	0.94
2500 m	0.91
3000 m	0.87
3500 m	0.82
4000 m	0.77

Table 2.5 b - Altitude factor

Then,

Effective Power = Rated Power x Temp. Factor x Alt. factor (2.3)

The temperature rise is the result of heat generated by motor losses during operation. At no-load, friction in the bearing, core losses (eddy current and hysteresis), and stator I^2R losses contribute to temperature rise; at full-load, additional losses which cause heating are rotor I^2R losses and stray load losses.

Since current increases with an increase in motor load and under locked-rotor, temperature rise will be significantly higher under these conditions. Therefore, applications requiring frequent starting and/or frequent overloads may require special motors to compensate for the increase in total temperature.

2.13 Motor Cooling

Since the total temperature of a motor is greater than the surrounding environment, heat generated during motor operation will be transferred to the ambient air. The rate of heat transfer affects the maximum load and/or the duty cycle of a specific motor design. IEC for method of cooling is IEC60034-6 [12].

Factors affecting this rate of heat transfer are:

1. Motor enclosure

   Different enclosures result in different airflow patterns which alter the amount of ambient air in contact with the motor. (see section 2.20 for motor enclosure)

2. Frame surface area.

Increasing the area of a motor enclosure in contact with the ambient air will increase the rate of heat transfer.

3. Airflow over motor

   The velocity of air moving over the enclosure affects the rate of heat transfer. Fans are provided on most totally-enclosed and some open motors to increase the velocity of air over the external parts.

4. Ambient air density

   A reduction in the ambient air density will result in a reduction of the rate of heat transfer from the motor. Therefore, total operating temperature increases with altitude. Standard motors are suitable for operation up to 1000 m; motors with service factor may be used at altitude up to 3000 feet at 1.0 service factor.

2.14 Insulation Class vs. Temperature

NEMA has classified insulation systems [2] by their ability to provide suitable thermal endurance. The total temperature is the sum of ambient temperature plus the motor's temperature rise. The following charts illustrate the maximum total motor temperature allowed for each of the standard classes of insulation. An additional 10 ^{0}C measured temperature rise is permitted when temperatures are measured by detectors embedded in the winding. Figure 2.4 – Figure 2.6 illustrate the temperature rise limits established for various insulation classes per NEMA MG1, part 12.

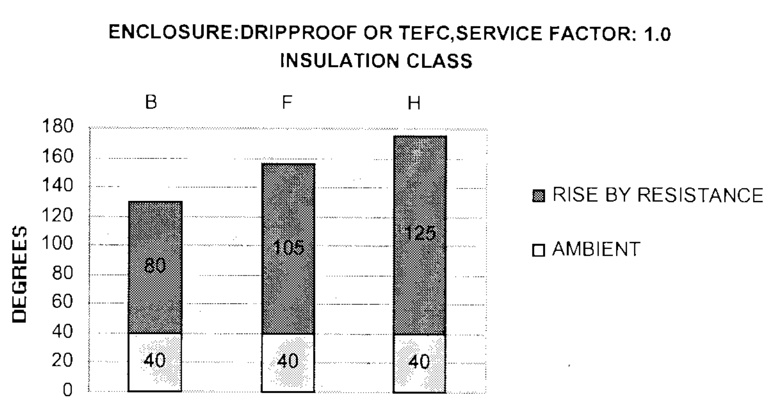


Figure 2.4 – Dripproof or TEFC enclosure, SF 1.0

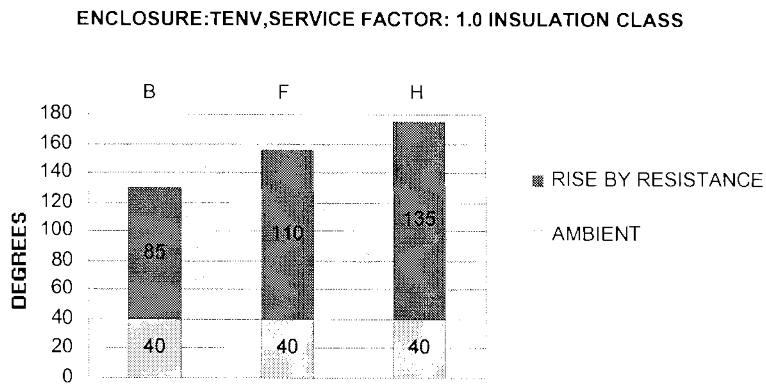


Figure 2.5 – TENV enclosure, SF 1.0

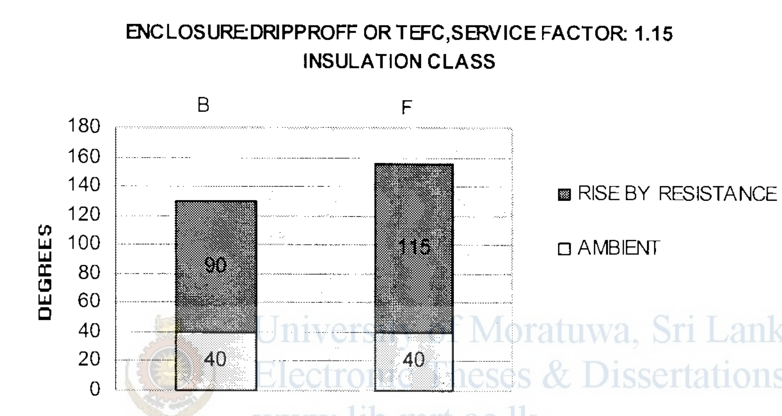


Figure 2.6 – Dripproof or TEFC enclosure, SF 1.15

2.15 Efficiency

Efficiency [2] is an important application consideration. That is especially true for application having high hours of operation where cost of motor operation is many times the initial purchase price of the motor. Energy efficiency classes are described in IEC60034-30 [12].

Efficiency is defined as,

$$\text{Efficiency} = \frac{\text{Watts Output}}{\text{Watts Input}} \tag{2.4}$$

$$\text{Efficiency} = \frac{(\text{Input - Losses})}{\text{Input}} \qquad (2.5)$$

The only way to improve efficiency is to reduce losses.

2.16 Motor losses

Typically, motor losses [2] are categorized, first, as those which occur while the motor is energized but operating at no-load; and second, those additional losses due to the output load. Specific losses are:

1. No-load losses
   a. Windage and friction
   b. Stator iron losses
   c. Stator I^2R losses

2. Load losses
   a. Stator I^2R losses (due to increase in current under load)
   b. Rotor I^2R
   c. Stray load losses

The no-load losses and the conductor losses under load can be measured separately; however, the stray load loss requires accurate input-output test equipment for determination. The stray-load loss consists of losses due to harmonic currents and flux in the motor.

Factors affecting stray load losses include:

Stator and rotor slot geometry

Number of slots

Air gap length

Rotor slot insulation

Manufacturing process

2.17 Power Factor

In a sense, motors are electromagnets and power factor [2] is a measure of the amount of magnetizing current required.

Power factor is an important consideration when selecting a motor for a particular application since low power factor may result in power factor penalty charges from the utility supplier.

Equation for Power factor in a three-phase system,

$$PF = \frac{\text{Watts Input}}{\left(\sqrt{3} \times V \times I\right)} \tag{2.6}$$

This equation is a numerical method of expressing the phase difference between voltage and current in a motor circuit. The current in an induction motor lags the applied voltage, and only the component that is in-phase with the voltage varies with motor power.

2.18 Load Connections

Two methods of mechanical connection [2] of the motor to the driven load are commonly used.

1. Direct connection

   Direct connection should always be considered where the required load speed coincides with an available motor speed. The preferred practice is to use a flexible coupling which will allow a slight amount of misalignment and minimize transmission of thrust to the motor bearings. Axial thrust loads are commonly encountered when a pump impeller or fan is mounted on the motor shaft. They also occur in direct connected helical gear drives and when the motor is mounted vertically or in an inclined position where any weight other than the rotor is supported by the motor shaft.

2. Belt, chain and gear drives

When connecting a motor to its load with this type of drives, proper selection is necessary to limit within radial load capacities.

2.19 Starting Methods

The following motor starting methods encountered when starting a motor

2.19.1 DOL starters

When an electric motor is started by direct connection to the power supply (DOL) [7], it draws a high current, called the starting current which is approximately equal in magnitude to the locked rotor current. Locked rotor current is normally up to 8 times the rated current of the motor. In circumstances where the motor starts under no load or where high starting torque is required, it is preferable to reduce the starting current by one of the following means.

2.19.2 Star-Delta starting

Through the use of a star-delta starter [7], the motor terminals are connected in the star configuration during starting and reconnected to the delta configuration when running. The benefits of this starting method are a significantly lower starting current, to a value about 1/3 of the DOL starting current, and a corresponding starting torque also reduced to about 1/3 of its DOL value. It should be noted that a second current surge occurs on changeover to the delta connection. The level of this surge will depend on the speed the motor has reached at the moment of changeover.

2.19.3 Electronic soft starters

Through the use of an electronic soft starter [7], which controls such parameters as current and voltage, the starting sequence can be totally controlled. The starter can be programmed to limit the amount of starting current. By limiting the rate of the current increase the startup time is extended. This starting method is particularly suitable for centrifugal loads (fans and pumps)

2.19.4 Variable Speed Drives

A drive is primarily recognized for its ability to manipulate power from a constant three 50/60Hz supply converting it to variable voltage and variable frequency power. This enables the speed of the motor to be matched to its load in a flexible and energy efficient manner. The only way of producing starting torque equal to full load torque with full load current is by using variable speed drive. The functionally flexible VSD is also commonly used to reduce energy consumption on fans, pumps and compressors and offers a simple and repeatable method of changing speeds or flow rates.

2.20 Motor enclosures

The type of enclosures [2] required is dependent upon the surrounding atmosphere in which the motor is installed and the amount of mechanical protection and corrosion resistance required. The two general classes of motor enclosure are open and totally-enclosed. An open machine is one having ventilating openings which permit passage of external air over and around the winding of the motor. A totally-enclosed machine is constructed to prevent the free exchange of air between the inside and outside of the motor, but not sufficiently enclosed to be termed air-tight. Derivatives of these two basic enclosures are described below. Enclosures come under IEC60034-7 [12].

- Open
    1. **Dripproof.** Dripproof motors are designed to be internally ventilated by ambient air, having ventilation openings constructed so that successful operation is not affected when drops of liquid or solid particles strike the enclosure at any angle from 0 to 15 degrees downward from vertical. Dripproof motors are typically used in relatively clean, indoor applications.

       Also Weather protected, open machines are of another type.

- Totally-Enclosed

  Totally-enclosed motors are designed so that there is no free exchange of air between the inside and outside of the enclosure, but not sufficiently enclosed to be airtight. Totally-enclosed motors are may be of three types of construction.

  1. **TEFC (Totally-enclosed fan-cooled).** This type includes an external fan mounted on the motor shaft. This fan is enclosed in a fan casing which both protects the fan and directs the output air over the motor frame for cooling.
  2. **TEAO (Totally-enclosed air-over).** This type is similar to TEFC designs except that the cooling air being forced over the motor frame is provided by a fan which is not an integral part of the motor.
  3. **TENV (Totally-enclosed non-ventilated).** This type of construction does not require forced air flow over the motor frame for cooling.

2.21 Enclosure material

Frame and end-shield materials that are normally used are listed below

Aluminum-alloy, Cast-iron, sheet steel

2.22 Terminal box

Terminal box is there for connecting power cables. As standard the terminal box is mounted on the right hand side when viewed from drive end. Motors are also available with terminal left hand side or top. They are fitted with conduit entries.

2.23 Mounting Configurations

Various mounting configurations are available, complying with IEC60034-7 [12].

- Floor mount
- Ceiling mount

- Wall mount, shaft horizontal
- Wall mount, shaft vertical

2.24 Dynamic Balance/Vibration

Motors should be dynamically balanced so as to fulfill vibration standards. Vibrations are tested as per NEMA standard MG1-12.08 and should be within the limits. IEC stands for vibration is IEC 60034-14 [12]

2.25 Bearing/Lubrication

All standard motors are equipped with "clean steel" corned deep groove ball bearings. Lubrication should be done as per instruction given by the manufacturer.

2.26 Noise limits

Noise limit of motors should comply with the IEC60034-9, 6 [12].

2.27 Shaft and key

Shaft and keys of motors should comply with the IEC60034-1, 11.2 [12].

2.28 Degree of protection

This is IP standards explanation and coming under IEC 60034-5 [12].

First characteristic numeral
Degree of protection of persons against approach to live parts or contact with live or moving parts (other than smooth rotating shafts and the like) inside the enclosure, and degree of protection of equipment within the enclosure against the ingress of solid foreign bodies.

4 protected against solid object greater than 1.0mm: wires or strips of thickness greater than 1.0mm, solids objects exceeding 1.0mm

5 Dust protected: Ingress of dust is not totally prevented but it does not enter in sufficient quantity to interfere with satisfactory operation of the equipment.

6 Dust tight: No ingress of dust.

Second characteristic numeral

4 Protected against splashing water. Water splashed against the enclosure from any direction shall have no harmful effect.

5 Protected against water jets: Water projected by a nozzle against the enclosure from any direction shall have no harmful effect.

6 Protected against heavy seas: Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities.

Note: first three numerals are not explained, since they have no use here.

2.29 Motor Name plate

A typical name plate of an AC induction motor is shown in Figure 2.7

<table>
<tr><td colspan="7">Name of Manufacturer</td></tr>
<tr><td>ORD.No.</td><td colspan="6">IN4560981324</td></tr>
<tr><td>TYPE</td><td colspan="3">HIGH EFFICIENCY</td><td>FRAME</td><td>286T</td><td></td></tr>
<tr><td>H.P.</td><td colspan="3">42</td><td>SERVICE FACTOR</td><td>1.10</td><td>3PH</td></tr>
<tr><td>AMPS</td><td colspan="3">42</td><td>VOLTS</td><td>415</td><td>Y</td></tr>
<tr><td>R.P.M.</td><td colspan="3">1790</td><td>HERTZ</td><td></td><td>4 POLE</td></tr>
<tr><td>DUTY</td><td colspan="3">CONT</td><td>DATE</td><td>01/15/2003</td><td></td></tr>
<tr><td>CLASS INSUL</td><td>F</td><td>NEMA DESIGN</td><td>B</td><td>NEMA NOM.EFF.</td><td>95</td><td></td></tr>
<tr><td colspan="7">Address of Manufacture</td></tr>
</table>

Figure 2.7 – Typical name plate of an Induction motor

Chapter 3

Motor selection for the application

3.1 Measurements

Machine speed range : Minimum 200rpm ; Maximum 740 rpm

Available supply : 3 phase, 400V

Ambient temperature: 32^0C

Altitude : 2.74 m

Armature voltage at maximum speed, V_a : 126 V DC

Armature current at maximum speed, I_a : 33A DC

Armature resistance, R_a : 0.54 Ω

3.1.1 Load profile

Figure 3.2 shows the load profile of the existing drive over a 14 machine cycles approximately 25 seconds each. And Figure 3.3 shows an enlarge view of one machine cycle. Method of data logged is shown in Figure 3.1

Note: Since Armature control is used for speed controlling of the motor at constant flux, Armature parameters are measured.

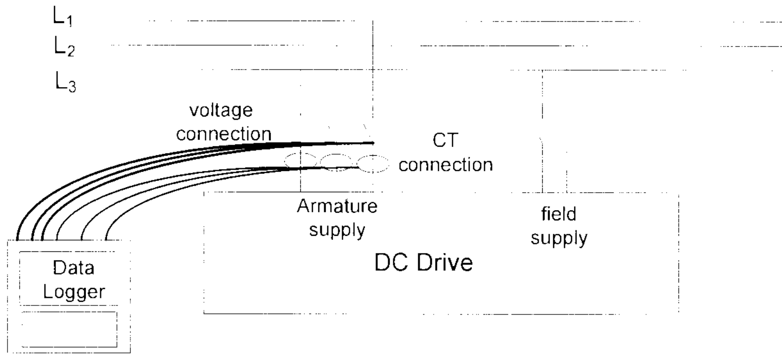


Figure 3.1 – Connection of data logger

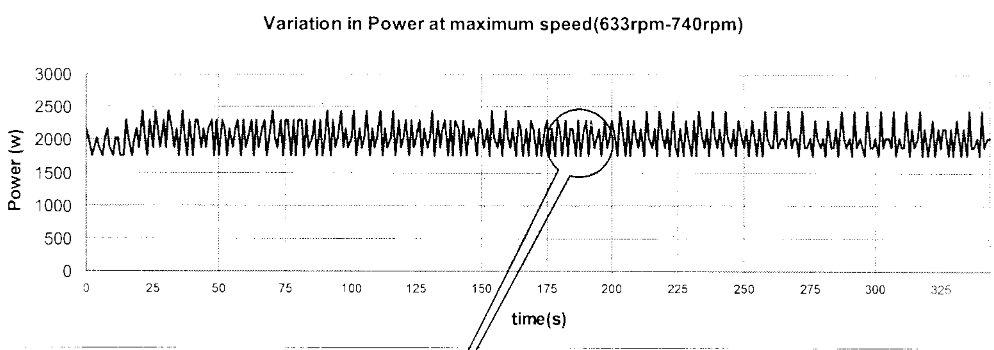


Figure 3.2 – Load profile at maximum speed

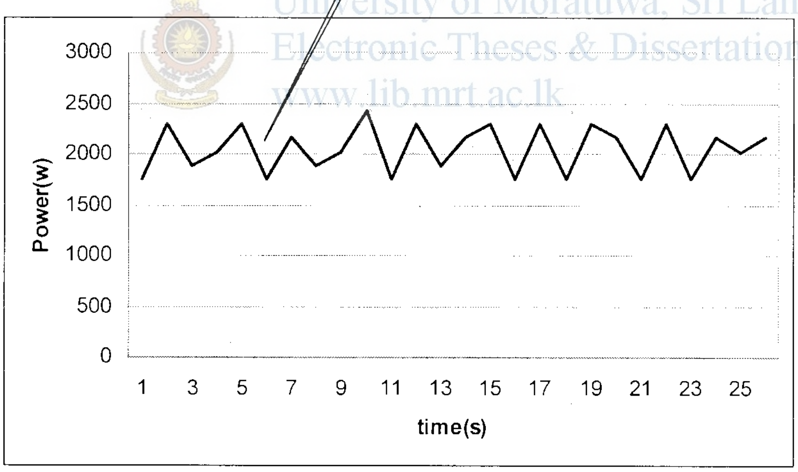


Figure 3.3 – Enlarge view of one machine cycle.

3.1.2 Measurement of Torque

Figure 3.4 shows the methodology used to measure the friction torque of the machine. A spring balance is used with a handle fitted to the machine main shaft and force is applied at the hook of the balance always perpendicular to the handle.

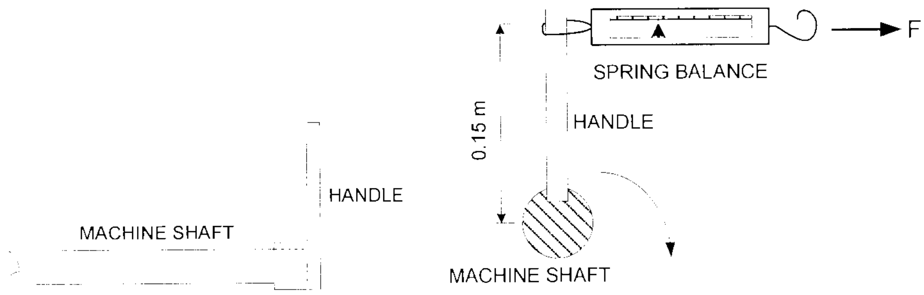


Figure 3.4 – Torque measurement

Force applied just to move the machine = 11kg

Force applied just to continue the rotational movement = 8 kg

Note : Full load of the machine will be calculated by means of V_a, I_a,R_a (sec.3.1)

3.2 Motor Standard

A motor with IEC standard is preferred. Machine requires a fairly high starting torque at the beginning. Therefore, a motor having high starting torque with low starting current and lows slip at full load is suitable for the application. IEC motor having equivalent performances as NEMA design class C is selected. Refer section 2.8

3.3 Motor type

Squirrel cage induction motor is selected.

It is simple and rugged design, low cost and low maintenance

3.4 Voltage and Frequency

Three phase, 415V, 50Hz

3.5 Speed

As per above measurement, maximum speed is 740rpm. Therefore, let's select the motor speed as1000rpm. So far, selection can be termed as below.

Select 3P, 415V,50Hz,1000rpm cage induction motor

3.6 Number of Poles

Since, motor speed has been taken as 1000rpm

Number of poles $= 120\ f / n_{syn}$

$= 120x\ 50 / 1000$

$= 6$

Select 6 pole motor

3.7 Motor power

Figure 3.2 shows the load profile of the existing DC drive. It is the power variation at maximum running speed; i.e. 740 rpm. Figure 3.3 shows the enlarge view over one machine cycle.

This power is measured as the power delivered to the armature of the existing DC motor. Supplied field current is not considered here and it is maintained constant by the drive.

It is seen from the graph, at maximum running speed, power varies as

$P_{min} = 1522.6$ W

$P_{avg} = 1753.3$ W

$P_{max} = 2427.6$ W

Therefore instantaneous peak power delivered to the motor is 2.4 kW

Closest available capacity should be greater than 2.4 kW

Further, it has to be considered the "Full load torque" requirement of the motor.

3.8 Friction Torque of the machine

Following shows a only a rough guide or indication about the friction torque of the machine.

From above measured data,

Force applied just to move the machine = 11kg

Force applied in Newton, (1kg=9.81N) F = 11x9.81 = 107.9N

Length of the handle, l = 0.15 m

Therefore, torque = Fxl

= 107.9x0.15

= 16.18 Nm

Force applied just to continue the rotational movement

= 8 kg

Force applied in Newton = 8 x 9.81 = 78.5N

Therefore, Torque = 78.5x 0.15

= 11.77 Nm

3.9 Motor Torque

Following describes calculation of motor torque at maximum machine speed from motor parameters. Equivalent circuit of a separately excited DC motor is considered for calculation. Refer Appendix-A

Load in the application is "Constant torque" and speed change is achieved through Armature voltage control.

From above measured data,

Armature voltage at maximum speed, V_a = 126V DC

Armature current at maximum speed, I_a = 33A DC

Armature resistance, R_a = 0.54 Ω

At maximum machine running speed, i.e.740 rpm,

From equations A.3 and A.4 in appendix-A

$$P_{conv} = \tau\omega = E_a I_a$$

$$V_a = R_a I_a + E_a$$

$$\tau\omega = (V_a - I_a R_a) \times I_a$$

$$\tau \times 740 \times 2\Pi / 60 = (126 - 33 \times 0.54) \times 33$$

$$\tau = 46 \text{ Nm}$$

This gives an idea about the torque delivered by the existing DC motor at maximum running speed. This can be considered as the required "Full load torque" of the proposed motor. Therefore, let's select a motor having the "Full load torque" which is equal or greater than 46 Nm. So far, selection can be termed as below.

Select 3P, 415V,50Hz,1000rpm, Power > 2.4 kW, full load torque >46Nm, cage induction motor

Hence, from CMG Motor selection catalogue, 5.5kW motor having full load torque of 54.4 Nm can be selected.

3.10 Motor inertia

Motor inertia is also a very important factor. Since the machine is a heavy mechanical, there is absorption of inertia. Machine comes to rest as soon as STOP button is pressed. At the starting also, machine comes to steady state condition within couple of seconds. Therefore it is assumed to have a small inertia and not disused here.

3.11 Temperature and Altitude

From above measurements, Section 3.1

Ambient temperature : 32^0C

Altitude : 2.74 m

Since the motor is running within standard ambient conditions of 40^0C at 1000m below sea level, no de-rating is required.

3.12 Duty cycle

Refer the Figure 3.1. Machine duty cycle is too small as 0.78 s and power varies from 1.1kw to 2.4 kW and no rest time.

Therefore this operation can be considered as continuous duty application. Refer section 2.9.

Select a continuous duty motor

3.13 Motor cooling

Enclosed fan cooled over an externally ribbed frame, with free movement of internal air by rotation of rotor blades is suitable for the application. Refer section 2.13.

3.14 Insulation temperature

The total motor temperature is the sum of ambient temperature plus the motor's temperature rise. Class F insulation is preferred for the application. Refer Figure 2.4 in section 2.14.

3.15 Efficiency

Efficiency (see section 2.15) of the selected motor as per the manufacture data sheet. Refer Annex B for data sheet.

At 100% of full load : 85.6

At 75% of full load : 85.9

At 50% of full load : 84.3

3.16 Power Factor

PF (see section 2.17) of the selected motor as per the manufacture data sheet. Refer Annex B for data sheet.

At 100% of full load : 0.81

At 75% of full load : 0.76

At 50% of full load : 0.64

3.17 Motor enclosure

Totally closed enclosure with fan cooled type (TEFC) is suitable for the application. Refer section 2.20.

3.18 Enclosure material

Cast –Iron : Frame, End-shields, Terminal box

Sheet steel : Fan cowl . (Refer section 2.21)

3.19 Terminal box

Terminal box, located on Top is preferred. Cable routing of the existing motor is terminated to top side and, therefore it will be easy for connections. Conduit entries are provided tapped. Refer section 2.22.

3.20 Mounting configuration

Since there is a machine bed to install the motor, Foot mount is suitable for the application. Refer section 2.23.

3.21 Bearings/lubrication/vibration/balancing/noise limits

Not specially considered. Selected as standard. Refer sections 2.24-2.26

3.22 Shaft and key

Standard shaft extension with standard key. Refer section 2.27

3.23 Degree of protection

IP55 protection for both motor and terminal box is IP55. Refer section 2.28.

3.24 Load connection

Existing system has belt driven system. From efficiency point of view, it is better to go for a geared coupling. But considering the extra difficulties encountered in modification with the existing set up, it is decided to use the same belt coupling system. Refer section 2.18.

While Figure 3.5 shows the present load connection, Figure 3.6 shows the load connection of the proposed system.

Figure 3.5 – Existing system

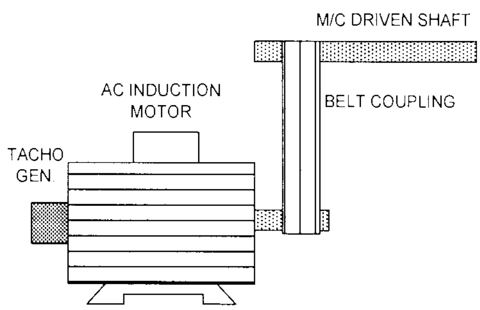


Figure 3.6 – Proposed system

3.25 Performance data of the selected motor

Source : CMG Motors, Australia

Three phase, 415V, 50Hz, 1000rpm (6 pole), 5.5kW, IP55, continues duty, F class insulation, fan cooled, foot mounted, extended shaft cage induction motor.

Table 3.1 describes the other performances. Also refer Annex B.

Efficiency % at % full load	125	84.4
	100	85.6
	75	85.9
	50	84.3
Power Factor, cos ϕ at % full load	125	0.84
	100	0.81
	75	0.76
	50	0.64
Current	Full load, I_N (A)	11.0
	Locked rotor, I_L/I_N	6.9
Torque	Full load, T_N (Nm)	54.4
	Locked rotor, T_L/T_N	2.4
	Break down, T_B/T_N	3.0
Moment of Inertia	kgm^2	0.045
Weight of foot mount motor	kg	90

Table 3.1 – Performance data

Chapter 4

Selection of a Motor Drive

As discussed in section 2.19 in Chapter 02, several methods are available to start and drive an AC induction motor. In this particular application, it requires to change the machine speed over the range of 200rpm to 740 rpm. Therefore, Variable frequency drive has to be selected as the drive mechanism.

4.1 Need for the electrical drive for an induction motor

Apart from the nonlinear characteristics of the induction motor, there are various issues attached to the driving of the motor. Let's look at them one by one [5].

Earlier motors tended to be over designed to drive a specific load over its entire range. This resulted in a highly inefficient driving system, as a significant part of the input power was not doing any useful work. Most of the time, the generated motor torque was more than the required load torque.

For the induction motor, the state motoring region is restricted from 80% of the rated speed to 100% of the rated speed due to the fixed supply frequency and the number of poles.

When an induction motor starts, it will draw very high inrush current due to the absence of the back EMF at start. This results in higher power loss in the transmission line and also in the rotor, which will eventually heat up and may fail due to insulation failure. The high inrush current may cause the voltage to dip in the supply line, which may affect the performance of other utility equipment connected on the same supply line.

When the motor is operated at a minimum load (i.e., open shaft), the current drawn by the motor is primarily the magnetizing current and is almost purely inductive. As a result, the PF is very low, typically as low as 0.1. When the load is increased, the working current begins to rise. The magnetizing current remains almost constant over the entire operating range, from no load to full load. Hence, with the increase in the load, the PF will improve.

When the motor operates at a PF less than unity, the current drawn by the motor is not sinusoidal in nature. This condition degrades the power quality of the supply line and may affect performances of other utility equipment connected on the same line.

When the supply line is delivering the power at a PF less than unity, the motor draws current rich in harmonics. This results in high rotor loss affecting the motor life. The torque generated by the motor will be pulsating in nature due to harmonics. At high speed, the pulsating torque results in the motor speed pulsation. This results in jerky motion and affects the bearing's life.

The supply line may experience a surge or sag due to the operation of other equipment on the same line. If the motor is not protected from such conditions, it will be subjected to higher stress than designed for, which ultimately may lead to its premature failure.

All of the previously mentioned problems, faced by both consumers and the industry, strongly advocated the need for an intelligent motor control.

With the advancement of solid state device technology (BJT, MOSFET, IGBT, SCR, etc.) and IC fabrication technology, which gave rise to high-speed microcontrollers capable of executing real-time complex algorithm to give excellent dynamic performance of the AC induction motor, the electrical variable frequency drive became popular.

4.2 Variable Frequency Drive

The VFD [5] is a system made up of active/passive power electronics devices (IGBT, MOSFET, etc.), a high speed central controlling unit (a microcontroller, like the PIC 18 or the PIC 16) and optional sensing devices, depending upon the application requirement.

The basic function of the VFD is to act as a variable frequency generator in order to vary speed of motor as per the user setting. The rectifier and the filter convert the AC input to DC with negligible ripple. The inverter, under the control of the microcontroller, synthesizes the DC into three-phase variable voltage, variable frequency AC. Additional features can be provided, like the DC bus voltage sensing, OV and UV trip, over-current protection, accurate speed/position control, temperature control, easy control setting, display, PC connectivity for real-time monitoring, Power Factor Correction (PFC) and so on. With the rich features set of the microcontroller, it is possible to integrate all the features necessary into get advantages, such as reliability, accurate control, space, cost saving and so on.

While a block diagram of an Inverter is shown in Figure 4.1, a typical modern-age intelligent VFD for the three-phase induction motor with single phase supply is shown in Figure 4.2

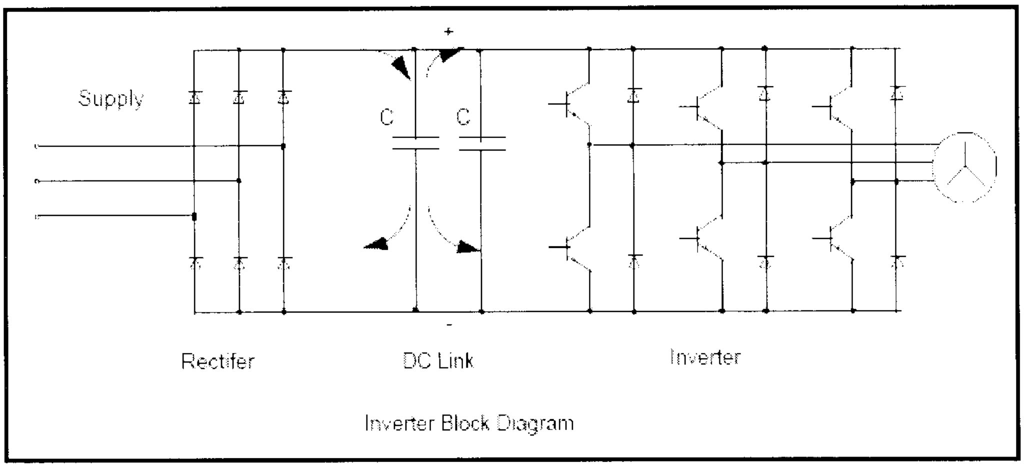


Figure 4.1 – An Inverter block diagram

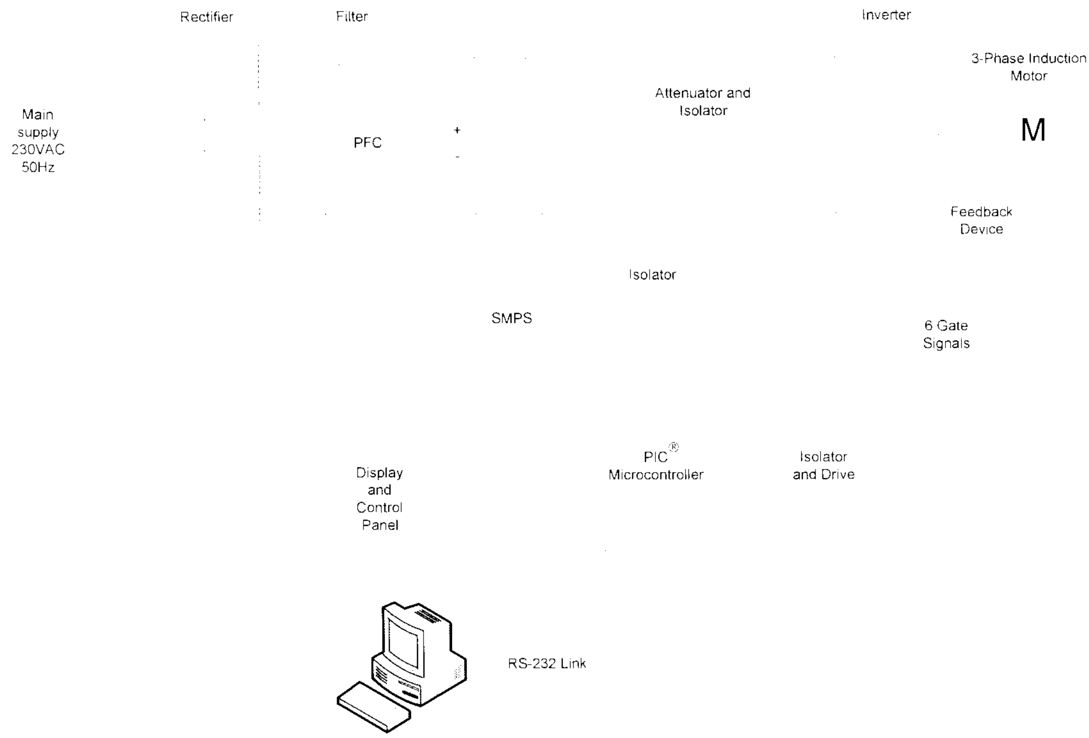


Figure 4.2 – A typical modern-age intelligent VFD

The based speed of the motor is proportional to supply frequency and is inversely proportional to the number of stator poles. The number of poles cannot be changed once the motor is constructed. So, by changing the supply frequency, the motor speed can be changed. But when the supply frequency is reduced, the equivalent impedance of electric circuit reduces. This results in higher current drawn by the motor and a higher flux. If the supply voltage is not reduced, the magnetic field may reach the saturation level. Therefore, both the supply voltage and the frequency are changed in a constant ratio. Since the torque produced by the motor is proportional to the magnetic field in the air gap, the torque remains more or less constant throughout the operating range.

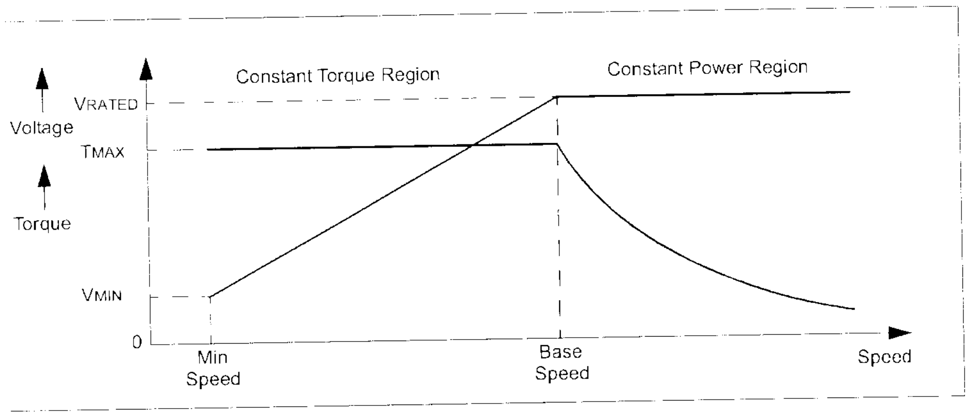


Figure 4.3 – V/f curve

As seen in the Figure 4.3, the voltage and the frequency are varied at a constant ratio up to the base speed. The flux and the torque remain almost constant up to the base speed. Beyond the base speed, the supply voltage can not be increased. Increasing the frequency beyond the base speed results in the field weakening and the torque reduces. Above the base speed, the torque governing factors become more nonlinear as the friction and windage losses increase significantly. Based on the motor type, the field weakening can go up to twice the base speed. This control is the most popular in industries and is popularly known as the constant V/f control.

By selecting the proper V/f ratio for a motor, the starting current can be kept well under control. This avoids any sag in the supply line, as well as heating of the motor. The VFD also provides over-current protection. This feature very useful while controlling the motor with higher inertia.

Since almost constant rated torque is available over the entire operating range, the speed range of the motor becomes wider. User can set the speed as per load requirement, thereby achieving higher energy efficiency (especially with the load where power is proportional to the entire range is smooth, except at very low speed. This restriction comes mainly due to the inherent losses in the motor, like frictional, windage, iron, etc. These losses are almost constant over the entire speed. Therefore, to start the motor, sufficient power must be supplied to overcome these losses and the minimum torque has to be developed to overcome the load inertia.

A PFC circuit at the input side of the VFD helps a great deal to maintain an approximate unity PF. By executing a complex algorithm in real-time using microcontroller, the user can easily limit flow of harmonics from line to motor and hence, near unity PF power can be drawn from the line. By incorporating the proper EMI filter, the noise flow from the VFD to the line can entirely be stopped. As the VFD is in between the supply line and the motor, any disturbance (sag or surge) on the supply line does not get transmitted to the motor side.

With the use of various kinds of available feedback sensors, the VFD becomes an intelligent operator in true sense. Due to feedback, the VFD will shift motor torque-speed curve, as per the load and the input condition. This helps to achieve better energy efficiency.

With the VFD, the true four quadrant operation of the motor is possible (i.e. forward motoring and breaking, reverse motoring and breaking). This means that it eliminates the need for mechanical breaks and efficiently reuses the Kinetic Energy (KE) of the motor. However, for safety reasons, in many applications like hoists and cranes, the mechanical breaks are kept as a standby in case of electrical break failure.

Care must be taken while breaking the motor. If the input side of the VFD is uncontrolled, then regenerative breaking is not possible (i.e. the KE from the motor can not be returned back to the supply). If the filter DC link capacitor is not sufficiently large enough, then the KE, while breaking, will raise the DC bus voltage level. This will increase the stress level on the power devices as well as the DC link capacitor. This may lead to permanent damage to the device/capacitor. It is always advisable to use the dissipative mean (resistor) to limit the energy returning to the DC link by dissipating a substantial portion in the resistor.

Compared to the mechanical breaking, the electrical breaking is frictionless. There is no wear and tear in the electrical breaking. As a result, the repetitive breaking is done more efficiently with the electrical breaking.

4.3 Selecting a Drive

Often drive selection [4] is straight forward, as a motor is already installed and the speed range requirement is not excessive. However, when a drive system is selected from first principles, careful consideration may avoid problems in installation and operation, and may also save significant cost.

Overall consideration

- Check the current rating of the inverter and the motor. Power rating is only a rough guide.
- Check that the correct operating voltage is selected. 230V single phase or 400V three phase.
- Check the required speed range. Operation above normal supply frequency (50Hz) is usually only possible at reduced power. Operation at low frequency and high torque can cause the motor to overheat due to lack of cooling.
- Check overload performance. The inverter will limit current to 150 or 200% of full current very quickly-a standard, fixed speed motor will tolerate these overloads.
- Quick stopping is needed? If so, consider braking facilities provided with the drive.
- Is it needed to operate with cables longer than 50m, or screened or armored cables longer than 25m? If so, it may be necessary to de-rate, or fit a chock to compensate for the cable capacitance.

4.3.1 Supply side requirements

In order to achieve reliable operation, the main power supply to the inverter system must be suited to the inverter and the anticipated power supplied. The following points should be considered.

4.3.1.1 Supply Tolerance

The inverters are designed to operate on a wide range of supply voltage as follows.

Low voltage units	208-140V+/- 10% i.e. 187-264V
High voltage units	380-500V+/- 10% i.e. 342-550V
Very Low voltage units	525-575V+/- 10% i.e. 472-633V

Inverters will operate over a supply frequency of 47-63 Hz

4.3.1.2 Supply Disturbance

The inverters are designed to absorb high level of supply disturbance-for instance, voltage spikes up to 4kV. However, the above equipment can cause power supply disturbances in excess of this. It will be necessary to suppress this interference-preferably at source-or at least by the installation of an input choke in the inverter supply. EMC filters do not suppress disturbances with this level of energy; over voltage protection products such as metal oxide varistors should be considered.

Damage can also be caused by local supply faults and the effects of electrical storms. In areas where these are expected, similar precautions are recommended.

4.3.1.3 Ungrounded supplies

Certain industrial installations operate with supplies that are isolated from the protective earth (IT supply). This permits equipment to continue to run following an earth fault. However this inverter is designed to operate on grounded supplies and are fitted with interference suppression capacitors between the supply and ground. Hence operation on ungrounded supplies must be restricted.

4.3.1.4 Low frequency Harmonics

The inverter converts the AC supply to DC using an uncontrolled diode rectifier bridge. The DC link voltage is close to the peak AC supply voltage, so the diodes only conduct for a short time at the peak of the AC waveform. The current waveform therefore as a relatively high RMS value as a high current flows from the supply for a short time.

This means that the current waveform is consists of a series of low frequency harmonics, and this may in turn cause voltage harmonic distortion, depending on the supply impedance.

Sometimes these harmonics need to be assessed in order to ensure that certain levels are not exceeded. Excessive harmonic levels can cause high losses in transformers, and may interfere with other equipment. In any cause, the rating and selection of cabling and protection equipment must take into account these high RMS levels.

4.3.2 Motor limitations

The motor speed is determined mainly by the applied frequency. The motor slows down a little as the load increases and the slip increases. If the load is too great the motor will exceed the maximum torque and stall or 'pull out'. Most motors and inverters will operate at 150% load for a short time, for instance, 60 seconds.

The motor is usually cooled by a built in fan that runs at motor speed. This is designed to cool the motor at full load and base speed. Cooling may be inadequate, if it runs at low speed and full torque.

4.3.3 Load considerations

The inverter and motor requirements are determined by the speed range and torque requirements of the load. The relationship between Speed and Torque is different for different loads. Many loads can be considered to be constant torque loads, such as conveyers, compressors, positive displacement pumps.

4.3.4 Acceleration and breaking requirements

If the load has high inertia and there is a requirement for fast acceleration or breaking, the load due to the inertia must be considered.

During acceleration, additional torque will be needed. The total torque needed will be the sum of the steady state torque and this additional torque.

4.3.5 Environmental Considerations

An inverter is designed for operation in an industrial environment. However there are certain limitations which must be considered. Some important points are as follows.

- The air flow through the inverter should not be blocked by wiring etc.
- Temperature of air does not exceed 50^0C.
- IP rating of the inverter to suit with the environmental condition.
- The inverters are designed for fixed installation and not designed to withstand excessive shock and vibration.
- The inverter will be damaged by corrosive atmospheres.
- Attention for Electromagnetic Compatibility (EMC).

Chapter 5

Selected Motor Drive

5.1 SIEMENS MICROMASTER 440

The MICROMASRET 440s [10] are frequency inverters for speed and torque control of three phase AC motors. The various models available cover the performance range from 120W to 200kW.

The inverters are microprocessor-controlled and state-of-the art Insulated Gate Bipolar Transistors (IGBT) technology. This makes them reliable and versatile. A special pulse- width modulation method with selectable Pulse frequency permits quiet motor operation. Comprehensive protective functions provide excellent inverter and motor protection.

The MICROMASTER 440 with its default factory settings, it is suitable for a many variable motor applications. Using functionally MICROMASTER 440 can be used both 'stand-alone' applications as well as being integrated into 'Automation Systems'. Figure 5.1 shows outside appearance of the drive and Figure 5.2 shows the block diagram. Table 5.1 describes the Performance rating of the drive.

Figure 5.1 – SIEMENS MICRMASTER 440

5.1.1 Block diagram

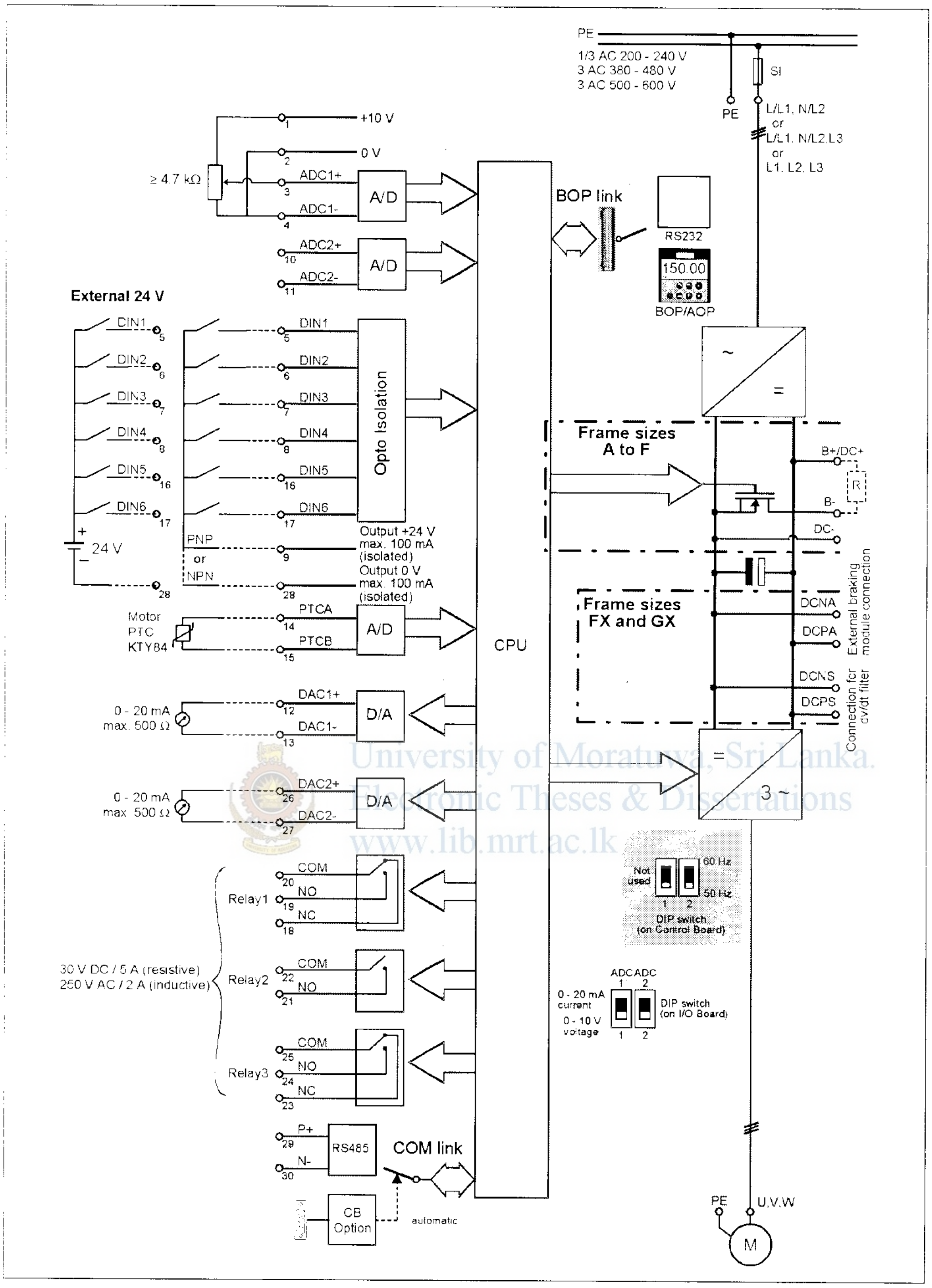


Figure 5.2 – Block diagram of the drive

5.1.2 Performance rating

Feature		Specification
Mains Operating Voltage & Power Ranges		1 AC 200 to 240 V ± 10 % CT 0,12 kW – 3,0 kW (0,16 hp – 4,0 hp) 3 AC 200 to 240 V ± 10 % CT 0,12 kW – 45,0 kW (0,16 hp – 60,0 hp) VT 5,50 kW – 45,0 kW (7,50 hp – 60,0 hp) 3 AC 380 to 480 V ± 10 % CT 0,37 kW – 200 kW (0,50 hp – 268 hp) VT 7,50 kW – 250 kW (10,0 hp – 335 hp) 3 AC 500 to 600 V ± 10 % CT 0,75 kW – 75,0 kW (1,00 hp – 100 hp) VT 1,50 kW – 90,0 kW (2,00 hp – 120 hp)
Input Frequency		47 to 63 Hz
Output frequency		0 Hz to 650 Hz
Power Factor		0.95
Inverter Efficiency		Frame Sizes A to F: 96 % to 97 % Frame Sizes FX and GX: 97 % to 98 %
Overload Capability	Constant Torque (CT)	Frame Sizes A to F: 1,5 x Nominal output current (i.e. 150 % overload) for 60 s every 300 s and 2 x Nominal output current (i.e 200 % overload) for 3 s every 300 s Frame Sizes FX and GX: 1.36 x Nominal output current (i.e 136 % overload) for 57 s every 300 s and 1.6 x Nominal output current (i.e 160 % overload) for 3 s every 300 s
	Variable Torque (VT)	Frame Sizes A to F: 1.1 x Nominal output current (i.e. 110 % overload) for 60 s every 300 s and 1.4 x Nominal output current (i.e 140 % overload) for 3 s every 300 s Frame Sizes FX and GX: 1.1 x Nominal output current (i.e. 110% overload) for 59 s every 300 s and 1.5 x Nominal output current (i.e 150% overload) for 1 s every 300s
Inrush Current		Less than rated input current
Power-ON-OFF cycle time		Frame Sizes A to E: every 30 s Frame Size F: every 150 s Frame Sizes FX and GX: every 300 s
Control Method		V/f control, output frequency between 0 Hz and 650 Hz Linear V/f control, Linear V/f control with FCC, Parabolic V/f control, Multi-point V/f control, V/f control for textile applications, V/f control with FCC for textile applications, V/f control with independent voltage setpoint. Vector control, output frequency between 0 Hz and 200 Hz. Sensorless Vector Control, Sensorless Vector Torque Control, Speed control with Encoder Feedback, Torque control with Encoder Feedback
Pulse Frequency		Frame Sizes A to C: 1/3AC 200 V to 5,5 kW (Standard 16 kHz) Frame Sizes A to F: other powers and voltages 2 kHz to 16 kHz (2 kHz steps) (Standard 4 kHz) power reduction see Table 5-3 Frame Sizes FX and GX: 2 kHz to 4 kHz (2 kHz steps) (Standard 2 kHz (VT), 4 kHz (CT)) power reduction see Table 5-3
Fixed Frequencies		15, programmable
Skip Frequencies		4, programmable
Setpoint Resolution		0.01 Hz Digital, 0.01 Hz Serial, 10 bit Analogue (motor potentiometer 0.1 Hz [0.1% (in PID mode)
Digital Inputs		6, programmable (isolated), switchable active high / active low (PNP:NPN)
Analog Inputs		2, programmable, both are parameterizable as 7th and 8th digital inputs 0 V to 10 V, 0 mA to 20 mA and –10 V to +10 V (ADC1) 0 V to 10 V and 0 mA to 20 mA (ADC2)
Relay Outputs		3, programmable 30 V DC / 5 A (resistive), 250 V AC 2 A (inductive)
Analogue Output		2, programmable (0 to 20 mA)

Table 5.1 - Performance rating of the drive.

5.2 Why this drive is preferred?

When application requirement are considered, basically it requires,

- Two analog inputs: one is for Speed potentiometer, other one is for feed back of the Tacho generator.
- Availability of JOG function: it is to setting up the machine with low speeds.
- Availability in small power range (4kW) with above two facilities.
- Internal relay with normally open (NO) and normally close (NC) contacts.
- V/f control function.
- Enhanced motor protection.

Some functions and techniques which are used in the application will be discussed below.

5.2.1 V/f Control

The V/f characteristic represents the simple technique. In this case the stator voltage of the induction motor or synchronous motor is controlled proportionally to the stator frequency. This technique has proven itself for a wide range of "basic" applications, such as Pump, fans, Belt drives, and similar processes.
The goal of V/f control [10] is to keep flux Q constant in the motor. In this case, this is proportional to the magnetizing current I_u and the ratio between voltage V and frequency f

$$Q \sim I_u \sim V/f$$

The torque M, developed by induction motor, is proportional to the product (precisely the vector product Q x I) of flux and current.

$$M \sim Q \times I$$

In order to keep flux Q constant, when frequency f changes, the voltage V must be changed in proportion so that a constant magnetizing current I_u flows. The V/f characteristics control is derived from these basic principles. Operating ratings and characteristics of an induction motor when fed from a drive inverter is shown in Figure 5.3. Change of V/f can be achieved through an automatic feed back or manual control.

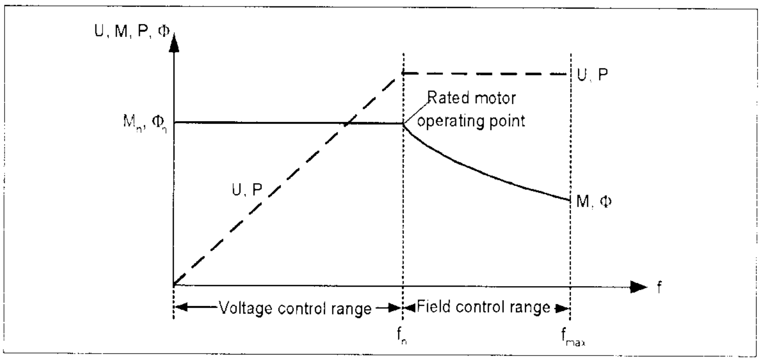


Figure 5.3 - Characteristics of an induction motor when fed from a drive inverter

5.2.2 JOG function

The JOG function [10] is used as follows.

- To check the functionality of the motor and drive inverter after commissioning has been completed (the traversing motion, checking the direction of rotation, etc.)
- Positioning a drive/ a driven load into a specific position
- Traversing drive, e.g. after a program has been interrupted

The drive is traversed using this function by entering fixed frequencies P1058, P1059 [11]. The JOG mode can be selected either using the operator panel, digital inputs or also via the serial interfaces. An ON/OFF command is not used to move the drive, but when the "JOG keys" are pressed. P1055 and P1056 are used for JOG right and JOG left simultaneously.

If both JOG keys are simultaneously pressed, then the instantaneous frequency is kept (constant velocity phase) and alarm A0923 is output. When a key pressed, the drive inverter accelerates the motor to the fixed frequency in the time entered in P1060 [11]. This frequency is only exited after the key has been cancelled and the drive breaks down to 0 Hz in the time entered in P1061 [11].

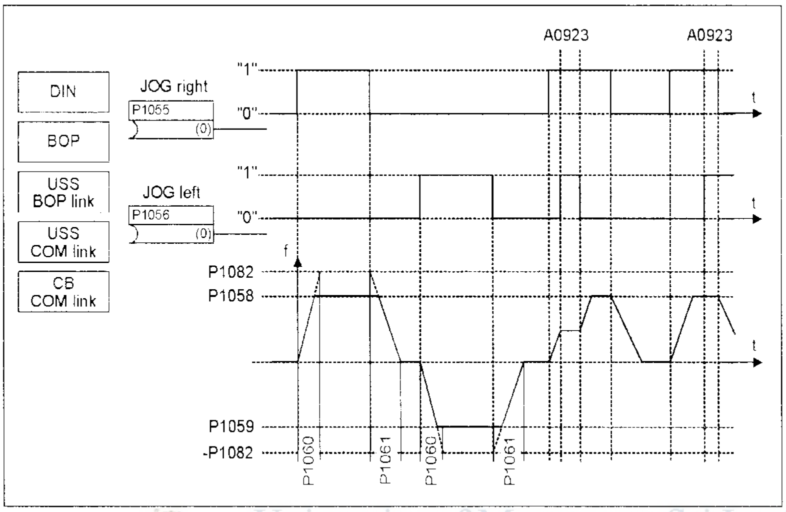


Figure 5.4 – JOG counter-clock wise and JOG clockwise

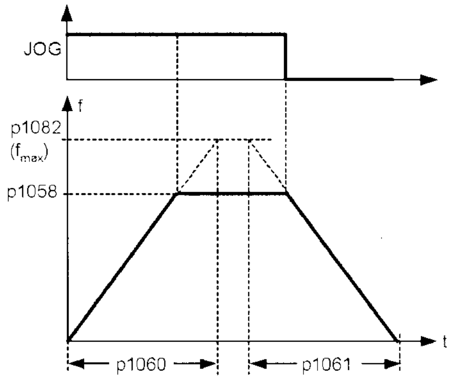


Figure 5.5 – JOG ramp up and ramp down

p1058 : JOG frequency right : Frequency in Hz when the motor is rotating clockwise in the jog mode. Figure 5.4

p1059 : JOG frequency left : Frequency in Hz when the motor is rotating counter-clockwise in the jog mode. Figure 5.4

p1060 : Ramp-up time: Ramp up time in s from 0 to the maximum frequency (p1082). Jog ramp-up is limited by p1058 or p1059. Figure 5.4 & 5.5

p1061 : Ramp-down time in s from the maximum frequency (p1082) to 0. Figure 5.5

5.2.3 Analog Inputs (ADC)

Number :	2
Features:	
- Cycle time	4 ms
- resolution	10 bits
- accuracy	1% referred to 10V/20mA
-electrical features	incorrect polarity protection, short-circuit proof

Analog set points, actual values and control signals are read-into the drive inverter using the appropriate analog inputs and are converted into digital signals/values using the ADC converter.

The setting as to whether the analog input is a voltage input (10V) or a current input (20mA) must be selected using the 2 switches DIP1(1,2) on the I/O board as well as also using parameter P0756.

Following Figure 5.6 shows the connection example for ADC voltage/current input.

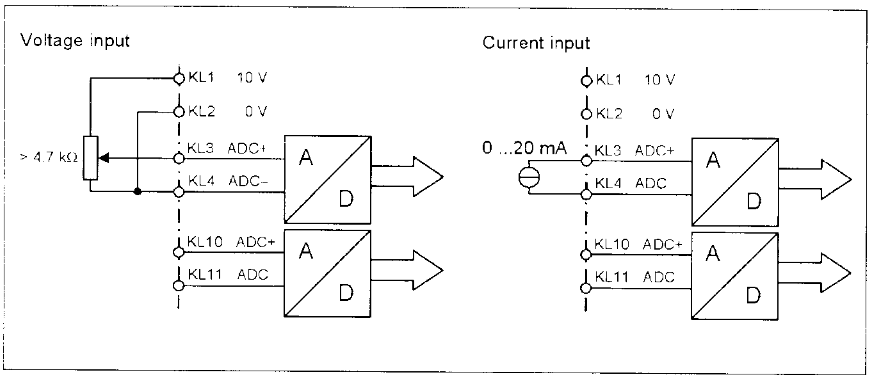


Figure 5.6 – two ADC channels, connection example for ADC

5.2.4 Digital inputs (DIN)

Number : 6+2

Features:

- Cycle time 2ms
- switch-on threshold 10.6 V
- switch-out threshold 10.6 V
- accuracy 1% referred to 10V/20mA
- electrical features electrically isolated, , short-circuit proof

External control signals are required for a drive converter to be able to operate autonomously. These signals can be entered via a serial interface as well as also via digital inputs. MICROMASTER has 6 digital inputs which can be expanded to a total of 8 by using the 2 analog inputs. The inputs, as far as their assignment, can be freely programmed to create a function.

Possible settings of the individual inputs are listed in the following Table 5.2

Parameter value	Significance
0	Digital input disabled
1	ON/OFF1
2	ON+reverse/OFF1
3	OFF2-coast to standstill
4	OFF3-quick ramp-down
9	Fault acknowledge
10	JOG right
11	JOG left
12	Reverse
13	MOP up (increase frequency)
14	MOP down (decrease frequency)
15	Fixed set point (direct selection + ON)
17	Fixed set point (binary-coded selection + ON)
25	Enable DC breaking
29	External trip

33	Disable additional frequency set point
99	Enable BICO parameterization

Table 5.2 - Possible settings of the individual inputs.

5.2.5 Digital outputs (DOUT)

Number: 3

Features:

- Cycle time 1ms

Binary states in the drive can be output via the digital outputs. As result of the fast cycle time, it is possible to control external devices and to display the state in real time. In order that higher power can also be output, the internal signal (TTL level) is amplified using a relay. Figure 5.7

Relay: Maximum opening/closing time: 5/10 ms

Voltage / current: 30VDC / 5A; 250VAC / 2A

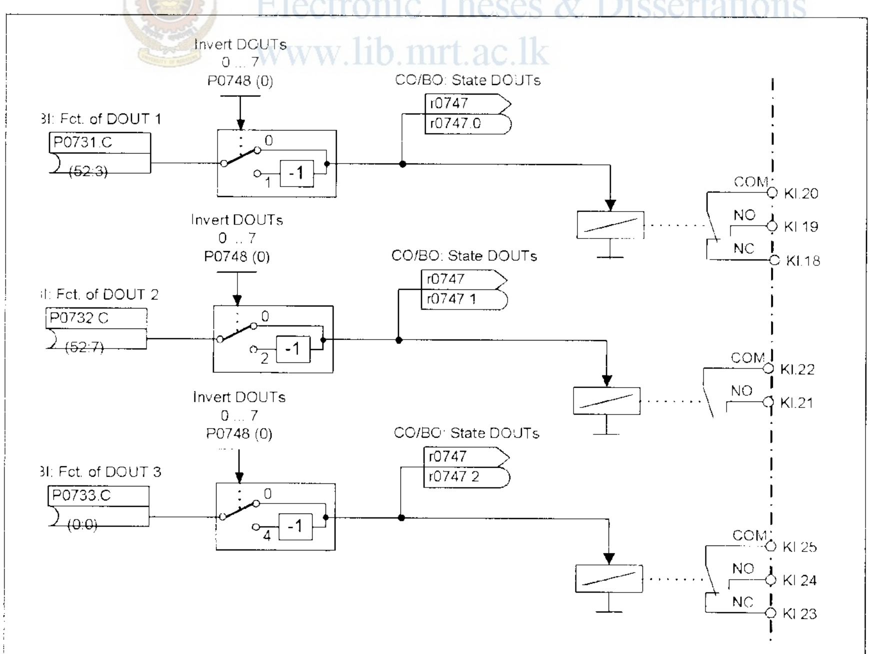


Figure 5.7 – Relay outputs

5.2.6 Thermal motor protection and overload response

The MICROMASTER 440 has a completely new integrated concept for thermal motor protection [10]. There are numerous possibilities of effectively protecting the motor but at the same time ensuring high motor utilization. The basic philosophy of this innovate concept is to detect critical thermal states, output warnings and initiate the appropriate responses. By responding to critical states it is possible to operate the drive thermal power limit and to avoid, under all circumstances, an immediate shutdown (where the drive inverter is tripped) Thermal motor model and PTC temperature sensors are discussed under this.

5.2.7 Power module protection

5.2.7.1 General overload monitoring

Just the same as for motor protection, MICROMASTER provides extensive protection for the power components. This protection concept is also sub-divided into 2 levels.

- Warning and response [10]
- Fault shutdown [10]

Using this concept, a high utilization of the power module components can be achieved without the drive inverter being immediately shutdown.
Monitoring functions are,

I_{max} controller for V/f

V_{dc_max} controller.

General protection of the power components.

- Overcurrent/short circuit(F0001)
- DC link overvoltage(F0002)
- DC link undervoltage(F0003)
- Line phase failure detection (F0020)

The monitoring thresholds are permanently saved in the drive inverter and cannot be changed by the user. On the other hand, the threshold levels for the "Warning and response" column can be modified by the user to optimize the system. These values have default settings so that the "Fault and shutdown" threshold do not respond.

5.2.7.2 Thermal Monitoring functions and overload responses

Similar to motor protection, the main function of the thermal power module monitoring [10] is to detect critical states. Parameterizable responses are provided to the user which allows the drive system to be still operated at the power limit thus avoiding immediate shutdown. However, the possibilities of assigning parameters only involves interventions below the shutdown threshold which cannot be changed by users.
Monitoring functions are

I^2t monitoring(r0036): The I^2t monitoring is used to protect components which have a long thermal time constant in comparison to the semiconductors. An overload reference to I^2t is present if the drive inverter utilization r0036 indicates a value greater than 100% (utilization as a % referred to rated operation)

Heat sink temperature (r0037[1]): The monitoring of the heatsink temperature r0037[0] of the power semiconductor (IGBT)

Chip temperature: Significant temperature differences can occur between the barrier junction of the IGBT and the heatsink. These differences are taken into account by the chip temperature r0037[1] and monitored.

When an overload occurs regarding one of these three monitoring functions, initially, a warning is output. The warning threshold P0294 (I^2t monitoring) and P0292 (heatsink temperature and chip temperature monitoring) can be parameterized relative to the shutdown values.

5.3 A typical Installation

Figure 5.8 demonstrates a typical installation [10] of an inverter. Switch gears used are explained below.

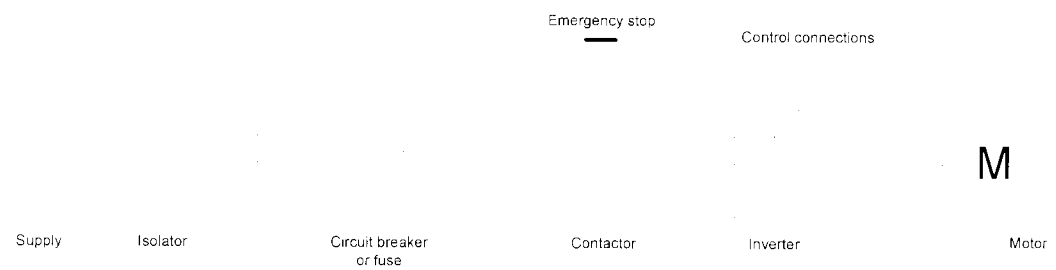


Figure 5.8 – A typical installation of an inverter.

5.3.1 Supply

The supply may be either single phase or three phase, depending on the inverter type. The recommended wire sizes should be used.

5.3.2 Isolator

An isolator is usually required for safety reasons.

5.3.3 Circuit breaker or Fuses

The protection rating is based on the input current as stated in the manual. The input current is higher than the output current because the form factor of the current is high. Do not use fast acting circuit breakers or semiconductor fuses. Motor circuit breakers are usually recommended for use with inverters.

Inrush currents on the latest inverters are typically only two or three times of full load current, so nuisance tripping is less of a problem.

5.3.4 Contactor

A contactor, with an emergency stop function connected may be required both for auxiliary control and safety isolation. Do not use the contactor as a stop start function. This will cause unnecessary wear on the contactor and there will always be a slight delay while the inverter initializes. Use the control terminals or push buttons to do this. It is not permitted to use the Run/Stop control of the inverter as an emergency stop function. It is not recommend fitting a contactor between the output of the inverter and the motor.

5.3.5 Motor

Many motors, particularly at low powers, are designed for low voltage (230V) or high voltage (400V) operation. The voltage is usually selected by fitting links at the motor terminals. Instruction for low voltage (star) connection or high voltage (delta) connection are usually shown on the inside of the terminal cover. Clearly an inverter with a low voltage single or three phase input will produce a low voltage three phase output, and the motor should be connected accordingly.

Chapter 6

Power and Control wiring

In this chapter, it is going to discuss in detail how the control switch gear of existing system is modified to adapt with the new system using the existing switchgears. User will not feel any difference in operation, because same operational switches perform the same function as it is now. Parameterization of the AC drive will not discuss here.

Figure 6.1 shows the inputs and outputs of the existing DC converter and Figure 6.2 shows the same in the proposed AC drive system.
General description on connected parts and supply will be given below.

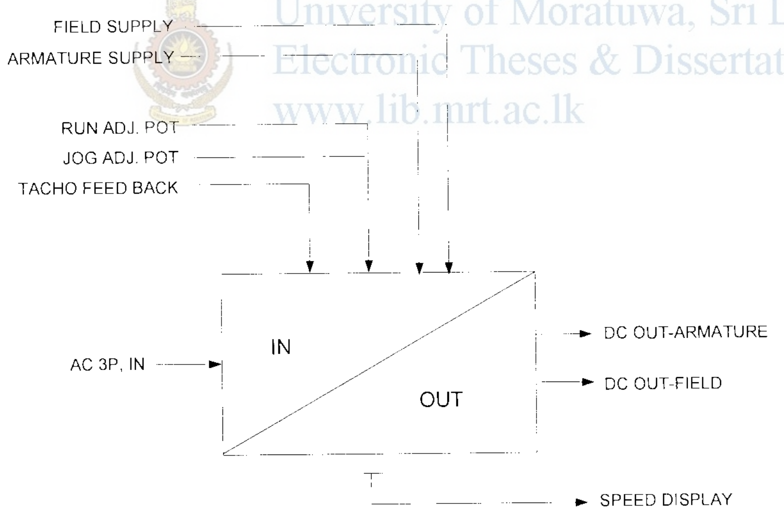


Figure 6.1 – Inputs/Outputs of the existing DC converter

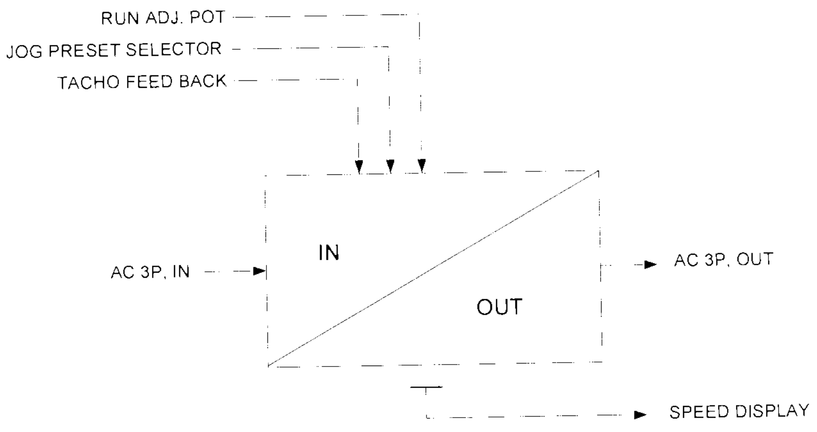


Figure 6.2 - Inputs/Outputs of the proposed AC inverter

AC IN: Commercial supply, 3 Φ, 400V, 50Hz

AC OUT : 3 Φ, variable frequency variable voltage out

RUN ADJ. POT : Potentiometer for adjusting running speed

JOG ADJ. POT : Potentiometer for adjusting jogging speed

TACHO FEEDBACK : Speed feed back to the drive

JOG PRESET SELECTOR: Selector to get desired preset jogging speed

FIELD SUPPLY: AC supply to DC converter for field control

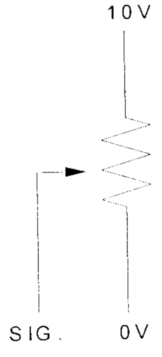
ARMATURE SUPPLY : AC supply to DC converter for Armature control

DC OUT-FIELD : Converter DC output to field coil

DC OUT-ARMATURE : Converter DC output to Armature

SPEED DISPLAY : Display for running rpm (shows no of products out per min.)

6.1 Potentiometer



Potentiometer is a variable resistor. While sliding contact point moves, it gives a variable voltage output. It is here in the range of 0-10V DC which controls the driver output. Figure 6.3

Figure 6.3 – Potentiometer

6.2 DC Tacho Generator

DC Tacho generator [3] is a unit which gives accurate DC voltage output proportional to speed of its mover. It is widely used in applications for feedback and display purposes. See appendix C for data sheet of DC Tacho generator.

Following sections will describe the modification that the existing control circuits are undergone.

According to Figure 6.4 [9], in armature connections contactor 5K1, Fuse 1F1, in field coil connections current overload 1Q4, contactor 5K4, overload 1Q5 can be removed since they are no more use. Overload 1Q6 for cooling fan can also be removed. Then N/O and N/C contact points used in various places in drawings have to be ignored and modified accordingly. Figure 6.5 shows after modification done on Figure 6.4.

Output of overload 1Q3 will be the AC input power of the AC drive which will be used in the proposed system.

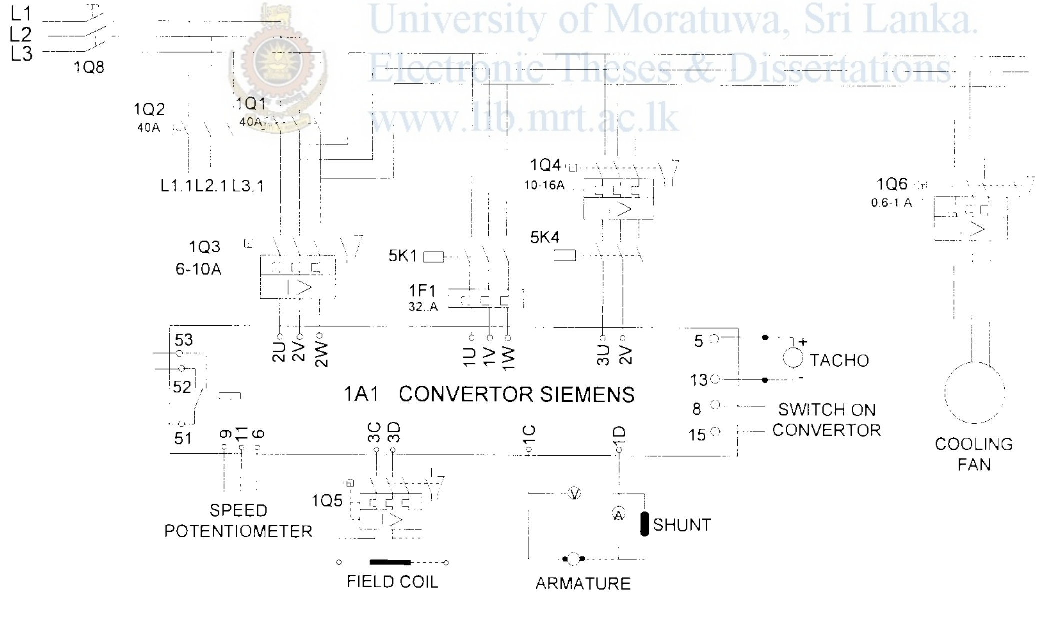


Figure 6.4 – Drawing of the existing converter

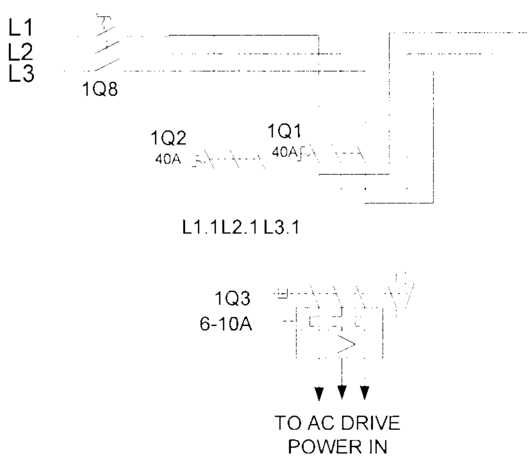


Figure 6.5 – Modified drawing

Existing diagram in Figure 6.6 [9] and modified diagram in Figure 6.7 show removal of 1Q4, 1Q5 and 1Q6 from control diagrams. Note that, existing diagram is undergone modification only inside dotted cage and shown in Figure 6.7

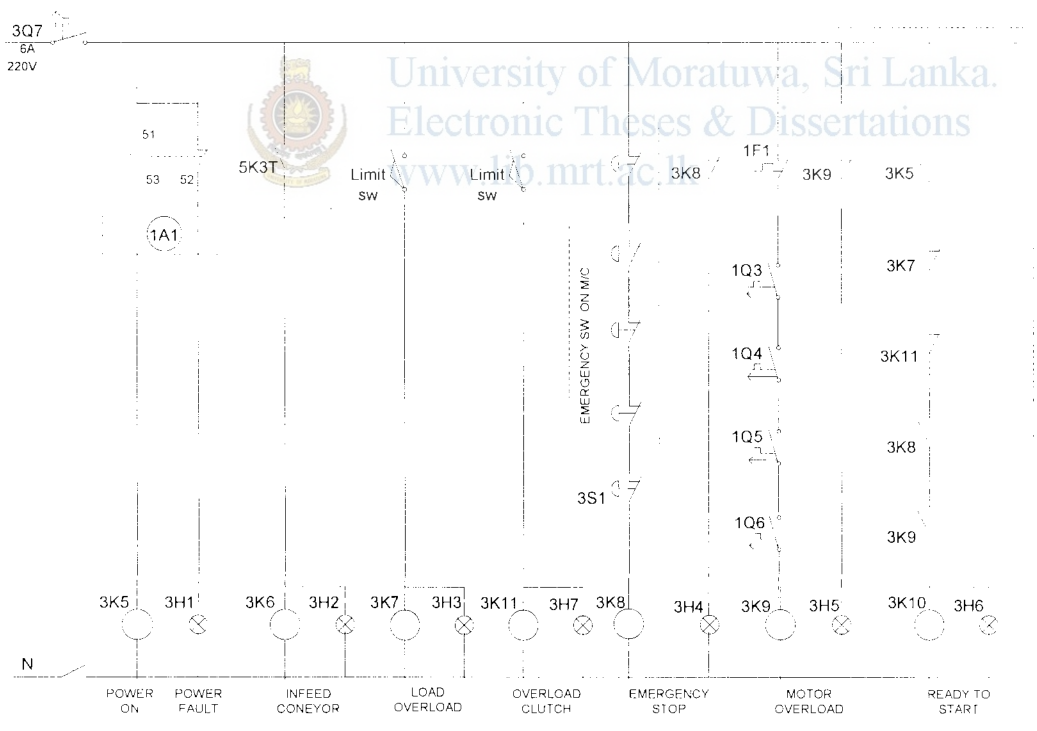


Figure 6.6 – Existing Control diagram

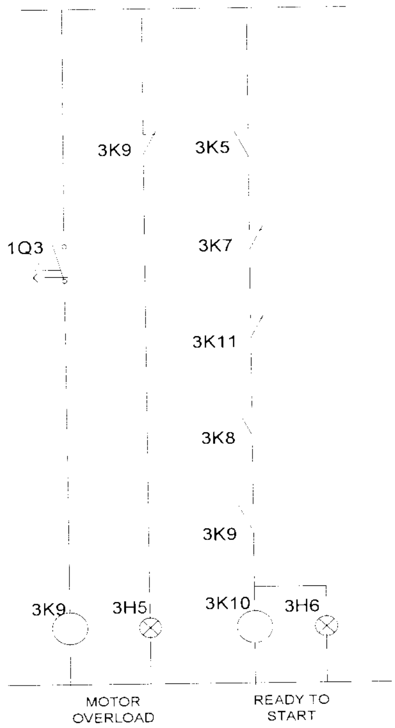


Figure 6.7 – Modified part of the above diagram

6.3 START/STOP (ON/OFF) function

Refer the Figure 6.8 [9] for RUN and JOG start. It has no any change.

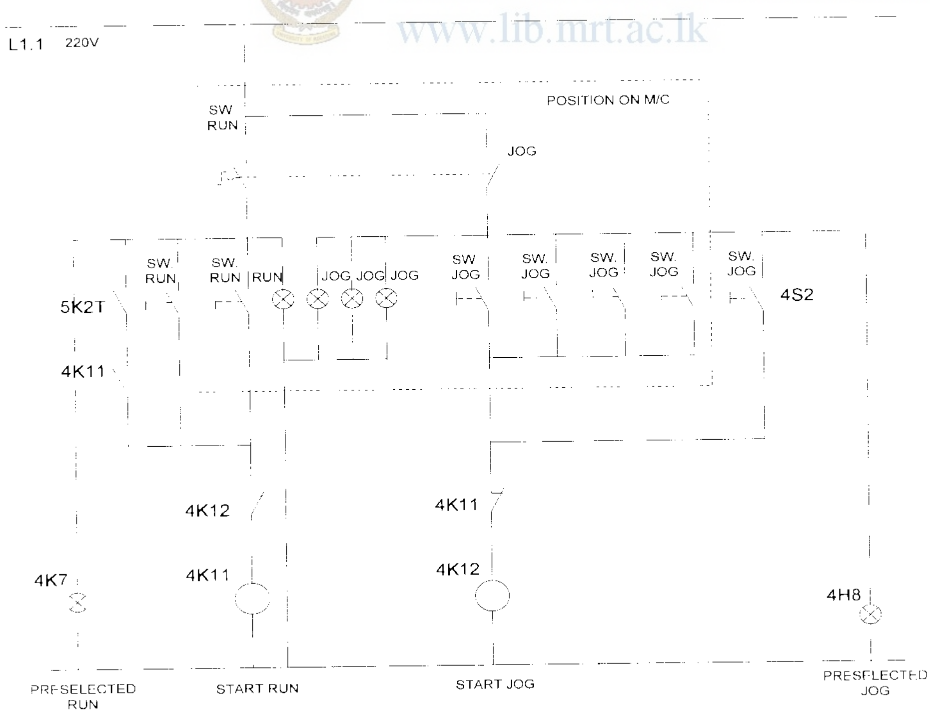


Figure 6.8 – RUN and JOG start

6.3.1 START(RUN) Function

Put selector to "SW RUN" ; Figure 6.8

Press "SW RUN" ; Figure 6.8

Contactor 4K11 energizes ; Figure 6.8

Contacts of 4K11 close and RUN SPEED POT is connected; Figure 6.12

Contactor 5K2 energizes; Figure 6.11

Contactor 5K3 energizes; Figure 6.11

Contacts of 5K3 close and drive STRART running; Figure 6.9b

6.3.2 STOP Function

Press "SW STOP" ; Figure 6.11

Contactor 5K2 de-energizes; Figure 6.11

Contactor 5K3 de-energizes; Figure 6.11

Contacts of 5K3 open and drive STOP; Figure 6.9b

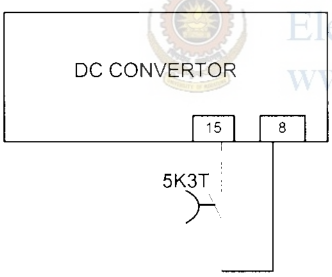


Figure 6.9 a – DC converter ON

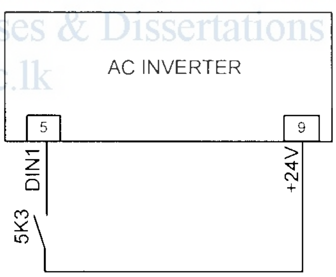


Figure 6.9 b – AC inverter ON

Note that OFF delay and ON delay timers used in the original circuit is not important for the proposed system. ON delay timer is there to ensure the availability of Armature and Field supply before switching ON the drive. OFF delay TIMER is there to ensure to cut off Armature and Field supply after switching OFF the drive. Therefore timer functions are removed and 5K2 and 5K3 are used in place of 5K2T and 5K3T. New contactor 5K5 is added for JOG operation.

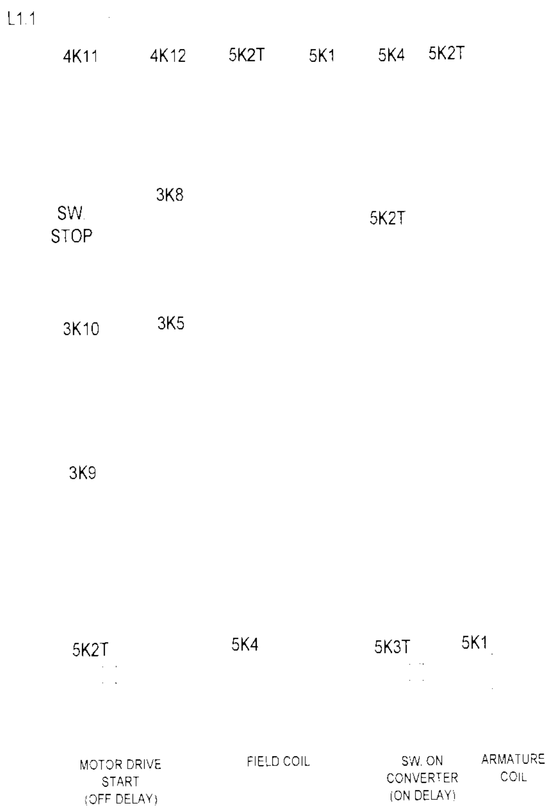


Figure 6.10 – START/STOP control diagram

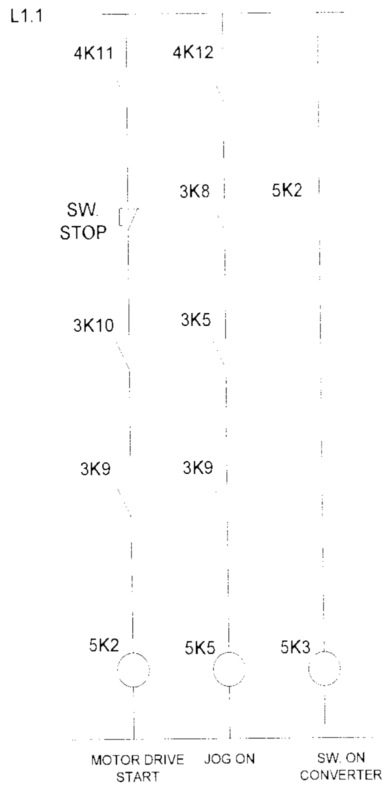


Figure 6.11 - START/STOP modified control diagram

Here, same switches are used and hence no any difference in operation from the user point of view.

6.3.3 RUN SPEED function

Once the contactor 4K11 energizes, RUN SPEED potentiometer connects with the drive through contacts points of 4K11. Voltage analog input is fed to the AC drive using one A/D channel. This input can be set either as 0-10V or 4-20mA through dip switches provided in the drive. Since potentiometer gives an output in voltage, 0-10V is set by putting dip to position 1. Operator can adjust the machine speed as desired. Following figures 6.12 [9] and 6.13 show the connections in the existing system and the proposed system respectively.

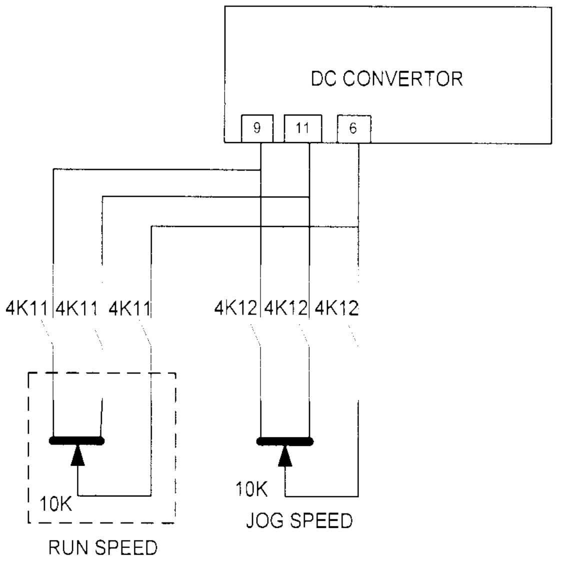


Figure 6.12 – RUN/JOG Speed control

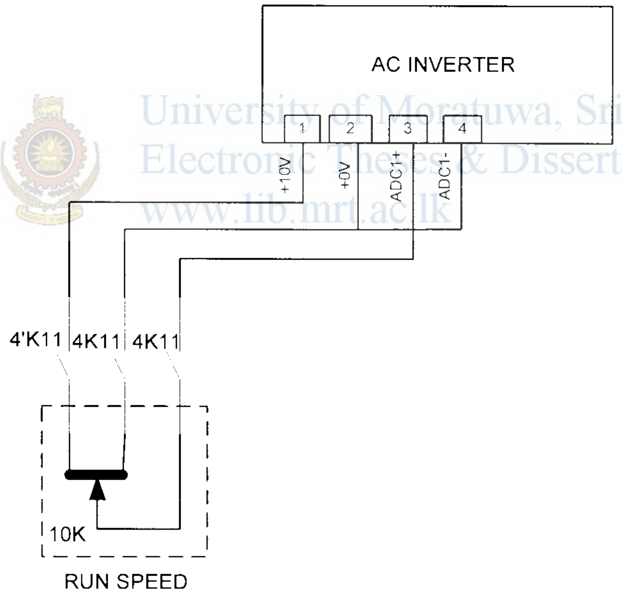


Figure 6.13 – RUN Speed control

6.3.4 JOG Function

Put selector to "JOG" ; Figure 6.8

Keep press "SW JOG" ; Figure 6.8

Contactor 4K12 energizes; Figure 6.8

Contacts of 4K12 close and contacts 5K5 energizes; Figure 6.11

Contacts of 5K5 close and DIN2 or DIN3 or DIN4 activates - drive starts running in JOG mode.; Figure 6.14b

In the existing system a potentiometer is used to adjust the speed at JOG operation, Figure 6.14a. In the AC drive JOG operation is not provided with a potentiometer control but provided with digital inputs. Therefore one modification is added here to get the desired preset speeds by selecting through a three position selector.

6.3.4.1 JOG SPEED function

Figure 6.14a [9] shows RUN/JOG speed control in the existing system and Figure 6.14b shows same operation in the proposed system. Selecting the selector to one of the three positions preset speed can be obtained. Inputs DIN1, DIN2,DIN3 are parameterized for three different frequencies.

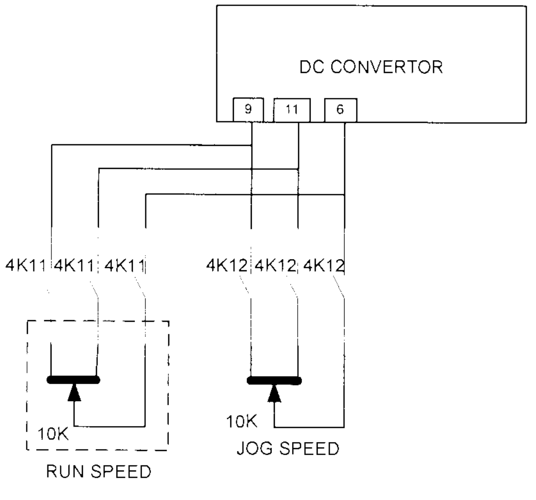


Figure 6.14 a RUN/JOG Speed control

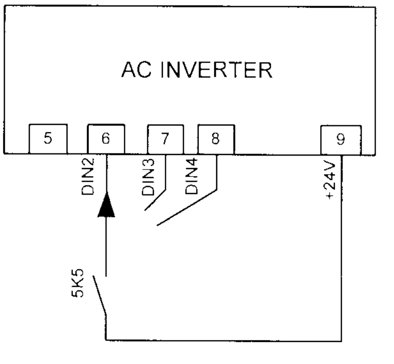


Figure 6.14 b JOG Speed

6.3.5 FEEDBACK Operation

Selected DC Tacho generator gives voltage output varying from 0-10VDC. Therefore, the second A/D channel of the drive is used to feed the voltage feedback. Dip switch should be put to position 1 to configure channel as 0-10V input. (Selection as the input is either 4-20mA or 0-10V). While Figure 6.15 a shows the TACHO connection in the existing system, Figure 6.15 b shows the same in AC inverter.

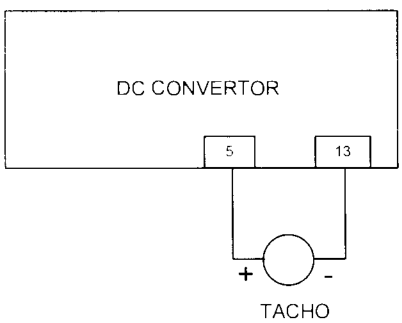


Figure 6.15 a – TACHO connection DC converter

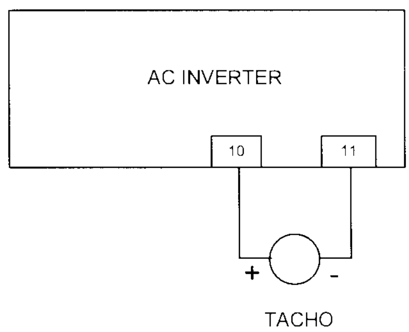


Figure 6.15 b – TACHO connection AC inverter

6.3.6 SPEED Display

In the existing system machine speed, i.e. number of bottles moving in a minute, is shown on a seven segment display, captured from a proximity sensor connected to the machine, pointing rotating metal sections. It is independent from the drive system and therefore same can be kept as it is. See Figure 6.16 below.

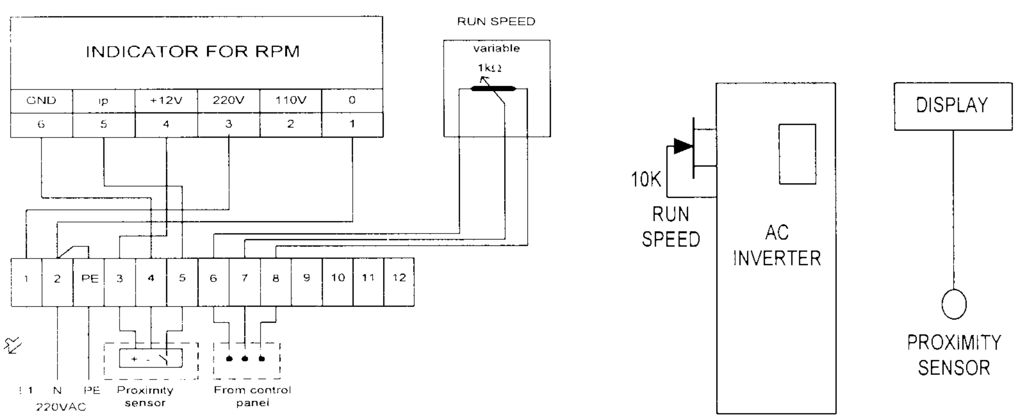


Figure 6.16 – Speed display in existing and proposed systems

6.4 POWER ON Function

As per the Figure 6.17a and 6.18a, "POWER ON" and "POWER FAULT" indications are provided to activate showing the condition of the drive. That is a internal relay operation of the DC converter. Similar operation is obtained with the AC drive by means of its inbuilt relay output. See Figure 6.17 b and 6.18b below.

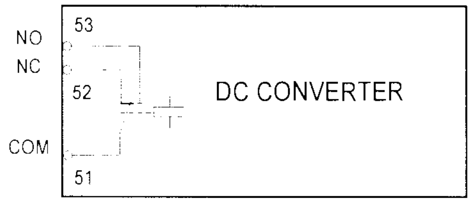


Figure 6.17 a – Relay contact DC converter

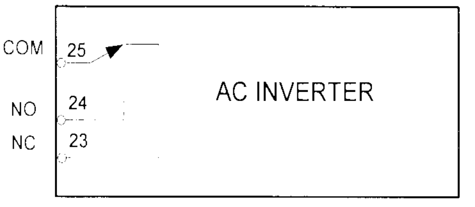


Figure 6.17 b – Relay contact AC inverter

Figure 6.18a and 6.18b show the Power ON circuit of existing and proposed systems respectively.

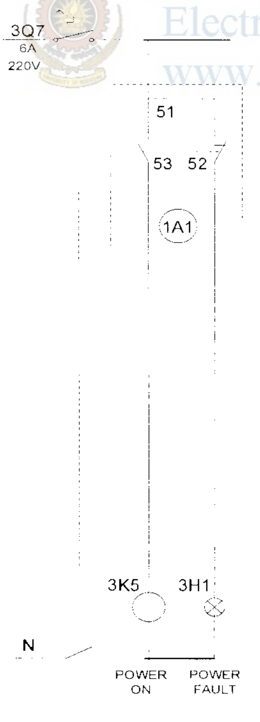


Figure 6.18 a – Power ON, DC Converter

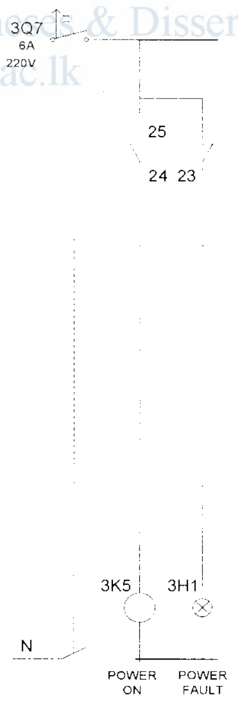


Figure 6.18 b – Power ON, AC Inverter

Chapter 7

Economic Consideration

This section analyses, how the proposed combination contributes against existing system in economics terms.

Analysis is undergone in following areas

- Loss incurred due to Down Time
- Loss incurred due to poor Power Factor (PF)
- Loss incurred due to harmonics

7.1 Measurements

From the existing system, data are logged by means of a data logger.
Figure 7.1 shows the connection of data analyzer to log the required data.
From Figure 7.2 to 7.8 show the graphical representation of logged data.

Parameters considered for data logging.

1. Current (I); (Figure 7.2)
2. Line Voltage (V); (Figure 7.3)
3. Active Power (W); (Figure 7.4)
4. Apparent Power (VA); (Figure 7.5)
5. Reactive power (Var); (Figure 7.6)
6. Power Factor (PF); (Figure 7.7)
7. Total Harmonic Distortion (THD); (Figure 7.8)

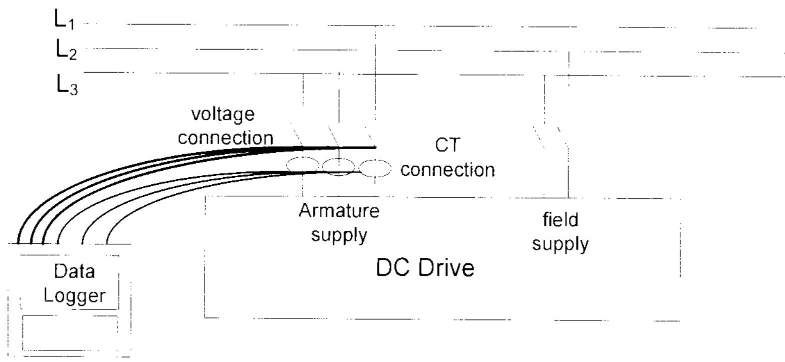


Figure 7.1 – Connection of data logger

Note: Since Armature control is used for speed controlling of the motor at constant flux, Armature parameters are measured.

Note: Calculations in the section are done considering the normal running speed of the machine. That is the speed of which majority of printing requirements are undergone. It has been observed that, speed of the machine is not stable and changing from minimum of 345rpm to maximum of 363rpm.

7.1.1 Data

Machine parameters

1. Machine speed: 350 rpm (taken through a Tachometer)
2. Power consumed at this speed: 0.85 kW (Figure 7.4)
3. Power Factor: 0.14 (Figure 7.7)
4. Current: 10A (Figure 7.2)
5. Voltage: 370V * (Figure 7.3)
6. Total Harmonic Distortion (THD) 84% (Figure 7.8)

* 400V is considered for calculations

General Parameters

1. Ambient temp. around the Motor 32^{0}C
2. Altitude: 2.74 m

Production Parameters

1. Average running hours 22 hours per day
2. Machine output: 40 bottles per minute
3. Minimum estimated sales value* of a print: Rs. 1.10 per bottle
   (Varies roughly from Rs. 1.10 to Rs. 2.80)
4. Minimum hours of machine down time due to problems of the DC motor:
   5 hrs per month

* This sales value of a print is estimated considering all fixed and variable cost involvement for the production.

Labor parameters

1. Labor cost –Permanent employee: Rs. 48 per person per hour
2. Number of permanent employees: 11
3. Labor cost –Casual employee: Rs. 56 per person per hour
4. Number of Casual employees: 9

Re-winding parameters

1. Cost of re-winding the motor, if burnet Rs. 85,000
2. Minimum number of days 3 days
   (taken as machine down time)

Investment for the proposed system

1. 3ϕ, 5.5kW, 6 pole cage Induction motor: Rs. 55,000
2. 3ϕ, 5.5kW VSD with filter Rs. 125,000
3. Tacho generator Rs. 77,500
4. Other accessories Rs. 10,000

5. Data logging Rs. 15,000
6. Labor for installation and commissioning Rs. 0 (In-house)

Total: **Rs. 282,500**

Other data-AC Drive

Expected Power factor	0.95 (Table 5.1)
Expected efficiency	96-97% (Table 5.1)
Expected THD in new drive	40% approximate figure

Tariff (Industrial purpose I-3)

Charge for Active Power	Rs. 9.10 per kWh
Charge for Maximum demand	Rs. 650 per kVA
Fixed Charge	Rs. 3000

7.2 Loss incurred due to Down Time

If motor has to be rewired, it results considerable down time in production. In recent past, motor has failed two times and only solution was to rewind and fix.
As stated above, minimum number of days for a rewinding is three days and it has to be out sourced since in-house skill is not available.

7.2.1 Calculation of Sales loss

From above data

Minimum estimated sales value* of a print:	Rs. 1.10 per bottle
Machine output:	40 bottles per minute
Therefore, no of bottles per hour	40x60

2400 bottles

Therefore loss incurred due to not printing bottles in one hour

= Rs. 1.10 x 2400

= Rs. 2,640.00

7.2.2 Calculation of labor loss

From above data

1.	Labor cost –Permanent employee	Rs. 48 per person per hour
2.	Number of permanent employees	11
3.	Labor cost –Casual employee	Rs. 56 per person per hour
4.	Number of Casual employees	9

Total labor loss, being idle them

=Rs.48x11+Rs.56x9

=Rs. 1,032

Therefore total loss from labor being idling and not bottle being printed

=Rs.1,032+Rs.2,640

=Rs. 3,432 per hour

Hence, loss for Three days =Rs. 3,432 x 24x3

=Rs. 247,104

To get the total loss, motor rewinding cost should be added to the above figure.

From above data

Cost of re-winding the motor, if burnet Rs. 85,000

Total loss = Rs. 247,104 + Rs. 85,000

= **Rs. 332, 104**

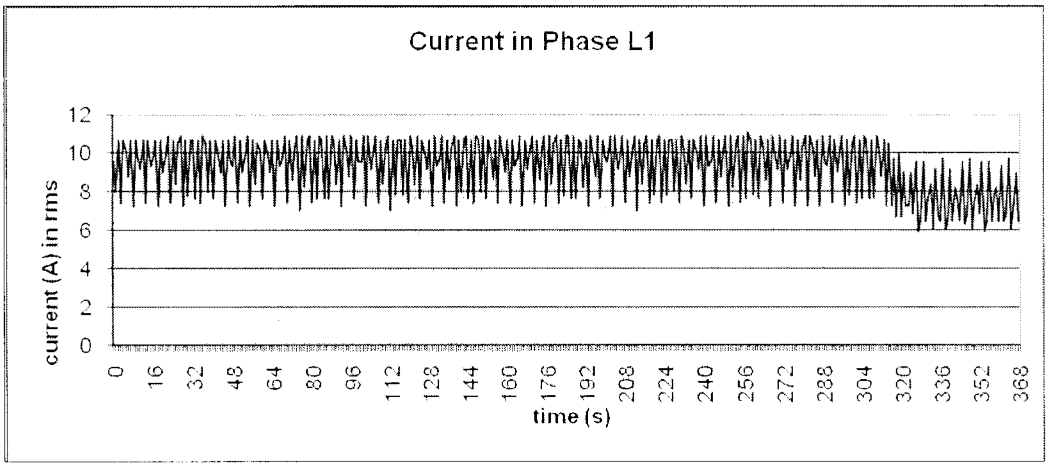


Figure 7.2 – Phase current in rms

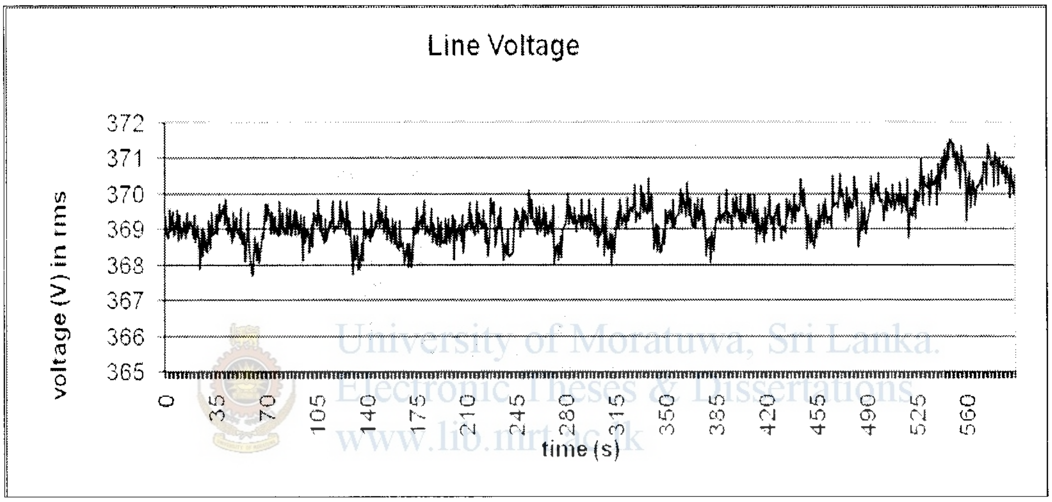


Figure 7.3 – Line voltage in rms

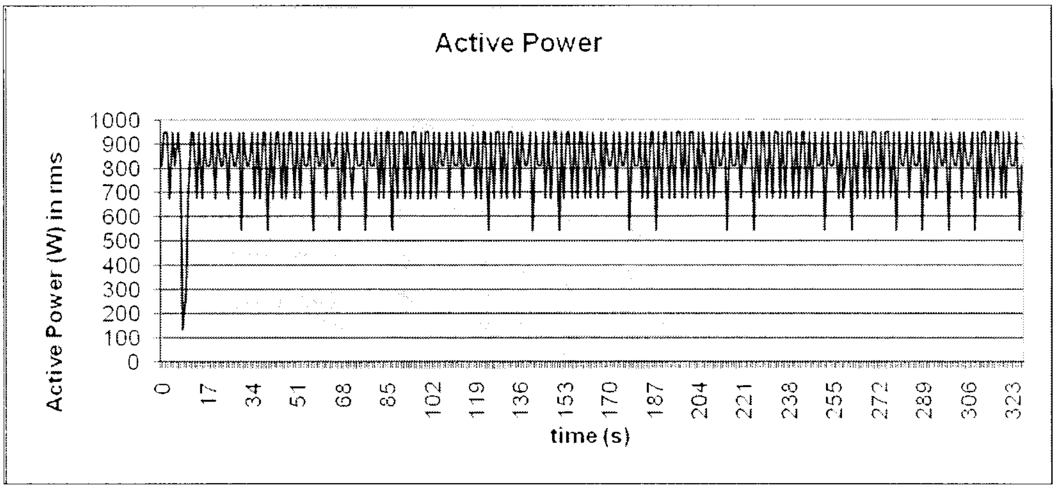


Figure 7.4 – Active Power in rms

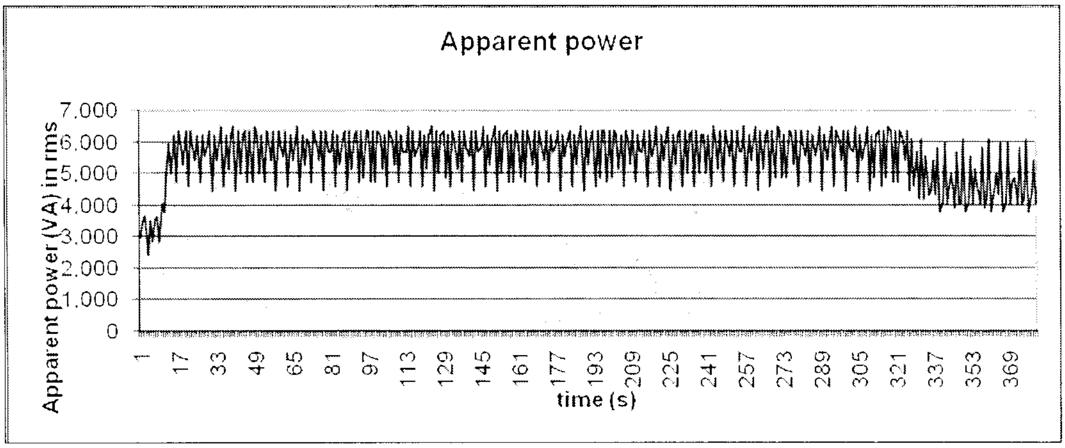


Figure 7.5 – Apparent Power in rms

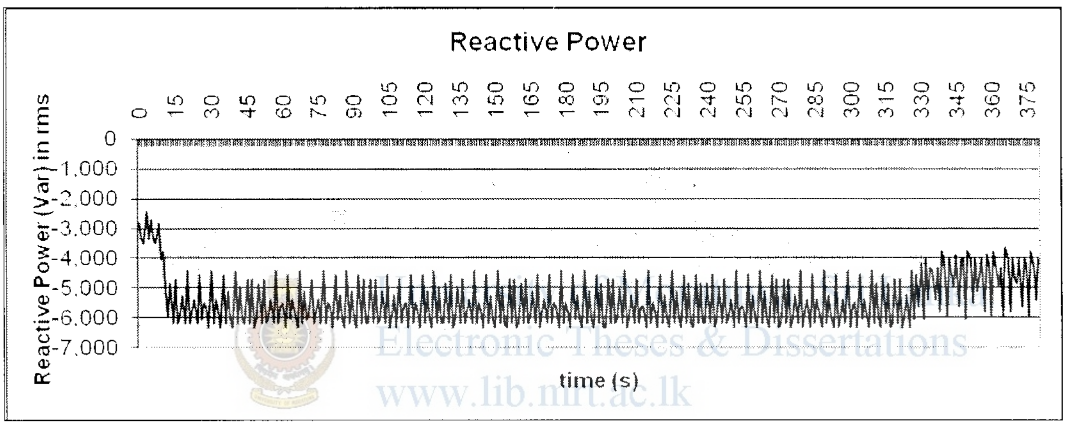


Figure 7.6 – Reactive Power in rms

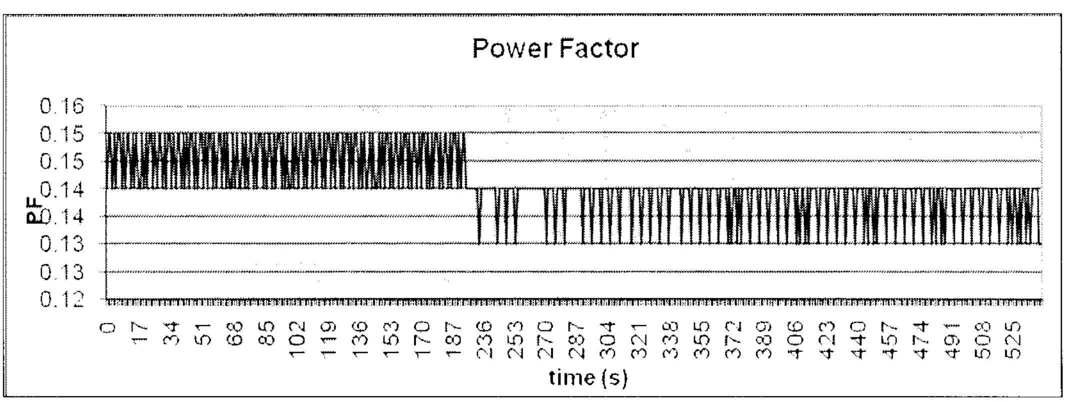


Figure 7.7 – Power Factor

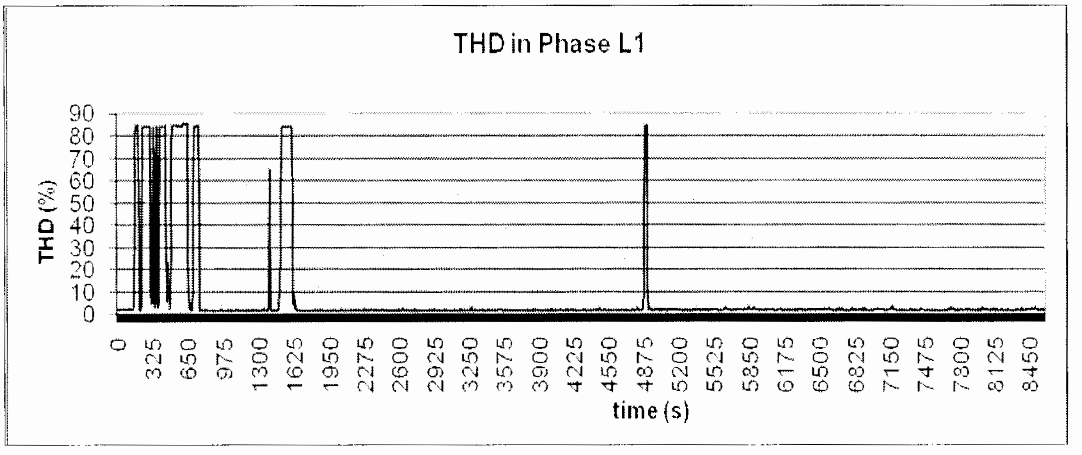


Figure 7.8 – THD in Phase L1

7.3 Loss incurred due to poor Power factor (PF)

7.3.1 Reduction in KVA due to improving PF

From data

Present power factor: 0.14

New, expected power factor: 0.95

(Micromaster Performance rating; table 5.1 in Chapter 5)

Power consumed at normal running speed: 0.85kW

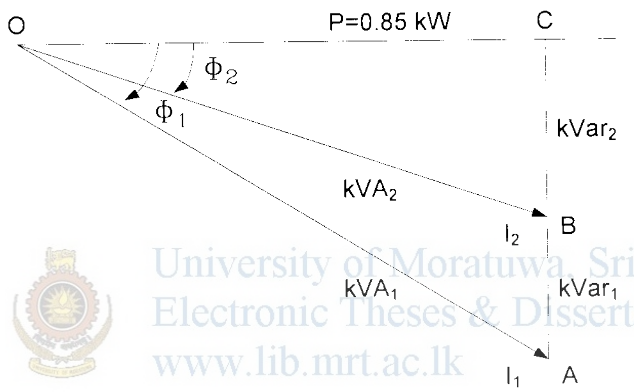


Figure 7.9 – Power Triangle

To supply same power of 0.85kW to the machine,

From the Power Tangle [1] in Figure 7.9

$PF_{existing}$	$=Cos\Phi_1$	$= 0.14$
$PF_{proposed}$	$= Cos\phi_2$	$= 0.95$

Triangle, OAC,

$$kVA_1 Cos\phi_1 = 0.85$$

$$kVA_1 = 0.85 / Cos\phi_1$$

Triangle, OBC,

$$kVA_2 Cos\phi_2 = 0.85$$

$$kVA_2 = 0.85 / Cos\phi_2$$

Reduction in KVA

$$kVA_1 - kVA_2 = 0.85 / Cos\phi_1 - 0.85 / Cos\phi_2$$

$$kVA_1 - kVA_2 = 0.85 / 0.14 - 0.85 / 0.95$$

$$kVA_1 - kVA_2 = 5.12 kVA$$

From data,

Charge for 1kVA = Rs. 650.00

Therefore saving in Rupees = Rs.5.12x650.00

= **Rs. 3,328 per month.**

7.3.2 Reduction in current by improving PF

$$\text{Current} = I_1 = kVA_1 / (\sqrt{3} x V) \qquad (7.1)$$

$$= \frac{P / Cos\phi_1}{\sqrt{3} x V}$$

Since V = 400V

$Cos\Phi_1$ = 0.14

P_1 = 0.85 kW

$$= \frac{0.85 \times 10^3 / 0.14}{\sqrt{3} x 400}$$

I_1 = 8.76 A

Current $= I_2 = kVA_2 /(\sqrt{3}xV)$ (7.2)

$$= \frac{P / Cos\phi_2}{\sqrt{3}xV}$$

Since V $= 400V$

$Cos\Phi_2$ $= 0.95$

P_1 $= 0.85$ kW

$$= \frac{0.85 \times 10^3 / 0.95}{\sqrt{3}x400}$$

I_2 $= 1.29$ A

Reduction in current, I_1-I_2 $= 8.76-1.29$

$= 7.47$ A

7.4 Loss incurred due to Harmonics

7.4.1 Reduction in current by reducing THD

Figure 7.10 – a load with Harmonics

$$I_b = I_1\sqrt{1 + THD^2}$$ (7.3)

Where, I_b - design current

I_1- fundamental current

THD- Total Harmonic Distortion

From Data,

I_1 = 10A (Figure 7.2)

THD = 84% (Figure 7.7)

If I_b is the I_{b1} for the present condition

$$I_{b1} = 10\sqrt{1+0.84^2}$$

$$I_{b1} = 13.06A$$

Expected THD in the new system is 40%. Fundamental current is assumed to be the same.

If I_b is the I_{b2} for this condition

$$I_{b2} = 10\sqrt{1+0.40^2}$$

$$I_{b2} = 10.77A$$

Reduction in current

= I_{b1}-I_{b2}

= 13.06-10.77

= 2.29 A

Therefore, reduction in Line current = 2.29 A

Hence, total saving in current through improving power factor and reducing THD

= 7.47A + 2.29 A

= 9.76 A

7.5 Pay back calculation

Pay back is calculated only considering the loss due to machine down time as a result of DC motor failures.

From section 2.7.1

Loss due to not printing bottles in 5hrs = Rs 2,640.00 x 5 per month

Therefore loss recovered = Rs. 13,200

Therefore saving =Rs. 13,200 per month

Total expected investment (section 7.1.1) =Rs. 282,500

Therefore Simple Payback Period in months =Investment/Rupee saving per month

= 282,500/13,200

= 21.4 months

SPP = 21 1/2 months (app.)

Chapter 8

Conclusion

Implementation of the proposed system replacing the existing DC drive system is shown to be a practical solution to improve reliability of the system. This eliminates unexpected down times in the drive system and hence ensures a smooth operation in the whole system.

Measured input power to the drive-motor system is 2.4kW at maximum speed, but the original motor capacity is 19kW. It is not clear why the original motor is unnecessarily over-sized in capacity. It is severely a fact that, earlier systems are mostly over designed. This resulted in an inefficient drive system, as a significant part of the input power was not doing any useful work. Most of the time, the available motor torque was much more than the required load torque.

In case of a machine failure, it results losses in labor hours and production as explained in "Economic consideration" in Chapter 7. It is however difficult to show accurate quantitative figures, because labor can be utilized for some other work and printing jobs can be delayed if it is not a on time delivery order.

Reduction in line current by improving power factor does not reduce the total power consumed by the drive system. Consumed active power by the same load should be the same under any power factor. Current, saved by reducing total harmonic distortion and apparent power i.e. kVA, saved by reducing kVA with improved power factor are direct positive impact of the proposed system.

Pay back period is somewhat high, since it is calculated only considering the machine down time occurred as a result of any failure in DC commutator motor. It should be noted that, this proposal is not saving oriented but reliability and customer satisfaction oriented.

References:

[1] J.B.Gupta, A Course in Electrical Power, S.K.Kataria & Sons, 2005.

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[4] Martin Brown, "Siemens Standard Drives Application Handbook," Seimens Standard drives, Congleton, 1997

[5] Rakesh Parekh, "AC Induction Motor Fundermentals," Microchip Technology Inc., 2003

[6] www.electricmotors.machinedesign.com, Retrieved 16 November 2009

[7] "CMG Motors," SGA 08099(edition 7.1.0)

[8] Dr. J.P.Karunadasa, "DC and AC motors," Lecture Notes in Electrical Machine Equipment and material selection

[9] "Electrical drawings of Strutz Printing M/C," Novopack s.r.l., Italy

[10] "SIEMENS MICROMASTER 440," Operating instructions, Issue 10/06, user documentation 6SE6400-5AW00-OBPO.

[11] "SIEMENS MICROMASTER 440," Parameter list, Issue 01/06, user documentation 6SE6400-5BB00-OBPO.

[12] "International Standard," Rotating Electrical Machines-Part1:Rotating and performance, IEC60034-1, Edition 11.0, 2004-04

APPENDIX-A: Separately excited DC motor

A.1 Equivalent circuit and Characteristic graph.

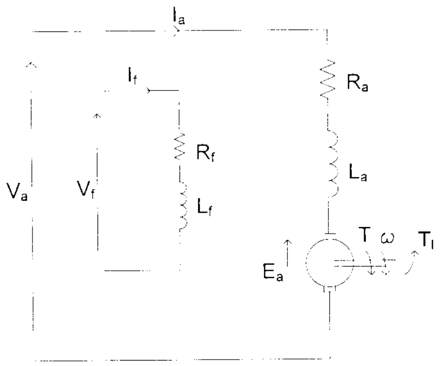


Figure A.1 – Equivalent circuit

Governing equations for the motor

$$\tau = k\phi I_a \tag{A.1}$$

$$E_a = k\phi\omega \tag{A.2}$$

$$P_{conv} = \tau\omega = E_a I_a \tag{A.3}$$

$$V_a = R_a I_a + L_a \frac{dI_a}{dt} + E_a$$

At steady state operating condition $\frac{d}{dt} = 0$

Performance of the motor is given by its output characteristics. i.e. τ vs ω
Characteristic applies at steady state

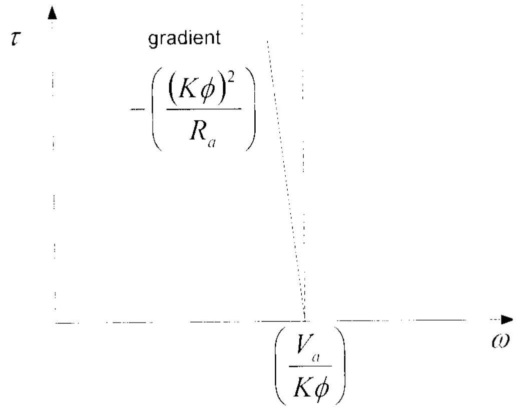
$$V_a = R_a I_a + E_a \tag{A.4}$$

$$V_a = R_a I_a + (k\phi)\omega$$

$$V_a = R_a\left(\frac{T}{K\phi}\right) + (K\phi)\omega$$

$$\tau = -\frac{(K\phi)^2}{R_a}\omega + \frac{K\phi}{R_a}V_a \tag{A.5}$$

Typical values of Kϕ and R_a suggest that the gradient $(K\phi)^2$ is very large implying that the output characteristic is almost vertical.
This is why the separately excited DC motor is known as a constant speed motor.



Where,

P_{conv}	: power converted from the motor
E_a	: internal generated voltage
V_a	: armature voltage
I_a	: armature current
R_a	: armature resistance
τ	: induced torque
ω	: speed
K	: constant
ϕ	: field flux

Figure A.2 - . τ vs ω characteristic

When the motor is connected to a load the combination runs at a speed compatible to the characteristic of each.

To change the speed below base speed, V_a should be adjusted keeping V_f at 100%.
To change the speed over base speed, V_f should be adjusted keeping V_a at 100%.
Figure A.3

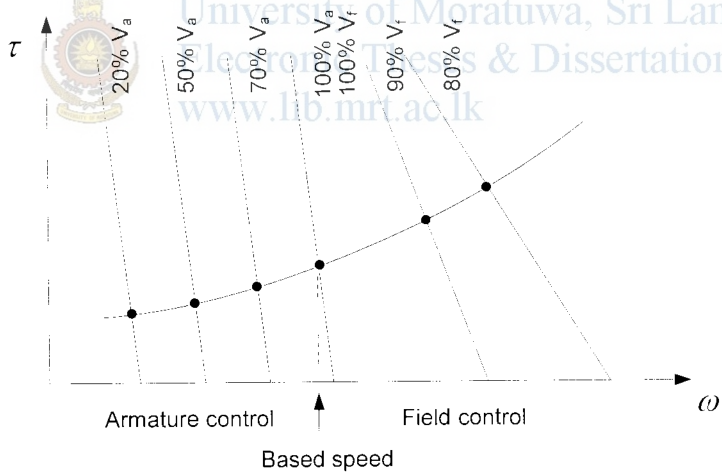


Figure A.3 – Armature and field control

APPENDIX – B: CMG Motors, Performance data

Performance data

SGA series, three phase 415V / 50Hz
IP55, F class insulation, B class temperature rise

kW	Motor frame	Speed [r/min]	Efficiency % at % full load: 125	100	75	50	Power factor, cos φ at % full load: 125	100	75	50	Current[1] Full load I_N [A]	Locked rotor I_L/I_N	t_E time[2] [sec]	Torque Full load T_N [Nm]	Locked rotor T_L/T_N	Break down T_B/T_N	Moment of inertia $J=¼GD^2$ [kg m²]	Weight of foot mount motor [kg]
1000 r/min = 6 poles - CENELEC frame allocations																		
0.37	80 A -19	915	64.3	67.5	67.6	63.4	0.77	0.70	0.60	0.48	1.08	3.4	55	3.9	1.8	4.3	0.002	18
0.55	[illegible]	925	64.7	68.6	66.8	64.7	0.74	0.66	0.58	0.45	1.60	3.3	40	5.7	1.4	2.1	0.002	19
0.75	90 S -24	935	72.8	74.4	74.1	70.7	[illegible]	0.72	0.63	0.50	1.93	4.6	30	7.7	2.4	2.6	0.003	24
1.1	90 L -24	930	72.9	75.6	76.6	74.8	[illegible]	0.77	0.70	0.57	2.7	4.5	25	11.3	2.3	2.4	0.004	30
1.5	100 L -28	950	76.1	77.7	77.6	74.9	[illegible]	0.73	0.66	0.53	3.7	5.1	8	15.1	2.2	3.0	0.007	35
2.2	112 M -28	945	78.9	80.2	80.2	77.1	0.80	0.76	0.67	0.53	5.0	5.6	12	22.2	2.7	3.0	0.014	45
3	132 S -38	970	[illegible]	84.6	84.5	82.0	0.82	0.77	0.70	0.57	6.4	6.7	12	29.5	2.3	[illegible]	0.029	70
4	132 MA -38	965	83.6	84.5	84.2	82.6	0.81	0.77	0.68	0.58	8.5	6.7	9	39.6	2.5	[illegible]	0.036	80
5.5	132 MB -38	965	84.4	85.6	85.9	84.3	0.84	0.81	0.76	0.64	11.0	6.9	9	54.4	2.4	3.0	0.045	90
7.5	160 M -42	970	[illegible]	88.4	88.5	87.0	0.79	0.76	0.70	0.59	15.5	6.0	20	74	2.2	2.6	0.088	130
11	160 L -42	970	[illegible]	89.3	89.9	89.2	0.80	0.79	0.74	0.65	23.6	5.8	16	108	2.2	2.4	0.116	160
15	180 L -48	980	[illegible]	89.2	89.2	87.9	0.85	0.83	0.79	0.69	28.4	6.0	20	146	2.0	2.7	0.207	195
18.5	200 LA -55	980	[illegible]	89.6	89.3	87.5	0.85	0.83	0.78	0.68	34.8	6.9	20	180	2.4	3.3	0.315	225
22	200 LB -55	980	89.9	90.9	91.1	90.1	0.85	0.84	0.79	0.70	40.3	6.6	15	214	2.2	3.5	0.36	255
30	225 M -60	985	[illegible]	92.7	92.6	91.4	0.87	0.86	0.84	0.77	52	7.2	25	291	2.1	3.0	0.547	297
37	250 M -65	985	92.6	92.9	92.9	91.8	0.88	0.88	0.85	0.78	63	6.6	25	359	2.0	3.0	0.834	413
45	280 S -75	985	93.1	93.3	93.3	92.1	0.88	0.88	0.87	0.80	77	6.9	25	436	2.0	3.1	1.39	536
55	280 M -75	985	92.6	93.0	93.0	91.9	0.88	0.89	0.88	0.84	92	6.6	25	533	2.0	3.2	1.65	595
75	315 S -80	990	94.3	94.2	93.7	92.0	0.88	0.88	0.85	0.79	126	7.1	-	724	2.1	2.9	4.11	990
90	315 MA -80	990	94.8	94.7	94.2	94.9	0.89	0.88	0.84	0.75	151	7.8	-	868	2.5	2.8	4.78	1080
110	315 LA -80	990	95.1	95.2	94.6	93.4	0.89	0.88	0.85	0.77	183	7.5	-	1061	2.9	3.1	5.45	1150
132	315 LB -80	990	94.9	94.7	93.9	92.2	0.88	0.86	0.82	0.72	227	7.6	-	1273	2.4	3.1	6.12	1210
160[1]	355 MA -95	990	94.9	95.0	94.8	93.5	0.90	0.89	0.87	0.81	262	8.3	-	1543	2.0	2.4	9.5	1590
200[1]	355 MC -95	990	95.2	95.1	95.0	94.1	0.90	0.91	0.90	0.86	322	6.5	-	1929	1.5	2.0	10.4	1750
250[1]	355 LB -95	990	95.0	95.0	95.0	94.0	0.88	0.88	0.87	0.84	416	6.4	-	2412	1.9	2.4	12.4	1990
Alternative frame allocations (SGAA)[3]																		
37	250SM -70	985	[illegible]	92.9	92.9	91.8	0.88	0.88	0.85	0.78	63	6.6	25	359	2.0	3.0	[illegible]	413
45	250SM -70	985	[illegible]	93.3	93.3	92.1	0.88	0.88	0.87	0.80	77	6.9	-	436	2.0	3.1	1.39	536
55	250SM -80	985	[illegible]	93.0	93.0	91.9	0.88	0.89	0.88	0.84	92	6.6	25	533	2.0	3.2	1.65	595
75	280SM -80	990	[illegible]	94.2	93.7	92.0	0.88	0.88	0.85	0.79	126	7.1	-	724	2.1	2.9	4.11	990
90	315SM -85	990	94.8	94.7	94.2	94.9	0.89	0.88	0.84	0.75	151	7.8	-	867.7	2.5	2.8	4.78	1030
110	315ML -85	990	95.1	95.2	94.6	93.4	0.89	0.88	0.85	0.77	183	7.5	-	1061	2.9	3.1	5.45	1150
132	315ML -85	990	[illegible]	94.7	93.9	92.2	0.88	0.86	0.82	0.72	227	7.6	-	1273	2.4	3.1	6.12	1210

This data is provided for guidance only.
Results are guaranteed only when confirmed by test results.
[1] F Class temperature rise
[2] t_E time applies to Ex e motors only and is explained in the hazardous areas section.
[3] The SGAA series are supplied as standard in South Africa.

APPENDIX – C: DC Hollow shaft Tacho-Generator

General

The 4-pole TDP 439 H D.C. hollow shaft tacho-generators are measurement converters for measurement, control and regulation technology. The function of these permanently excited D.C. generators is to convert the speed at which they are driven into a speed-proportional D.C. voltage.

Mechanical Design

- low profile, short machine : A4 construction (without own bearings), in a mechanically robust design.
- torsionally-rigid connection between tacho armature and drive machine, designed specially for highly dynamic reversing.
- no coupling, no long intermediate flange, simple and cost-effective fitting to the drive machine.
- a wide selection of drive shaft diameters – from 12 to 30 mm dia.
- positive fitting to cylindrical shaft extensions to DIN 748 Part 3 with feather keyway.
- interference fitting to cylindrical, plain shaft extensions of 16, 20, 25 and 30 mm dia.
- the possibility of passing the drive shaft through the tacho so that an additional shaft extension of up to 25 mm dia. is available (e.g. for a crank handle).
- high degree of protection – IP 56 – when fitting is carried out according to instructions.
- large, sealed terminal box with captive cover fixing screws for IP 55 and higher.
- simple maintenance, easily accessible brush area; commutator contact surface can be checked, cleaned and refurbished without dismantling the armature.
- simple mounting and removal of the machine; the stator housing is pushed on over the fixed armature

Electrical

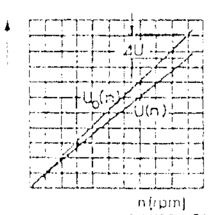
- available voltages from 10 to 120 V at 1000 rpm.
- harmonic voltage content kept to a minimum by the high number of segments/slots.
- temperature compensation up to + 100°C (optional/additional price)

Type Code Example: TDP 4 39 H 16 S - 2

- DP permanent magnet — TDP
- Poles: 4 — 4
- Segments/slots: 39 — 39
- Hollow shaft bore, dia. 12 to 25 mm — H 16
- Armature shaft connection by means of: — S
  - S with clamping sleeve (dia 16/20)
  - F feather keyway (dia 12, 14, 16, 19, 24, 25)
  - Lock clamping device Ø 25)
- Voltage required at 1000 rpm.: – 1 to – 12 (i.e. 10 to 120 V) — 2

Voltage

The standard voltages are given in the technical tables:



Speed/voltage curve

Connections, Polarity

The tacho armature is connected via commutator/brushes to a 2-pole terminal board. When the machine is running clockwise (view from the driving side), the A1 terminal is positive and the A2 terminal negative.

Brushes

The sizing and quality of the silver-graphite brushes used, do guarantee long maintenance-free operation. Brush life is however extremely dependent on ambient conditions and speed. For normal operating conditions it is approx. 15.000 operating hours.

Temperature coefficient
Temperature compensation

The temperature coefficient of the permanent magnets used is dependent on the material used and is approx. +/– 0,3 % per 10 degrees K of temperature change. This value applies to a temperature range of approx. – 40°C up to + 100°C and is reversible.
If temperature compensation is required, this should be specified on ordering (extra cost). In the temperature range 0 – 100°C the temperature coefficient of the permanent magnets can be compensated up to a tolerance of +/- 0,05 % per 10 degrees K.

Harmonics

An essential characteristic of a good tacho voltage is a low percentage of harmonic content in a large speed range. In general, the RMS value of the total harmonic mix is measured by a thermionic voltmeter and refers to the D.C. voltage value. The harmonic voltage is approx. 0,5 % at speeds between 100 and 3000 rpm. Machine harmonics result from the mechanical and electrical design and the electrical use, as well as the production tolerances of symmetry.

Linearity and optimum load current

The suitability of a tacho-generator for different control functions is determined by the linearity of the output voltage relative to the speed.
The max. permissible load current is given for each machine which should not be exceeded with respect to the linearity errors. (0,5 % at max. current.)
However, for high precision requirements in the range of +/– 0,15% speed deviation, we recommend to select the optimum load resistance.

Brush contact voltage

Silver-graphite brushes with very low contact voltage are mainly used for D.C. tacho-generators.
The total voltage drop at the sliding contact is affected by speed, current density under the brushes, brush pressure and the conditon of the patina on the brush contact surface.

Insulation

Insulation class B. Additional protection against aggressive ambient conditions can be provided by special insulation (extra cost).

Construction

The machine in A4 construction does not have own bearings. A torsionally-rigid connection results from pushing the tacho onto the drive shaft. Uncontrolled oscillations which are induced and amplified by couplings will thus be avoided. Mounting of the machine by means of two cheese-head screws, M 5 x 50 (included in scope of supply).
Note: max. drive-in torque 200 Ncm.

Degrees of protection

DIN/VDE 0530 part 5 (for rotating electrical machines).

IP 55
Fully enclosed. Protection against harmful dust deposits and against water spray from all directions.

IP 56
Protection against flooding.

Note: Mounting surface of tacho to be sealed.

IP 44
Protection against granular objects and water splashing (with plastic terminal box or connecting cable, no aluminium casting).

Paint, surface protection

IP 55/IP 56
Finish paint light grey RAL 7030.

IP 44
Surface protection: galvanized and black chromed.

Tachos exposed to aggressive gases and fumes will be supplied, in addition to special insulation with an appropriate special coat of paint.

Selection table

Technical Data

Excitation:	Permanent		
Rated voltage tolerance:	+/– 5 %	Reversing error:	+/– 0.2 %
Direction of rotation:	reversible	Insulation:	Class B
Polarity/connections:	dependent on direction of rotation	Temperature coefficient:	+/– 0.05 % per 10 degrees K, compensated magnet system +/– 0.3 % per 10 degrees K, uncompensated magnet system at a power consumption of approx. 0.04 W/1000 rpm Temperature range up to + 100° C
No. of poles:	4		
No. of slots:	39		
No. of segments:	39		
Brushes per machine:	4 quality AG 35 dimensions 3 x 5 x 10		
Harmonic voltage:	ΣU (RMS) ≤ 0,5 % (100 – 3000 rpm)	Winding test:	2 x Umax + 500 V, Repeat test max. 800 V
Linearity error:	+/– 0,15 % (100 – 3000 rpm) +/– 1 % (10 – 100 rpm) at a power consumption of approx. 0,04 W/1000 rpm	Moment of inertia:	2,2 kgcm²
		Weight of complete machine:	approx. 2.3 kg in IP 55/IP 56 approx. 1.2 kg in IP 44 (TDPL 2 kg)

Preferred voltages

Type	Rated Voltage at 1000 rpm [V]	Max. Speed [rpm]	Max. Permissible Current at 1000 rpm [mA]	Optimum Load [kΩ]	Armature Resistance at 20° C [Ω]
TDP 439-1	10	9000	40	2,5	28
TDP 439-2	20	9000	20	10	96
TDP 439-3	30	8000	13	23	227
TDP 439-4	40	6000	10	40	361
TDP 439-5	50	5000	8	62	545
TDP 439-6	60	4000	7	90	810

Voltages with 80 V, 100 V and 120 V are possible with Type TDPL 439.

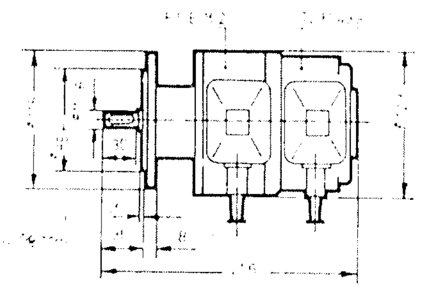
Combined Units

The **combined units (with own bearings)** do comprise of the **tacho** described on the preceding pages plus **an incremental encoder or overspeed switch** mounted together on a single shaft. (Encoder + overspeed switch + tacho on request). These totally enclosed machines are supplied in **B5 construction with one free shaft extension** having two terminal boxes.

The commutator and brush area of the D.C. tacho are easily accessible from the back side.

The mounting dimensions are identical to those of the following single units in B5 construction: D.C. tacho TDP 0.7/8 overspeed switch FSE 102 and incremental encoder FG 4.

FSE 102 + TDP 439 H

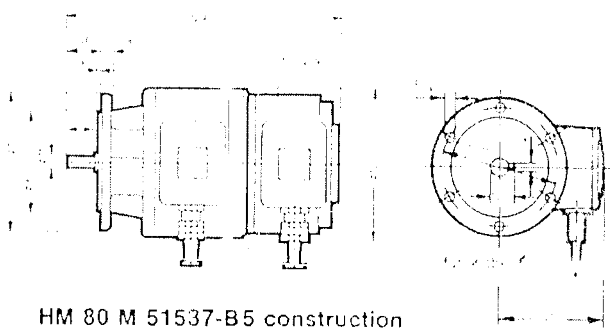


HM 80 M 51536 – B5 construction

D.C. tacho and overspeed switch type FSE 102.
The overspeed switch type FSE 102 is a speed-dependent electro-mechanical switching device which releases a contact at a pre-set switching speed.

Separate data sheets of FG 4 and FSE 102 available on request.

FG 4 + TDP 439 H



HM 80 M 51537-B5 construction

D.C. tacho and incremental encoder type FG 4.
The incremental encoder type FG 4 is a robust unit for very extreme ambient and operational conditions, of high reliability and long life time. Its function is to convert the speed into a proportional frequency and to generate further digital signals.

Subject to modification!

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