Palestine Polytechnic University

College of Engineering and Technology
Electrical and Computer Engineering Department
Industrial Automation Engineering

Correction of Consumed Power By Electrical Machines at Starting

A graduation project submitted in partial fulfillment of the requirements for the
degree of Bachelor of Engineering in Industrial Automation

Project Supervisor:

Eng. Abed alqader al-zarow

SUBMITTED BY:-

MOHAMMAD ABD. ARAR **OMAR R. ALQADI**

HEBRON-PALESTINE
JULY-2004

CERTIFICATION

Palestine Polytechnic University

(PPU)

Hebron – Palestine

The Senior Project Entitled:

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Project Supervisor Signature	Department Manage Signature
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ABSTRACT

In this graduation project we make study and research for factories and industrial plant in Hebron to detect power consuming during production process and specially through starting these machines.

Then, try to create some methods to reduce these consumed powers.

However, how to manage consumed energy by reduce energy losses during industrial process. Which performed by make studies to improve energy consumed.

إهداء

إلى الزهرة التي لا تذبل .... نبع الحنان .... إلى أمي

إلى الماس الذي لا ينكسر .... نبع العطاء .... إلى والدي

إلى ملائكة الأرض .... .شقائق النعمان .... إلى أشقائي

إلى من قتلت رهبانيتي.......... من ملكت قلبي .... إلى حبيبتي

إلى قناديل الدرب .... الشموع التي لا تنطفئ .... إلى أساتذتي

إلى رفاق الدرب .... بناة المستقبل .... إلى أصدقائي

إلى صناع الكرامة .... رايات المجد .... إلى شهدائنا

إلى من رفضوا الخضوع .... من طلبوا العزة.......... إلى أسرانا

إلى كل المخلصين .... العاملين للإسلام.......... إلى حملة الدعوة

إليكم جميعا أحبتي اهدي هذا الجهد المتواضع

فريق العمل
عمر القاضي
محمد عرعر

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Chapter One

Introduction

1.1- Over view

As development of industrial process in overall the world, demands to the energy resources became argent factor to an industry. Since that looking for new and more efficient energy resource was established and still until now to fined out inexpensive and more economical energy source.

And because of the energy resources are very limited in the nature and it may ceased to exist then conservation of our energy resources begin represents a critical demand for a life not only for the industry.

Saving of the electrical energy used to move on industrial wheel can employed by several ways, but there is a critical technique can be improved in very small time interval compared to totally operated time of the electrical machine and this time interval is eliminated in several cases.

So in this project we tray to treat with a starting time interval of an electrical machines and make some examination on several starting techniques on most popular motors used in our industrial phenomena. And then finally compare the existence results to perform a general observation of allover starting technique against all motors power rating.

1.2- Project's contents description

This project contains about six chapters including with this one, and in the next paragraphs there is a briefly description of each one of them.

-Chapter Two -Theory- In these chapter basic facts taken in account and the main base of project's idea are shown.

-Chapter Three –Previous Studies- This chapter displays what was reached in this field by other researches done by specialists in this field.

-Chapter Four –Measurements Analysis- problem is represented in this chapter as displaying of current fall after starting time period for some cases of factories.

-Chapter Five –Analytical Results- This chapter is regarded as most significant one because it contains all examination of all machines classes and in respect to all assumed starting techniques. Also the approximation used such as depending in numerical analysis methods to interpolate values of current at discrete time moments and to calculate average value of starting current.

-Chapter Six –Conclusions and Recommendations- In these chapter main results and recommendations are presented supported with graphical chart.

Chapter Two

Theory

2.1-Introduction

Induction motors do not present types of starting problem that other A.C motors do. In many cases induction motors can be started by simply connecting them to the power lines. However, there are sometimes good reasons for not doing this. For example, the starting current required may cause such a dip in the power system voltage that across-the-line starting is not acceptable.

For wound-rotor induction motors starting can be achieved at relatively low current by inserting extra resistance in the rotor circuit during starting. This extra resistance not only increases the starting torque but also reduce the starting current.

For squirrel-cage induction motors, the starting current can vary widely depending primarily on the motor's rated power and on the effective rotor resistance at starting condition. To estimate the rotor current at starting conditions, all squirrel-cage induction motors now have a starting code litter (not to be confused with their design class litter) on their nameplates. The code litter sets limits on the amount of current the motor can draw at starting conditions.

These limits are expressed in terms of the starting apparent power of the motor as a function of its horsepower ratings. Next table will show the starting kilo-volt-ampere per horsepower for each code litter.

Table 2.1 (NEMA Code Letters for Locked-Rotor KVA)

Nominal code litter	Load rotor (KVA/hp)	Nominal code litter	Load rotor (KVA/hp)
A	0-3.15	L	9.0-10.0
B	3.15-3.55	M	10.0-11.2
C	3.55-4.0	N	11.2-12.5
D	4.0-4.50	P	12.5-14.0
E	4.5-5.0	R	14.0-16.0
F	5.0-5.6	S	16.0-18.0
G	5.6-6.3	T	18.0-20.0
H	6.3-7.1	U	20.0-22.4
J	7.10-8.0	V	22.4 and up
K	8.0-9.0		

To determine the starting current for an induction motor, read rated voltage, horsepower and code litter from its nameplate. Then, the starting current can be found from next equation

$$I_{st} = \frac{S_{start}}{\sqrt{3}V_t} \qquad (2.1)$$

2.2-Why starting current is high

Since equivalent circuit of an induction motor is similar to that of transformer then, induction motor can be treated as a transformer but with a deference which is there is a rotating part in induction motor called rotor in place of stationary secondary of a transformer.

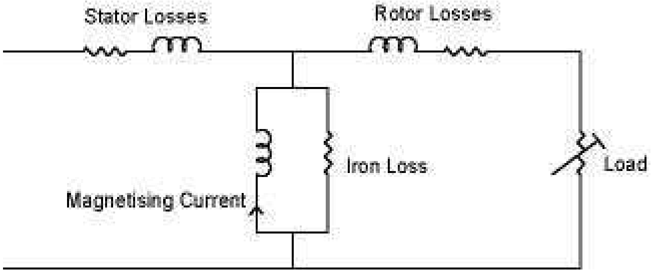


Fig 2.1 (equivalent circuit of an induction motor)

So like any transformer there is certain resistance and self inductance in the primary (stator) windings and also in rotating secondary (armature) windings. Also there is induced voltage across rotating secondary windings as a result of applied voltage across stationary stator windings (transformer reacts).

In an induction motors when a voltage is applied to the stator windings a voltage is induced in the rotor windings of the machine. In general the greater the relative motion between the rotor and the stator magnetic fields, the greater the resulting rotor voltage. The largest relatively motion occurs when the rotor is stationary called the locked rotor or blocked rotor condition. So the largest voltage is induced I the rotor windings at that condition. And in other hand the smallest voltage is induced when the rotor moves at the same speed as the stator magnetic field, resulting in no relative motion.

The voltage induced in the rotor at any speed between these extremes is directly probation to the slip (difference between rotor speed and stator magnetic filed speed) of the motor. Therefore, if the induced rotor voltage at locked rotor condition is referred as (E_{R0}), the induced voltage at any speed (variable slip) will given as

$$E_R=sE_{R0} \qquad (2.2)$$

This voltage is induced in a rotor containing both resistance and reactance. The rotor resistance is constant (except for the skin effects) independent of the slip. While the rotor reactance is affected in a more complicated way by the slip.

The reactance of an induction motor rotor depends on the inductance of the rotor and the frequency of the voltage and current in the rotor. So the rotor reactance (X_R) is given by :-

$$X_R = 2\pi*f_r*L_R \qquad (2.3)$$

$$X_R = 2\pi*sf_e*L_R \qquad (2.4)$$

$$X_R = s*X_{R0} \qquad (2.5)$$

Where X_{R0} is the locked rotor reactance

Fr is frequency

L_R is reactance

So the resulting rotor current follow dependant on the equivalent circuit can found out as:-

$$I_R = \frac{E_R}{R_R + JX_R} \qquad (2.6)$$

$$I_R = \frac{s\,E_{R0}}{R_R + JsX_{R0}} \qquad (2.7)$$

$$I_R = \frac{E_{R0}}{\frac{R_R}{s} + JX_{R0}} \qquad (2.8)$$

2.3 Starting Characteristics:

In order to perform useful work, the induction motor must be started from rest and both the motor and load accelerated up to full speed. Typically, this is done by relying on the high slip characteristics of the motor and enabling it to provide the acceleration torque.

Induction motors at rest, appear just like a short circuited transformer, and if connected to the full supply voltage, draw a very high current known as the "Locked Rotor Current". They also produce torque which is known as the "Locked Rotor Torque". The Locked Rotor Torque (LRT) and the Locked Rotor Current (LRC) are a function of the terminal voltage to the motor, and the motor design. As the motor accelerates, both the torque and the current will tend to alter with rotor speed if the voltage is maintained constant.

The starting current of a motor, with a fixed voltage, will drop very slowly as the motor accelerates and will only begin to fall significantly when the motor has reached at least 80% full speed. The actual curves for induction motors can vary considerably between designs, but the general trend is for a high current until the motor has almost reached full speed. The LRC of a motor can range from 500% Full Load Current (FLC) to as high as 1400% FLC. Typically, good motors fall in the range of 550% to 750% FLC.

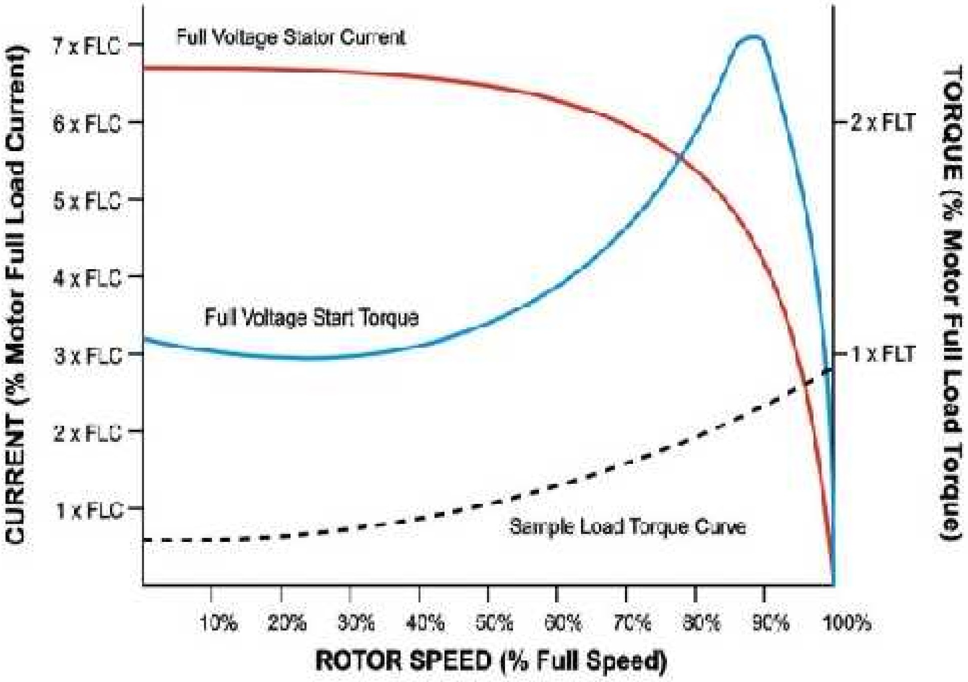


Fig 2.2: actual curves for induction motors

The starting torque of an induction motor starting with a fixed voltage, will drop a little to the minimum torque known as the pull up torque as the motor accelerates, and then rise to a maximum torque known as the breakdown or pull out torque at almost full speed and then drop to zero at synchronous speed. The curve of start torque against rotor speed is dependant on the terminal voltage and the motor/rotor design.

The LRT of an induction motor can vary from as low as 60% Full Load Torque (FLT) to as high as 350% FLT. The pull-up torque can be as low as 40% FLT and the breakdown torque can be as high as 350% FLT. Typical LRTs for medium to large motors are in the order of 120% FLT to 280% FLT.

The power factor of the motor at start is typically 0.1 - 0.25, rising to a maximum as the motor accelerates, and then falling again as the motor approaches full speed. A motor which exhibits a high starting current, i.e. 850% will generally produce a low starting torque, whereas a motor which exhibits a low starting current, will usually produce a high starting torque. This is the reverse of what is generally expected.

The induction motor operates due to the torque developed by the interaction of the stator field and the rotor field. Both of these fields are due to currents which have resistive or in phase components and reactive or out of phase components. The torque developed is dependant on the interaction of the in phase components and consequently is related to the I^2R of the rotor. A low rotor resistance will result in the current being controlled by the inductive component of the circuit, yielding a high out of phase current and a low torque. Figures for the locked rotor current and locked rotor torque are almost always quoted in motor data, and certainly are readily available for induction motors. Some manufactures have been known to include this information on the motor name plate. One additional parameter which would be of tremendous use in data sheets for those who are engineering motor starting applications, is the starting efficiency of the motor. By the starting efficiency of the motor, I refer to the ability of the motor to convert amps into newton meters. This is a concept not generally recognised within the trade, but one which is extremely useful when comparing induction motors. The easiest means of developing a meaningful figure of merit, is to take the locked rotor torque of the motor (as a percentage of the full load torque) and divide it by the locked rotor current of the motor (as a percentage of the full load current). i.e

$$\text{Starting efficiency} = \frac{\text{Locked Rotor Torque}}{\text{Locked Rotor Current}} \qquad (2.9)$$

If the terminal voltage to the motor is reduced while it is starting, the current drawn by the motor will be reduced proportionally. The torque developed by the motor is proportional to the current squared, and so a reduction in starting voltage will result in a reduction in starting current and a greater reduction in starting torque. If the start voltage applied to a motor is halved, the start torque will be a quarter, likewise a start voltage of one third will result in a start torque of one ninth.

Chapter Three

Previous Studies

3.1:INDUSTRY OVERVIEW

3.1.1:Introduction

Productivity can be improved in many ways. Purchasing new machines and developing new processes are the most obvious ways to increase your productivity. However, maximum start-up time is one area that can be improved which may be overlooked. The proper method of starting motors can result in reduced downtime and increased productivity.

This publication addresses the selection of electro-mechanical and solid-state methods of starting AC induction motors. After a brief review of the history of starting AC motors and technology, the key issues involving trade-offs of the various starting methods are described.

3.1.2:History

Electromechanical starting has been available since the AC induction motor was invented. Initially the manual starter was more predominant than the electromechanical. The manual starters are still available and are used in specific applications. Today electromechanical starting is preferred either in full voltage or reduced voltage for starting three-phase AC motors.

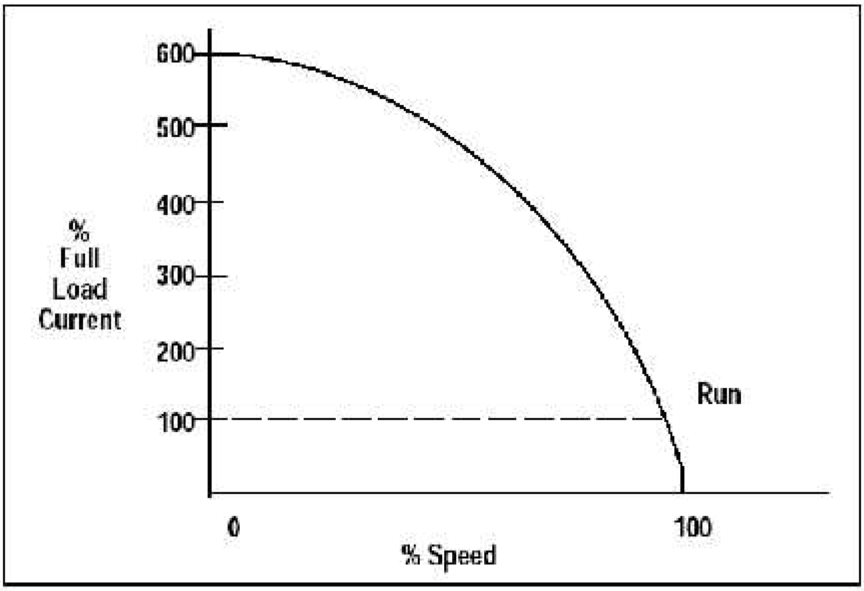
Solid-state controllers are a relatively new way to start motors. In the early 1970s, solid-state controllers began to replace electromechanical reduced voltage starters. Although solid-state controllers can be used for full voltage starting, the majority of applications use solid-state controllers for soft starting or step less reduced-voltage starting of AC motors.

3.2:INDUSTRY SOLUTIONS

3.2.1:Full Voltage Starters

Full voltage starting is the most widely used way to start motors. These starters have specific voltage and current ratings and can be used on a wide range of motors. The control input of the full voltage starter is its coil. The user must select a starter with a coil voltage properly that is coordinated with the control voltage available.

When starting a motor, the current drawn from the power line is typically 600% of normal full load current. This high current flows until the motor is almost up to speed and then decreases, as shown in Figure 1.



Figure(3.1) Full Load Current vs. Speed

In addition to high starting currents, the motor also produces starting torques that are higher than full load torque. The magnitude of the starting torque depends on the motor design. NEMA publishes standards for torques and currents for motor manufacturers to follow. Typically, a NEMA Design B motor has a locked rotor or starting torque that is about 180% of full load torque.

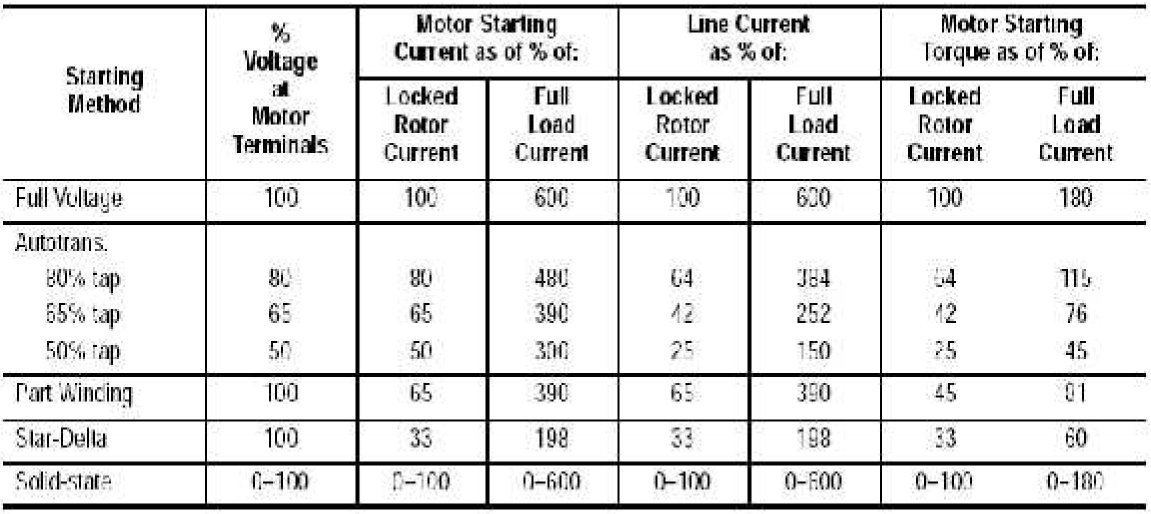
3.2.2:Reduced Voltage Starters

In the United States, the most widely used method of electromechanical reduced voltage starting is the auto-transformer type. Part winding starting is the next most popular method. In the rest of the world, Wye-Delta (Y-Δ), also referred to as Star-Delta, is the predominant form of reduced voltage starting.

All forms of reduced voltage starting affect the motor current and torque characteristics. When reduced voltage is applied to a motor at rest, the current drawn by the motor is reduced. In addition, the torque produced by the motor is reduced by a factor that is approximately the square of the percentage voltage reduction.

For example, if 50% voltage is applied to the motor, a starting torque that is approximately 25% of the normal starting torque would be produced. In the previous full voltage example, the NEMA Design B motor had a starting torque of 180% of full load torque. With only 50% voltage applied, this would equate to approximately 45% of full load torque. Table 1 shows the typical relationship of voltage, current, and torque for a NEMA Design B motor.

Table (3.1) Typical Voltage, Current, and Torque Characteristics for Motors



Starting Method	% Voltage at Motor Terminals	Motor Starting Current as of % of:		Line Current as % of:		Motor Starting Torque as of % of:	
		Locked Rotor Current	Full Load Current	Locked Rotor Current	Full Load Current	Locked Rotor Current	Full Load Current
Full Voltage	100	100	600	100	600	100	180
Autotrans.							
80% tap	80	80	480	64	384	64	115
65% tap	65	65	390	42	252	42	76
50% tap	50	50	300	25	150	25	45
Part Winding	100	65	390	65	390	45	81
Star-Delta	100	33	198	33	198	33	60
Solid-state	0–100	0–100	0–600	0–100	0–600	0–100	0–180

With the wide range of torque characteristics for the various methods, selection of the electromechanical reduced voltage starter is more application-dependent. In many instances, available torque becomes the factor in the selection process.

Limiting line current has been the main reason for using electromechanical reduced voltage starting. Utility current restrictions, as well as in-plant bus capacity, may require motors above a certain horsepower to be started with reduced voltage. Some areas of the world require that any motor above 7-1/2 horsepower be started with reduced voltage.

A second reason for using reduced voltage motor starting is to control torque. For example, electromechanical reduced voltage starting has been used on high inertia loads to control the acceleration of the motor and load.

Electromechanical reduced voltage starters must make the transition from reduced voltage to full voltage at some point in the starting cycle. At this point there is normally a line current surge. The amount of surge depends on the type of transition being made and the speed of the motor at the transition point.

There are two methods of transition, namely, open circuit transition and closed circuit transition. Open transition means that the motor is actually disconnected from the line for a brief period of time while the transition takes place. With closed transition, the motor remains connected to the line during transition. Open transition produces a higher surge of current because the motor is momentarily disconnected from the line. Figure 2 shows examples of open and closed transition currents.

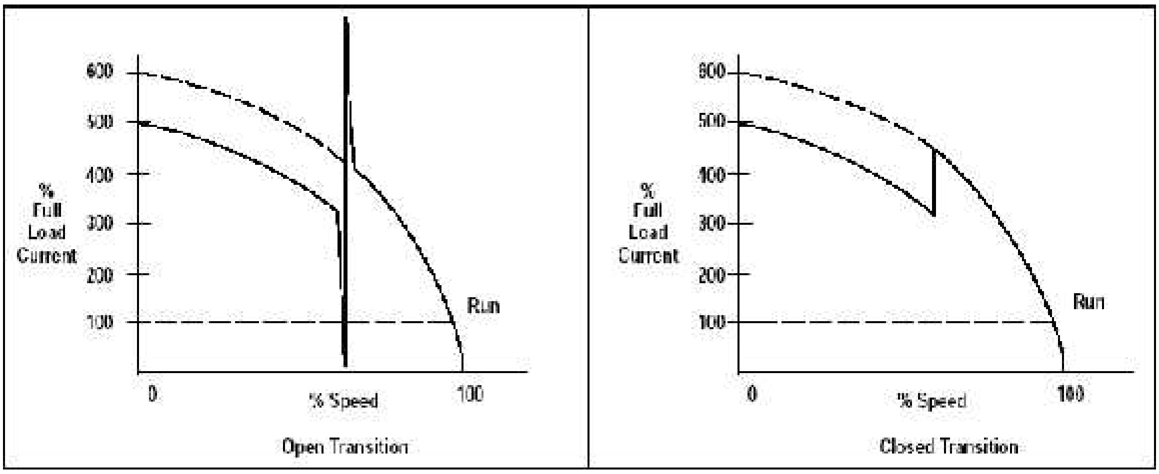


Figure 3.2: Open Circuit Transition vs. Closed Circuit Transition

The motor speed can determine the amount of current surge that occurs at transition. Transition from reduced voltage to full voltage should occur as close as possible to full speed. This helps minimize the amount of surge on the line. Figure 3 illustrates transition both at low motor speed and at near full speed. The transition at low speed shows the current surge as transition occurs at 550%, which is greater than the starting current of 400%. The transition near full speed shows that the current surge is 300%, which is below the starting current.

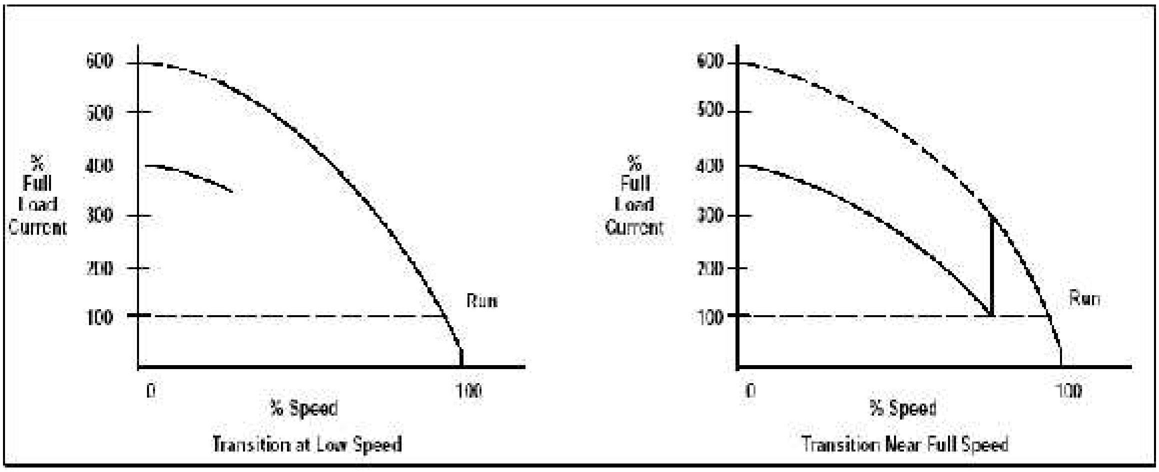


Figure 3.3: Transition at Low Speed vs. Transition Near Full Speed

3.2.3:Solid-state Controllers

Solid-state controllers are mainly used to provide soft start or step less reduced voltage starting of AC motors. The same principles of current and torque apply to both electromechanical reduced voltage starters and solid-state controllers. Solid-state controllers offer the choice of three starting modes in the same device: soft start, current limit, and full voltage.

Not only can you select the mode of the solid-state controller, you can also adjust:

- the soft-start ramp time
- the current limit maximum value

The most widely used mode is the soft start. This method provides a smooth start for most applications.

Solid-state controllers eliminate the current transition point, and the time to full voltage can be adjusted usually from two to 30 seconds. The result is no large current surge when the solid-state controller is set up and correctly matched to the load as illustrated in Figure 4.

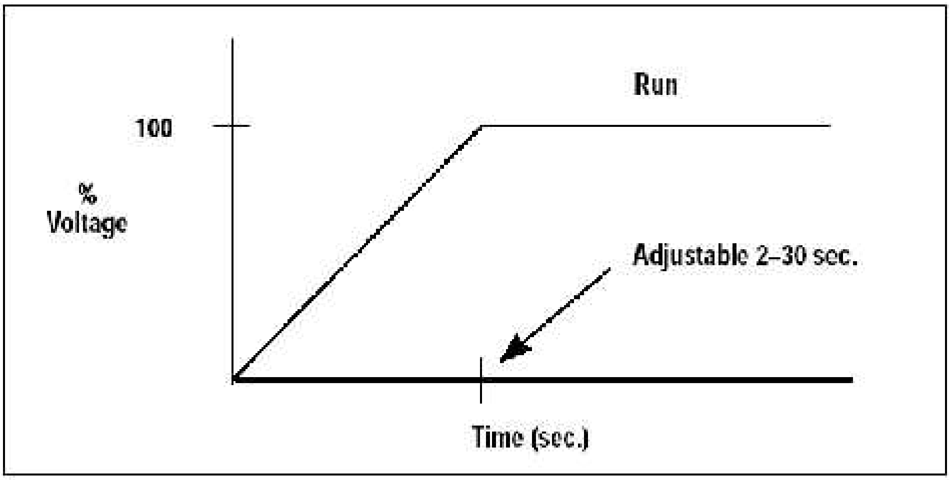


Figure 3.4: Soft Start

Current limit can be used where power line limitations or restrictions require a specific current load. Figure 5 shows a 450% current limit curve, though other values can be easily selected. Current limit is also used where higher starting torque is required compared to soft start which typically starts at less than 300% current. An example where current limit is used is on high inertia loads such as ball mills.

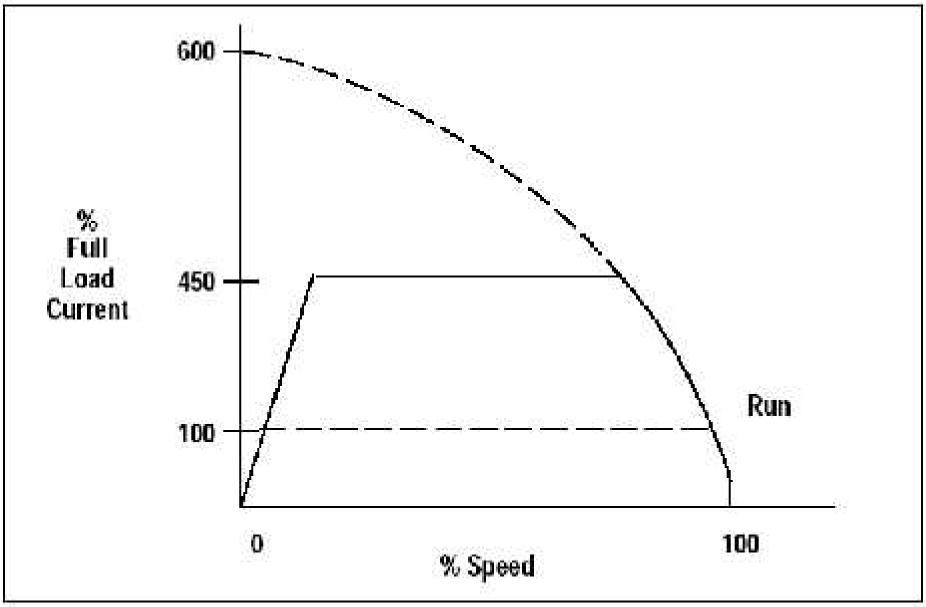


Figure 3.5: Current Limit Acceleration

Solid-state controllers control the voltage applied to the motor even when the motor is up to speed because of semiconductors used in the power circuit. This allows solid-state reduced voltage to provide energy savings for motors that run unloaded or lightly loaded for long periods of time. Intelligence within the solid-state controller determines when the motor is lightly loaded. The voltage to the motor can then be reduced by properly controlling the semiconductors until the motor is operating at an optimum point. This same intelligence detects when a load is reapplied and increases the voltage to prevent stalling.

Other available features of solid-state controllers include additional protection to the motor and controller and diagnostics to aid in set-up and troubleshooting. Protection typically provided includes:

- shorted SCR
- phase loss
- open load line
- SCR overtemperature
- stalled motor

Appropriate LEDs illuminate to aid in troubleshooting when one of these faults trip the solid-state reduced voltage controller.

3.3:CORRECT SOLUTIONS

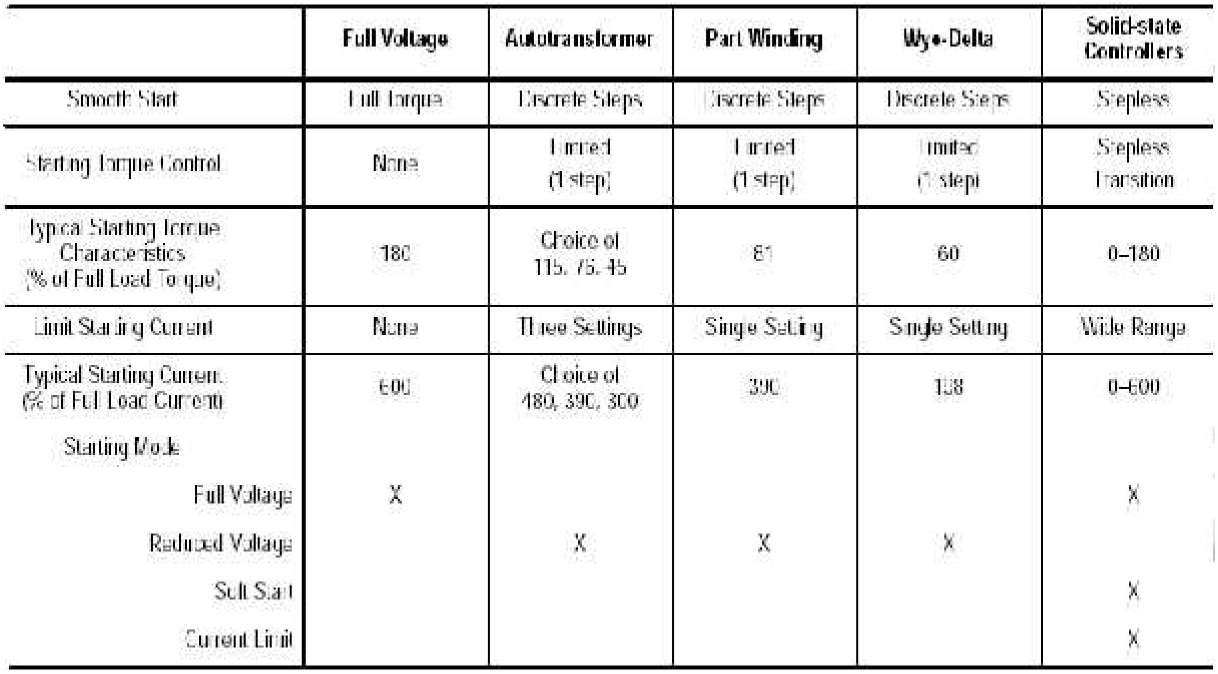
3.3.1:Proper Selection

In terms of solutions there are three major methods of starting AC motors available:

- Full Voltage
- Electromechanical Reduced Voltage
    - ⇒ Autotransformer
    - ⇒ Part Winding
    - ⇒ Wye-Delta
- Solid-state Controller

Proper selection of a starting method is critical to achieving maximum productivity on any motor control application. Consider the installation of each method when matching the requirements of your specific application Table 2 on the following page is a selection guide of the different starting methods to help you select the appropriate product.

Table 3.2: Motor Starting Selection Guide



	Full Voltage	**Autotransformer**	**Part Winding**	**Wye-Delta**	**Solid-state Controllers**
Smooth Start	Full Torque	Discrete Steps	Discrete Steps	Discrete Steps	Stepless
Starting Torque Control	None	Limited (1 step)	Limited (1 step)	Limited (1 step)	Stepless Transition
Typical Starting Torque Characteristics (% of Full Load Torque)	180	Choice of 115, 75, 45	81	60	0–180
Limit Starting Current	None	Three Settings	Single Setting	Single Setting	Wide Range
Typical Starting Current (% of Full Load Current)	600	Choice of 480, 390, 300	390	198	0–600
Starting Mode					
Full Voltage	X				X
Reduced Voltage		X	X	X	
Soft Start					X
Current Limit					X

Chapter Four

Measurements Analysis

4.1- Introduction:-

In this chapter and the follower the analytical calculations have been performed for measured values of industrial machines. The analytical process based on make classifications of motors according to its power rates and then; deals with each class as independent case

In the following sections the classifications are displayed and before dealing with each class we will examine the situation of each factory during transient period of time represents starting of motors until reached a steady state condition to identify the effect of this transient period on consumed power and on the maximum current rate of each factory and its behavior through this time as what will appeared in the next.

4.2- Measurements Tabulation:-

In the next topic the classification of motors will accomplished according to its power rating as mentioned above.

These motors are classified to four categories each one with suitable power rating range and these categories will describe bellow.

- Category # 1 consists motors with power ratings bellow than 6KW
- Category # 2 consists motors of power ratings between 6KW and 25KW
- Category # 3 consists motors of power ratings between 25KW and 50KW
- Category # 4 consists a huge motors which of power ratings more than 200KW up to 1000KW.

So the following schedule displays the tabulation of each category alone each table consists of measured and calculated values.

4.2.1:- Category # 1 (less than 6KW)

Table 4.1.a **:** Category # 1

Serially	**Power rate (KW)**	**Terminal voltage (V)**	**Starting current (A)**	**Starting time (Sec)**	**Load current (A)**	**Nominal current (A)**	$\frac{\textbf{Ist}}{\textbf{In}}$ **(100%)**
01	2.5	220/380	2.0	1.0	1.2	3.0	0.66
02	3.0	220/380	9.0	2.0	6.0	6.6	1.36
03	3.0	220/380	39.0	6.0	4.1	10.0	3.90
04	0.08	400	0.604	1.0	0.6	0.6	1.0
05	0.37	400	1.40	1.0	1.3	1.3	1077
06	0.25	380	0.48	1.5	0.37	0.37	1.297
07	0.55	380	1.51	1.0	1.40	1.4	1.078
08	0.75	380	2.07	1.5	1.93	1.93	1.073
09	1.50	400	4.14	1.0	3.9	3.90	1.062
10	2.20	400	5.52	1.0	5.10	5.10	1.082
11	2.20	380	5.70	1.5	5.25	5.25	1.086
12	3.0	400	7.21	2.0	6.0	6.6	1.20
13	3.3	400	8.5	2.0	7.0	7.4	1.214
14	4.0	380	9.0	2.0	7.5	8.0	1.20
15	4.80	400	10.0	2.0	8.0	8.5	1.25
16	5.50	400	14.0	2.0	12.0	12.5	1.11.
17	5.50	380	16.0	2.0	12.0	12.51	1.333

Table 4.1.b: Category # 1

Factory	**Starting technique**	**# of starting (daily)**	**Average starting power (W.h)**	**Overall consumed power (W.h)**	**Js — Jove (100%)**
Nyrogh	On line star	2	609.70	384.10	1.59
Nyrogh	On line star	2	2429.20	1943.36	1.25
Al sharq	On line star	2	6980.0	1324.00	5.27
Al haddad	On line star	2	262.0	253.60	10.33
Al haddad	On line star	2	570.50	549.40	10.38
Al haddad	On line star	2	170.60	148.60	11.48
Al haddad	On line star	2	584.20	562.10	10.40
Al haddad	On line star	2	803.00	774.87	10.36
Al haddad	On line star	2	2088.80	2026.50	10.31
Al haddad	On line star	2	2759.20	2650.00	10.41
Al haddad	On line star	2	2594.50	2488.00	10.43
Al haddad	On line star	2	3432.50	3117.70	11.01
Al haddad	On line star	2	4027.00	3637.30	11.07
Al haddad	On line star	2	4072.50	3702.30	11.00
Al haddad	On line star	2	4801.20	4267.80	11.25
Al haddad	On line star	2	6935.10	6401.70	10.83
Al haddad	On line star	2	7095.20	6081.60	11.67

4.2.2:- Category # 2 (6KW up to 25KW)

Table 4.2.a: Category # 2

Serially	**Power rate (KW**	**Terminal voltage (V)**	**Starting current (A)**	**Starting time (Sec)**	**Load current (A)**	**Nominal current (A)**	$\frac{\textbf{Ist}}{\textbf{In}}$ **(100%)**
01	9.00	380/660	86.00	8.00	28.00	28.00	3.07
02	11.00	400/690	28.00	2.50	6.60	7.00	4.00
03	15.00	380/660	23.00	4.00	11.00	11.70	1.97
04	15.00	400/690	160.00	4.00	40.00	68.00	2.35
05	11.00	380/660	13.00	3.00	5.00	6.00	2.167
06	15.00	380/660	95.00	12.00	25.00	30.50	3.11
07	22.00	400/690	90.00	7.50	11.00	41.00	2.20
08	22.00	380/660	77.00	7.00	28.00	43.50	1.77
09	18.00	400/690	37.00	21.00	15.00	35.00	1.05

Table 4.2.b: Category # 2

Factory	**Starting technique**	**# of starting (daily)**	**Average starting power (W.h)**	**Overall consumed power (W.h)**	**Js — Jove (100%)**
Al juidy	Double star/star	20.00	19.494	9576.00	2.04
Al juidy	Star/delta	3.00	6.159	4069.60	1.51
Al juidy	Star/delta	3.00	5.168	5792.00	0.9
Al baid	Star/delta	2.00	34.800	24.11	1.44
Al baid	Star/delta	2.00	2.87	2.76	1.04
Al qasrawee	Star/delta	2.0.00	19.38	14.55	1.332
Al qasrawee	Star/delta	20.00	17.37	6.554	2.651
Al haddad	On line delta	2.00	29.716.00	15.85	1.88
Al haddad	Star/delta	2.00	17.789	8937.4	2.00

4.2.3:- Category # 3 (25KW up to 50KW)

Table 4.3.a: Category # 3

Serially	Power rate (KW)	Terminal voltage (V)	Starting current (A)	Starting time (Sec)	Load current (A)	Nominal current (A)	Ist — In (100%)
01	30.0	380/660	138.0	17.0	29.0	50.0	2.76
02	45.0	380/660	250.0	16.0	31.0	85.0	2.94
03	45.0	380/660	180.0	12.0	47.0	49.0	3.67
04	40.0	380/660	90.0	11.0	26.0	53.0	1.70
05	30.0	380/660	60.0	4.0	40.0	50.0	1.20

Table 4.3.b: Category # 3

Factory	Starting technique	# of starting (daily)	Average starting power (W.h)	Overall consumed power (W.h)	Js — Jove (100%)
Al haddad	On line delta	2	27287.80	16415.00	1.662
Al haddad	On line delta	2	79527.80	17547.10	4.53
Al qasrawee	Star / delta	2	37523.10	26913.00	1.40
Al qasrawee	Star / delta	20	20648.00	16031.90	1.29
Al junaidi	Star / delta	3	16530.00	2290.46	7.22

4.2.4:-Category # 4 (more than 200KW up to 1000KW)

Table 4.4.a: Category # 4

Serially	**Power rate (KW)**	**Terminal voltage (V)**	**Starting current (A)**	**Starting time (Sec)**	**Load current (A)**	**Nominal current (A)**	**Ist — In (100%)**
01	300	380	900.0	6.00	220.00	592.00	152.00
02	810	500	1500.00	11.00	200.00	1100.00	136.40

Table 4.4.b: Category # 4

Factory	**Starting technique**	**# of starting (daily)**	**Average starting power (KW.h)**	**Overall consumed power (KW.h)**	**Js — Jove (100%)**
Al haddad	Star / delta	2.0	359002.30	124527.5	2.88
Al haddad	Slip resistance	2.0	1296250.00	85000	15.25

4.3:- Problem Identification:-

The main aim of this section is to discuss the effect of a huge starting current on the machines; maximum rated current and the cost of consumed power for each factory and then, show graphically the behavior of current against time during starting transient interval.

We have several cases to study and analyze it (around six cases or factories). And each one of them has its own operation condition such as continuous operation of machines as in feeding factories, discreet operation of machines as in pumps. So the purpose of the load is the main factor to identify number of starting and stopping, time period of starting operation.

4.3.1:- Al-Haddad Investment Company:-

From experimental measured values then we fined out that this factory is started at first moment of operation with about (3000.00 Amp) and it will continue decayed until reached its constant full-load current of about (596.00 Amp) represents about 20% of starting current during the transient time period of (21.00 Sec).

Back to tabulated motors we can see that there are at least four motors have a critical role in maximizing the current because of its large starting current and power ratings and then by correction of those motors we can correct starting current to reduced value.

The four machines mentioned above are listed in the following table.

Table 4.5: Al-Haddad factory

Power ratings (kw)	Starting current (A)	Load current (A)	Starting technique
30.0	138.0	29.0	On line delta
45.0	250.0	31.0	On line delta
300.0	900.0	220.0	Star/delta
810.0	1500.0	200.0	Slip resistance

If we back again to numerical tabulated values of current at first moment of starting and at steady-state condition for all motors included within Al-Haddad factory we can detect characteristics of current and the relation between declaration of current and time through transient starting time interval.

This relation can be accomplished by linearization drop of current during transient time for each motor and then take the algebraic sum of machine's current at distinct moments of time along overall transient starting time.

So the following table and graphical chart both are representing the relation between decaying of current in respect to transient starting time.

Table 4.6: Transient Starting Time Interval

Time (Sec)	Current (Amp)
0.0	3000.00
4.0	2564.30
8.0	775.25
12.0	690.70
16.0	606.15
20.0	595.35

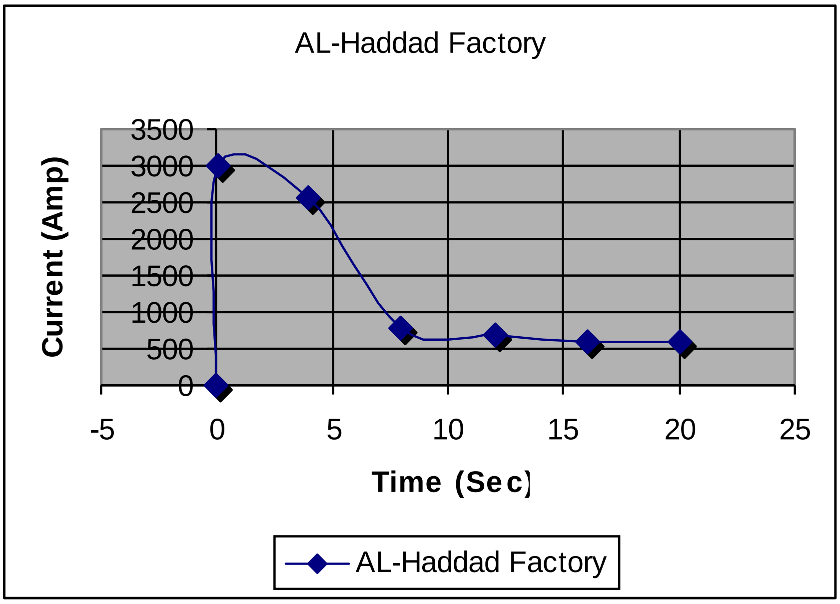


Fig 4.1

So by calculate the main value of this transient current over transient starting time and perform that for variation of terminal voltage we can detect the consumed power through that time interval which may reaches to about 760 KW

4.3.2- Al-Junaidi Factory:-

Because of the factory's specialist is in victuals manufacturing as the yoghurts then, almost motors characterized with continuous operation condition. So the most critical machines of the factory are those which used as a compressor, pumps or in ventilation purposes such that compressors or ventilation motors are started and stopped for a several times each day.

As above, the following table lists accounted motors with there measured and calculated characteristics.

Table 4.7: Al-Junaidi Factory

Power ratings (kw)	Starting current (A)	Load current (A)	Starting time (Sec)	Starting technique
9.0	86.0	28.0	8.0	Double star/star
11.0	28.0	6.6	2.5	Star/delta
15.0	23.0	11.0	4.0	Star/delta
30.0	60.0	40.0	5.0	Star/delta

As a result of measured values of starting current and the time required for each motor to reach its steady state case which tabulated in the motors rating schedules we can detect the relation ship between transient current and transient time period which also represented in following table and chart.

Table 4.8: Transient Starting Time Interval

Time (Sec)	Current (Amp)
0.0	337.0
2.0	220.08
4.0	147.60
6.0	133.10
8.0	118.60

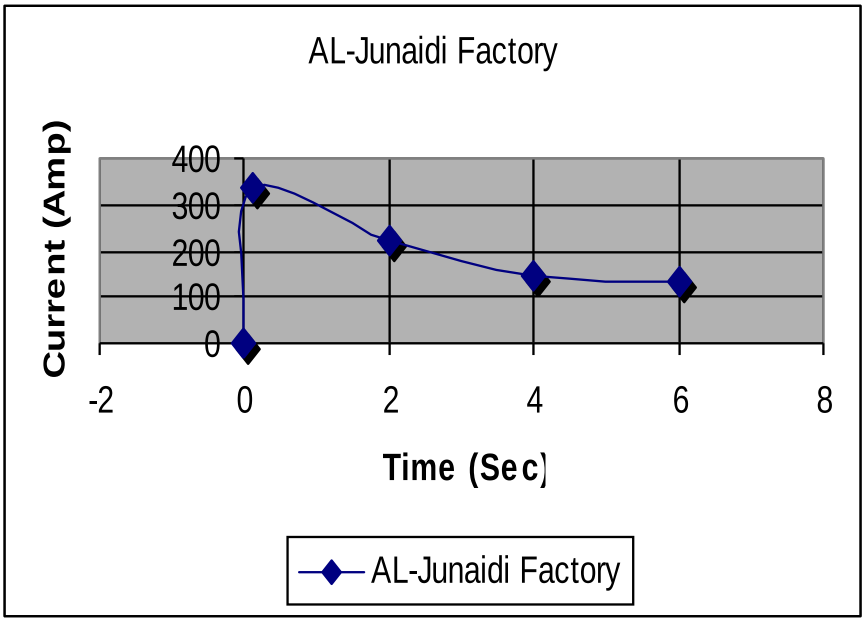


Fig 4.2 Al-Junaidi Factory

Finally after calculate the main average value of starting current we may detect that this factory may consumed about 112.42 KW during starting transient period,

4.3.3-Al-Qasrawee Factory:-

Because of similarity between this factory and previous one (Al-Junaidi) in productivity activities then, we suggest that both two factories have the same characteristics and behavior during the transient time interval as what we will see in the next.

Firstly we have to display the critical machines of that factory in the following table.

Table 4.9: Al-Qasrawee Factory

Power ratings (kw)	Starting current (A)	Load current (A)	Starting time (Sec)	Starting technique
15.0	90.0	11.0		Star/delta
22.0	95.0	26.0		Star/delta
40.0	90.0	26.0		Star/delta
45.0	180.0	47.0		Star/delta

Now as what did done for previous two manufacturer plant we will do here so overall decaying of transient current as function of transient time interval.

The following table and graphical chart will describe the relation between those transient parameters against each other.

Table 4.10: Transient Starting Time Interval

Time (Sec)	Current (Amp)
0.0	455.00
2.0	396.38
4.0	355.74
6.0	279.10
8.0	220.44
10.0	161.83
12.0	109.00

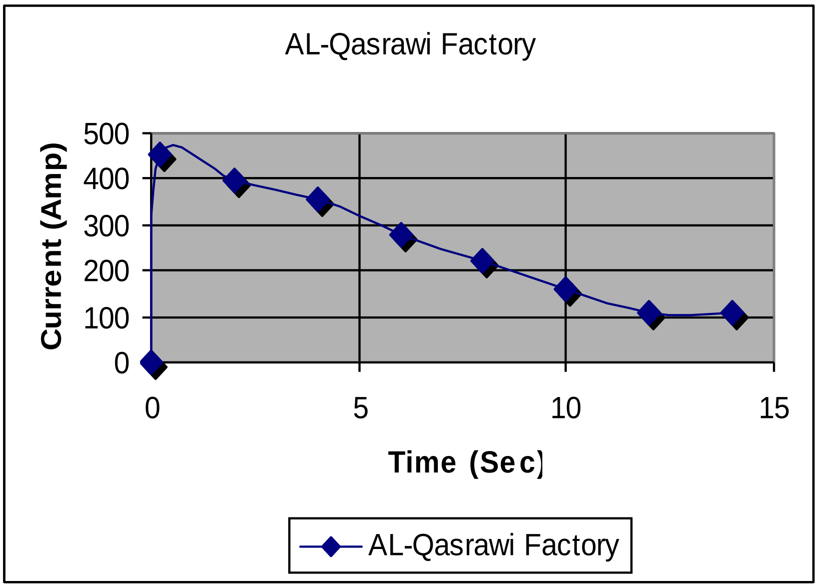


Fig 4.3: Al-Qasrawee Factory

By integrate current function along starting period of time to fined main average value of current we may detect consumed power during starting which may be reaches 100 KW.

Chapter five

Analytical Results

5.1- Introduction

Main aim of the topic of this chapter is to make diction if employed staring techniques for each motors category perform our demand of saving the electrical energy through starting time period and the efficiency of these techniques according to its cost price.

Best way to perform that is reanalyze previous tabulated values listed at beginning of last chapter but in new form. Such that when we have to examine the starting techniques for each ratings class we have to perform that examination on the average case of each class such that examinations process and included calculations become dealing with one case respect to all cases. And according to the results of that general case we detect if we most replace used technique by modified one or we decide that used techniques are adequate for our demand.

Based on the measured and studied readings tabulated previously which divided in to main four categories or classes. The following schedule will display basic parameters of them and then, we will take main average case of each class and then, examine it alone.

Table 5.1

Power rating range (KW)	Number of motors	Starting techniques	Number of starting times
(0-6.0)	17	On line star	2 - 4
(6.0-25.0)	09	Star/delta, on line delta, ÝÝ/Ý	2-20
(25.0-50.0)	05	Star/delta, on line delta	2-20
(200.0-1000.00)	02	Star/delta, rings resistors	2 - 4

5.2.1- Category # 1 (0-6.0) KW.

Firstly the parameters of an average theoretical motor of the class 1 are listed in the following table.

But before that a small explanation of starting method has to be represented here. This class of electrical motors is operated directly on line voltage with star connection of the interior windings so at starting moment the phase voltage is applied to motor's windings with out any reduction then, maximum induced torque remained at constant value. So there is no additional coast most paid over motor's coast, but in the other hand a huge inrush current is consumed.

Table 5.2: Category # 1

Power ratings (KW)	Terminal voltage (V)	Starting current (A)	Load current (A)	$\frac{Ist}{Il}$ (%)	t Starting time (Sec)	Number of starting
2.50	380	8.0	4.92	162.6	180	2

The following table shows the transient current's behavior during the transient time interval.

Table 5.3: On Line Star

Time (Sec)	Current (Amp)
0.0	8.0
0.9	6.46
1.8	4.92

So with known terminal voltage, motor's power factor and by integration the transient current over transient time interval we may detect an approximated value of consumed power at starting interval which may be reaches 2.0 KW.

After complete description of transient current variation and the starter technique characteristics. We will examine some other starting techniques with modified characteristics and then, compare new results with original ones according to the efficiency of them such that percentage value of extra saved energy to totally coast of starting technology.

Starting techniques based on reduction of terminal voltage at start moment and then growing up that voltage as motor's shaft and load speeds up until reach nominal terminal voltage. Then, this process can be accomplished using more than one device such as autotransformer, A.C voltage controller, soft-start device, line resistors or reactance and so on. Star/delta starter has been eliminated because windings of this class's motors are connected with star connection only then, to employ star/delta starter an additional transformer is needed to reduce phase voltage to nearly half its value.

Because of starting current her represents only 1.63 times full load current then, we have to be very carefully when we choose starting terminal voltage to be within a safe value such that low terminal voltage at starting may not beat over the load torque which may damages motors.

The following paragraph of this section will discuss an autotransformer, AC voltage controller and soft-start frequency converter.

In autotransformer starting technique we operate the motor with a part of its rated voltage according to secondary winding of a transformer and then when motor reaches 0.75 % of its rated speed full voltage is applied to motor's terminals. And because of reduction in terminal voltage a reduction in maximum torque is taken place and then, starting transient time will increased but with reduction in starting current and voltage.

The following table appears starting current and its variation according to transient time interval

Table 5.4: Autotransformer transient time interval

Time (Sec)	Current (Amp)
٠.٠	5.33
<3.30	٤.٦٠
>3.30	٦.٩٠
4.63	4.92

By integrating the transient current over the transient starting time interval we can detect that the consumed power at starting interval may reaches 1.20KW

The AC voltage controller characteristics are not similar to those of autotransformer because the out put voltage of AC voltage controller varied continuously with respect to time according triggering angle (α) until out put voltage reaches maximum value at (α) equal zero.

Also her we will discuss the transient current variation in respect to transient starting time interval numerically as shown in the next table.

Table 5.5: AC voltage controller

Time (Sec)	Current (Amp)
0.0	5.33
<3.00	5.09
3.00	5.70
4.25	5.20
4.25	6.90
5.00	4.90

The consumed power through starting time interval may reaches 1.17KW and this value is very close to that of autotransformer technique. So there is no need to examine one more modified starting technology because of a narrow change in consumed power at starting interval as what we will see next in examine soft-start technique using frequency converter.

Table 5.6: Soft-Start frequency converter

Time (Sec)	Current (Amp)
0.0	7.80
<1.12	3.66
>1.12	7.25
<1.74	3.98
>1.74	7.46
2..22	4.9

Then, consumed power at starting time interval may reaches 1.34 KW.

In the next graph chart the real description of and comparing between previous starting techniques are appeared to observe the differences between them, to maximization of a validity of these techniques characteristics and performing scientific comparing between them.

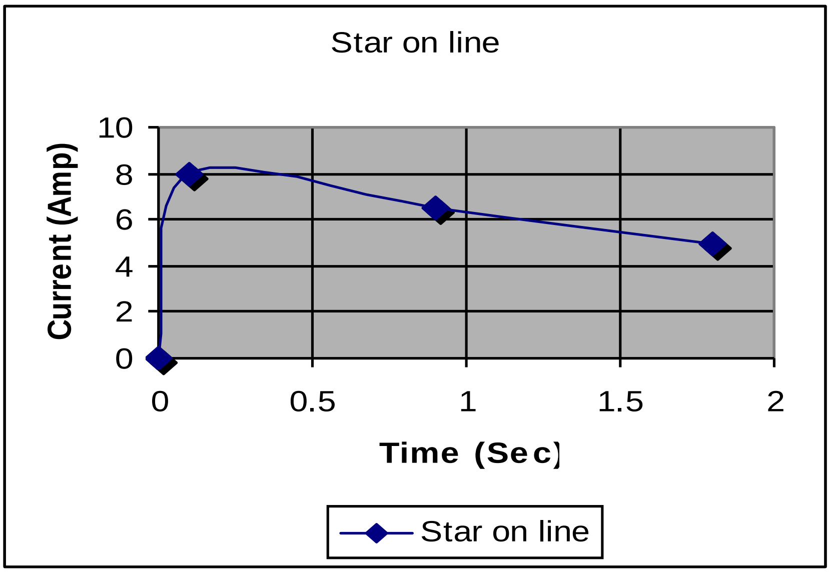


Fig. 5.1: On Line Star

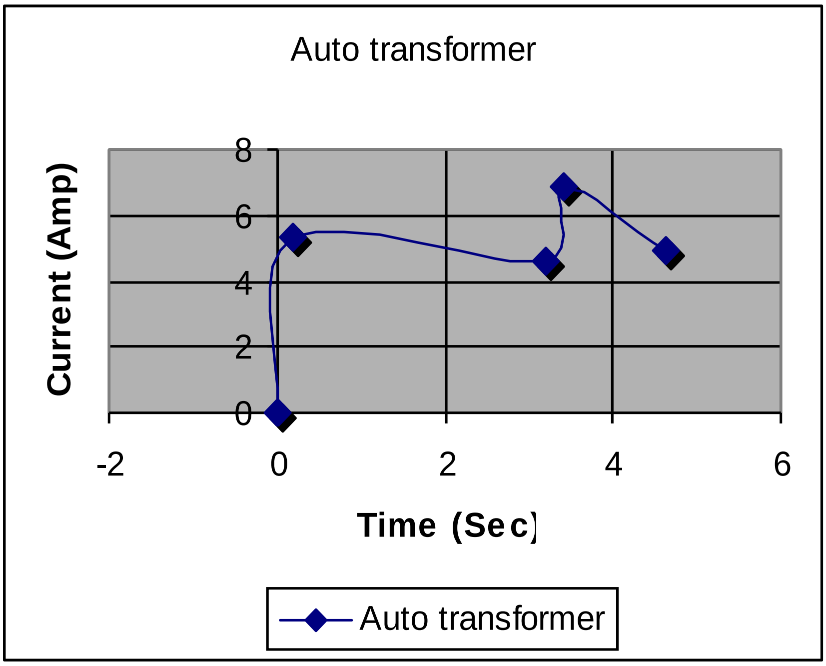


Fig. 5.2: Autotransformer

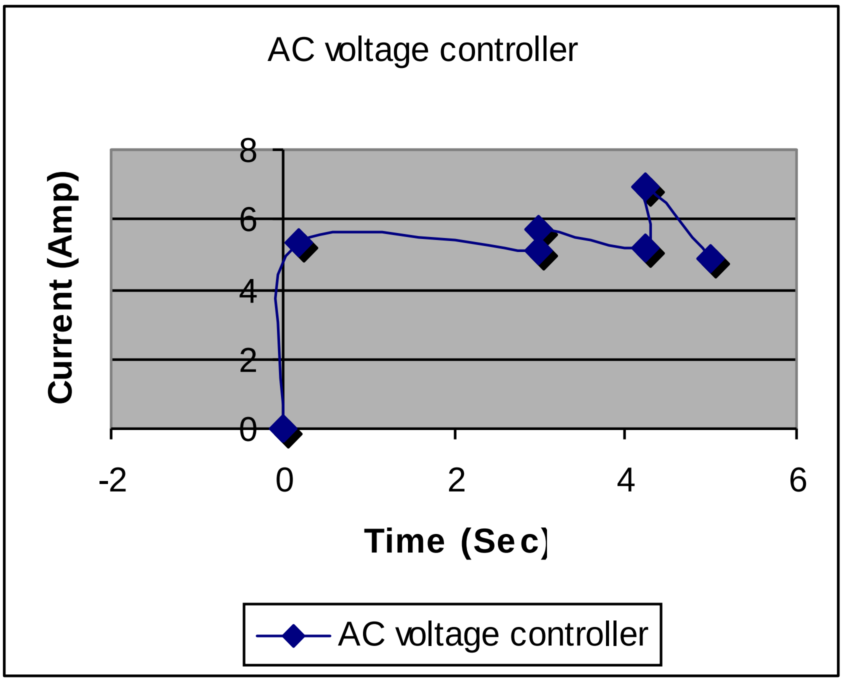


Fig. 5..3: AC voltage controller

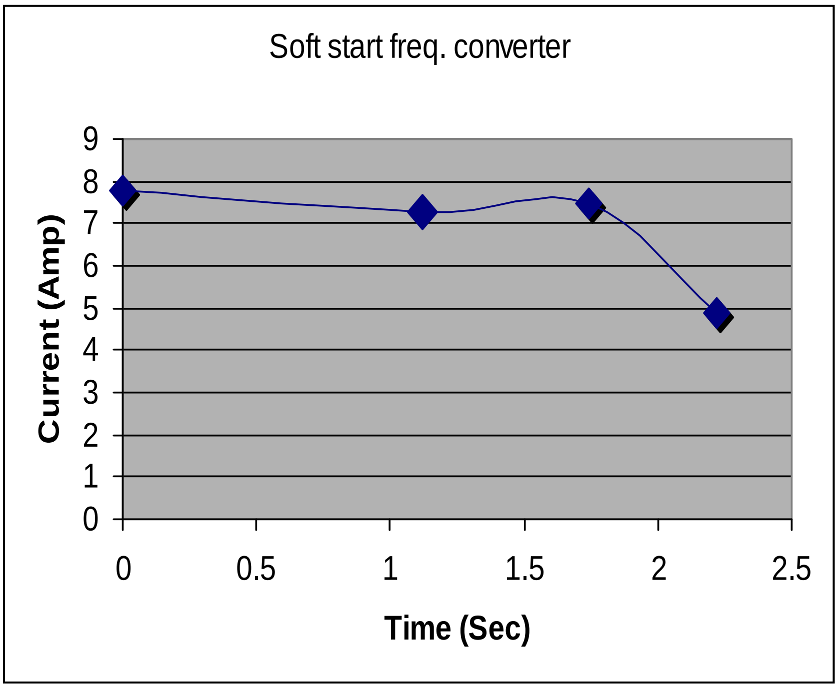


Fig 5.4: Soft-Start frequency converter

5.2.2- Category # 2 (7-25) KW.

The following table will display assumed characteristics for a theoretical average motor which we have to treat with it.

Table 5.7: Category # 2

Power ratings (KW)	Terminal voltage (V)	Starting current (A)	Load current (A)	$\frac{Ist}{Il}$ (%)	Starting time (Sec)	Number of starting
15.33	380/660	67.67	18.84	3.59	767	2-20

As shown at category # 2 table motors of this category operated with difference starting techniques depending on load demand. So we will examine each case lonely and analyze its parameters.

the next table the transient starting current is described by representing the relation of decaying current as a function of transient starting time interval

Table 5.8: On Line Delta

Time (Sec)	Current (Amp)
0	116.25
2	88.54
4	60.83
6	33.12
8	19.27

The detected power consumed may reaches 33 KW.

According to large load demand motor may not be able to be operated with reduced starting torque according of reduction in the starting voltage applied to motor's terminals then, stare / delta or AC voltage controller techniques are in acceptable her then, remained technology (soft-start frequency converter) may be acceptable in this case.

In the next table characteristics of starting transient current are lied out with respect to starting time interval when a frequency converter applied as a starting technology.

Table 5.9: Soft-Start frequency converter

Time (Sec)	Current (Amp)
0.0	106.00
1.30	109.00
2.67	111.00
4	19.27

Consumed power during starting time period may reaches 28 KW. And the following graphical chart may contribute in understanding the variation between these two techniques.

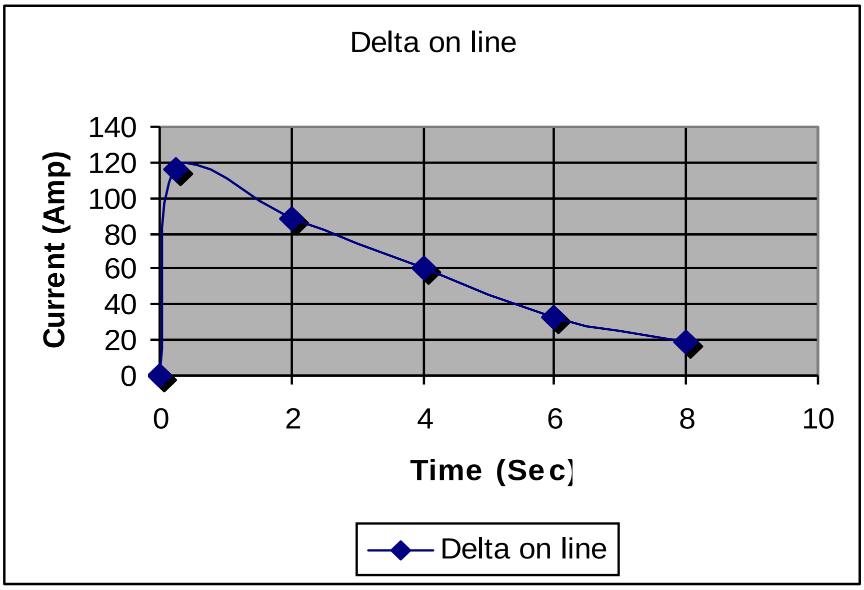


Fig 5.5: On Line Delta

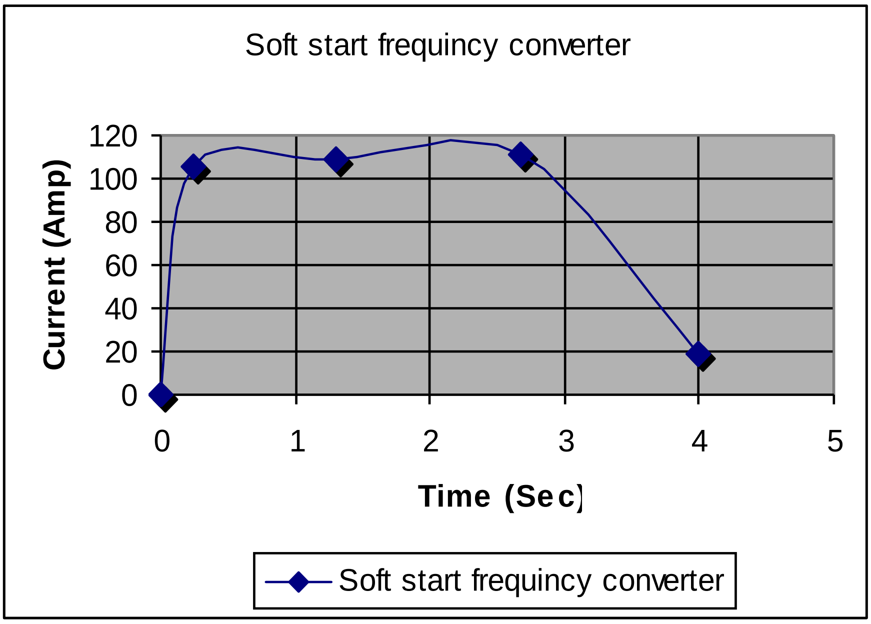


Fig 5.6: Soft-Start frequency converter

After what mentioned above let us study the case of started using star / delta starting technique. This method of starting depends on reduction terminal voltage to (1/ √3) of rated voltage at starting and along period of time until motor's shaft speeds up approximately to 0.75 of its nominal speed and then, voltage switched to the nominal rated voltage.

Such that techniques are employed when the coupled load demand is not very large at starting because of induced torque depends on square of terminal voltage directly. So this technique and similar ones are described in detail in the next tables and graphical charts.

Soft start frequency converter also may used and the characteristics of a transient current in respect to transient starting time interval are shown at table and graph of last paragraph.

Star/ delta starting behavior are listed in following table in form of decaying of transient current as function of starting time interval as done in overall previous cases described.

Table5.10: Star/delta

Time (Sec)	Current (Amp)
0	67.30
4	60.42
8	53.54
12	46.67
16	39.78
20	32.9
20	56.9
21	19.27

Consumed power at starting interval may reaches to 19.81 KW.

In the following we will treat with AC voltage controller starting technique by represent it as a function between decayed transient current and growth transient starting time as shown

Table5.11: AC voltage controller

Time (Sec)	Current (Amp)
0	27.9
17.92	49.85
19.18	61.23
21	19.28

Power consumed at starting time period using this technique may reaches 8.11 KW

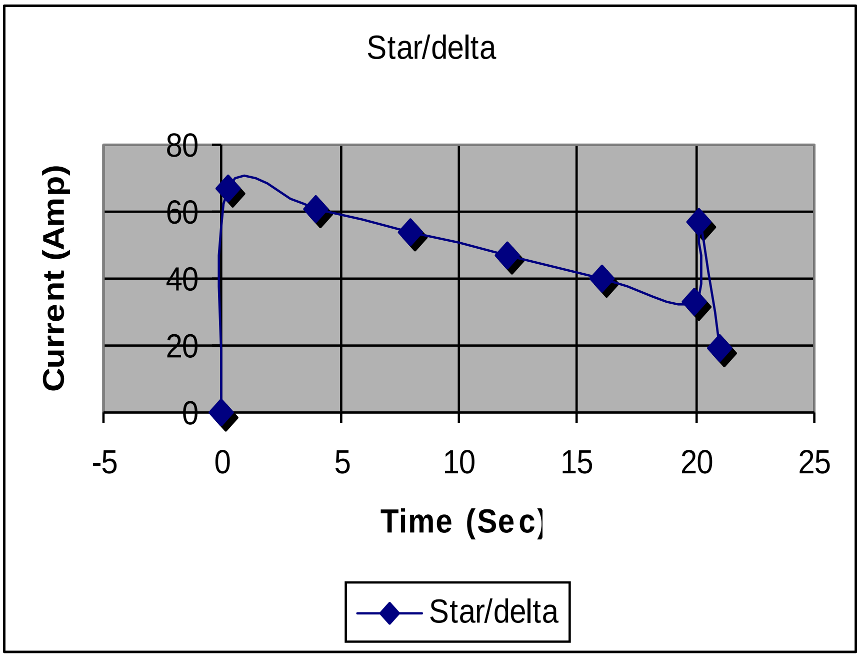


Fig 5.7: Star/delta

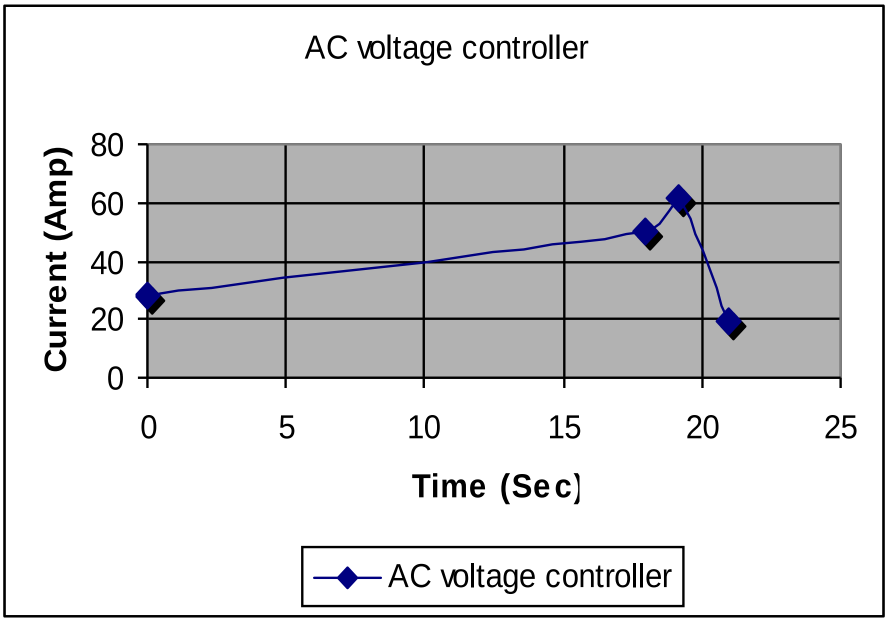


Fig 5.8: AC voltage controller

The following tables and graphs may an adequate and briefly description of starting motors without any starter (directly on line) but with star connection of interior windings.

Table 5.12: On Line Star

Time (Sec)	Current (Amp)
0	67.11
2	55.89
4	44.67
6	33.44
8	22.22
10	11.0

Consumed power during period of starting time may reach 8.6 KW

In the next table the description is performed on AC voltage controller in place of starting directly on line with star connection

Table 5.13: AC voltage controller

Time (Sec)	Current (Amp)
0	38.75
18	51.87
20	28.42
22	11.0

Consumed power may reach 8.4 KW

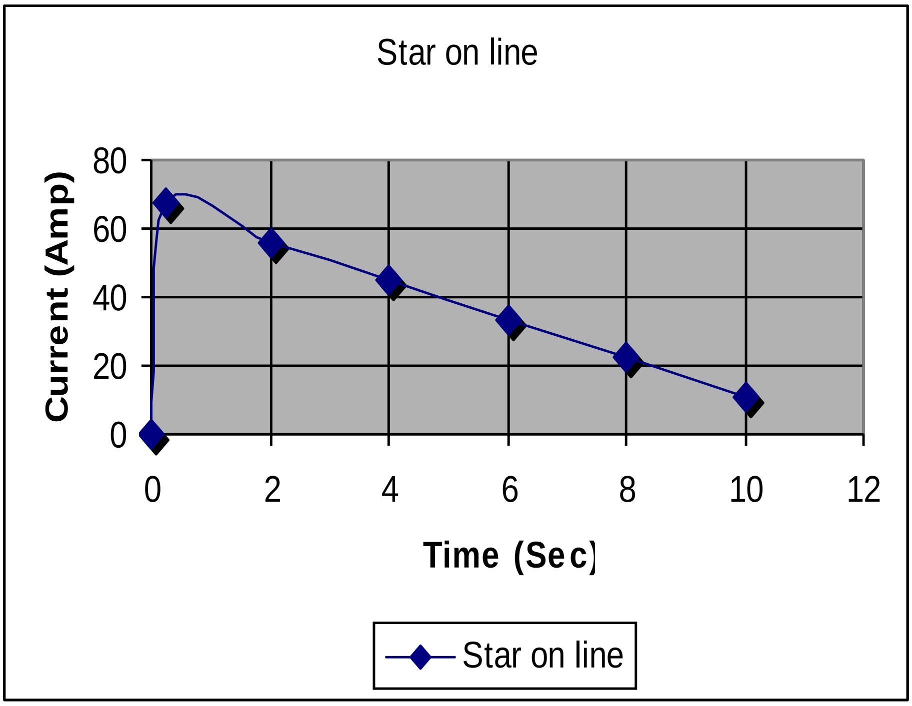


Fig 5.9: On Line Star

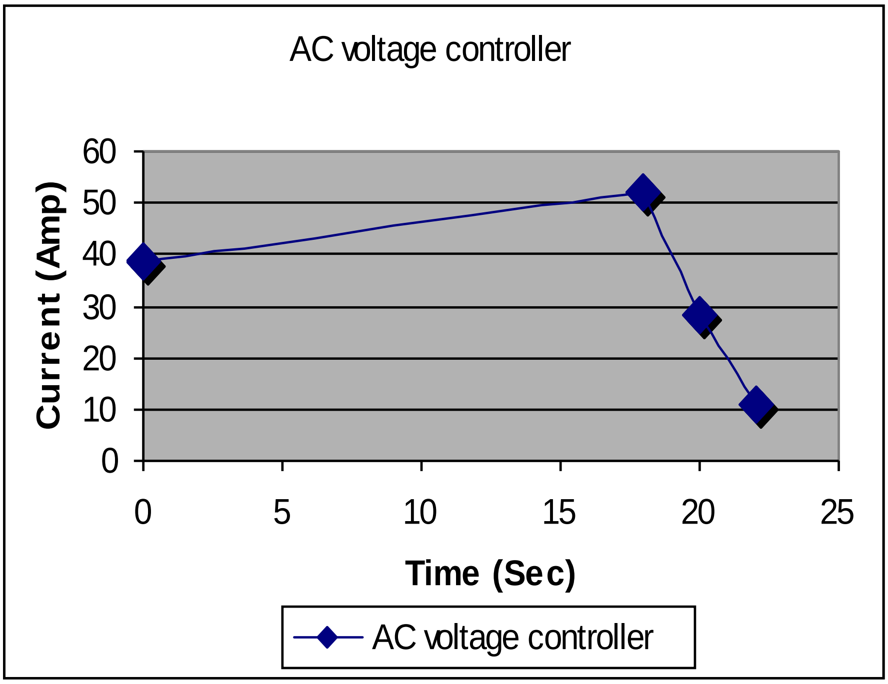


Fig 5.10: AC voltage controller

5.2.3- Category # 3 (25-50) KW

In this class also the variation in starting techniques occurs again such that there are some loads required large starting torque and then motors of these description can not started with reduced voltage across its terminals. So this type of motors either operated directly on voltage line to get maximum torque ore applying soft-start frequency converter start with reduced terminal voltage and in same time large started torque is kept.

In the other hand there are other types of loads may handled at reduced voltage so motors handled loads like that can started using star / delta connection ,AC voltage controller ore soft-start frequency converter.

In the following topic we will discuss first case of this category by consider a general theoretical motor parameter as shown at next table

Table 5.14: Category # 3

Power ratings (KW)	Terminal voltage (V)	Starting current (A)	Load current (A)	$\frac{Ist}{Il}$ (%)	Starting time (Sec)	Number of starting
37.5	380	194	30.0	647	18.0	2

The following tables will describe current variation characteristics as growth of starting time until motor reaches its steady state condition and then, absorbed current become constant.

Directly on line and soft-start frequency converter techniques are described respectively her.

Table 5.15: On Line Delta

Time (Sec)	Current (Amp)
0	194.0
2	175.8
4	157.60
6	139.30
8	121.10
10	102.90
12	84.67
14	66.44
16	48.22
18	30

Consumed power may reach 61.23 KW.

Behavior of transient current in respect to transient time interval if on line delta connection starting technique is improved to soft-start frequency converter technology is describe in the following graphical chart and table.

Table 5.16: Soft-Start frequency converter

Time (Sec)	Current (Amp)
0	92.50
5.2	95.0
10	106.4
16	101.05
21.2	106.38
27.1	140.83
30	30.74

Consumed power may reach 20.0 KW

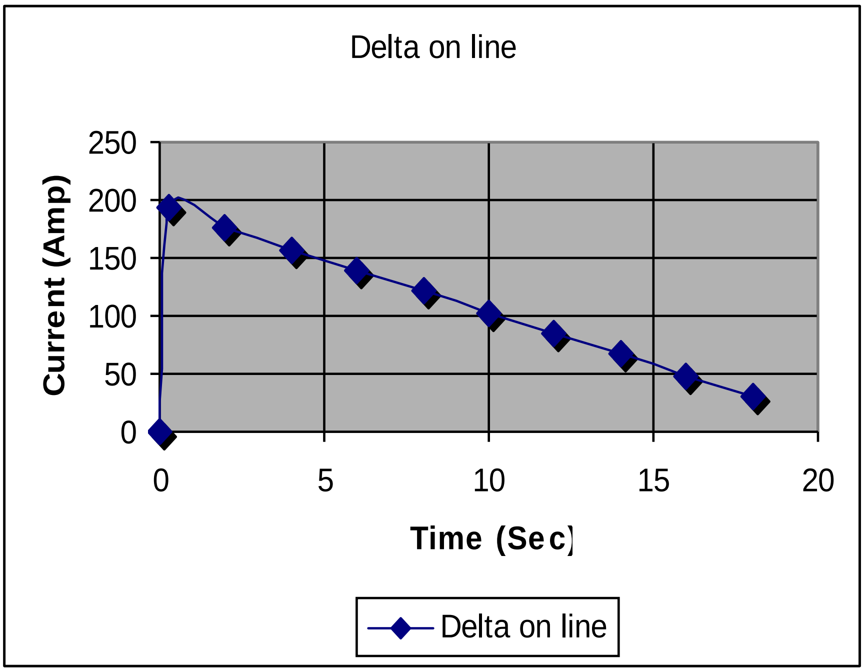


Fig 5.11: On Line Delta

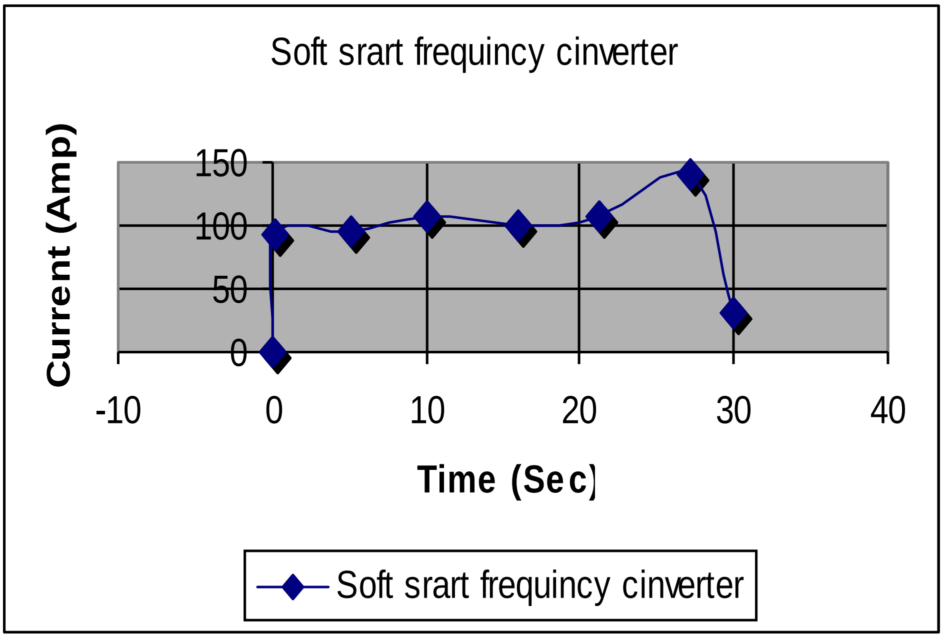


Fig 5.12: Soft-Start frequency converter

Now let us consider the case of starting with star/delta connection technique. The theoretical motor's parameters are shown in the next table.

Table 5.17: Category # 3

Power ratings (KW)	Terminal voltage (V)	Starting current (A)	Load current (A)	$\frac{Ist}{Il}$ (%)	Starting time (Sec)	Number of starting
38.30	380	110	37.67	292	9.0	2-20

Again in the following table we show the characteristics of transient current according transient starting time interval.

Table 5.18: Star/delta

Time (Sec)	Current (Amp)
0	110
2	93.93
4	77.85
6	61.78
7	70.5
9	37.67

Consumed power may reach 29.3 KW

Now we will examine soft start frequency converter, so the following table and graph will display its characteristics as implementation of the relation between decaying in starting current in respect of increasing in transient starting time interval

Table 5.19: Soft-Start frequency converter

Time (Sec)	Current (Amp)
0	70
5	75
12	82
17	106
21	37.67

Consumed power may reach 15.6 KW.

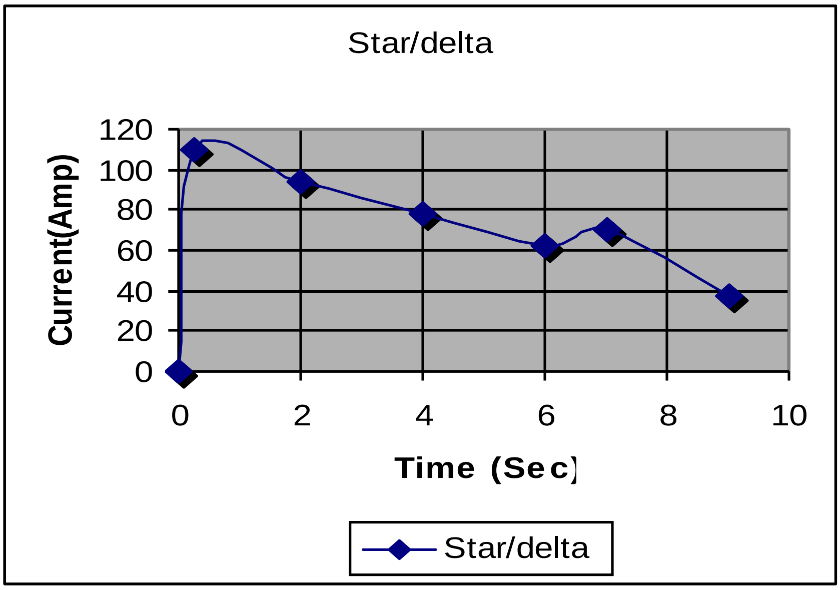


Fig 5.13: Star/delta

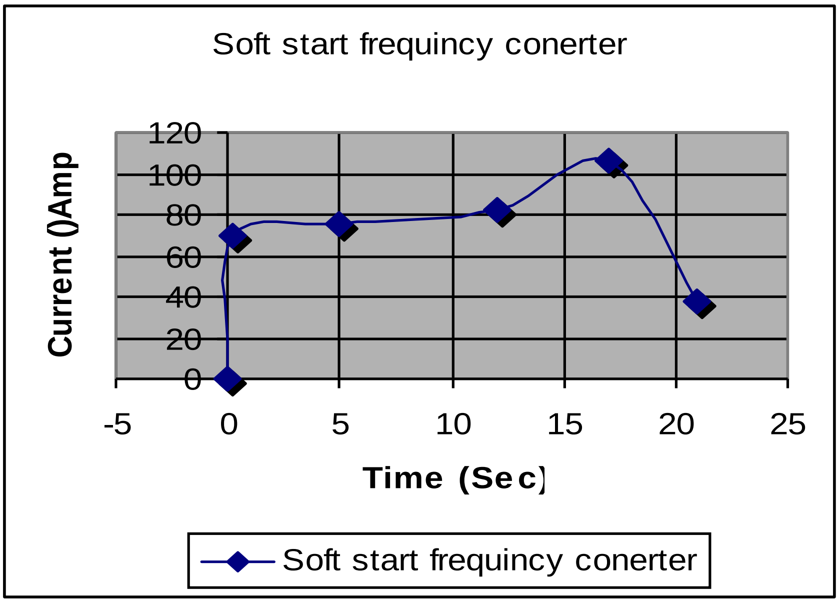


Fig 5.14: Soft-Start frequency converter

5.2.4- Category # 4 (200-1000) KW.

Motors of this class are largest motors can be fined in our industrial environment. So because of its huge ratings then, starting and braking of these motors represent big problem as the effects of a large inrush current at first moment of starting operating process.

As we have just two motors in this class we will take larger one to consider it's starting current behavior according to deference techniques or methods of starting and then, treats with the results as a general case of this class motors.

In the following table the basic characteristics of studied motor.

Table 5.20: Category # 4

Power ratings (KW)	Terminal voltage (V)	Starting current (A)	Load current (A)	$\frac{Ist}{Il}$ (%)	Starting time (Sec)	Number of starting
810	500	1500	200	750	11	1-2

Next table considers natural starting technique employed which is variation of rotor resistance during starting interval.

Table 5.21: Rotor resistance

Time (Sec)	Current (Amp)
0	1500
<4	1000
>4	1600
<7	800
>7	1000
11	200

Consumed power may reach 780 KW.

Finally is performed in the next table and graphical chart which describe current behavior of transient current according starting time interval.

Table 5.22: Soft-Start frequency converter

Time (Sec)	Current (Amp)
0	996
2.08	1049.62
4.30	915.38
6.48	1130.19
8.25	1156.53

10.36	1339.60
14.0	200

Consumed power at starting period of time may reach 480 KW.

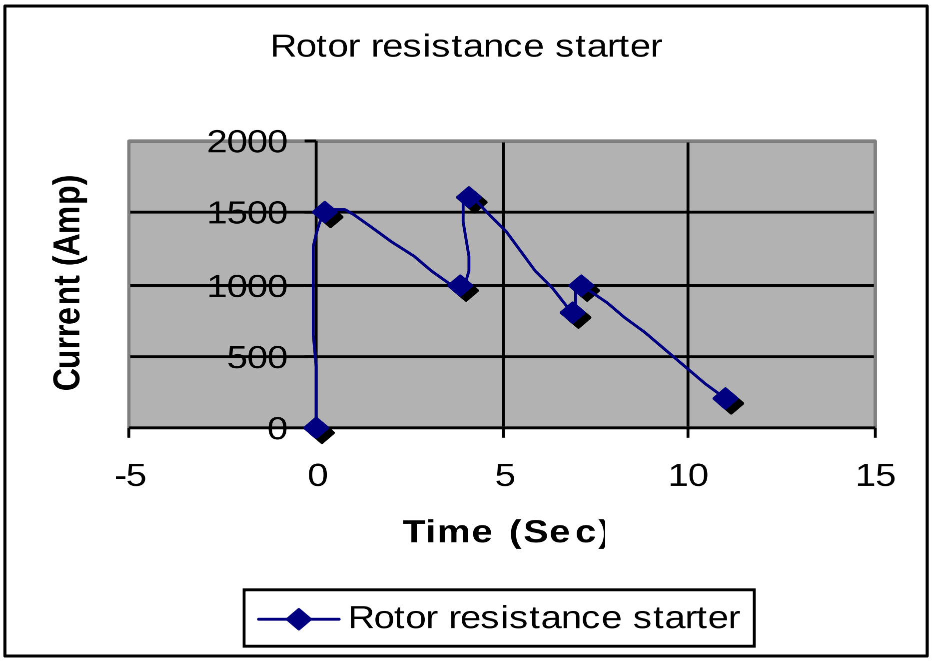


Fig 5.15: Rotor resistance

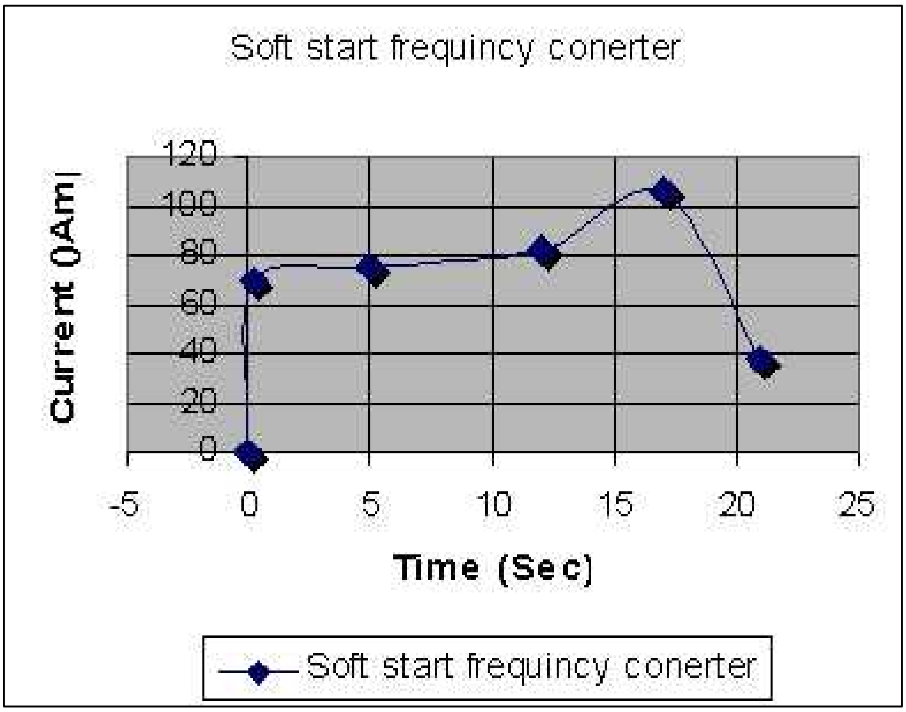


Fig 5.16: Soft-Start frequency converter

Chapter Six

Recommendation and Conclusion

6.1- Introduction.

Basic objective of this chapter is to summarize the results approached in previous chapters and then, main recommendation and conclusions of this research are accomplished.

The recommendation we are looking for is related to performance and efficiency of employed technique (efficiency means that amount of conserved energy to fixed cost of the technology employed).

So according of those both parameters we decide if employed starting technique is faced the conservation purposes are it can not and we have to looking for other graded techniques.

Recommendation of overall this topic is based on to facts one of them is performed in last chapter when we detected transient current behavior as function of variation the transient time interval for employed starting technique and to other suggested modified techniques.

Second item have to completed is determining a fixed cost of each techniques and the depreciation of its cost over certain number of years in order to estimate the efficiency of each techniques.

The procedures required to accomplish this purpose are as listed in the following notes.

- Conceder fixed cost of the technology and its life age to detect its depreciation over that period.
- Conceder consumed power for both employed technology and the suggested one.
- Estimate the efficiency of each starting techniques during life age period.
- Make a decision about technology selection according to results of previous notes.

6.2- Experimental Results

To improve noted statement mentioned above we have to tabulate a fixed cost for each technology including required cables and suggest the live age parameter which estimated to be around fifteen years.

Firstly in the following table the fixed cost and depreciation of each device are listed also current contribution from electric company or the municipality including cables and main breaker switch per phase are listed.

Table 6.1: Fixed cost and Depreciation of each Device

Deice technology	**Ratings (Amp, KW)**	**Fixed cost ($)**	**Yearly cost ($)**
Frequency Converter	5 KW	1000	66.67
Frequency Converter	16 KW	3000	200
Frequency Converter	40 KW	15000	1000
Frequency Converter	810 KW	31000	2061
Contactor	8 A	10	1.5
Contactor	67 A	30.0	2.0
Contactor	110 A	111	7.5
Contactor	190 A	740	50
Seconds Timer	—	15	1
Resistance	—	60	4
AC Voltage Controller	5 KW	500	33.33
AC Voltage Controller	16 KW	1200	80
AC Voltage Controller	40 KW	9000	600
AC Voltage Controller	810 KW	25000	1666.67
Current Contribution	—	60	4

Now each rating class is considered separately and then it will have its own conclusions and observations

6.2.1- category # 1

Table 6.2: Cost Category # 1

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
On Line Star Connection	2	0.000013	32.0
Auto Transformer	80	0.00002	21.32
AC Voltage Controller	27	0.000022	21.32
Frequency Converter	70	0.000011	31.2

The next graphical chart implementation of variation performance between these starting techniques is represented clearly.

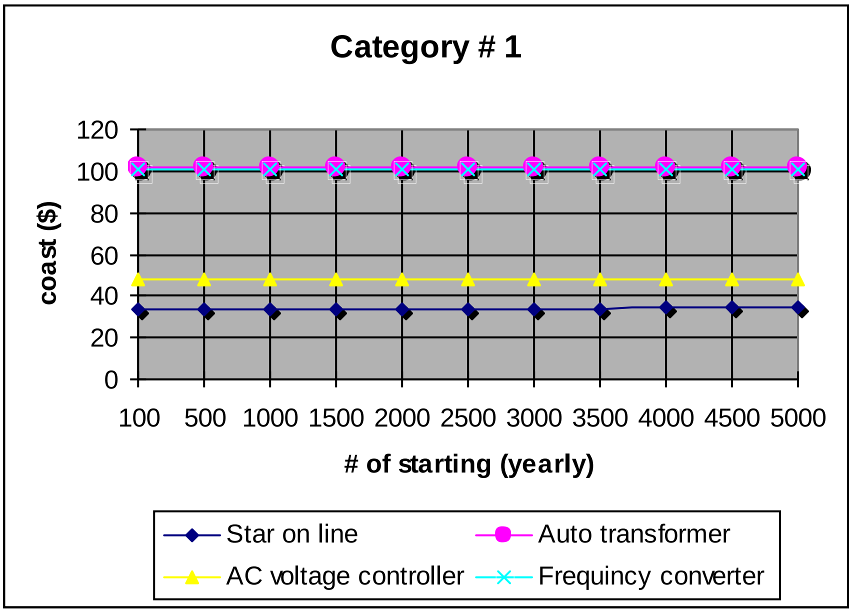


Fig 6.1: Cost ($) vs. # of Starting yearly

6.2.2- Category # 2

Firstly we will examine starting directly on line with delta connection

Table 6.3.a: Cost Category # 2

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
On Line Delta Connection	2	0.0009	464
Frequency Converter	200	0.0004	424

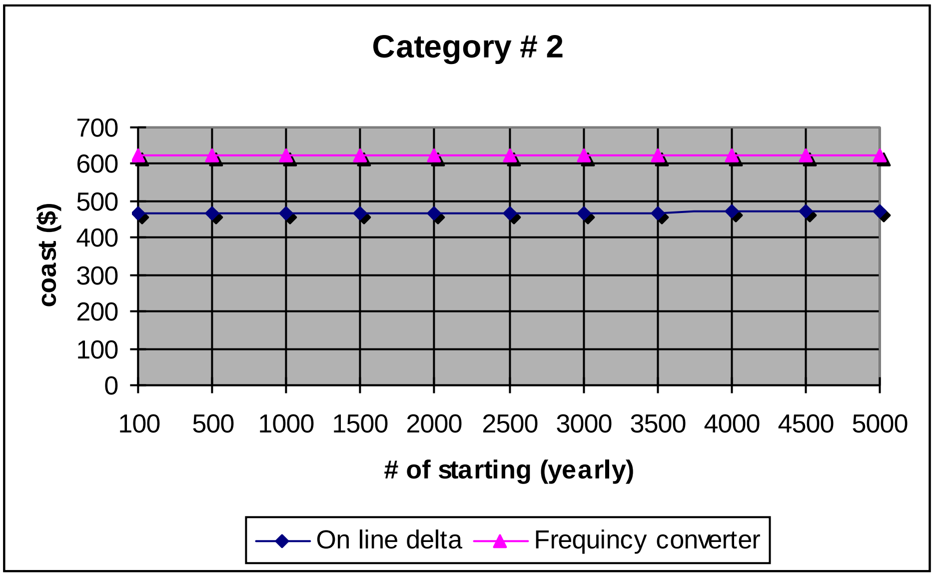


Fig 6.2.a: Cost ($) vs. # of Starting yearly

-Starting method using star/delta technique

Table 6.3.b: Cost Category # 2

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
Star / Delta	12	0.0015	268
Soft start	205	0.0006	244

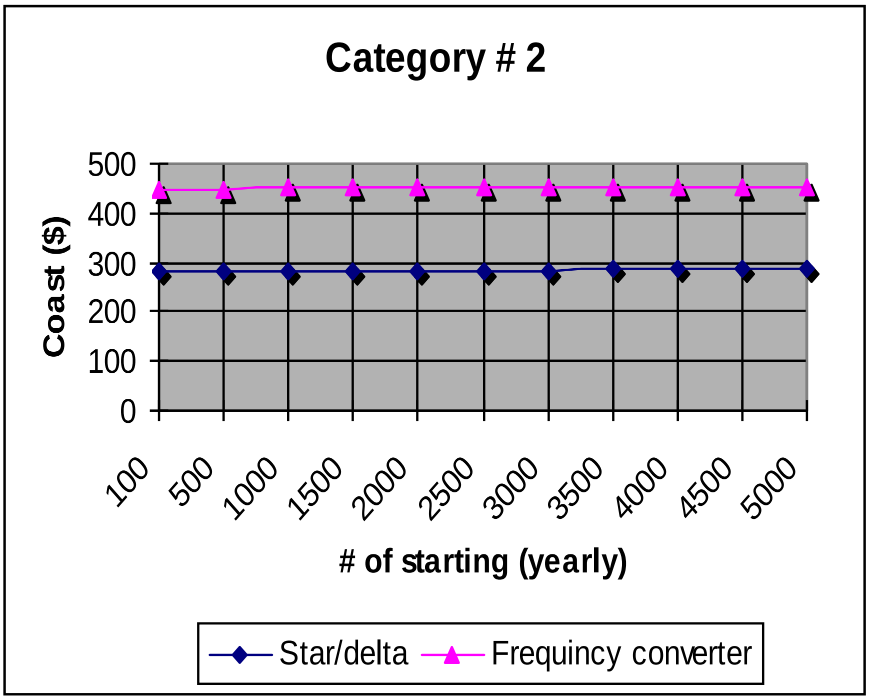


Fig 6.2.b: Cost ($) vs. # of Starting yearly

Table 6.3.c: Cost Category # 2

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
On line	2	0.0013	268
AC voltage controller	85	0.0007	204

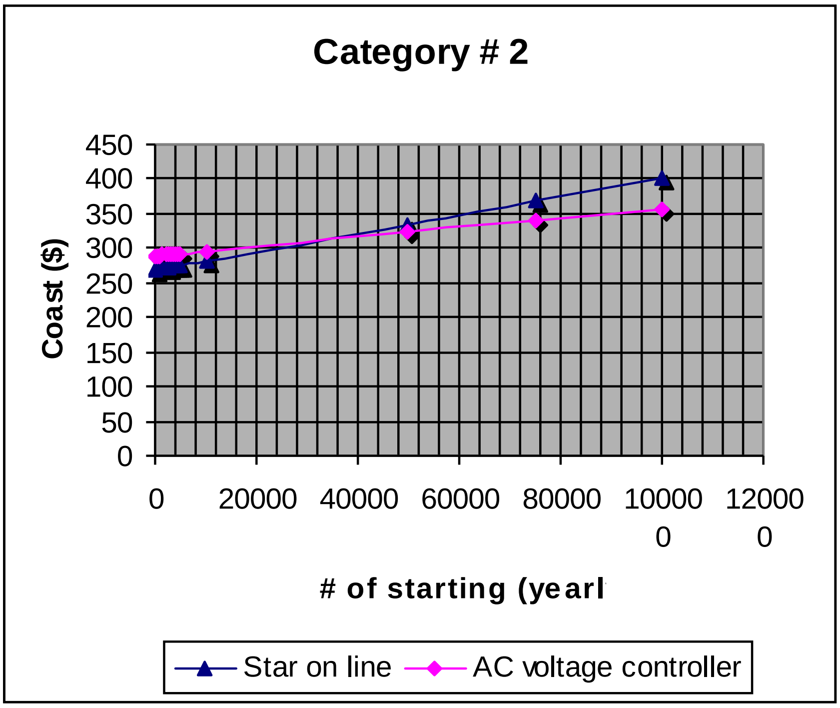


Fig 6.2.c: Cost ($) vs. # of Starting yearly

6.2.3 Category # 3

Motor starting directly on line with delta connection

Table 6.4.a: Cost Category # 3

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
On Line Delta Connection	4	0.0041	776
Frequency Converter	1000	0.002	370

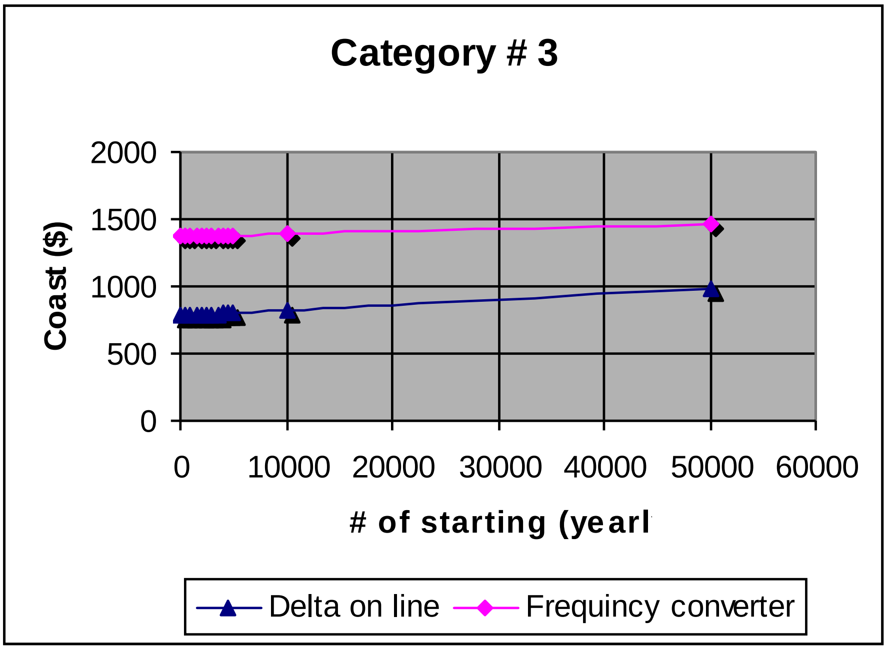


Fig 6.5.a: Cost ($) vs. # of Starting yearly

Motors started by star/delta technique

Table 6.4.b: Cost Category # 3

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
Star / Delta	120	0.01	440
Soft start	605	0.001	424

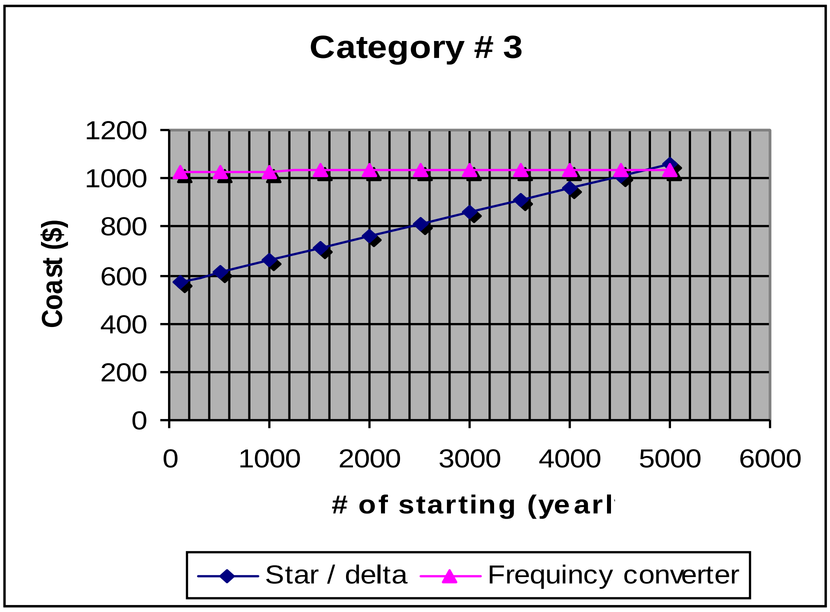


Fig 6.5.b: Cost ($) vs. # of Starting yearly

6.2.4- Category # 4

Table 6.5: Cost Category # 4

Starting Techniques	Cost of Tech ($)	Consumed Power Cost ($/ one time)	Cost of Current ($)
Armature resistance	555	0.032	6400
Soft start	2060	0.023	4900

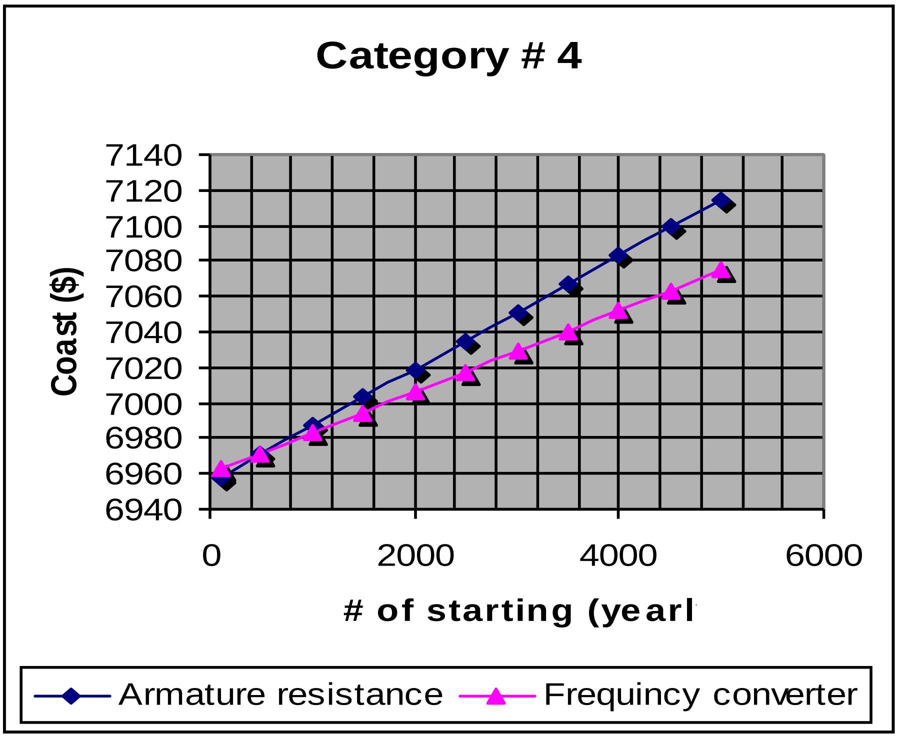


Fig 6.6: Cost ($) vs. # of Starting yearly

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