USE OF HIGH EFFICIENT MOTORS FOR DSM IN SOUTH AFRICA'S PETROLEUM REFINERIES

Peter Ng'ang'a Mithamo

Cape Peninsula
University of Technology

USE OF HIGH EFFICIENT MOTORS FOR DSM IN SOUTH AFRICA'S PETROLEUM REFINERIES

By

Peter Ng'ang'a Mithamo
205278566

Thesis submitted in fulfilment of the requirements for the degree

Master of Technology Electrical Engineering

In the Faculty of Electrical Engineering

At the Cape Peninsula University of Technology

Supervisor: Prof. M.T.E. Kahn

Bellville Campus

8th April 2012

DECLARATION

I Peter Ng'ang'a Mithamo declare that the contents of this thesis represent my own unaided work, and that the thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed: **Date:** 8th April 2012

ABSTRACT

Electric motors consume over 60% of the world's generated electricity. In South Africa approximately 65% of the energy generated is consumed by electric motors (Niekerk, 2009). About 95% of motors in use in South Africa are Standard-Efficient Motors (SE-motors) that operate at an average efficiency of 84% to 90%, depending on the size of the motor and the load driven by them. High-Efficient motors (HE-motor) run at an efficiency of 2% to 8% higher than that of SE-motors. In recent years, a drive to replace SE-motors with HE-motors has been promoted for the purpose of Demand Side Management (DSM).

The rationale of using HE-motors as a tool of DSM is to harness a small difference in operating efficiency per motor, which can result in a huge reduction in electricity consumption, depending on the number of HE-motors that will replace SE-motors. Reducing the demand for electricity is the key driving factor for DSM in South Africa, so as to relieve the already stressed power generation capacity. Other consequential factors of DSM are to reduce the amount of pollutant gases emitted into the atmosphere. To the electricity users DSM will be a great incentive, as reduced consumption of electricity will decrease the amount of money spent on electricity.

Much has been written on the ability of HE-motors to reduce electricity consumption, cost of electricity and global pollution. ESKOM has even demonstrated the faith they have in these motors by giving rebates to motor users who are willing to exchange their existing SE-motors with new HE-motors. The rebates are paid by ESKOM through a newly established DSM program. However, it must be mentioned that savings through HE-motors is not a perfect guarantee. HE-motors have inherent design limitations that may inhibit the saving of energy.

To achieve higher efficiency, HE-motors are designed to operate on a smaller slip that consequently increases their speed compared to that of SE-motors (Cheek et al., 1995). Higher rotor speed impacts energy saving abilities of HE-motors when they are used to drive fans, pumps and compressors, normally referred to as centrifugal loads. An increase in speed results in a proportional increase in flow. Power consumed by a motor goes up as a cube of the speed, and the flow rate increases linearly with speed. Motor loads in the petrochemical industry are generally centrifugal, and that is why this thesis focuses on refineries.

Many motor efficiency tests have been performed in laboratories and in motor-manufacturing plants, and the efficiency test results have been used to market the HE-motors on high-gloss motor pamphlets. Motor users have been promised that they will reduce electricity consumption and save electricity bills if they use HE-motors instead of SE-motors. No after-installation tests are ever performed to confirm whether or not the promised savings have been realised.

In this thesis, field motor tests were performed to confirm whether or not using the more expensive HE-motor, instead of a SE-motor in a particular application will reduce the electricity bill. These types of tests are rarely carried out, as many motor users do not have the expertise, time or the money to perform such academic tests. Therefore motor users receive the shorter end of the stick when it comes to deciding whether or not to invest in HE-motors. For lack of better knowledge they end up believing what the motor salesperson tells them. For this reason, tests analysed in this thesis are crucial to existing and future HE-motor users and even more important to those who are advocating use of HE-motors.

ACKNOWLEDGEMENTS

I wish to thank:

- God Almighty who through Jesus Christ gave me life, health and the opportunity to complete this thesis.
- My family, Lillian and young Maina, for their moral support and encouragement throughout the research.
- Prof M.T.E. Khan, for his valuable supervision and mentorship.
- Chevron South Africa (PTY) LTD for giving me the opportunity to purchase and test motors on their premises.
- Staff of Chevron South Africa:
  - Peter Kulentic (E&I department), for motivating the need for this research.
  - Julian Braun (Reliability & maintenance), for approving the motor test proposal.
  - Ian McArthur, (Principal Electrical Engineer), for his priceless technical mentorship.
  - Inus Basson and Daniel Maksa, (senior electrical engineers) for assisting in locating archived motor data and other relevant information.
  - Nigel Willie, (electrical maintenance supervisors) for availing an electrician to assist in motor testing.
  - David Ngantweni, (R&M electrician) for assisting in isolating and connecting test equipment.
  - Richard Sterrenberg, (construction supervisor), for organizing hot-work permits during the motor test.
- William Willemse, Senior Electrical Engineer in Sasolburg for freely sharing usage of HE-motors in Sasol.
- ZEST (South Africa) for allowing me to use their motor data sheets in this report.

DEDICATION

To my dear wife Lillian Mithamo and my three year-old son Maina Mithamo, for their encouragement and inspiration.

TABLE OF CONTENTS

LIST OF FIGURES

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

LIST OF TABLES

Chapter 1

Chapter 2

Chapter 3

Chapter 5

Formula list

TERMS AND CONCEPTS

ABB	Asea Brown Boveri LTD
CEE	Consortium of energy efficiency
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the parties
CPUT	Cape Peninsula University of Technology
DSM	Demand Side Management
EFF1	Energy efficiency 1
EFF2	Energy efficiency 2
EFF3	Energy efficiency 3
ESKOM	South African Electricity Supply Authority
FLC	Full Load Current
GHGes	Green House Gasses
HE-motor	High efficient Motor
HFCs	Hydro fluorocarbons
HP	Horse Power
IIEC	International Institute of Energy Conservation
kW/KWH	Kilowatts/Kilowatthour
Load-factor	Ratio of actual load to possible load
LRC	Locked Rotor Current
MCC	Motor Control Centre
Mega-flex	An electricity billing system used by ESKOM on industries
MTTF	Mean Time To Failure
N_2O	Nitrous Oxide (Laughing gas)
NEMA	National Electrical Manufacturers Association
NERSA	National Electricity Regulation of South Africa
PFCs	Perfluoro compounds
Refineries	Petroleum refineries
SE-motors	Standard Efficiency Motors
SF_6	Sulphur Hexafluoride
SOPAC	South Pacific Applied Geosciences Commission
UNFCCC	United Nations Framework Convention on Climate Change
VSD	Variable Speed Drives

CHAPTER ONE: INTRODUCTION

1.0. Chapter overview

This chapter gives a complete overview of the work that will be covered in this research. The thesis introduction is stated at the beginning followed by the research problem and the proposed objectives. Details of the methodology and the cost of the project are also included in this chapter.

1.1. Background

The concept of Demand Side Management (DSM) was developed to address issues related to global warming, through recognition that energy efficiency represents the most cost effective option of reducing the demand for energy, which in effect reduces pollution. By definition, DSM is a method geared to influence customers on how to use electricity (Cheek et al., 1995). DSM might be a new concept in South Africa, but very familiar in developed nations in Europe and America.

In 2005 ESKOM initiated an extensive DSM program to manage and to reduce utility loads. The South African government through the National Energy Regulator of South Africa (NERSA) and ESKOM are urging Industries and commercial sectors to apply energy saving methods, for the purpose of reducing consumption of electricity (Willemse, 2008). This is because the amount of electricity generated does not meet the demand.

Emission of Green House Gases (GHGes) is another important reason for South Africa to apply DSM. If left unchecked, global warming has a potential to threaten all life here on Earth. In December 1997 during a world summit held in Kyoto Japan, 183 member states adopted a treaty called the Kyoto protocol, which imposed targets on industrialized nations to reduce emission of GHGes (Dagoumas, 2004). South Africa is not bound by the same emission control requirements that bind developed countries. However, she has voluntarily taken initiatives to control emissions since we lead the rest of the African continent in the emission of GHGes.

Electric motors consume a major portion of the world's generated power in both industrial and service sectors (Nadel et al., 2006). The Majority of motors are Induction motors, which are regarded to be the workhorses of the modern industry due to their efficiency, rugged construction, reliability, cost effectiveness and high starting torque (Akbaba, 1999). According to Almeida et al., (2008), worldwide motors use 70% of generated energy. In South Africa 65% of the total generated electric power is consumed by motors, almost all of which are SE-motors with efficiencies between 2% and 8% less than those of HE-motors (Mtombeni, 2007) According to various publications, the energy lost by SE-motors can be salvaged if HE-motors are extensively used. Various stakeholders are in agreement that well designed HE-motors and motor systems are potential masterpieces in salvaging valuable electrical power, reducing pollution and lessening electricity bills (Author Mithamo, 2010).

Increasing motor efficiency is a trade-off between efficiency levels and a realistic motor price. Viability of using HE-motors is determined by whether or not the savings derived from using such motors can offset the initial cost of investment within a reasonable time. The payback period is sometimes as short as 3-20 months depending on the system design, type of application and duty. In other applications such pay-back time is unreasonably long (Nadel et al., 1993).

This research will investigate the viability of using HE-motors for the purpose of saving electricity in South Africa's petroleum refineries. Actual field motor tests will be conducted to determine the effects that a HE-motor has on user's electricity bill. Two 45 kW induction motors, one HE-motor and the other SE-motor, both from the same manufacturer, connected to the same power supply, and both driving a similar load, will be tested to verify if the HE-motor is superior over SE-motor in reducing the electricity bill.

The research focuses on petroleum refineries because power generation has a direct relationship to supply of electricity. Electricity production depends on petroleum, and production of petroleum products depends on electricity. Some electricity generating plants use petroleum or gas as fuel. Mining and transportation of coal used by ESKOM to generate electricity heavily depends on petroleum. On the other hand, refining and some transportation of petroleum depend on electricity.

1.2. Research problem

HE-motors have been widely publicised as potential tools to save electricity and to reduce the cost of electricity, but tests to verify the viability of HE-motors to save electricity are rarely done in the industry. The concern is that there are many instances where motor users purchase and install HE-motors to save electricity, but the expected savings are never realised due to poor designs, poor motor selection and poor decision making.

1.3. Objectives of the research

The objective of the research is to verify the viability of using HE-motors in petroleum refineries, to reduce electricity consumption and the cost of electricity.

1.4. Deliverables

The following are tasks that need to be completed in this thesis:

- Study the theory of HE-motors and DSM.
- Purchase two electric motors, a HE-motor and a SE-motor and associated mechanical drives.
- Complete installation of the motors and the mixers in crude oil storage tanks.
- Compare power drawn by the two motors under similar power supply and load conditions.
- Analyse power (kW), power factor and current drawn by the two motors.
- Use the motor test results to determine whether or not significant amounts of electricity would be saved by using HE-motors in place of SE-motors.
- Analyse challenges facing implementation of HE-motor for DSM in petroleum refineries.

1.5. Research methodology

Studying the theory of HE-motors, DSM and petroleum refineries will form the initial part of this research.

Interviews will be conducted using phones, emailed questionnaires and plant visits will be conducted in order to:

- gather information from refineries in South Africa on the usage of HE-motors,
- gather technical information on a typical make of a HE-motors from motor vendors,

Field tests will be performed in a petroleum refinery to determine the effectiveness of using HE-motors to reduce expenditure on electricity. The test will compare power consumption by HE-motors and that consumed by SE-motor under similar power supply and load conditions. Both motors will be of the same make and the same rating.

1.6. Ethics code of conduct

The objective of this research will be to seek information and gain knowledge on the application of HE-motors in South Africa's refineries, for the purpose of fulfilling the requirements of a master's degree in electrical engineering. This will be accomplished without purposely infringing on any known ethics and codes of conduct.

Private and confidential information regarding persons or companies will not be included in this research without prior acknowledgement of the source.

Information that may damage reputations of a particular company or individuals will be omitted in this thesis. Only justifiable and accurate information on manufacturing, supply, application and effects of HE-motors will be included in this booklet.

1.7. Research design

The structure of this research is based on the following four aspects:

- Research on the theory of HE-motors.
- The application of HE-motors in South Africa's Petroleum Industries as a tool of DSM to save energy.
- Field tests in a petroleum refinery to determine viability of using HE-motors for energy saving.
- Study of barriers and mitigation of application of HE-motors for DSM in petroleum refinery.

The research is divided in to seven chapters as shown in table 1.1 overleaf, and as per the brief description in section 1.7.1.

Chapter Four: Case study

This chapter discusses in detail a test to compare power consumption of a 45kW HE-motor and a 45 kW SE-motor in a field setup. Test procedure and test design are discussed in this chapter.

Chapter Five: Analysis of the case study results

Motor test results attained in the previous chapter are represented in graphic format and analysed. Calculations of the payback period when investing in HE-motors are done in this chapter. The three main results discussed are those of power (kW), power factor and current drawn by the HE-motor and the SE-motor.

Chapter Six: Challenges and mitigation of successful implementation of HE-motors

Chapter six looks at the opportunities of using HE-motors in petroleum refineries for DSM. Maintenance, motor repair and motor winders are covered in this chapter. Barriers of implementing HE-motors in petroleum refineries for DSM are analysed.

Chapter Seven: Conclusions and recommendations

Conclusion drawn from the work done in the previous chapters is analysed and recommendations suggested. The most important part of the conclusion is that one derived from the case study performed in chapter five.

1.8. Delineation of the research

- Only 45kW induction motors were tested.
- Only Petroleum refineries were considered in this research.
- Quality of power supply was not part of this research
- Motor rewind details were not considered in this research
- VSDs did not form part of this research, but they are featured in chapter five and seven.

1.9. Expected outcome

- To understand HE-motors as potential energy saving machines.
- To understand the running characteristics of typical motors in a petroleum refinery.
- To determine the payback period of HE-motors in a typical motor application.
- To understand barriers of implementing HE-motors as tools of saving electricity

1.10. Time frame and planning

This thesis was done over a period of three years. The first and second year were dedicated to gathering information, reading material relevant to HE-motor and motors data collection. The final year was committed to testing various motors, data analysis and writing of the final report.

Table 1.2 Time planning table

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gatherings material		■	■	■	■	■	■	■	■	■	■	■
Research study		■	■	■	■	■	■	■	■	■	■	■
Project proposal		■	■	■	■	■	■	■	■	■	■	■

Tasks for 2009

Research study		■	■	■	■	■	■	■	■	■	■	■
Gathering of data and information		■	■	■	■	■	■	■	■	■	■	■
Visit to an HE-motor manufacturing plant												

Tasks for 2010

Research study		■	■	■	■	■	■	■	■	■	■	■
Gathering of data and information		■	■	■	■	■	■	■	■	■	■	■
Field tests			■	■	■	■						
Data analysis							■	■	■			
Visit to an HE-motor manufacturing plant		■	■									
Final report and dissertation		■	■	■	■	■	■	■	■	■	■	■

1.11. Budget

A total of R931,700 was spent over a period of three years as indicated in the table below.

Table 1.3 Budget table

Research Activities	**Amount**
Specialised Books	R 6,000
Journals	R 1,200
Conference registration	R 2,500
Internet connection	R 4,000
Travelling and accommodation	R 15,000
Specialized consultant/supervisor	R 3,000
Stationery	R 1,500
Data collection	
Travelling	R 5,000
Laptop & software	R 9,000
Document	
Editing	R 2,000
Printing and binding	R 2,500
Industrial test	
Tank mixers drives	R 300,000
Motors	R 70,000
Electrical equipment	R 90,000
Electrical installation	R 40,000
Commissioning	R 20,000
Total	**R 931,700**

1.13. Chapter summary

This chapter has given vital information on how the research is designed and the expected outcome. The delineation section stated what is in the scope and what is outside the scope. The objective of the research, research problem, cost analysis, timeline and the methodology used in this research are covered in this chapter as well. Chapter two covers the literature of DSM, refineries, SE-motors, HE-motors and Centrifugal loads.

CHAPTER TWO: LITERATURE REVIEW

2.0. Chapter overview

Chapter two covers the core theories related to this thesis namely DSM, induction motors and high efficient motors. Induction motor losses and design of low-loss HE-motors form the backbone of this chapter. Theories of petroleum refineries and centrifugal loads are also covered. Particular attention is given to petroleum refineries in South Africa.

2.1. Global warming

Our carbon footprint, greenhouse gases, global warming and energy efficiency are just but a few intimidating concepts that will continue dominating the scientific world, national speeches and media for years to come. They describe phenomena that the existing generation need to understand and to act upon for this planet to continue being habitable (Author, Mithamo, 2010). The terms describe the existing global concern with regards to the rate at which the environment is degenerating due to industrial emissions.

The Kyoto Protocol and global warming

Emission of Green House Gases (GHGes) is a serious environmental concern that has a potential to threaten life on Earth. In December 1997, 183 member states adopted a treaty called the Kyoto protocol in a world summit that imposed emission targets on industrialized nations to reduce emission of GHGes (Dagoumas, 2004). The protocol was adopted at the conference of the parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC). The industrialized countries signed a legal binding agreement to reduce emission of gases by 5.2% below 1990 levels. The period of commitment was between 2008 and 2012. GHGes are CO_2, CH_4, N_2O, HFCs, PFCs, SF_6 (Loz, 2008).

In compliance with the Kyoto Protocol, DSM has successfully been implemented in many parts of the world, especially in Europe and America, to reduce emission of GHGes and consequently to replenish the environment (El-Ibiary, 2003). According to Pool (2004), carefully implemented DSM could cut current electricity consumption in the UK by 25%, hence reducing the emission of GHGes by amounts much more than previously expected.

Reduced energy consumption also reduces exploitation of natural resources like coal, natural gases, land, forest/vegetation and water. This then results to less green-house-gas emissions, reduced rate of global warming and decreased depreciation of the ozone layer (Almeida et al., 2002).

Small scale energy saving interventions may lead to a far reaching environmental benefit if they are done collectively and consistently. Energy consumers need to be aware that every kilowatt-hour of energy used has an impact on plants, animals and human life. Cancer and pulmonary diseases are examples of human suffering that is aggravated by the effects of global warming. Scientists have recorded polar bears drowning due to melting ice as illustrated in the photograph in figure 2.1.

Figure 2.1 Photograph of a helpless polar bear

South Africa along other developing nations has been exempted from the same targets that affect industrialized nations. However, as Africa's largest economy and highest emitter, South Africa is taking the responsibility of leading the rest of Africa in implementing energy efficiency campaigns, with an intention of reducing emission of GHGes.

By implementing DSM in the nation, South Africa is heeding the message that says the following: *"The message to heed is that if those who are empowered to save energy don't do so willingly now, they will be compelled under legal threat to do so in future"* (Volutet al., 2008).

2.2. Demand Side Management

DSM describes the implementation of utility activities that are designed to influence how end-users use electricity (Cheek et al., 1997). Other sources define it as schemes intended to influence the way end-users use electricity (Ibrahim et al., 2002). Regardless of the type and the size of the words that describe DSM, its fundamentals are to influence how end-users utilize electricity. The concept of DSM was developed to address issues related to global warming, through recognition that energy efficiency represents the most cost effective option of reducing the demand for energy, which in effect reduces pollution.

Successful implementation of DSM will only yield the desired results if well designed strategies are used to enhance its success. This is because DSM is a concept directly related to human behaviour (Volut et al., 2008). Change of behaviour remains one of the world's most complicated challenge that mankind contends with on daily basis, and nothing less can be said about effective implementation of DSM.

DSM is the cheapest and the most effective method of producing reliable energy. The high cost of electricity has seen many industrial and commercial sectors embank on DSM. The main stakeholders who benefit from a successful implementation of DSM are the electricity end-users, the society, and power supply authorities, who in most cases are affiliated to governments. These benefits are highlighted in table 2.1, (DSM Best Practices Guidebook, 2006).

2.3. Electricity supply in South Africa

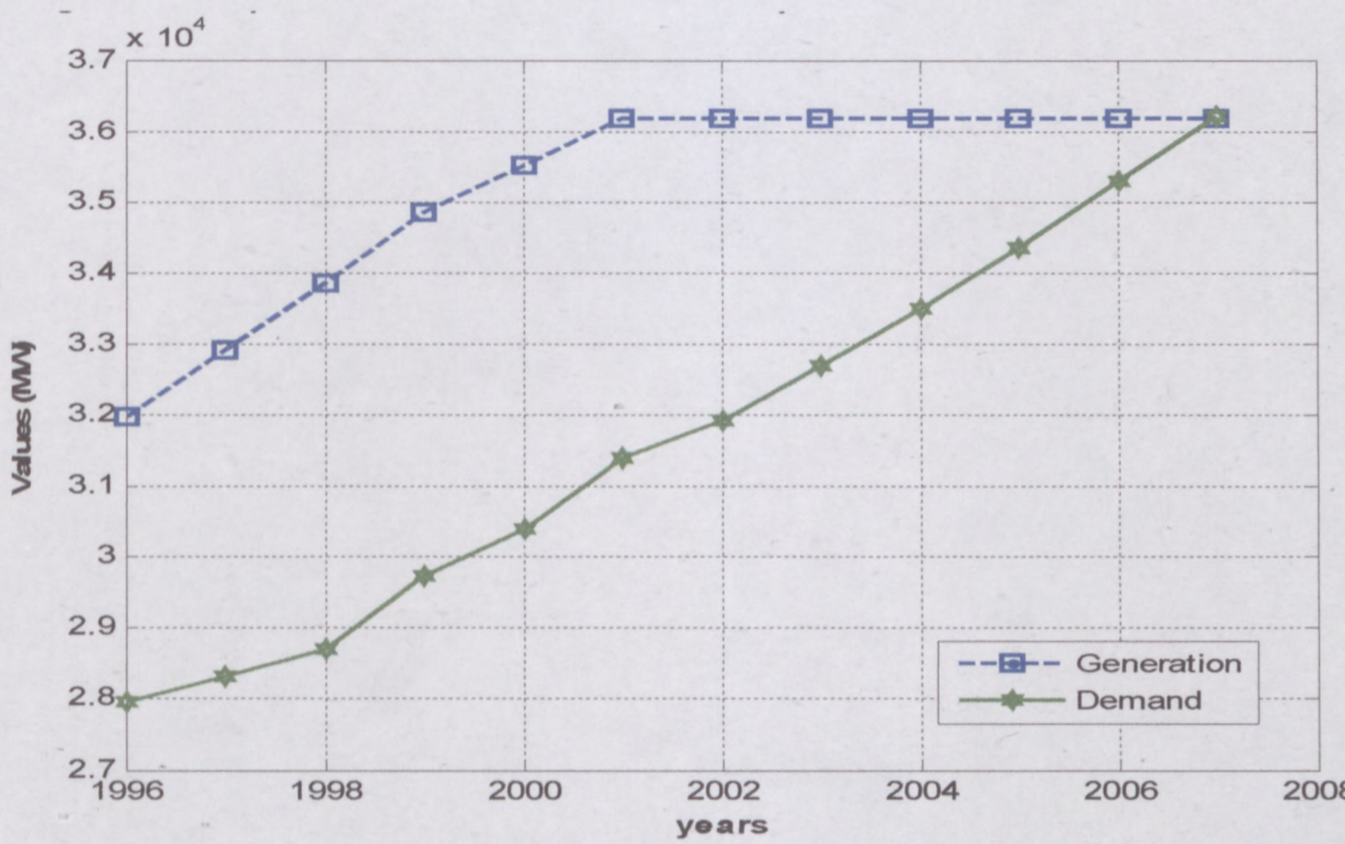
The South African government through the National Energy Regulator of South Africa (NERSA) and ESKOM have urged industries and commercial sectors to apply energy saving methods, for the purpose of reducing demand for electricity, and to mitigate global pollution (Dennis W, 2008). For DSM to succeed, energy saving mechanism must be considered on an individual electricity consumer basis. Different intervention methods may apply to one industry but not to the other. Different industries/sectors have different requirements, politics, policies and applications.

ESKOM has a power generation capacity of approximately 39,154MW, which is about 332,880GWh per year when generating at full capacity. In year 2006, 214 736GWh was consumed nationally (Johan, 2009). It had been foreseen that the demand of electricity would outstrip the supply late in 2007, but this happened earlier than expected (Mtombeni, 2008). In 2007 ESKOM could hardly meet demand for electricity without hick-ups.

It is now worldwide knowledge that South Africa was caught unprepared by the surge in demand for electricity, which it could not meet. In the recent past the country has experienced its fair share of rolling blackouts and power rationing, which has had devastating effects on both commercial and industrial sectors. This would not have happened if proactive measures were taken 10 years ago to address future power supply needs.

Figure 2.2 indicates that the last time electricity generation capacity was expanded was in 2000. Increase in demand for electricity from industrial, commercial and residential customers, has not been responded to with an increase in supply.

Figure 2.2 Power generation and demand in South Africa



According to Smith 2008, the power crisis South Africa is going through is caused by political influences, poor planning, decision blunders and administrative incompetence. The genesis of the crisis was in 2000 and 2001 when proposals by ESKOM to build new power stations were blocked by the government (Smith, 2008).

High electricity bills are probably the main reason that would make industries participate in energy saving measures. For many years South Africa has enjoyed supply of low priced electricity. This has now changed as the National Energy Regulator of South Africa (NERSA) has permitted ESKOM's proposals to increase electricity prices by 30% per annum over a period of three years. The effects of these increases will reverberate across the entire country. Former governor of the reserve bank Tito Mboweni said *"High electricity prices leads to high prices of chains of trade, and the opposite is also true"* (Mboweni, 2009).

Permanent solution to energy crisis

The solution to excessive environmental pollution, high electricity prices and the reduced electricity supply is to build enough clean power generating stations and harness natural sources of energy like hydro, wind, solar, biogas and sea wave. Even better, to close down power stations that are the worst in polluting the environment. But these are long term solutions that are very difficult to achieve in a few years due to political and procedural hurdles, requirements of huge capital outlay and a lack of skilled manpower.

Interim solution to energy crisis

There is now a desperate move by ESKOM to amass resources to build new power stations, which will ensure that the country will have sufficient energy in the future. In the interim however, managing the available power capacity is the only known short-term solution to mitigate the energy crisis. Efficient use of the available energy and use of alternative renewable sources has been identified as pivotal measures of easing the current energy crunch and reduce environmental pollution.

It is easier, cheaper and quicker to implement DSM strategies than building new power generation capacities (Pool, 2004). Although DSM is a new concept in South Africa, it has been successfully implemented in the Western countries, and yielded resounding results. Successful implementation of DSM campaigns means that industries can save on electricity bills, and in turn re-invest the savings to expand business cases.

2.4. Benefits of DSM

There are numerous social and economic benefits that would be realized if DSM is implemented successfully. The table below groups the benefits in three categories namely;

- Benefits to electricity users,
- Benefits to the electricity supply authority,
- Social benefits.

Table 2.1 Benefits of DSM

Beneficiaries	Benefits
Electricity user	• Lower electricity bill, • Less expenditure on projects aimed at stabilizing electricity supply, • More effective plant maintenance, • High machine reliability, • Money saved this way can be used to improve business case.
Electricity supply authority	• Reduced demand for electricity, • More stable power supply, • Less strain on electrical infrastructure, • More time to maintain the existing infrastructure, • Better customer relations, • Reduced spending on generation, transmission and distribution, • Postponement of building new power stations.
Social factors	• Reduced pollution and release of greenhouse gasses, • Increase in employment opportunities, • Less exploitation of natural resources, • Improved life style, (IIEC, SOPAC, 2006).

2.5. The process of planning and implementing DSM

DSM programs are tailored according to utility and consumer's specific needs and requirements. Proper planning is vital before a particular DSM program is deployed. Five steps of implementing DSM are as listed and tabled below.

1. Load research
2. Define load shape
3. Assess program implementation
4. Implementation
5. Monitoring and evaluation

Table 2.2 Process of planning and implementing DSM

Load research	• In this stage a study is performed to understand electricity consumption characteristics of a particular electricity user. • Information on power utilization, billing pattern and available subsidies is collected. • Load measurements are done and a load profile is analysed.
Define load shape	• The results collected during the load research are used to define the load shape of the particular user. • Load shape characteristics are explained in 2.6.
Assess program implementation	• In this section a suitable DSM strategy is defined. • Success factors of a chosen strategy are identified. This includes, payback period, cost of implementation, available subsidies and social impact.
Implementation	• This is a stage where design and implementation of a chosen program is done. • Training is given, incentives are provided, penalties are applied, advertisement leaflets are distributed, lobby groups established among other strategies.
Monitoring and evaluation	• This is the stage when assessments are done to determine the success of the implemented strategies. • The aim of monitoring and evaluation is to ensure that the established DSM strategy is providing the anticipated results.

2.6. Types of load shapes

There are six different types of load shapes as stated below;

- Peak clipping,
- Valley filling,
- Load shifting,
- Load building,
- Variable load,
- Conservative load shape.

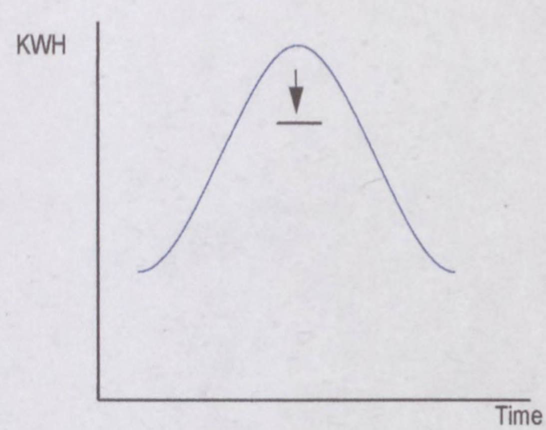
The six load shapes are explained below with the aid of diagrams.

2.6.1. Peak clipping

Peak clipping is applicable when the power supply authority has insufficient power over a short period of time. Power demand in this type of load shape is characterized by high power demand in the mornings or evenings. A typical example of this type of demand is increased domestic power utilization in the morning and in the evening, and machines start-up in heavy industries (DSM Best Practices Guidebook, 2006).

Demand management is achieved through focused energy efficiency programmes or interruption of electricity supply. The objective of these types of programmes is to avoid investing in additional power generation facilities and power network to only address short term high demand.

Figure 2.3 Peak clipping load shape

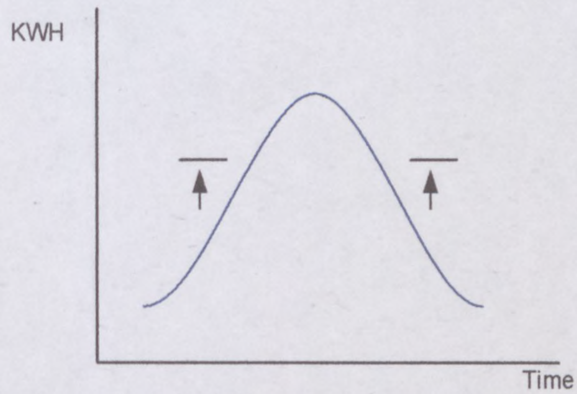


Peak Clipping

2.6.2. Valley filling

Valley filling is described as the scenario where there is excessive availability of power over extended periods, succeeded by peak demands. In this case customers are encouraged to use the available capacity at normal terms so as to improve the system load factor (DSM Best Practices Guidebook, 2006).

Figure 2.4 Valley filling load shape

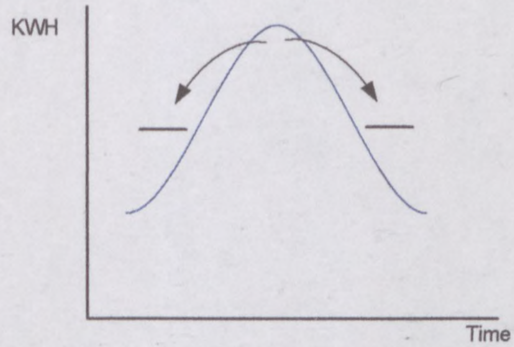


Valley filling

2.6.3. Load shifting

Load shifting describes a demand management strategy applied when there is excessive demand of electricity over a short period, followed by a low demand period.

Figure 2.5 Load shifting load



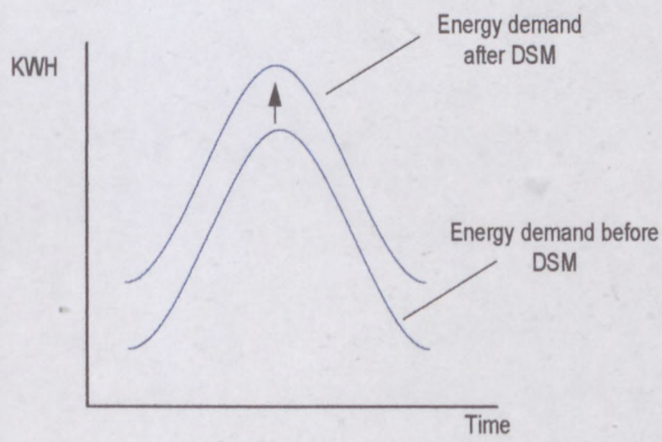
Load Shifting

The objective of this strategy is to attempt to shift some peak-period loads to low demand periods. The net demand remains the same, since reduction of utility loads during peak-periods and increase of utility loads during periods of low demand is done sequentially. Typical cases are heating by use of accumulators or changes in the production pattern in industry (DSM Best Practices Guidebook, 2006).

2.6.4. Load building

Load building, also referred to as load-growth defines a strategy aimed at promoting increase in power utilisation, more or less equally, during all or most hours of the day. Emphasis is put on promoting electricity consumption during periods of low demand so as to maximise utilisation of generation and network assets (DSM Best Practices Guidebook, 2006).

Figure 2.6 Load building

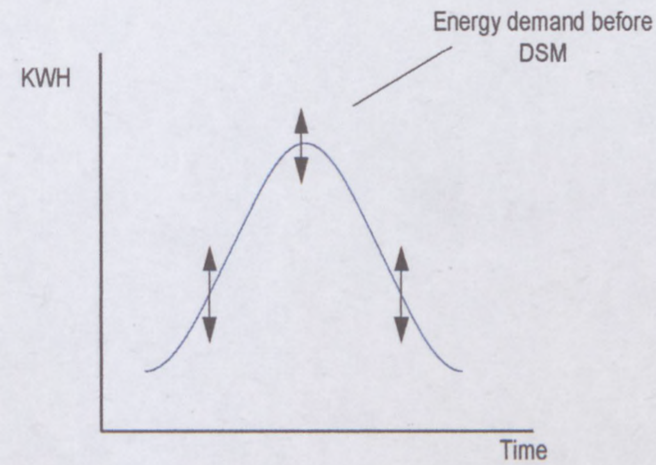


Load building

2.6.5. Valuable load

Valuable load refers to programs that are set up to alter customer energy consumption on a need basis, as in interruptible agreements. Demand controls like priority service pricing and demand subscription services are examples of a valuable load mechanism whereby communication between the supplier and customer allows the supplier/distributor to control the customer demand.These are used to tailor reliability of service to individual customer needs. Utilities can realise both operating and future fixed cost by allowing dispatchers flexibility to reduce or postpone demand for selected customers (DSM Best Practices Guidebook, 2006).

Figure 2.7 Valuable load shapes



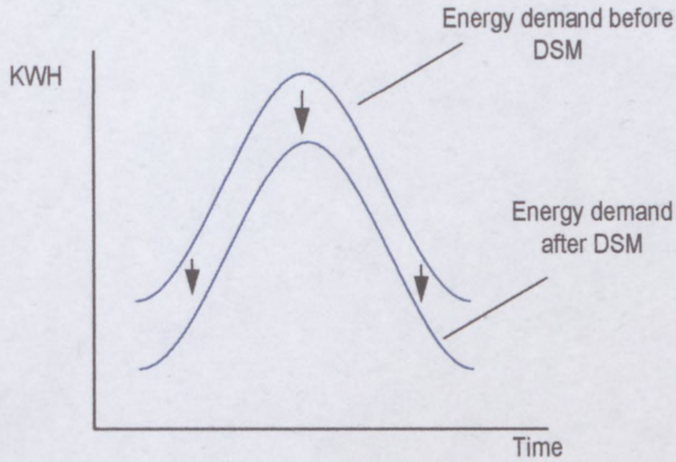
Flexible load shape

2.6.6. Conservation load shape

Conservation load shape defines a load management strategy aimed at reducing utility loads, more or less equally, during all or most hours of the day. Overall reduction of demand is archived by applying energy efficiency programmes.

Some examples of such strategies are use of energy efficient equipment (i.e. HE-motors and efficient lighting), improved machine and plant design, switching off lights during the day and making use of natural light. Besides reducing energy consumption, these load management strategies are vital in reducing environmental pollution and mitigating global warming. Figure 2.8 overleaf illustrates reduced total utility load as a result of applying energy efficiency programs (DSM Best Practices Guidebook, 2006).

Figure 2.8 Conservation load shape



Conservation load shape

2.7. Methods of promoting DSM strategies

Various methods are employed to enhance successful implementation of DSM.

Table 2.3 Method of promoting DSM

Type of intervention	Nickname	Meaning
Incentives	Carrots	Using substance to encourage and reward energy saving efforts.
Penalties	Sticks	Punish customers for noncompliance, i.e. charging high prices for excessive use of electricity.
Awareness	Tambourine	Informing electricity users about the importance of energy efficiency, and the ramifications of noncompliance.

2.7.1. Incentives

The word incentive in DSM is a subtle replacement of the word bribe, and that describes strategies used to entice and persuade electricity consumers to use electricity efficiently. The nickname 'carrot' is also commonly used to describe the method (Tshikalanke, 2007). Consumers who comply with proposed strategies of energy saving become beneficiaries of a reward scheme (Hamidi, 2008). ESKOM has started a subsidy scheme that rewards consumers for purchasing HE-motors. They have also been giving away free energy saving bulbs, covering residential hot water cylinders with blankets for free and offering energy efficiency information on the internet, magazines and pamphlets.

2.7.2. Penalties

Penalties, also nicknamed, 'sticks' describe initiatives aimed at gruelling consumers who do not actively adhere to calls for energy saving (Hamidi, 2008). ESKOM charges higher tariffs for higher consumers of electricity. Beyond a predetermined kWH rating, the price of electricity increases so as to make sure that larger electricity consumers pay more.

A maximum demand tariff is another method of making high consumers of electricity pay more.

2.7.3. Awareness

'Tambourine' is a nickname used to describe the initiatives aimed at providing awareness to electricity consumers about the following;

- The need to use energy efficiently,
- Penalties of not using electricity efficiently,
- Environmental ramifications of not saving energy,
- The available energy saving technologies,
- Available incentives and the process of claiming them.

Educating and informing electricity consumers is a cheaper, amicable and a sustainable strategy of encouraging energy efficiency as opposed to imposing penalties and providing incentives (Hamidi, 2008). ESKOM has used local press, Internet, electronic media and pamphlets to educate citizens about energy efficiency.

2.8. Industrial DSM technologies

There are various DSM technologies available to energy users, but their viability is dependent on the characteristics of particular applications under consideration. Proper audits and assessment can offer reliable leads of which technologies are more likely to succeed and which ones would not. Some of the common technologies are:

1. Replacing inefficient motors with HE-motors (Akbaba,1999),
2. Replacing faulty motors with new HE-motors instead of rewinding (Akbaba,1999),
3. Use of variable speed controls (VSD) for process control applications, (Akbaba, 1999),
4. Power factor correction,
5. Use of high efficient electric transformers,
6. Over sizing electric cables so as to reduce heat/energy loss,

7. Use of fluorescent tubes instead of incandescent lights,
8. Advanced lighting control.

2.9. Social factors

Successful DSM has the following social advantages:

- Environmental (reduced pollution),
- Expansion of employment opportunities,
- Readily available electricity without interruptions, which leads to a good relationship between the electricity consumer and the power generating authority,
- Stable supply of fuel dependant products including electricity.

2.10. Induction motors

Induction motors are electromechanical machines that convert electrical energy to mechanical energy by rotating the rotor shaft. Induction motors are regarded to be the workhorses of the modern industry due to their efficiency, rugged construction, reliability, cost effectiveness and high starting torque (Akbaba, 1999). Three-phase squirrel cage induction motors are the majority in industry, commercial and domestic use. Application of variable speed control with induction motors has become popular over the years.

2.10.1. Application of Induction motors in petroleum refineries

In petroleum refineries induction motors are used to drive pumps, mixers/stirrers, fans and compressors (Nadelet al., 2006).These loads are called centrifugal loads. Motor sizes in refineries vary from as low as 0.18kW to 400kW.

2.10.2. Efficiency of Induction motors compared to other machines

Since motors are not high fidelity machines, only about 80-90% of the electrical energy supplied to a SE-motor is converted to mechanical torque. Compared to other industrial machines, efficiency of induction motors is nothing short of spectacular. Figures 2.9 to 2.13 are pie charts that compare efficiency of induction motors to various other industrial machines (Wheat, 2008).

By observing the following charts it is clear that induction motors are inherently very efficient machines. Their close relatives gas turbines and widely used combustion engines are 50% and 20% efficient respectively. These pie charts indicate that induction motors do not have much of a margin to be improved on.

Figure 2.9 Gas turbines

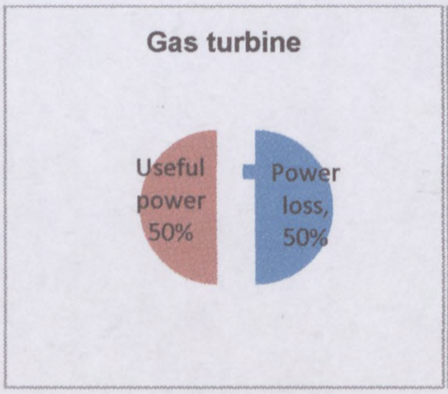


Figure 2.10 Nuclear plants

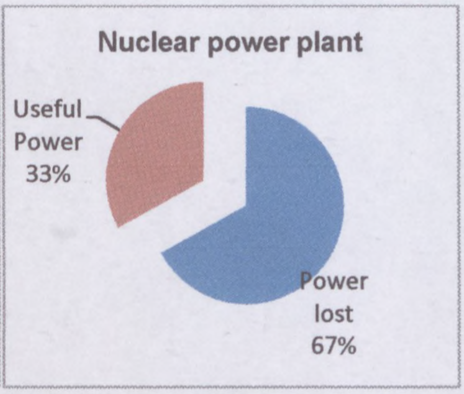


Figure 2.11 Combustion engine

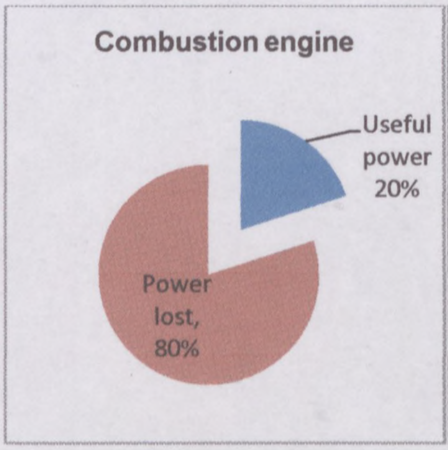


Figure 2.12 Silicon solar cells

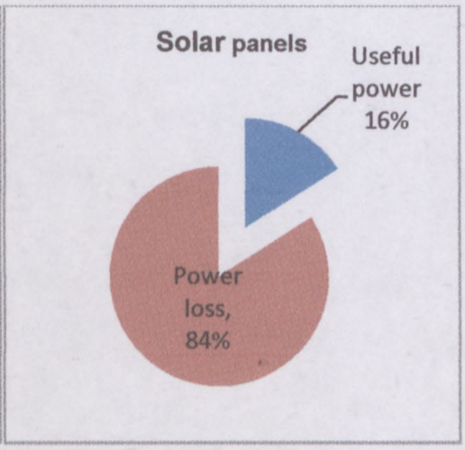
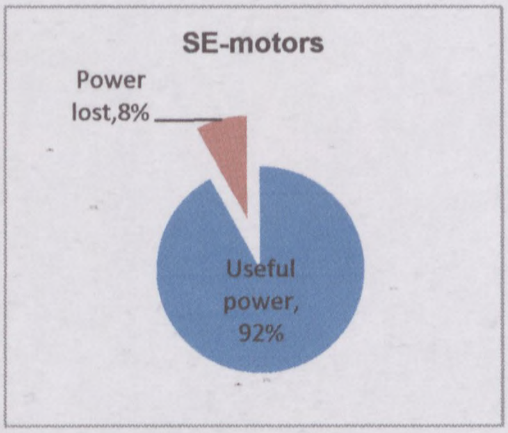


Figure 2.13 SE-motors



Motor efficiency formulas

Efficiency (□) of an induction motor is determined by the relationship between input power to the machine and the power developed on the motor shaft (Nadel, 1989). Any of the following formulas can be used to determine efficiency:

$$Efficiency\ \% = \frac{Watts\ (output)}{Watts\ (input)} * 100 \tag{2.1}$$

$$Efficiency\ \% = \frac{Watts\ (input) - watts\ (losses)}{Watts\ (input)} * 100 \tag{2.2}$$

$$Efficiency\% = \frac{746 * Horsepower(output)}{Watts(input)} * 100 \tag{2.3}$$

2.10.3. Losses in an induction motor

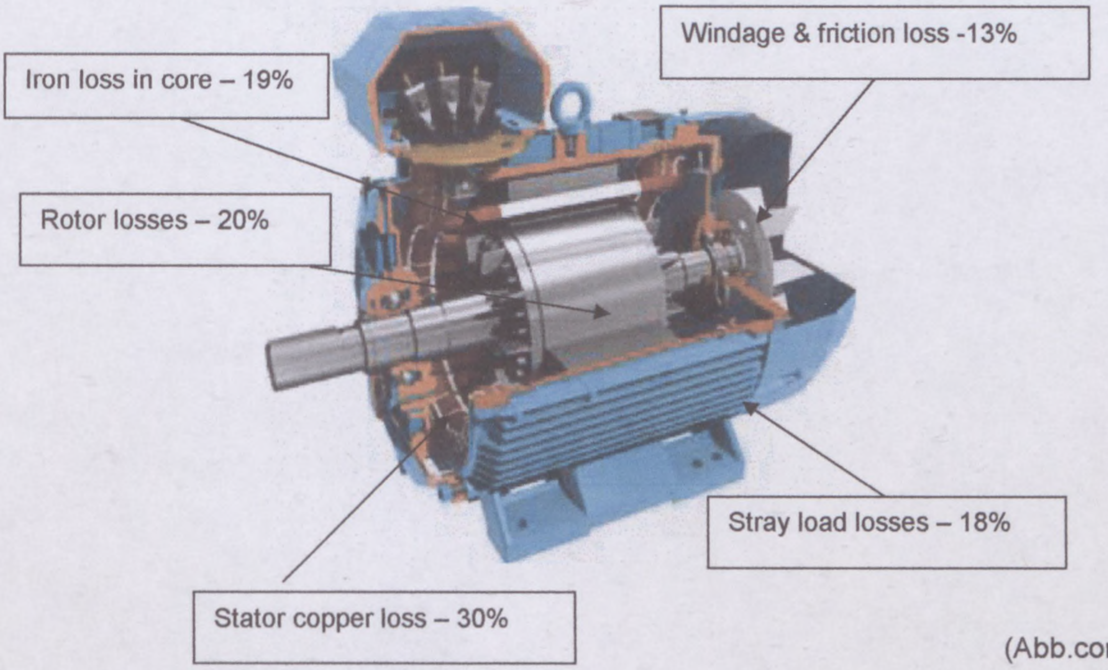
A 100% efficient motor would be a motor that does not have loses. In motors, efficiency is inhibited by copper losses, core losses, winding and friction losses. There are four categories of losses in electric motors namely;

a) Electrical losses,
b) Magnetic losses,
c) Mechanical losses,
d) Stray load losses.

a) Electrical losses (stator and rotor losses) 50%

They are the most dominant of all losses as they account for more than 50% of total motor power losses, 30% in the stator and 20% in the rotor (Cowern, 2002). These are normally I^2R losses or commonly known as copper losses that occur due to resistance offered to current flow by electrical conductors in both stator and the rotor. Stator copper loses occur due to electrical resistance of the stator winding while rotor copper losses are caused by electrical resistance on the rotor bars (El-Ibiary, 2003). Electrical losses are referred to as variable losses and they are only present under load conditions. These losses are represented in figure 2.15.
The figure below shows the distribution of the four motor loss categories listed above.

Figure 2.14 Motor losses indicator



(Abb.com, 2009)

b) Magnetic losses or Iron loss in core 19%

Magnetic losses accounts for 19% of the total motor losses. Eddy currents and hysteresis effects in the steel laminations both in the stator and the rotor are responsible for magnetic losses. Magnetic and friction losses are normally referred to as fixed losses as they are present both at load and at no load conditions. These losses are represented in figure 2.15.

c) Mechanical losses (13%)

Mechanical losses are about 13% of the total losses which occur due to bearing friction and windage losses. They are normally referred to as fixed losses as they are present both at load and at no load conditions. These losses are represented in figure 2.15.

d) Stray load losses (18%)

Stray load losses equal roughly 18% of the total losses. They are caused by leakage flux that is induced by load current, non-uniform current distribution, mechanical imperfection of the air gap, and irregularities in the air gap current density (Nadelet al., 2002).

Stray losses are referred to as variable losses and they are only present under load conditions. These losses are represented in figure 2.15.

Formula for power losses

$$P_{loss} = P_{diss} + P_{core} + P_{rotation} + P_{stray} \quad (2.4)$$

(Nadel, 1989)

P_{loss}- Motor power loss.

P_{diss} - I^2R ohms losses in the stator and rotor.

P_{core} - Core losses due to stator and hysteresis of the eddy current losses of the in the rotor and stator.

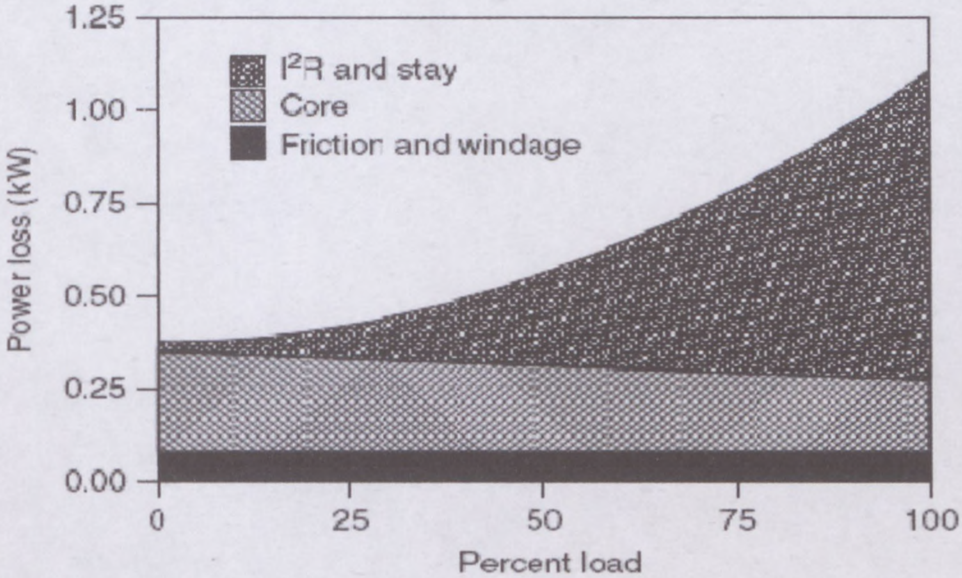
$P_{rotation}$-Rotational losses associated to bearing friction, windage and cooling fan.

P_{stray}- Miscellaneous losses. Losses that are not in the other three categories of losses.

Fixed and variable losses

The figure overleaf shows the distribution of fixed and variable loses. At low load copper and stray losses are at their lowest, while core losses are high. As the load increases the copper and stray losses increases, while the core losses decrease slightly. Friction and windage losses remain constant from low to high loads.

Figure 2.15 Motor losses graph



Loses due to voltage motor and current imbalance

Other loses in a motor are caused by voltage and motor imbalances. A voltage imbalance of 1% is significant enough to cause losses in a motor. Causes of voltage imbalance are harmonic distortion, over-voltage and under-voltage. Voltage imbalance in turn causes a current imbalance.

Motor imbalance is sometimes caused by imbalanced heating of the stator, poorly rewound motors, rotor misalignment, and negative sequence current. Motor imbalance leads to motor heating.

2.11. HE-motors

2.11.1. Origin and design of HE-motors

Over the years scientists and electrical engineers have identified electric motors with improved efficiency as potential machines for saving energy. This is because electric motors consume a major portion of world's generated power in both industrial and service sectors (Nadelet al., 2008). According to Almeida T et al., (2009), worldwide motors use 70% of generated energy. In South Africa 65% of total generated power is consumed by motors, almost all of which are SE-motors, their efficiency is 2% to 8% less than that of HE-motors (Mtombeni, 2008). According to various publications, the energy lost by SE-motors can be salvaged if HE-motors are extensively used. Various stakeholders are in agreement that well designed HE-motors and motor systems are potential masterpieces in salvaging valuable electrical power, reducing pollution and lessening consumer's electricity bills (Author, Mithamo, 2010).

HE-motors are not a new invention, they have been in the market for the last 30 years and ABB claims that they have had them since 1984 (www.abb.com). In 1992, an energy policy act was enacted in the USA to define minimum efficiencies for general application motors. In 2002 NEMA and CEE (Consortium of energy efficiency) established a NEMA premium level of motor efficiency. Motor users found this move to be valuable and influence motor manufacturers to establish a line of premium efficiency motors (William et al., 2007).

2.11.2. Designing HE-motors

Researchers and motor design engineers work on improving the efficiency of SE-motors by using the following three broad categories:

1. By spending extra time in designing a superior motor. This is a very challenging method of improving efficiency, but the cost involved is minimal.
2. By building motors with tighter tolerances. This method requires extra investment to optimize tolerances.
3. Design using high quality materials. This method significantly increases capital investment and hence the motor price.

Designers of high efficient motors use a combination of the three methods listed above, with close consideration of the cost of the motor (Poolet al., 2002). A cost effective HE-motor design should have a payback time of 3 to 20 months, depending on the size, application, duty and the loading of the motor (Cheek et al., 1997).The development and construction of HE-motors is based on a design that aims at minimizing motor losses that are stipulated in section 2.10.3. Methods of reducing motor loses are explained in section 2.11.5.

2.11.3. Design characteristics of HE-motors

1. HE-motors have lower losses than SE-motors hence their high efficiency.
2. HE-motors operate at a smaller slip and higher speed than SE-motors (Cheek et al., 1997).
3. The smaller slip also reduces the torque developed by the motors; meaning that HE-motors should not be used on loads where starting current is critical (Pool et al., 2002).

4. HE-motors have higher transient currents due to lower core resistance. Sometimes the transient current may be as much as 13 to 20 times full load current (FLC). LRC is a steady state current, since it is always on when the motor is not moving. Motors are inductive loads and that is why they generate inrush current. This happens when the motor is connected to the power supply. At the time of connection there is no back EMF to oppose the current flow. The only limiting factor to the current is rotor resistance. The lower the resistance the higher the transient currents.
5. HE-motors have a higher temperature rise than SE-motors.

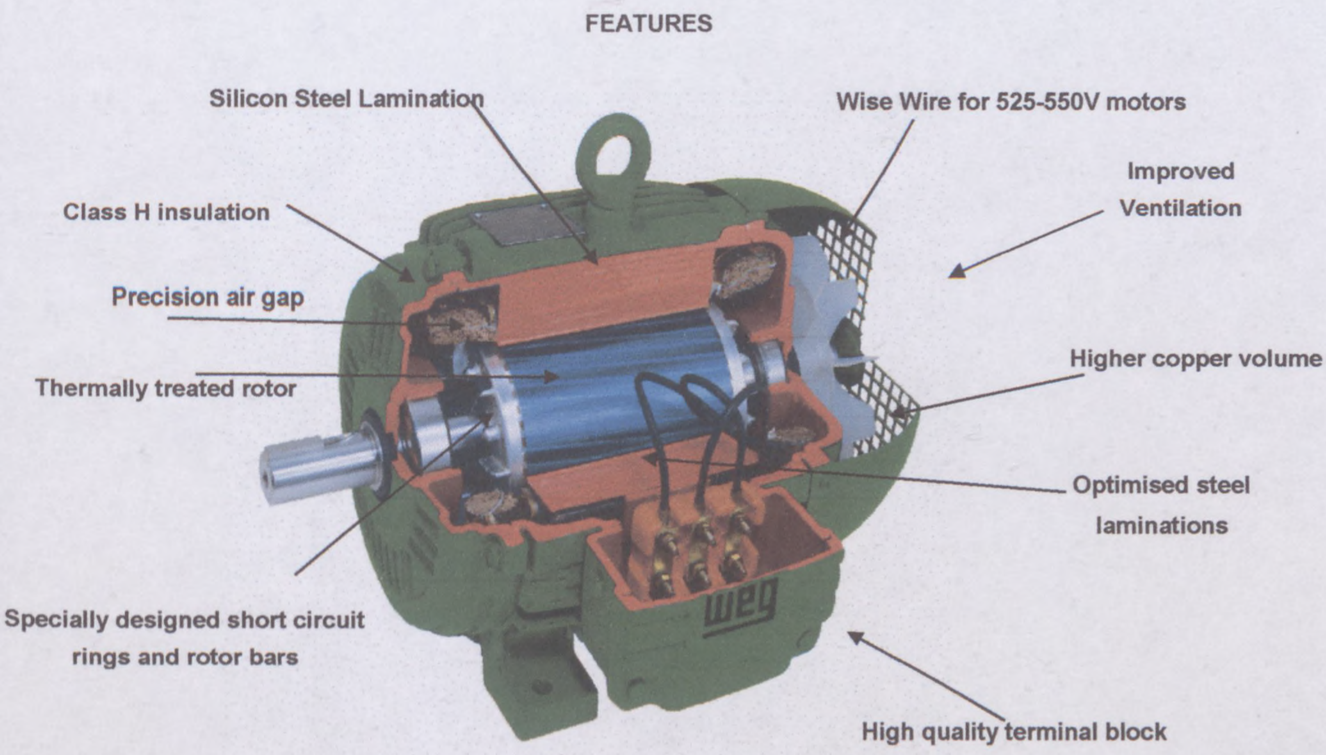
2.11.4. Classifications of motor efficiencies

For many years classifications of motor efficiency have been loose in many parts of the world. Different countries and regions had different motor efficiency standards, and used various wording to describe efficiencies. International Electro-technical Commission (IEC) stepped in and published a motor energy efficiency standard (IEC 60034-30), which replaces previous national efficiency standards. South Africa has adopted the motor classifications standards in IEC 60034-30 and named them SANS 60034-30:2009.HE-motor classifications based on IEC 60034-30 are shown in the table below.

Table 2.4 Motor efficiency classification

Numeral	Description	Definition
1	Standard	Low ranking motors efficiency category (comparable to eff.2).
2	High	Motor efficiency category higher than Standard, but lower than Premium (comparable to eff.1).
3	Premium	Motor efficiency category higher than Standard and High efficiency.
4	Super-premium	The highest motor efficiency category still under consideration. (Almeida et al., 2008)

Figure 2.16 Design details of HE-motor



2.11.5. How losses in induction motors are reduced to make HE-motors

The design criterion focuses on some or all of the following:

- Increasing the length of a rotor,
- Increasing the amount of magnetic material (iron) in a motor,
- Making motor windings with thicker wires,
- Reducing the size of the motor fan,
- Reducing the size of the air-gap.

Electrical losses - Stator and rotor copper losses (50%)

To reduce stator copper losses, the core is modified to accommodate more stator windings. The thickness of the stator windings is also increased to reduce electrical resistance. In some designs better quality, low resistance copper is used on the windings. HE-motors therefore have substantially more copper than SE-motors.

Mechanical losses (13%)

Methods of mitigating mechanical losses include modifying the design of the cooling fan, and using heavier duty bearings and proper greasing methods. Mechanical losses are low in small motors but are substantial in large high speed motors. (El-Ibiary, 2003).

Magnetic losses or Iron loss in core (19%

Eddy currents, and hysteresis can be reduced by using better quality steel and increasing the cross-sectional area of the laminations (El-Ibiary, 2003).

Stray load losses (18%)

Stray load losses are caused by leakage flux induced by load current; Mitigation measures are to improve the construction and alignment of the stator slots. Leakage flux induced by load current is responsible for stray load losses.

Figure 2.17 HE- motor

2.11.6. Reliability of HE-motors

In general over 50% of motor failures are caused by bearing failure. High quality bearings and lubrication of HE-motors means that HE-motors can last longer and hence have a high MTTF rate. Electric motors are machines that convert electrical energy to motion on the shaft of the motor. Efficiency of a machine is a measure of how well it converts the input electrical energy into output mechanical energy.

Highest motor efficiency is a good design target to meet, and it is every motor engineer's dream. But this is nothing less than an engineering utopia, because efficiency is reciprocal to cost.

Therefore increased motor efficiency is a trade-off between the level of efficiency and a realistic motor price (Bonnett, 46). This is the very reason why HE-motors are generally more expensive than SE-motors, and hence difficult to sell. Surprisingly the payback period of the money invested in purchasing HE-motor is as short as 3-12 months, depending on the size of the motor and the load characteristics (Nadel et al., 2002).

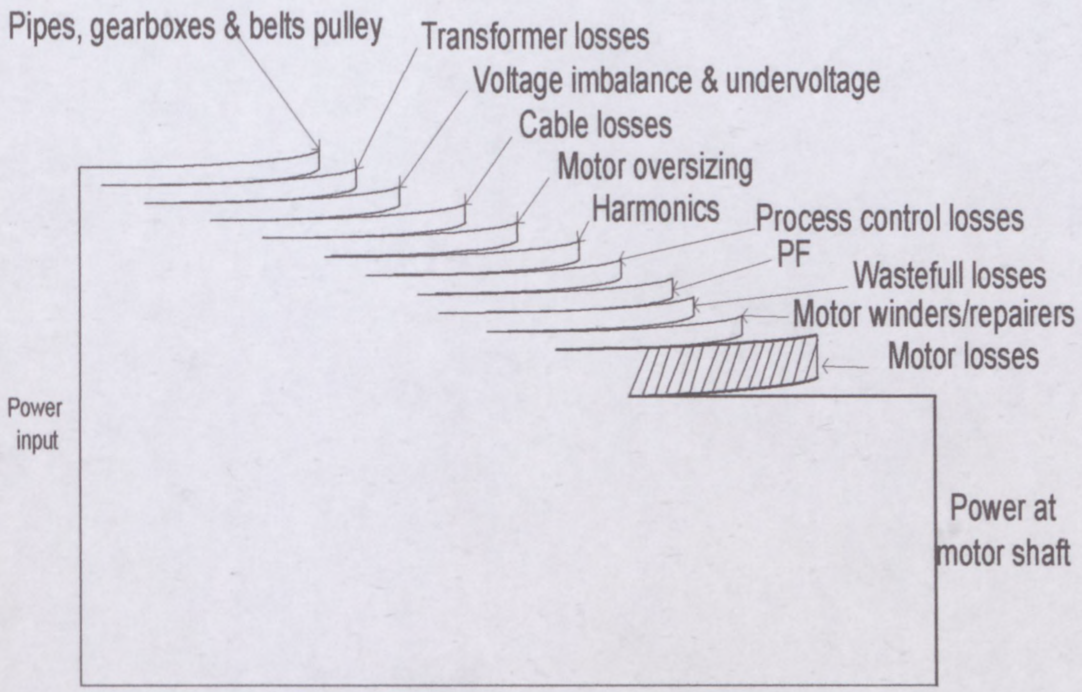
In some applications HE-motors consume less energy, run cooler and are able to withstand higher duty cycle rate than their counterparts SE-motors. The meantime-to-failure rate for high efficient motors also tends to be longer. The reason for this is because HE-motors are constructed with high quality materials and with greater engineering precision (Mohammed, 2008).

2.12. Motor systems losses

Great testimonies have been given in many parts of the world of how prolific HE-motors are in saving energy. Over the years motors have been proven to be a viable means of saving energy. However, it needs to be understood that such savings are not a perfect guarantee, but a moving target (Wheat, 2008). Motor savings cannot simply be calculated from motor nameplate information. Such savings can only be determined by considering various factors like load characteristics, state of power system, maintenance strategies, plant operation and social factors among many other variables (Wheat, 2008). A motor is only one component in an entire motor-system that requires efficiency consideration hence a broad-based motor-system approach can never be overemphasized.

Figure 2.18 shows different losses related to a motor system. Motor losses form a small part of the entire motor system losses (Nadel et al., 1993).

Figure 2.18 Motor system losses



Taking a closer look at refinery operations would reveal that there is far more that could be done to save energy than considering motor efficiency alone. Various other energy saving opportunities exist such as:

1. Power system harmonics,
2. Power factor,
3. Voltage unbalances,
4. Oversized motors,
5. Use of old motors with greatly reduced efficiency,
6. Motor starting methods,
7. Motor control methods,
8. Mechanical loses, i.e. coupling and belts,
9. Poorly planned motor operation plan.

2.13. Petroleum Refineries

A study focusing on an individual industry/sector cannot be over emphasised for the energy efficiency campaign to be a success. This research focuses on the HE-motors to save energy in South African petroleum refineries.

Petroleum and petroleum products are important commodities in South Africa's economy, and hence petroleum refineries are industries of key national interest. Production of petroleum products has a direct relationship with the generation and supply of electricity (Gail et al., 2008).

In South Africa electricity is largely produced by burning coal. Coal is mined and transported by diesel driven machines. Staff who work in these industries use diesel and petrol driven vehicles. Efficient use of power in petroleum refineries will not only benefit the industries themselves but the nation at large through improvement of electricity supply, a stable fuel supply, the creation of job opportunities and a reduction in environmental pollution. Petroleum refineries are recipients of significant amounts of power from ESKOM, most of which is used to drive electric motors. Sasol alone has 16,000 installed electric motors, drawing a total of 2000 MW.

Petroleum refineries are one of the many categories of industries in South Africa where HE-motors can be applied. Motor loads in this type of industry may have completely different effects to that of an industry like mining.

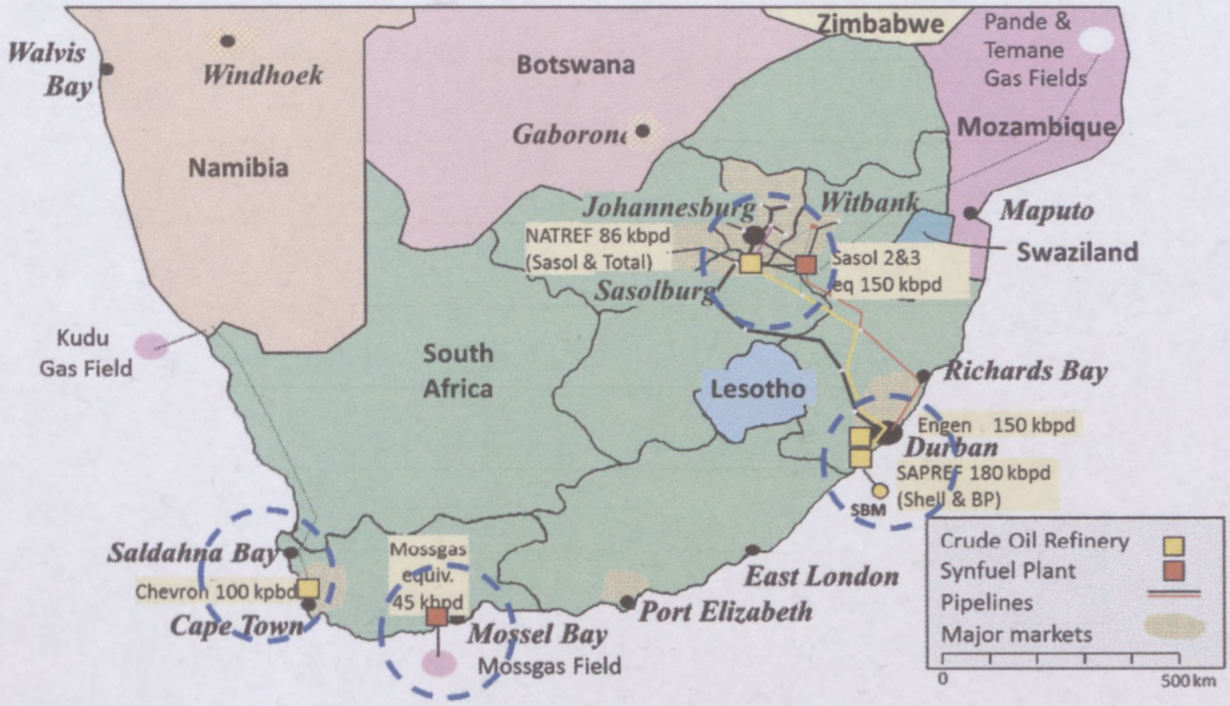
As indicated earlier, this thesis focuses on refineries, because of their unique load characteristic and their importance in the energy chain.

Figure 2.19 shows the location of petroleum refineries in South Africa and their related production capacity.

Refineries in South Africa are

1. CHEVRON REFINERY, Cape Town
2. PETROSA, Mosselbay
3. ENGEN Refinery, Durban
4. SASOL, Mpumalanga
5. SAPREF, Durban

Figure 2.19 Refineries in South Africa



2.13.1. Role of Refineries in the energy chain

ESKOM, South Africa's power generating and supply authority uses petroleum and gas products as fuel in some power generating facilities. Mining and transportation of coal used by ESKOM to generate electricity heavily depends on petroleum as well (Gail et al., 2008).

Just like the rest of the world, South Africa's economy depends on petroleum and petroleum products. For this reason a slight upset in the supply of petroleum greatly affects the economy. On the other hand small improvements in energy usage at petroleum refineries may be of great benefit to the economy.

Petroleum refineries have a significant impact on the environment, through mining of gas and coal, and emissions produced from refining and processing plants. It is obvious that improved efficiency in production of electricity would reduce environmental pollution.

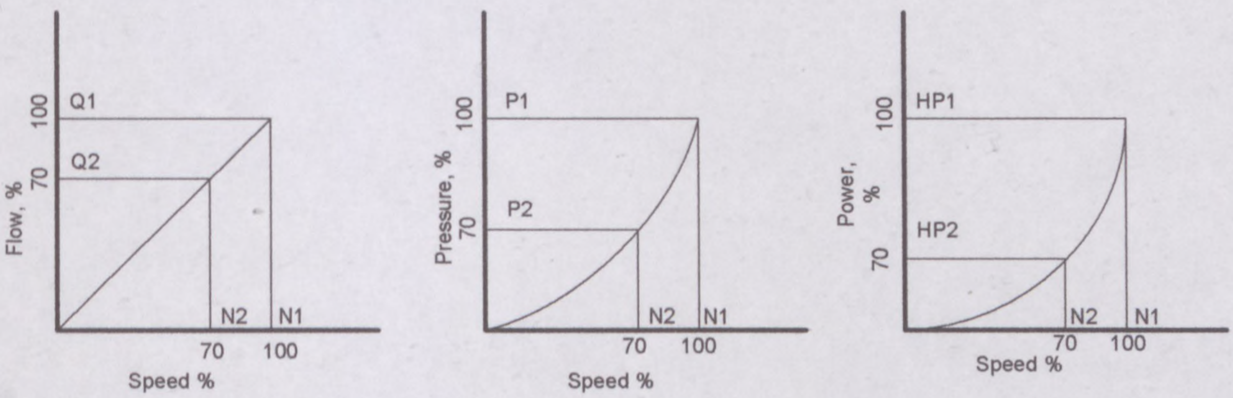
Petroleum refineries are recipients of huge amounts of power supplied by ESKOM, most of which is used to drive electric motors. Sasol alone has 16,000 installed electric motors, drawing a total of 2000 MW (Willemse, 2008). A more efficient running of refineries would translate to a lower demand of electricity from ESKOM.

Efficient use of power in petroleum refineries will not only benefit the industries themselves but the nation at large through improvement of electricity supply, stable fuel supply, creation of job opportunities and reduction in environmental pollution.

2.14. Centrifugal loads and HE-motors

To achieve higher efficiency, HE-motors are designed to operate on a smaller slip that consequently increases their speed as compared to that of SE-motors (Cheek et al., 1997). Higher rotor speed impacts on energy saving of HE-motors when they are used to drive fans and pumps (normally referred to as centrifugal loads). Increase in speed results in a proportional increase in flow. Flow rate increases linearly with speed, but power consumed by a motor goes up by a cube of the speed as shown in the figure below.

Figure 2.20 (a) Flow/Speed curve, (b) Pressure/Speed curve, (c) Power/Speed curve



N = Speed

Hp = Power (in kW)

P = Pessure

Q = Flow

A fan or pump installed in an unchanging system, the flow is directly proportional to the speed of the fan or pump.

$$Q \infty N \text{ ....Formula 2.5}$$

Change in pressure difference (P) is proportional to the square of the flow rate (Q) in litres per minute. If the flow doubles, the pressure drop quadruples.

$$P \propto Q^2 \qquad (2.6)$$

Power (P) is proportional to speed (N) cubed. If the speed of a pump is doubled, the power requirements are cubed.

$$P \propto N^3 \qquad (2.7)$$

Since most loads in the Petrochemical Industry are centrifugal, care needs to be taken when considering HE-motors as a replacement for SE-motors. The other effect of the smaller slip is that it causes the motors to have a lower starting torque than SE-motors. HE-motors also require stricter repair/rewind methodology as in comparison to SE-motors (Nadel et al., 2002). With increased fossil fuel prices around the globe Petrochemical Industries are among the most important investments not just in South Africa but worldwide. In South Africa they are among the largest consumers of electricity hence the application of HE-motors in these and associated companies cannot be overemphasized.

Equipment installed in petroleum refineries must be correctly specified as per the hazard classification zone of the area in which they are installed. This is to ensure that the equipment does not cause a fire or an explosion during normal or abnormal application. This equipment is referred to as explosion protected (Ex). Imported Ex equipment must be accompanied by a certificate issued by an Approved South African Test Laboratory, certifying that the equipment is suitable for use in a hazardous area. Electric motors used in classified areas must be explosion protected.

2.15. Chapter summary

Theories and concepts relevant to these theses were covered in this chapter namely: HE-motors, motor losses, refineries and their relevance in energy saving, and the cube law - in relation to centrifugal loads. The application of these theories is in the following chapter.

CHAPTER THREE: METHOD

3.0. Chapter overview

This chapter deals with the method used in this research. Research instruments, methodology type of data to be collected and data characteristics are explained in detail here in. The equipment used in the test will also be discussed.

3.1. Purpose of the study

The purpose of this test was to determine the viability of using HE-motors for DSM in a petroleum refinery, as opposed to the commonly used SE-motor.

3.2. What was hoped to be achieved

The method stated in this chapter hoped to be applied in this thesis to determine the viability of using HE-motors to save electricity in petroleum refineries.

3.3. Results expected from the study

- Power, power factor and current drawn from the HE-motor and the SE-motor.
- Determination of which of the two motors consumes the least power under the same load conditions.
- The minimum period it would take to payback the premium invested to purchase HE-motors.
- Method of mitigating barriers of using HE-motor in refineries to save energy

3.4. Categories of the study

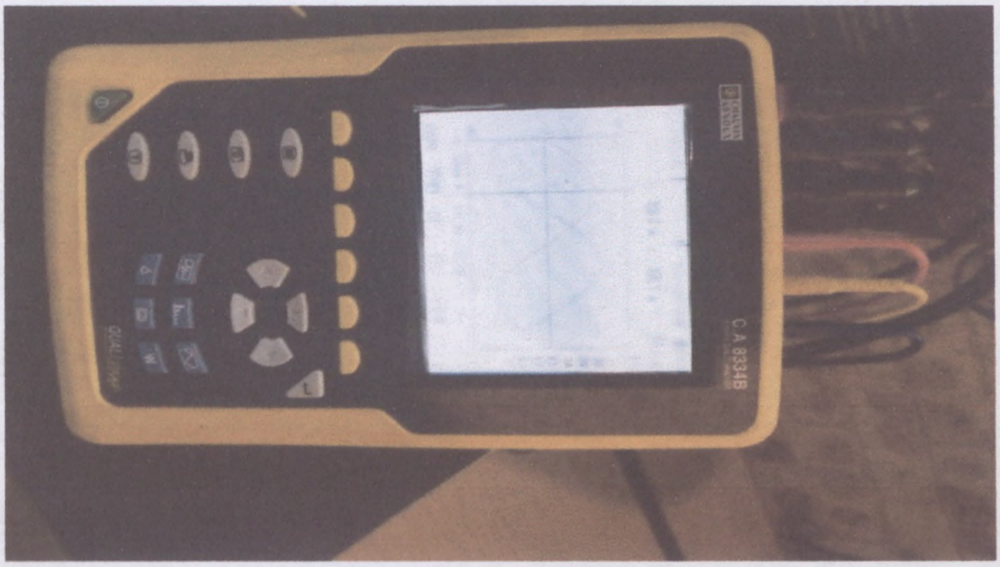
Studies performed in this thesis are grouped into four categories as follows:

- Research on HE-motors, SE-motors, DSM and refineries,
- Phone interview and emailed questionnaires to various Refineries in South Africa,
- Conducting site visits to other Refineries in South Africa,
- To conduct a comparison test between a HE-motor and a SE-motor.

3.5. Research instruments

- A power analyser was used to measure power drawn by the motors, motor voltage and current drawn by the motors.

Figure 3.1 Power analyser



- A Clip-on current meter were used to confirm current measured by the analyser,
- A voltmeter was used to confirm the analyser's voltage reading,
- A tachometer was used to test motor speed.

3.6. Strengths and weaknesses of the data collected

<u>Strength</u>

- The equipment used in the test had a valid calibration certificate, hence the data collected is assumed to be accurate.
- The measuring equipment used on the HE-motor was the same as that used on the SE-motor.
- The two motors are supplied by voltage from the same MCC, hence the motor power measurement is accurate as far as operating voltage is concerned.
- The two motors were connected to identical mechanical drives, and the loads driven by the two motors were identical.

Weakness

- It was noted from both interviews and questionnaires that engineers and engineering managers tend to give a biased report on the experience they have had with HE-motors.
- Unlike motor tests that are done in laboratories and workshops, there were no opportunities to repeat the tests. This is because performing a field motor test is an expensive operation that involves a team of people, and it must be scheduled with the operations department.

3.7. Motor power measurements

Power measurement results were the most important parameter measured in the motor test. Comparison of the motor power readings taken by the two motors were used to draw a conclusion on the energy saving capability of HE-motors. Other parameters that were considered are power factor, current and voltage readings.

3.8. Petroleum storage tank

The motors that were tested were used to drive stirrers in a petroleum fuel tank as shown in figure 3.2 and 3.3 below. Two mixers fitted in the tank, one on each side, are normally both operated at the same time. For the test purposes each motor was run independently.
The tank is 50meters in diameter and 15 meters high. This is a multipurpose tank that is used as store high viscosity crude oil, or gasoline that has a low viscosity.

Figure 3.2 Petroleum storage tank

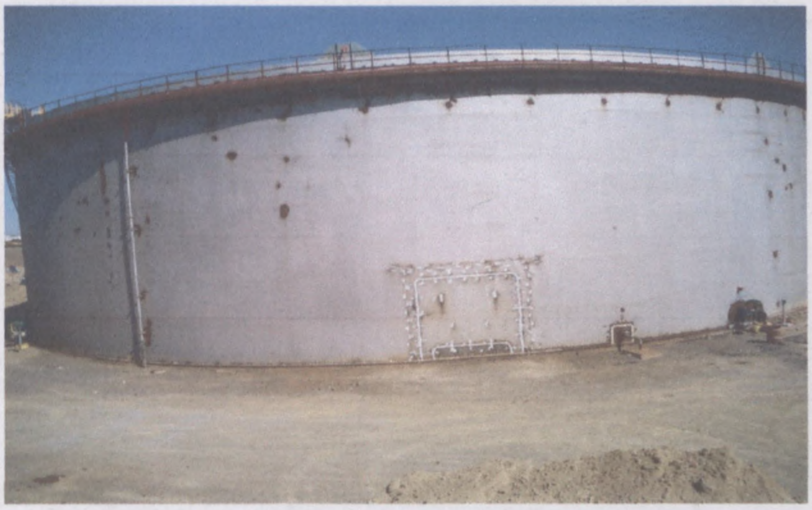


Figure 3.3 Crude oil storage tank with mixers and motors attached

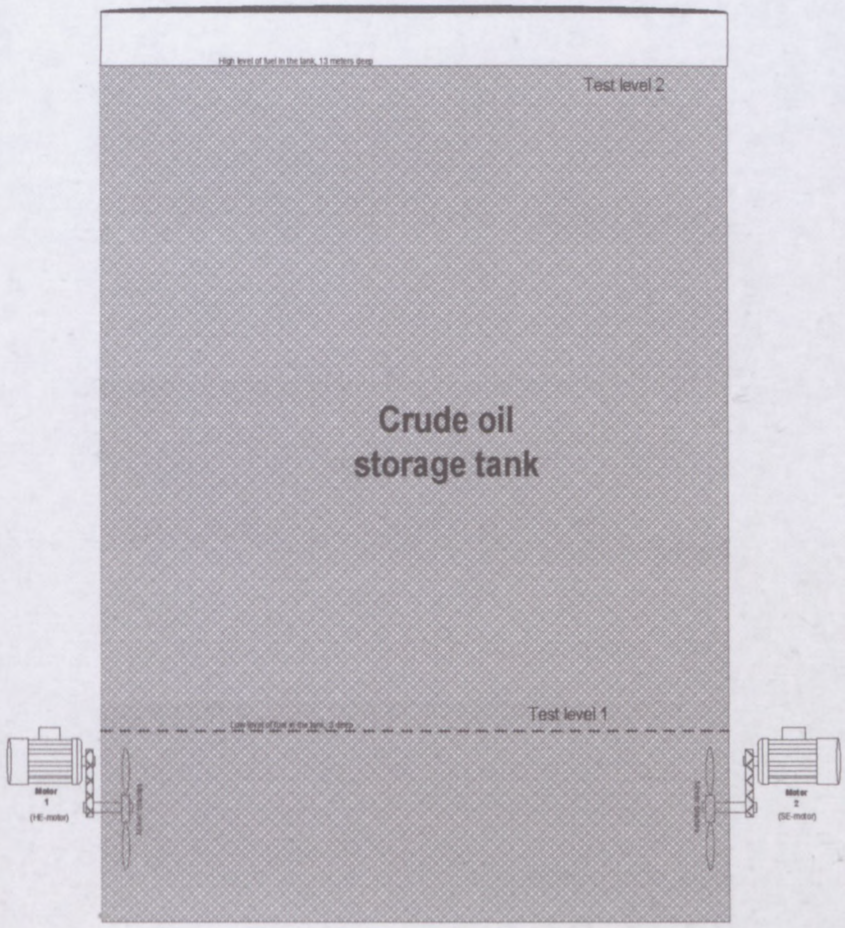
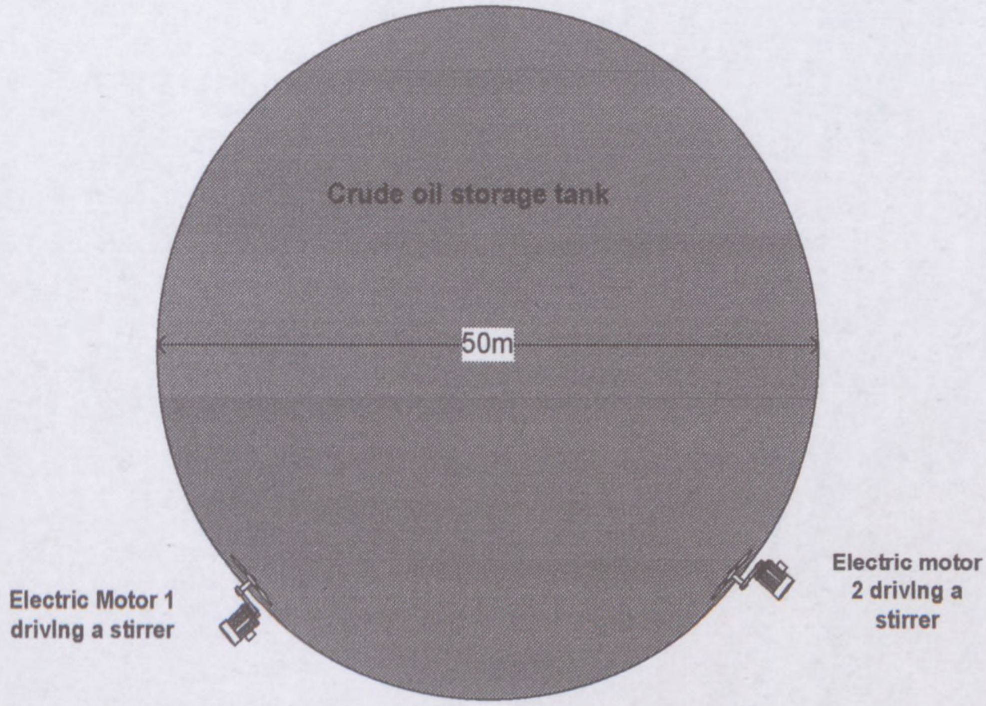


Figure 3.4 overleaf shows a top view of the same petroleum storage tank. The stirrers are useful in making the product homogenous especially before the product is pumped out of the tank. The particular tank that the test was done in contains crude, therefore making it the ideal tank to test the motors in since crude oil has the highest viscosity.

Figure 3.4 Bird's-view of the crude oil storage tank



3.9. The stirrers (mechanical loads)

The two induction motors are prime-movers of stirrers shown in figure 3.5overleaf. All efforts were made prior to the test to ensure that the two motors were subjected to identical mechanical loads as follows:

1. Both stirrers were made by the same manufacturer, and they had been newly purchased. The two were of identical specifications,
2. The drive belts were tightened to the same tension,
3. Each drive was independently run during the test,
4. The time delay between motor test one and motor test two were kept to the minimum, so as to ensure that load condition was maintained.

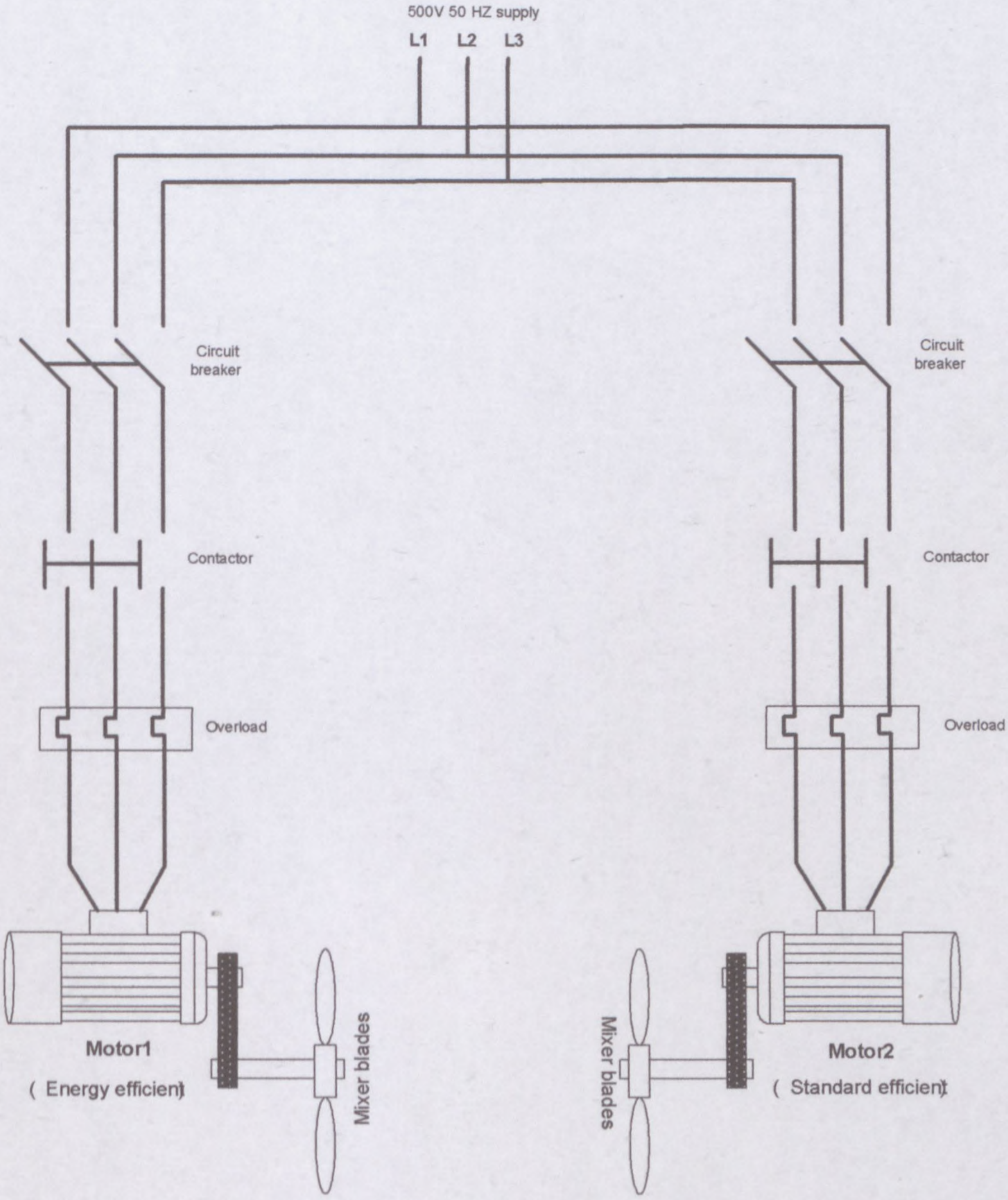
Figure 3.5 Motor and mechanical coupling of the stirrer

3.10. The motor power circuit

The circuit diagrams shown in figure 3.6 overleaf represent the power circuits of the motors that were tested. Power to the motors was supplied from the same transformer.

A direct-on-line starter was used since the motor size and the application did not warrant a more complicated starter. VSD was not a requirement for the stirrer motors since speed variation was not a requirement.

Figure 3.6 Power circuit of the HE-motor and SE-motor and their datasheet details



Power-	45kW	
Voltage-	500V	
Full load current-	62.9A	
Speed-	1480rpm	
Load	**power factor**	**efficiency**
100%	0. 88	93.9 %
75 %	0.83	93.9 %
50%	0.76	93.6%

Power-	45kW	
Voltage-	500V	
Full load current	65.3A	
Speed-	1475rpm	
Load	**power factor**	**efficiency**
100%	0. 86	92.6 %
75 %	0.80	92.4 %
50%	0.71	91.5%

Table 3.1 shows the datasheet information of the two motors that were tested, the SE-motor and the HE-motor. The actual datasheets can be found in the Annexure of this document. The datasheets shows that the two motors have an identical power rating at a supply of 500VAC. However, current drawn by the HE-motor is less than the current drawn by the SE-motor. This is because a HE-motor has less motor losses due to its design and construction. The HE-motor runs 5 rpm faster than the SE-motor, because its slip is less than that of SE-motor.

Table 3.1 Motor data sheets

Parameter	SE-MOTOR	HE-MOTOR
Type of load	mixer/stirrer	mixer/stirrer
Motor power rating	45kW	45kW
Voltage	500V, 3 phase, 50HZ	500V, 3 phase, 50HZ
Full load current	65.3A	62.9A
Rated speed	1475	1480
Locked rotor torque	240%	240%
Pull up torque	200%	200%
Breakdown torque	300%	300%
Motor starter	DOL	DOL
Motor type	WEG	WEG
Frame size	225SM	225SM
Efficiency (50%, 75%, 100%)	91.5%, 92.4%, 92.6%	93.6%, 93.6%, 93.9%
Power factor (50%, 75%, 100%)	0,71, 0.80, 0.86	0,76, 0.83, 0.88

3.11. Calculations of cost savings and payback period

Power (kW) results from the motor tests were used to determine if HE-motors would consume less power than the SE-motor while driving identical mechanical loads. The power results were used to determine how long it would take to payback the extra premium paid to purchase the HE-motor. The period used in the payback calculations was years. Stirrers in a crude tank operate at an average of 6,240 hours per year, which is an average of 17 hours a day.

3.12. Chapter summary

This chapter dealt with the method used to achieve the objectives stipulated in chapter one. Details of the data expected and the methods of achieving that data have been discussed. Possible data error, strengths and weaknesses of the data collected were discussed.

Chapter four will deal with the field test that determined the power consumption of a HE-motor and a SE-motor.

CHAPTER FOUR: CASE STUDY

Comparison of power consumed by a 45kW SE-motors and a 45kW HE-motor

4.0. Chapter overview

This chapter discusses a case study of a field test performed in a petroleum refinery to determine the viability of using a HE-motor to save energy. Power related data will be taken from a HE-motor and a SE-motor, and the results will be used to determine whether or not there is significant energy saving by using a HE-motor as opposed to a SE-motor.

4.1. Test initial conditions and assumptions

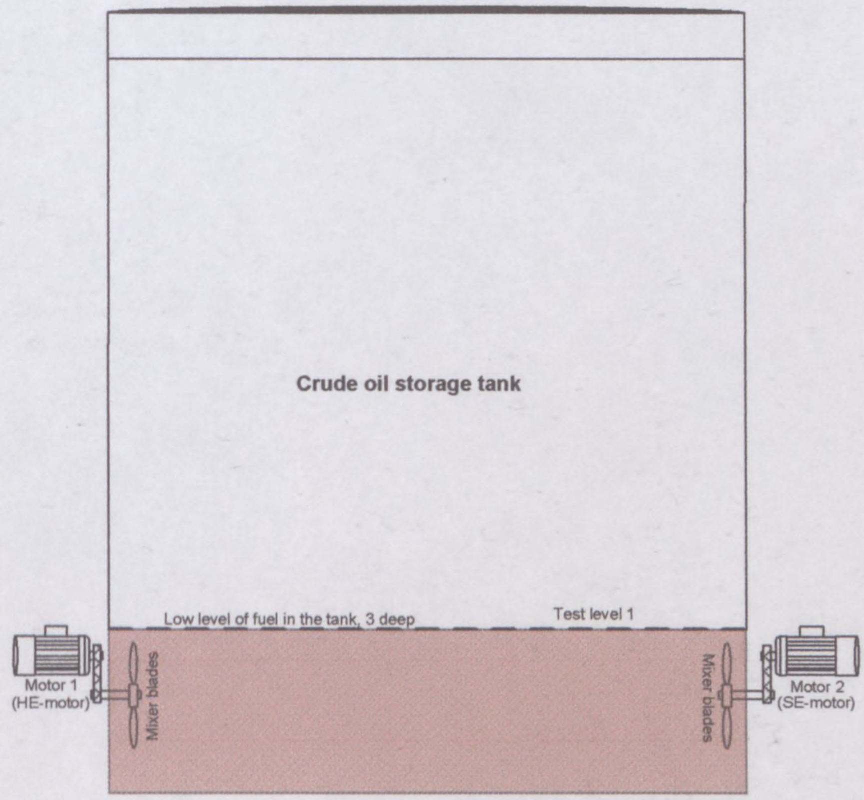
- The stirrers and the associated mechanical loads were of identical specifications, and purchased at the same time from the same manufacturer.
- The tension of the coupling belts (link between the motor shaft and the mechanical drive) were identical, meaning that the loads exerted on the motors were identical.
- The motors were at the same temperature before the test, and the test period for both motors was the same. Motor temperature affects power drawn by a motor.
- The interval between test one (SE-motor) and test 2 (HE-motor) was made as short as possible, to ensure that the condition of the product remained the same.
- Each motor was made to run a minimum of three minutes before the test was carried out, to ensure that the load in the tank was stable before the test. Sludge build up on the motor blades can impair the power reading.
- The same measuring equipment was used to carry out the motor tests. All the equipment used had valid tool calibration certificates.
- The supply voltage to the motors was identical. Both motors were supplied from the same motor control centre.

4.2. Motor test at low product level and high product level

Two sets of tests, (test one and test two) were conducted. Test one was carried out with the product at low level in the product tank, only 3 meters from the base of the tank. Test two was done with the product at high level in the product tank, about 13 meters deep. The two tests were important to determine whether product level has an effect on the motor load

4.2.1. Test one: Low product level (3 m deep)

Figure 4.1 Low product level



Testing the SE-motor

Equipment for testing the motors were connected to the SE-motor as shown in figures 4.1 and 4.2. At the time, the HE-motor located on the opposite side was switched off, to ensure that the stirring process of the HE-motor did not affect power measurements of the SE-motor.

The motor was left to run for 5 minutes before data-logging was initiated.

Motor running parameters (power, running current, power factor and applied voltage) were recorded as shown in Appendix A.

Testing the HE-motor

Motor test equipment was connected to the HE-motor as shown in figure 4.1 and 4.2.

At the time, the SE-motor located on the other side of the tank was switched off, to ensure that the stirring process of the SE-motor did not affect power measurements of the HE-motor.

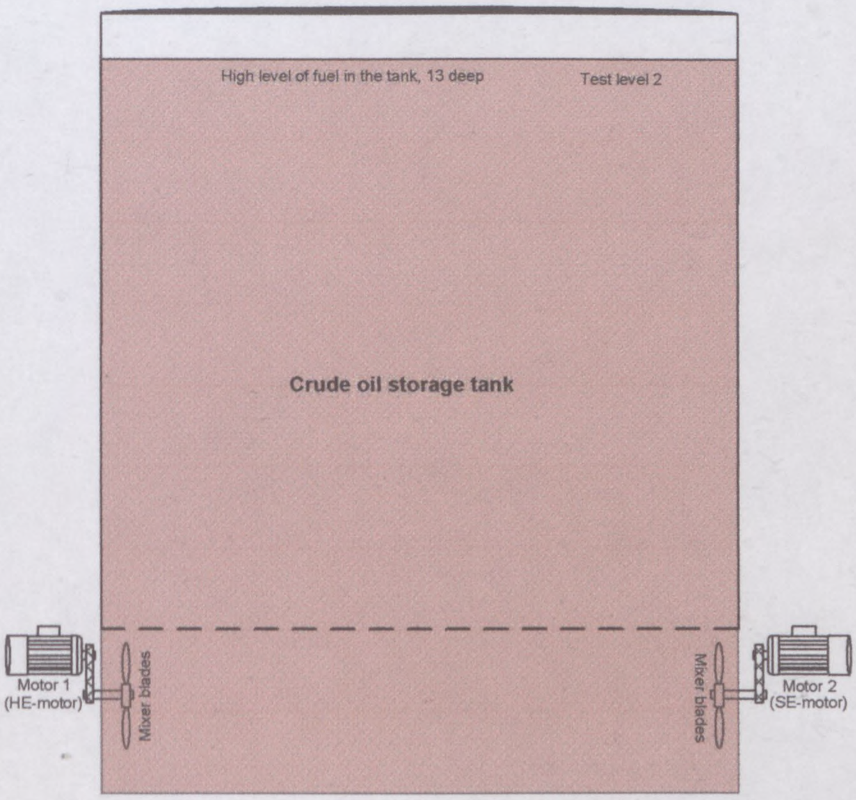
The motor was left to run for 5 minutes before data-logging was initiated.

Motor running parameters (power, running current, power factor and applied voltage) were recorded as shown in Appendix B.

Figure 4.2 Motor test equipment connected to a motor

4.2.2. Test two: High product level (13m deep)

Figure 4.3 High product level



Testing the SE-motor

Motor test equipment were connected to the SE-motor as shown in figures 4.3 and 4.4.

At the time, the HE-motor located on the other side of the tank was switched off, to ensure that the stirring process of the HE-motor did not affect power measurements of the SE-motor.

The motor was left to run for 5 minutes before data-logging was initiated.

Motor running parameters (power, running current, power factor and applied voltage) were recorded as shown in Appendix C.

Figure 4.4 Current transformers connected to a HE-motor during a motor test

Testing the HE-motor

Motor test equipment were connected to the HE-motor as shown in figure 4.3 and 4.4.

At the time, the SE-motor located on the other side of the tank was switched off, to ensure that the stirring process of the SE-motor does not affect power measurements of the HE-motor.

The motor was left to run for 5 minutes before data-logging was initiated.

Motor running parameters (power, running current, power factor and applied voltage) were recorded as shown in Appendix D.

4.3. Motor speed test

While the motors were still in the workshop before they were taken to the field, speed was measured using a tachometer shown in figure 4.5 overleaf. The intention of the speed test was to verify the fact that a HE-motor runs 5rpm faster than a SE-motor.

Figure 4.5 Artisan measuring motor speed with a tachometer

The motor speed results that were taken from the tachometer were erratic and unreliable.

4.4. Chapter Summary

This chapter covered the actual field tests conducted on the SE-motor and the HE-motor. The results attained from the test equipment are presented in the appendices, and they are analysed in chapter five.

Although speed did not form part of the scope of this project, the test was done on the two motors to verify the fact the HE-motor runs 5rpm faster than the SE-motor.

CHAPTER FIVE: ANALYSIS OF CASE STUDY RESULTS

5.0. Chapter overview

This chapter covers the results attained from the field motor tests done in chapter four. The raw data is in the Appendices A to F, but graphs representing the test results are shown in this chapter. The overall analysis of the power in kW, current, and power factor of the two motors is discussed in point 5.2 of this chapter. Individual graphs describe the measured parameters in more detail.

5.1. Test one and test two

The motor test results are grouped into two motor categories:

Test one: Motor test results of the motor-tests performed with the product at a minimum level

- Power (kW) graph showing results from the SE-motor and the HE-motor
- Current (A) graph showing results from the SE-motor and the HE-motor
- Power factor graph showing results from the SE-motor and the HE-motor

Test two: Motor test results of the motor tests performed with the product at a maximum level.

- Power (kW) graph showing results from the SE-motor and the HE-motor
- Current (A) graph showing results from the SE-motor and the HE-motor
- Power factor graph showing results from the SE-motor and the HE-motor

The motor-test raw data downloaded from the power analyser is included in annexures A to section D in this thesis.

Each graph shown in this chapter represents two test results that are superimposed into one graph. For example, figure 5.1 shows power (kW) measurements from the HE-motor and the SE-motor, taken with the product at the lowest level in the tank.

A motor-speed graph showing the speed (rpm) measured on the SE-motor and the HE-motor is also shown and discussed in this chapter.

5.2. Overall motor test results

Table 5.1 below shows details of the four motor-test results. The columns with text in green indicate the test results, and the columns with text in red indicate the motor data sheet parameters.

Table 5.1 Overall motor test results

	Power (kW)		Power factor		Current (red)		Voltage (red)	
	Rated	Actual	Rated	Actual	Rated	Actual	Rated	Actual
Test one (low product level)								
SE-motor	45	31.4	0.8 (75% load)	0.7	65.3	51.4	500	510
HE-motor	45	32.9	0.83 (75% load)	0.8	62.9	46	500	515
Test two (high product level)								
SE-motor	45	21.8	0.71 (50% load)	0.7	65.3	48.1	500	511
HE-motor	45	21.6	0.76 (50% load)	0.7	62.9	40.5	500	513.3

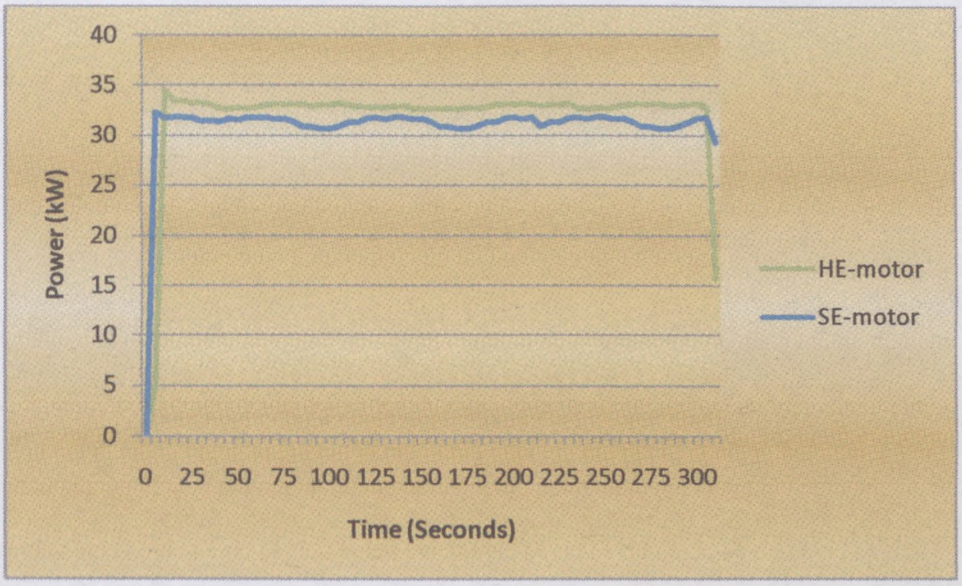
5.2.1. Motor test results at low product level

Power (kW)

The test results taken while each of the two motors was driving identical product mixers (with the product at low tank) were as follows:

- Figure 5.1 overleaf shows the results of the power measurements of the SE-motor and HE-motor superimposed on one graph.
- The SE-motor drew an average of 31.4 kW while the HE-motor drew 32.9 kW.
- The SE-motor drew an average of 1.5 kW less power than the HE-motor while driving identical loads.

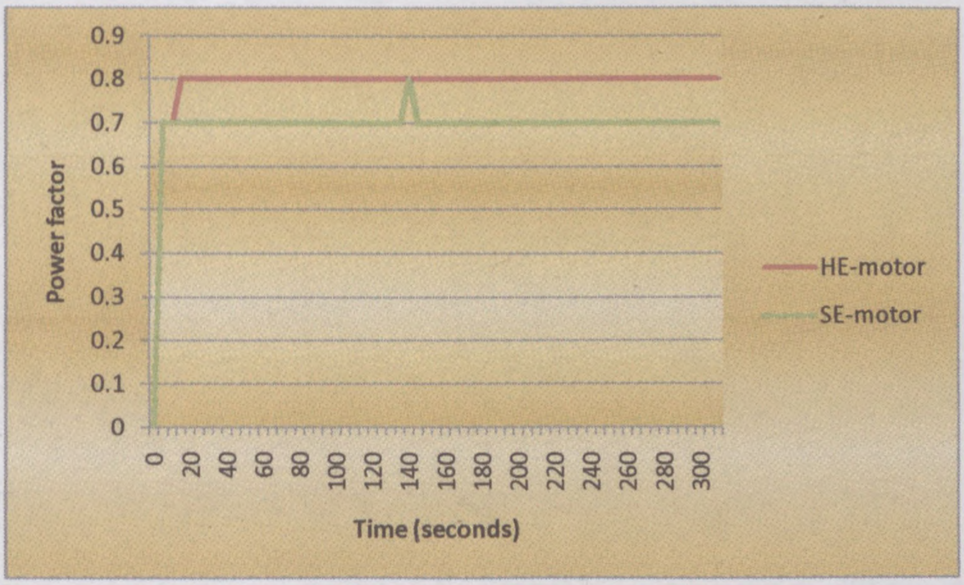
Figure 5.1 Power measurement results



<u>Power factor</u>

- The SE-motor ran at an average power factor of 0.7 while the HE-motor ran at a power factor of 0.8. Figure 5.2 below represents the power factor at which the two motors run at.

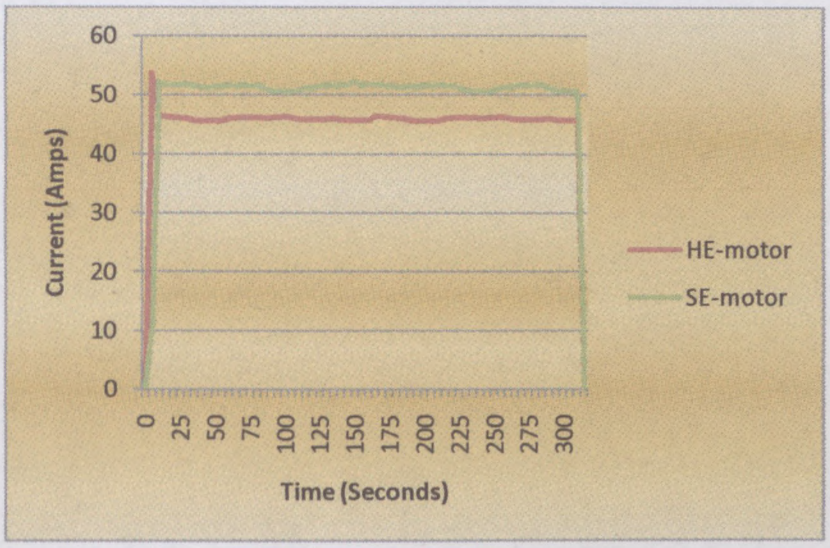
Figure 5.2 Power factors measurements results



Current (Amps)

- The test results indicate that the SE-motor drew an average of 51.4A measured on the blue phase, while the HE-motor drew an average of 46A. The HE-motor drew 5.4A less than the SE-motor.

Figure 5.3 Current measurement results



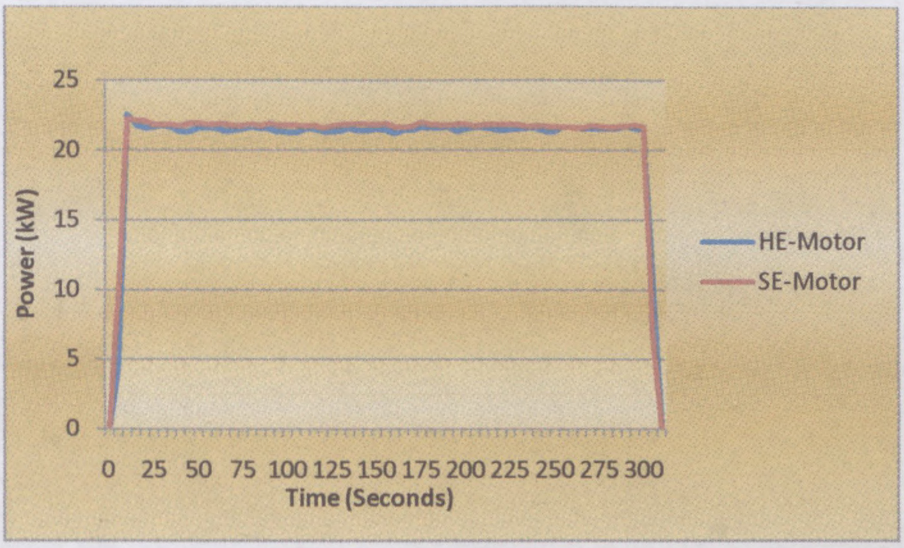
5.2.2. Motor test results at high product level

The following are mixer motor test results taken while mixing product at high tank level.

Power (kW)

- Figure 5.4 overleaf shows the results of the power measurements of the SE-motor and HE-motor superimposed on one graph.
- The two motors drew almost the same amount of power while subjected to identical load conditions. The SE-motor drew an average of 21.8 kW while the HE-motor drew 21.6 kW.
- The HE-motor drew marginally less power (0.2 kW) than the SE-motor.

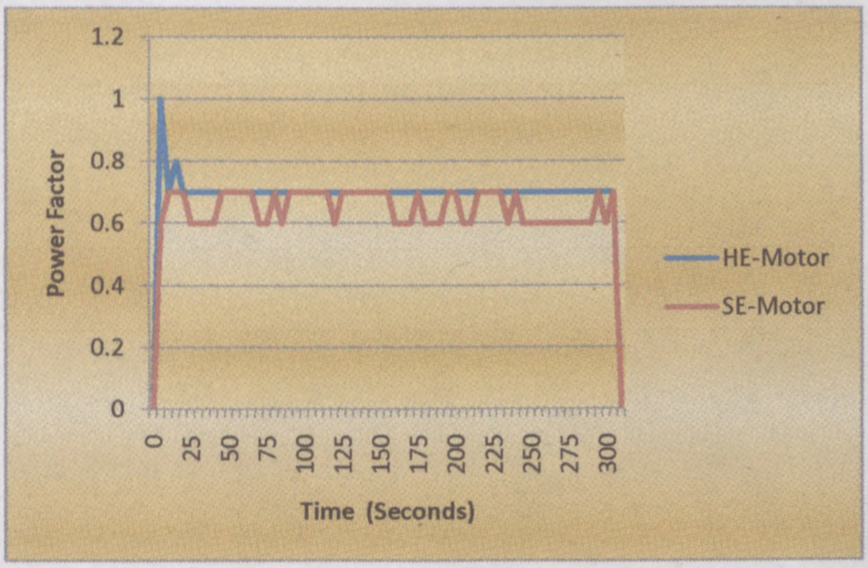
Table 5.4 Power measurement results



Power factor

- The HE-motor operated at an average power factor of 0.7 (see figure 5.5)
- The SE-motor operated at a power factor between 0.6 and 0.7. The power factor readings were very erratic as seen in figure 5.5.

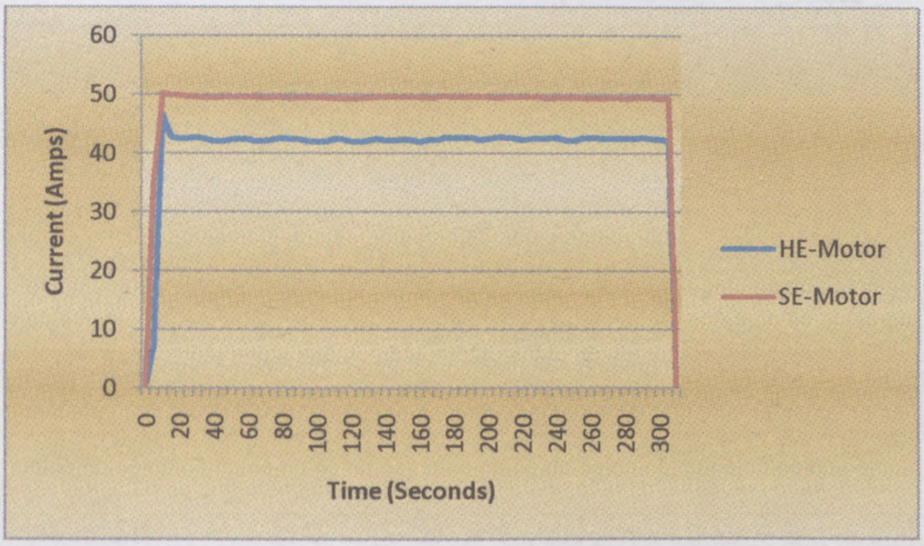
Figure 5.5 Power factors measurements results



Current (Amps)

- The test results indicate that the SE-motor drew an average of 48.1A measured on the blue phase, while the HE-motor drew an average of 40.1A. The HE-motor drew 7.6A less than the SE-motor.

Figure 5.6 Current measurement results



5.2.3. Deductions of the motor test results

Low tank level

The following is the conclusion of the motor power measurements performed with the product at low level in the product tank:

- At low product level the motor load factor was 70%, which is within the recommended load factor of induction motors for optimum power factor and efficiency. (Motoring forward).
- The HE-motor drew more power than the SE-motor when driving a petroleum product mixer at low level. This is contrary to the expectation of a HE-motor.
- HE-motors are 15% more expensive than SE-motors.
- There will be no savings to be attained from running a HE-motor in the mixer tank while the product is at low level, as the calculations in table 5.2 overleaf illustrates.

Table 5.2 Calculations of the payback period

	kW	Operation hours/year	R/kW	R/year	Initial motor cost	Payback period (years)
SE-motor	31.4	6,240	0.69	135,196	17,700	
HE-motor	32.9	6,240	0.69	141,654	20,355	
Difference	-1.5	0	0	-6458.4	-2655	Payback not possible

<u>High tank level</u>

The following is the conclusion of the motor power measurements performed with the product at high level in the product tank.

- At high product level the motor load factor was 48%, which is below the recommended load factor.
- The payback period of the HE-motor will be 23 years based on the information in table 5.3 below.
- The motors run for 6240 hours per year, and the cost of electricity on Mega-flex is 0.69 R/kWh
- It will not be possible to repay the extra money invested to purchase a HE-motor. A payback period of 23 year is much longer than the lifespan of a motor in a refinery.

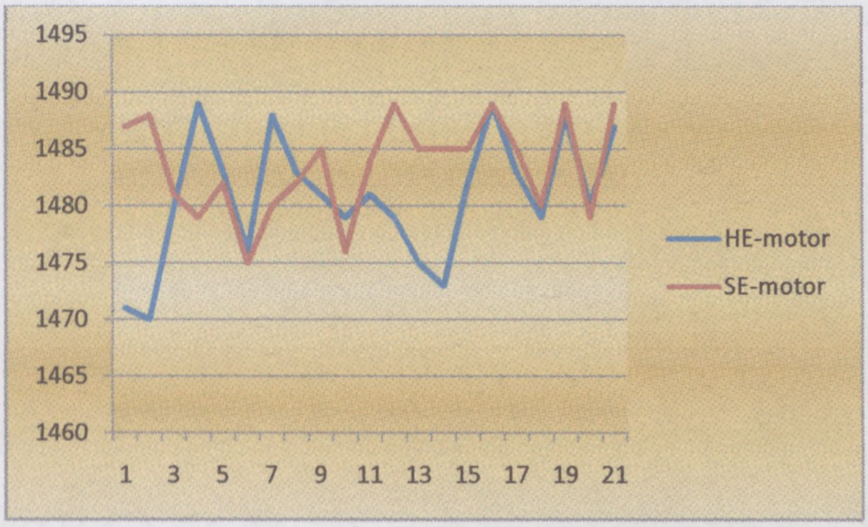
Table 5.3 Calculations of the payback period

	kW	Operation hours/year	R/kW	R/year	Motor cost	Payback period (years)
SE-motor	21.8	6,240	0.69	93,862	17,700	
HE-motor	21.6	6,240	0.69	93,001	20,355	
Difference	0.2	0	0	861.12	-2655	23.6

5.2.4. Motor speed test results

Figure 5.7 below indicates the attained speed measurements from a tachometer. The results were very erratic and unreliable, most likely due to the inferior method chosen.

Figure 5.7 Speed measurements results of the SE-motor and the HE-motor



On average the results indicated that the HE-motor operated at 1483 rpm while the datasheets indicate that the running speed should be 1480 rpm.

The SE-motor operated at an average speed of 1480 rpm while the datasheets indicate that the running speed should be 1475 rpm.

Table 5.4 Results of the motor speed

	Speed indicated in the datasheets	Average tested speed
SE-motor	1475 rpm	1480 rpm
HE-motor	1480 rpm	1483 rpm

5.3. Overall summary of the motor test results

The results of the motor test described in chapter four and chapter five indicated the following:

Summary of the motor power consumption results with low product level

- Both the HE-motor and the SE-motor operated at a load factor of 70%, which is within the recommended motor load factor for optimum power factor and efficiency.
- The HE-motor drew an average of 1.5 kW more power than the SE-motor. This is contrary to what is expected of HE-motors.
- The average power factor the two motors run at was 0.7 for the SE-motor and 0.8 for the HE-motor. The results of the power factor measurements of the HE-motors were as per the datasheets. A power factor of 0.7 for the SE-motor is lower than expected 0.78. The low reading might be due to the measuring equipment error.
- The test results indicated that the SE-motor drew an average of 51.4A on the blue phase, while the HE-motor drew an average of 46A. This means that the HE-motor drew 5.4A less than the SE-motor. This is true as the HE-motor operated at a higher power factor than the SE-motor.
- The reason why the HE-motor drew more power than the SE-motor while supplied from the same power supply and while driving identical loads is because tank mixers are centrifugal loads.

$$P \propto N^3$$

- HE-motors have smaller slip hence they have a higher operating speed. The small increase in motor speed increases the motor power consumption by a cube.
- HE-motors are 15% more expensive than SE-motors.
- There will be no savings attained from running a HE-motor in the mixer tank while the product is at low level.

Summary of the motor power consumption results with high product level

- The load factor of the two motors was 48%, which is below the recommended load factor for optimum power factor and motor efficiency.
- The two motors drew almost the same amount of power, which is 21.8 kW for the SE-motor and 21.6 kW for the HE-motor. Therefore the HE-motor was 0.44% more efficient than the SE-motor
- The payback period of the HE-motor will be 23 years, which is longer than the average lifespan of such a motor at a refinery.
- The test results indicate that the SE-motor drew an average of 48.1A on the blue phase, while the HE-motor drew an average of 40.5A. Therefore the HE-motor drew 7.6A less than the SE-motor.
- The low current drawn by the HE-motor was due to the high power factor of 0.7 at which it operated on, as compared to the power factor of 0.6 that the SE-motor operated at.
- The speed test results were not useable since the instrument used to measure produced very erratic results.

Conclusion

It is not worthwhile to invest in HE-motors for the purpose of reducing electricity bills if the motors will be used to drive centrifugal loads like tank mixers. This is because HE-motors operate at a higher speed than the SE-motors. The increase in speed increases power consumed by the motor by a cube while delivering the same amount of work.

If a fan or pump is installed in an unchanging system, the flow is directly proportional to the speed of the fan or pump.

$$Q \propto N \quad (4)$$

A change in pressure difference (P) is proportional to the square of the flow rate (Q) in litres per minute. If the flow doubles, the pressure drop quadruples.

$$P \propto Q^2 \quad (5)$$

Power (P) is proportional to speed (N) cubed [9]. If the speed of a pump is doubled, the power requirements are cubed.

$$P \propto N^3 \quad (6)$$

It is not possible to quantify whether or not the extra speed the HE-motor spins the mixers by will homogenizes the petroleum product better. This fact makes it difficult for the operators to harness the capability of the HE-motors to operate faster.

5.4. Chapter summary

Chapter five is probably the most important chapter of all, as it adds meaning to all the theory discussed in the preceding chapters. The focal point of chapter five was to discuss the results attained from the field motor test that was performed in chapter four.

The results that were collected from questionnaires, phone calls and visits to other refineries with regards to the application of HE-motors in refineries are discussed in chapter six.

CHAPTER SIX: CHALLENGES AND MITIGATION OF SUCCESSFUL IMPLEMENTATION OF HE-MOTORS

Chapter overview

Chapter four and chapter five described the motor field test and the analysis of the test results, to determine the viability of using HE-motors in refineries for energy saving purposes. Chapter six is a summary of the results that were received from various stakeholders from different refineries in South Africa, on the challenges of implementing HE-motors for energy saving purposes. Methods of mitigating the challenges are also discussed in this chapter.

6.1. Challenges of successful implementing of HE-motors for DSM

Implementing HE-motors in refineries has always been met with both internal and external challenges. Without a proper study of the load characteristics, plant operation philosophies and maintenance procedures, implementing HE-motors can be a waste of precious time and money. This section analyses the challenges of implementing HE-motors in refineries, based on the information the researcher gathered from various refineries he visited and contacted during the course of his studies.

6.1.1. Inherent design characteristics of HE-motors

High start-up transient

HE-motors have higher transient currents due to lower core resistance. Sometimes the transient current may be as much as 13 to 20 times FLC. These high transient currents cause nuisance tripping of the motor protection circuit breaker if the starter system is not designed properly. The high transient current characteristics of the HE-motor require an upgrade of the motor starter if a SE-motor is to be replaced with a HE-motor thus increasing the cost of retrofitting.

Inferior starting torque

HE-motors have a smaller slip as compared to SE-motors. The smaller slip reduces the torque developed by the motors, meaning that HE-motors should not be used on loads where starting torque is critical (Poolet al., 2002). A good example is a high inertia fans.

Low speed

The lower slip of the HE-motor causes the motors to operate at a higher speed as compared to the SE-motor. The increase in speed causes the motors to consume more power when driving centrifugal loads. This is a concern in petroleum refineries where the majority of loads are centrifugal. Centrifugal pumps obey what is referred to as 'infinity laws', which state that for a fixed-size pump and impeller diameter, the pump flow varies directly with speed, a pump's head varies with speed squared and shaft power varies with speed cubed. This means that using HE-motors on centrifugal loads like pumps may not necessarily save energy because their increased speed actually increases flow which in turn consumes more power. It is very likely that using HE-motors may get the product pumped faster but the electricity bill may remain unchanged or even become higher. This fact was clearly proven by the motor test described in chapter four and chapter five. The HE-motor under test consumed more power than a SE-motor.

Figure 6.1 Pump drive in a petroleum refinery

6.1.2. Need for saving electricity is not yet a reality

As mentioned in point 2.4, the three main motivating factors for saving electricity are

1. Limited availability of electricity
2. The environmental impact caused by GHGes
3. The high cost of electricity

These three factors by themselves have not been sufficient to influence South Africans to save electricity. As industrial contribution to global warming is not a very easy subject to understand; hence it does not influence electricity users to save electricity.

The prices of electricity in South Africa have not been a good motivation for saving electricity either, since they are among the lowest in the world. But this is about to change especially after the *national energy act* becomes active this year (2010), which permits a 30% increase in the price of electricity for the next three years.

Insufficient supply of electricity in the country is the main factor that has been encouraging consumers to save electricity, especially after recent power black-outs and power rationing were experienced country wide.

6.1.3. Insufficient or non-existent motor-related regulations

Important regulations that are necessary to support importation, supplying and repairing of H-E motors are either missing or are insufficient. Requirements for high efficient motors are presently not clearly defined. For example there is confusion among motor importers on what the minimum efficiency and minimum power factor H-E motors should have. Some motor importers claim that they import better constructed, high specifications HE-motors than their competitors. There are also very few motor winders and repair shops in the country who can meet the minimum requirements for an approved motor repair shop. This means that some of the unapproved winders may soon be repairing HE-motors.

6.1.4 High cost of HE-motors

HE motors are 10% - 15% more expensive than SE-motors. This is based on a standard motor delivery period, as quicker deliveries attract higher motor prices. With the current world economic crunch, the Rand to Dollar exchange rate and the increase in copper prices leads to increased motor prices. Therefore, high motor price is a deterrent towards implementation of HE-motors.

Inherently petroleum refineries pay more money for motors since almost all of their motors are Ex-motors or flame-proof motors. Such motors are 15-20% more expensive than non-Ex motors. Therefore, the project funder (refinery) would want to know that additional premium invested to purchase HE-motors would bring about a saving

6.1.5. Motor incentives are temporal

As stated in section 2.7.1, offering incentives is one method of encouraging energy consumers to embrace DSM, but unfortunately incentives are not meant to be permanent. Therefore, factoring incentives into the pay-back period and total-cost-of-ownership may lead to inaccurate figures. To illustrate this point further, according to Mtombeni (2008), 1.1kW to 90kW motors qualify for the ESKOM rebate program that commenced in 2007.In a resent presentation, ESKOM confessed that they have run out of funds for the motor rebate program, a mare three years since the program's inception.

6.1.6. Use of available motors during a plant breakdown.

Therefore in the event of a breakdown in the plant, maintenance personnel use whatever motors are available, whether SE-motor, or a motor that has been rewound for four or five times already.

Some refineries use motors of non-standard voltage, i.e. 500V rating as opposed to 525V. Normally such motors are purchased on special order which takes 8 to 10 weeks to deliver. This is a long time to wait should a motor be required urgently.

Figure 6.2. Petroleum storage tank. Inset: Mixer motor

6.1.7. Awareness of the HE-motor capability

Although HE-motors were developed 20 years ago and have been used in DSM programs in many countries, they are not widely known in South Africa (Pool, 2004). There is a lot of disagreement among many engineers and technicians in the industries, on the effectiveness of using HE motors for energy saving. Some parties have chosen to believe rumours that claim HE-motors are not effective for energy saving, whist others know the capabilities of HE-motors, but are still unwilling to embrace the concept. Simplified methods of determining HE-motor savings are not readily available, which makes it even more difficult to determine the viability of the motors for DSM.

6.1.8. There are no binding regulations from the authority

The South African government has not yet enacted regulations that enforce the use of HE motors. There is a tendency for people to be obedient only when they know of a pending penalty for noncompliance. Even with threats of monetary penalty more often than not people chose to suffer the consequence than to comply.

6.1.9. Rationale of project engineers and consultants.

Project engineers and consultants avoid specifying high efficient equipment in projects, especially if the benefit of using such equipment is not proven. It is therefore easy for them to specify SE-motors regardless of the possibility that HE-motors may save electricity and repay themselves over time. Many project engineers and consultants have a controlled budget, and their incentives are based on performance, which includes better budget control. Motor payback time and how green a project is has no bearing in making an existing project look impressive.

6.1.10. Social factors

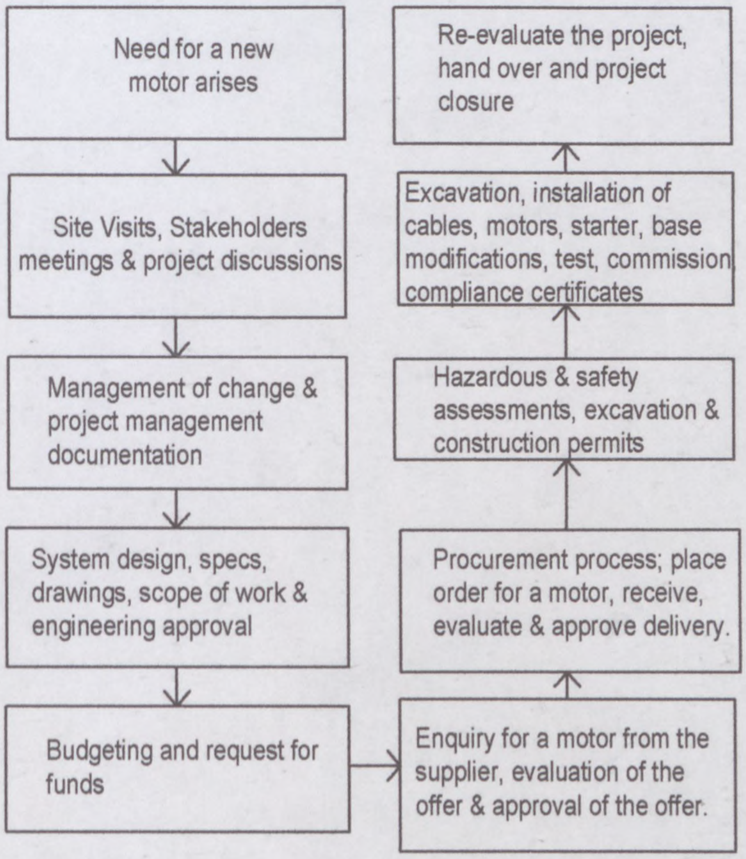
The motor management best practices recommend that faulty small motors should be replaced with new HE-motors instead of rewinding them. Such a practice would polarise the dozens of small motor winders whose primary business is rewinding motors.

6.1.11. Unwilling to change working systems

With the current economic challenges, many companies are only maintaining a minimum number of employees. This means that companies are only prepared to fund critical projects while less important ones are not considered. This throws energy efficiency projects out of scope.

The cost and engineering hours it takes to complete a project is a discouragement for energy efficiency projects. Therefore, many refineries live by the rule of 'if it isn't broken don't fix it'. Figure 6.3 below shows the process of ordering a motor in a refinery and illustrates the above point.

Figure 6.3 Process of ordering a motor



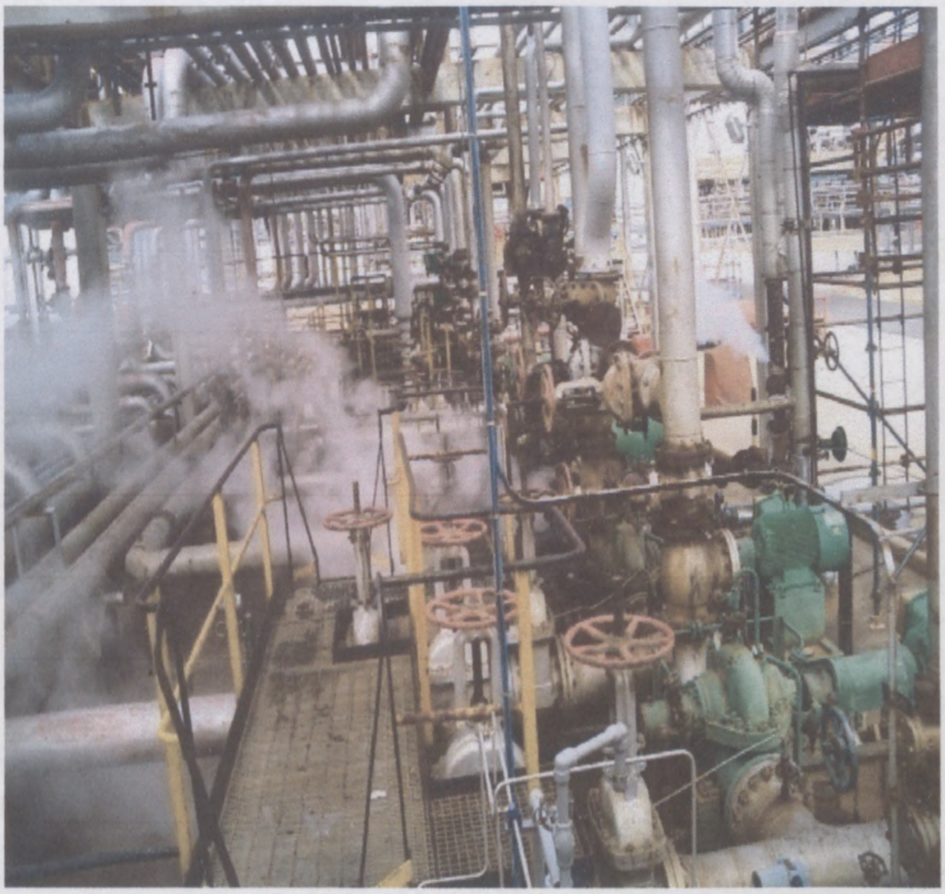
6.1.12. Perception that HE-motors are not a high priority tool for DSM

There is a general belief that there are many other opportunities of saving power besides the use of HE-motors. It is very difficult to justify a purchase of a HE-motor for the benefit of 0.44kW of saving while:

- There are numerous plant repair and maintenance opportunities that have not been attended to (see steam leak in a refinery in figure 6.4).
- compressors are throttled to the atmosphere,

- there is a non-functional management system, no records of rewound motors, new motors, missing motor name-plates, no set specifications of when to rewind and when not to, no stipulated procedures of how motors should be rewound,
- mechanical engineers are specifying oversized motors,
- there are no proper plant operation procedures and philosophies

Figure 6.4 Steam leaks in an oil refinery



6.2. Methods of mitigating challenges of using HE-motors for DSM

This section deals with methods of mitigating challenges of successful implementation of HE-motors in refineries for energy saving.

6.2.1. Truth about HE-motors as an energy saving tool

People who market motors should always be truthful to their customers. Some of the efficiency figures and payback periods that have been thrown around by motor salespersons leave a lot to be desired. A clause that states that 'the efficiencies stated in motor brochures are just claims, and chances are that they may not be achieved' should be printed on every HE-motor marketing manuals and brochures.

6.2.2. Acquiring detailed process requirement prior to designing a system.

Proper system analysis and proper sizing of equipment are vital when designing a motor system. A good motor design should be in such a way that the motor load factor is between 60% and 100%. Full system information is vital prior to carrying out a new design.

6.2.3. DSM awareness campaigns

Extensive DSM awareness programs need to be aimed at motor users through courses, publications, brochures and campaigns. Provision of reliable and simplified motor payback period calculators need to be made available to customers.

6.2.4. Carrying out motor tests after completing an installation

Rarely do engineers go back to the field to determine motor performance after an installation has been completed. Information from such a test would go a long way in ensuring that future designs are optimized. The economic crunch is causing engineers to work like guerrilla soldiers, i.e. 'hit, run and assume it is dead'.

6.2.5. Effects of the community and social factors.

The South African government claims that they are on a mission to increase employment in the country, especially in small scale sectors. Recommendations that small motors should not be rewound will end up curtailing small enterprises that are in the business of rewinding motors. Research on the impact of replacing small faulty motors in South African context needs to be undertaken.

6.2.6. Plant process requirements

Sometimes process requirements specify that products should be pumped at a higher pressure than the system was initially designed to perform. This means that bigger than normal motors and pumps are specified for a retrofit. The load factor and efficiency of such a system ends up being low. The same case applies when plant operations require a particular plant to handle products with different load characteristics. Better plant operation controls would assist in using motors systems more efficiently.

6.2.7. Motors installed in most plants are oversized.

The majority of motors that are in operation in many plants are over-sized. This is inherently because of poor designs, unknown processes and load requirements during design. Over sizing affects motor efficiency and running power factor.

Replacing such oversized motors with HE-motors may not necessarily bring about a saving. It is better to invest in other energy efficient measures rather than replacing HE-motors with SE-motors.

6.2.8. HE-motors: Useful for low consumption of electricity or better MTTF?

Primarily HE-motors have longer MTTF (mean-time to failure) and in some cases they use less electricity while developing the same amount of output as a SE-motor would.

However there are many instances when HE-motors are not viable for use, especially when they are used to drive centrifugal loads. In such instances, some motor salespersons would still justify use of HE-motors due to their long MTTF. Caution is required in doing so because a number of plant mechanical drives fail many times over before a motor failure occurs. In other words, chances are that motor bearing will fail once in a specified period while mechanical drives fail five times. More often than not, replacement mechanical drives are purchased as a pack that contains a new motor anyway. Hence it is not always economical to purchase HE-motors for their long MTTF.

6.2.9. Maintenance crew are required to maintain HE-motor systems

Motor systems require regular maintenance for them to run efficiently. It is not prudent to invest in HE-motors if there are no maintenance personnel to maintain the systems. The on-going reduction of staff through retrenchments leaves many plants with few maintenance personnel who end up attending to plant breakdowns while neglecting regular motor maintenance. Hence HE-motors require a maintenance crew for them to operate efficiently.

6.2.10. Incentives

There are a lot of bureaucracies surrounding HE-motor rebate systems. This discourages motor users to pursue the option due to lack of time and manpower to pursue such rebates. A sleeker rebating process needs to be put in place by ESKOM to encourage motor users to explore options of using HE-motors for energy saving purposes.

6.3. Chapter summary

Chapter six dealt with the challenges of using HE-motors for energy efficient purposes. It also covered various methods of mitigating those challenges. Chapter seven covers the conclusion and further recommendations.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.0. Chapter overview

Conclusions of the work done in the previous chapters are analysed and recommendations given.

7.1. Summary of research problem

HE-motors have been widely publicised as potential tools of saving the scarce commodity of electricity and to reduce the cost of electricity. But tests to verify the viability of HE-motors to save electricity are rarely done in the industry. The concern is that there are many instances whereby motor users purchase and install HE-motors in the name of reducing consumption of electricity, but the expected savings are never realized. The main factors that inhibit reduction of electricity consumption by using HE-motors are poor system designs, poor motor selection and poor overall decision making in this regard.

The motor tests performed in this research confirmed that use of HE-motors to reduce the electricity bill is not a perfect guarantee. At some point it may even be that the HE-motors may consume more energy than SE-motors.

7.2. Summary of research findings

Motor load factor

At low product level both the HE-motor and the SE-motor operated at a load factor of 70%, which is within the recommended motor load factor for optimum power factor and efficiency. At high product level the load factor of the two motors reduced to 48%, which is below the recommended load factor for optimum power factor and motor efficiency (motoring forward).

Power consumed by HE-motor and SE-motor

At low product level the HE-motor drew an average of 1.5 kW more power than the SE-motor. This is contrary to what is expected of HE-motors.

At high product level the two motors drew almost the same amount of power, 21.8 kW for the SE-motor, and 21.6 kW for the HE-motor. Therefore the HE-motor was only 0.44% more efficient than the SE-motor

Pay-back period

At high product level, the additional premium invested to purchase a HE-motor will be 23 years, which is longer than the average lifespan of a motor at a refinery. At low product level the additional premium invested in purchasing a HE-motor will never be recovered. These conclusions are based on the fact that the HE-motor was purely purchased for the purpose of reducing the electricity bill.

Cost of a HE-motor compared to a SE-motor

Generally HE-motors are 15% more expensive than SE-motors. This cost difference may differ from one motor size to the next and from one motor supplier to another.

Operating power factor

The test results indicate that the HE-motor drew an average of 40.5A, while the SE-motor drew an average of 48.1A. Therefore the HE-motor drew 7.6A less than the SE-motor. This is likely due to the high power factor of the HE-motor. It operated at a power factor of 0.7 compared to the SE-motor which operated at a power factor of 0.6.

At high product level the SE-motor operated at an average power factor of 0.7, and the HE-motor operated at 0.8. The power factor test results for the HE-motor were as per the data sheets. A power factor of 0.7 for the SE-motor was lower than the expected 0.78, which was possibly due to errors in measurement.

Why did the HE-motor draw more power than the SE-motor

The reason why the HE-motor drew more power than the SE-motor, while both were supplied from the same power supply and driving an identical load was because tank mixers are centrifugal loads.

7.3. Deductions

It is not worthwhile to invest in HE-motors for the purpose of reducing the electricity bill if the motors will be used to drive centrifugal loads. This is because the HE-motor operates at a higher speed than the SE-motor. The increase in rotor speed increases power consumed by a cube while delivering the same amount of work.

The effect of increased speed of a HE-motor on electricity bill

The fact that the majority of loads in petroleum refineries are centrifugal loads makes HE-motors the wrong tool for DSM. The inherent high speed of HE-motors over SE-motors causes power consumed by the motor to increase as a cube without an increase in flow. In a mixer application like the one described in this thesis the increase in speed does not enhance the production requirements, because the mixers run all the time regardless of the status of the product. The fact that the motor runs faster or slower is immaterial to the process requirements.

Using HE-motors to save energy

Application of HE-motors is not a straight forward choice. Good understanding of their short and long term ramifications and social implications is crucial before they are used as an effective tool of DSM. Just like how a new drug is studied, tested, analysed and appraised before being sold to the public, implementation of HE-motors needs thorough investigation and appraisal on a case by case basis. Induction motors are robust, resilient, highly efficient machines, with very little room for improving efficiency. HE-motors are just a small component of the total amount of energy that can be saved

7.4. Recommendations and suggestions for future research

Research on the use of a combination of HE-motors and VSDs in petroleum refineries for energy saving purposes will increase knowledge of reducing power consumed by motors. This is because the majority of motor loads in refineries are centrifugal loads.

The social impact of replacing small faulty motors with HE-motors is a wealthy field of study, as replacing faulty motors with HE-motors may force small motor winder shops to go under. This is a very relevant topic in South Africa as the government is on a drive to increase employment.

7.5. Final comments from the author

One of the ethical obligations of professional engineers is to analyse systems, theories and designs, and be able to draw accurate and simplified deductions that can be applied to improve the living standards for animals, plants and the environment at large. This statement has not been fully adhered to in the HE-motor initiatives. Engineers and the associated parties have not always told the end users that swapping motors might indeed not save them energy.

Presentations done on HE-motors mostly hide behind laboratory test results on the energy saving capability of HE-motors. Well, this is true, but as explained earlier priorities need to be set on which areas energy savings can be achieved at a minimum cost, especially on matters that affect behaviour. It is stated that using HE-motors will consequently reduce the emission of greenhouse gases. Well, that is also true but once again, customers must be informed upfront that they are spending extra cash not necessarily to save energy, but to reduce pollution.

7.6. Accomplishment of research objectives

This research was able to accomplish the intended objectives, through motor testing and research done on various refineries in South Africa.

REFERENCES

[1]. A. Boglietti, A Cavagnino, M. Lazzari, M. Pastorelli (2003), '*Induction motor Efficiency measurements in accordance to IEEE 112-B, IEC 34-2 and JEC 37 international standards',* IEEE journal 0-7803-7817-2, 2003.

[2]. A.S. Dogoumas, G.K. Papagiannis, P.S. Dokopoulos (2004), *'an economic assessment of Kyoto Protocol application'* Elvservier journal, EP 34 (2006) 26-39.

[3]. Ahmed Eltom, Mohammed A. Aziz (2005), The economics of energy efficient motors during imbalanced voltage conditions, 0-7803-9327-9, IEEE

[4]. AK Mohamed, MTE Kahn (2008), *'Contribution analysis of electrical energy management in the industrial and commercial sector: a challenge to the Tanzania utility industry'.* Journal of energy in South Africa, Vol.19 No1 Feb.

[5]. Anibal T. de Almeida, Paula Fonseca & Paolo Bertoldi (2002), *'Energy-efficient motor systems in the Industrial & in the service sectors in European Union*: Characterization, Potential, barriers & Policies', Science Direct publishers, 28: 673-690.

[6]. Anibal T. de Almeida, Fernando J.T.E. Ferreira, Joao A.C.Fong, Conrad U. Brunner (2008), *'Electric motor standards, Ecodesign and Global Market Transformation'*, IEEE Industrial & Commercial Power Systems Technical Conf. (ICPS'08), Florida, USA

[7]. B.L. Theraja & A.K. Theraja (2003), *'A text book of Electrical Technology'*, S Chand & Company publishers, New Delhi, 2003.

[8]. Clark w. Gellings (1985), *The concept of Demand Side Management for Electric utilities',*0018-9219/85/1000, IEEE

[9]. David Ratcliff (2006), '*How Employees can save energy'* Energy Management News magazine, Volume 12 no.1, ERC publishers, Mar 2006.

[10]. David Walters (1999), Energy efficient motors, Saving money or costing the earth, Power engineering journal

[11]. *DSM Best Practices Guidebook (2006)'*, Published by International Institute for Energy Conservation (IIEC), www.iiec.org.

[12]. *Demand side management overview of key issues (1984)'* Battelle- Columbus Division, Columbus, Ohio and synergic resources Corporation Balacynwyd, PA, for EEI and EPRI Project, August 1984, Vol. 1, pp, 14-25.

[13]. Dennis Willemse, Gerhard Bergh, Thava Perumal & Henk Van Zyl (2008), *'The influence of proposed energy bill on Sasol's motor management strategies'*, ICUE conference, Cape Town May, 2008

[14]. Dr. G. Thomas Bellarmine, *'Load management techniques'* by P.E. Electronic Engineering Technology, Florida University. Ieee 2000 0-7803-6312-4/00, p139

[15]. Dr. Pragasen Pillay, Kelli A. Fendley (1995), *'The contribution of energy efficient motors to demand and energy saving in the petrochemical industry'*, Vol. 10, no. 2, May 1995.

[16]. Dr.Tsakani Lotten Mthombeni (2007), *'Energy Efficient Motor Systems For ESKOM Demand Side Management'*, ICUE conference paper, CPUT, 2007

[17]. Edward Cowern (2002), *Baldor motors and drives, Cowern papers,* Baldor electric company, www.baldor.com

[18]. ESKOM (2009), *'Motoring Forward'* Engineering News magazine, Creamer Media publisher, Vol. 29:4, '09.

[19]. ESKOM DSM program, http://www.ESKOMdsm.co.za, Website

[20]. Gail E. Tverberg (2008), *'Path from Petroleum shortage to electricity shortage'*, 13 August, 2008, The Oil Drum,

[21]. Geoff Irvine, Ian H. Gibson (2000), *'The use of variable speed drives as a final control element in the petroleum industries'* 0-7803-6401-5,IEEE,

[22]. Hamidi B, (2008),

[23]. Hans DeKeulaer, Ronnie Belmans and others (2004), *'HE-motor Driven Systems - The Motor Challenge Program',* European Copper Institute, Brussels, Belgium, April 2004.

[24]. Harald Winkler (2008), *'Cleaner Cooler Climate: Developing Sustainable Energy Solutions for South Africa'*, Energy Management News magazine, ERC publishers, Vol. 14 no. 4, Dec 2008.

[25]. http://www.mbendi.com/indy/oilg/ogrf/af/sa/p0005.htm

[26]. Juergen F. Fuchslosh (2006), Next generation NEMA premium efficient motors Substantially lower operating costs, IEEE, PCIC- 2006-8

[27]. Johan van Niekerk (2009), *'Energy Situation in South Africa'*, Electricity + control magazine, Crown Publications, Jan 2009.

[28]. Joe Hill house, Gary Donner, JW Hodson, Nobert Klekowski (2004), *'An evaluation of TEFC vs WP11 motors in a harsh petrochemical application'*, 0-7803-8698-1, IEEE.

[29]. Kelli F. Cheek, Pragasen Pillay (1995), *Impact of energy efficient motors in Petrochemical industries',* Elsevier, EPS, 42.

[30]. Loni Prinsloo (2008), *'HE-motor Subsidy will Change the face of power use in Industry'*, is engineering news Magazine, Creamer Media publisher, 18th April 2008.

[31]. Lorraine K Padden, Rick Bried, James Dymond (2003), *'Guide for application of electric motors in Class 1 Division 2 hazardous locations',* PCIC -2003-06, IEEE.

[32]. Lynn Wheat (2008), *'Do high efficient motors always save energy?' Control Engineering magazine*, Reed Business Info. Publishers, issue Vol.1, No.2, Feb '08.

[33]. M A Khan, D. Pati and HM Mzungu, (2008), *'Comparison of a 3kW Standard and high efficient induction motor'*, energizer journal, Nov 2008.

[34]. Mehmet Akbaba (1999), *'Energy conservation by using energy efficient electric motors'* Elsevier journals, applied energy 64 (1999) 149-158

[35]. M Lotz (2008), *'Review of carbon dioxide capture and sequestration and the Kyoto Protocol's clean development mechanism and prospects for South Africa',* Journal of energy in South Africa, Vol.19 No1 Feb 2008.

[36]. Nicky Smith (2008), *'ESKOM the inside story, road to a blackout'*, financial mail, May 2008.

[37]. P. Pillay (1997), *'Applying Energy Efficient Motors in the Petrochemical industries'*, 1077-2618/97, IEEE.

[38]. P. Pillay, *'practical considerations in applying Energy Efficient Motors in the Petrochemical industries'*, PCIC-95-21, IEEE.

[39]. Paul S. Hammer, Debra M. Lowe & Stanley E.Wallace (1997), *'Energy Efficient Induction Motors Performance Characteristics and Life-Cycle Cost Comparisons for Centrifugal Loads'*, IEEE conference paper, S 0093-9994(79)06554-7, 1997:2.

[40]. Phillp Tshikalanke (2007), *Implementing energy efficiency in South Africa industries,* ICUE conference paper, CPUT.

[41]. Power Optisa, *Electric motors and voltage,* www.eere.energy.gov,

[42]. R.L. Nailed (1992), *Energy efficient motors, myths vs reality*, IEEE,

[43]. Rebecca Pool (2006),*'Could energy efficiency save our planet',* IEEE article, Vol. 20, no3, ISSN: 1479-8344, June 2006.

[44]. Richard Worthington (2007), *'South Africa emissions to peak in 2015'*, Energy Management News magazine, Volume 13 no.4, ERC publishers, December 2007.

[45]. South African National Standards (2009), Rotating electrical machines, Part 30: Efficiency classes of single-speed, three-phase, cage-induction motors (IE-code), ISBN 978-0-626-22878.

[46]. Stephen D. Umans (1989), *AC induction motor efficiencies*, IEEE, CH2788-8/89/0000-0099

[47]. Steve Nadel, R. Neal Elliott, Michael Shephard and others (2006), *'Energy efficient motor systems'*, 2nd edition, *Text Book*, American Council for Energy Efficient Economy, Washington DC,ISBN0-918249-40-6.

[48]. Steven Nadel (1993), *Electric motor systems in developing countries: Opportunities for efficiency improvement,* US department of energy publication.

[49]. Tito Mboweni (2009), *'recovery will take longer than expected'*, business report newspaper, Page 22, Wed, April 8 2009.

[50]. Tristen Taylor (2007) *'ESKOM Load Shedding and Industrial Power Usage'* Energy Management News magazine, Vol.12 no.4, ERC publishers, Dec 2007.

[51]. Vicky Spinks (2008), *'The application of DSM and DMP to metalloys'*, Control Engineering magazine, Reed Business Info. Publishers, issue Vol.2, No.2, July.

[52]. Williams R. Finley, Bill Veerkamp, Doug Gehring, Philip Hanna (2007), *'Advantages of using high efficient motors such as Nema Premium around the world',* IEEE, PCIC-2007-13.

[53]. www.apc.com, American electrical savings agency

[54]. Yehia El-Ibiary (2003), *'An Accurate Low-Cost Method for Determining Electric Motors' Efficiency for Purpose of Plant Energy Management'*, IEEE 10.1109/TIA.2003.813689

Annexure A: SE-motor test results at low product level

Date & Time	Power (VA)	Power (W)	Pf	Current (Red)	Voltage (Red)	Current (White)	Voltage (White)	Current (Blue)	Voltage (Blue)
5/3/2010 16:44	0	0	-1	0	0	0	0	0	0
5/3/2010 16:44	4716	4713	1	8.5	25.7	8.7	25.7	8.1	4.7
5/3/2010 16:44	6298	3219	0.6	11.5	42.9	12	43.2	11.1	30
5/3/2010 16:44	45600	32310	0.7	50.4	510.6	52.8	513	52.4	511.8
5/3/2010 16:44	45030	31720	0.7	49.9	511.3	52	513.3	51.6	512.3
5/3/2010 16:44	45130	31810	0.7	49.9	511.4	52.1	513.6	51.8	512.5
5/3/2010 16:45	45150	31800	0.7	50	511.6	52.1	513.7	51.7	512.7
5/3/2010 16:45	45080	31720	0.7	49.9	511.6	52	513.9	51.7	512.7
5/3/2010 16:45	44810	31420	0.7	49.6	511.5	51.7	513.7	51.4	512.6
5/3/2010 16:45	44880	31490	0.7	49.7	511.6	51.8	513.8	51.4	512.7
5/3/2010 16:45	44780	31360	0.7	49.6	511.8	51.7	513.9	51.2	512.9
5/3/2010 16:45	45040	31650	0.7	49.8	511.7	52	513.9	51.5	512.8
5/3/2010 16:45	44900	31520	0.7	49.7	511.7	51.8	513.9	51.4	512.8
5/3/2010 16:45	45100	31790	0.7	50	511.3	52.1	513.4	51.6	512.4
5/3/2010 16:45	45040	31720	0.7	49.9	511.3	52	513.4	51.5	512.4
5/3/2010 16:45	45090	31790	0.7	50	511.2	52	513.3	51.7	512.2
5/3/2010 16:45	44940	31620	0.7	49.8	511.2	51.9	513.4	51.5	512.3
5/3/2010 16:45	44990	31680	0.7	49.8	511	51.9	513.2	51.6	512.1
5/3/2010 16:46	44670	31340	0.7	49.5	510.9	51.6	513.1	51.2	512
5/3/2010 16:46	44220	30850	0.7	49	510.7	51.1	512.9	50.7	511.8
5/3/2010 16:46	44220	30860	0.7	49	510.6	51.1	512.9	50.8	511.7
5/3/2010 16:46	44040	30670	0.7	48.8	510.5	50.9	512.7	50.6	511.6
5/3/2010 16:46	44020	30670	0.7	48.8	510.4	50.9	512.7	50.6	511.6
5/3/2010 16:46	44220	30900	0.7	49	510.3	51.2	512.6	50.8	511.4
5/3/2010 16:46	44550	31300	0.7	49.4	510.4	51.6	512.6	51.2	511.5
5/3/2010 16:46	44550	31320	0.7	49.4	510.2	51.6	512.5	51.2	511.3
5/3/2010 16:46	44960	31770	0.7	49.8	510.3	52	512.5	51.7	511.4
5/3/2010 16:46	44840	31580	0.7	49.7	510.6	51.9	512.9	51.5	511.7
5/3/2010 16:46	45070	31770	0.7	49.8	511	52.1	513.3	51.7	512.1

5/3/2010 16:47	1596	811.5	0.8	2.5	32.8	2.6	32.8	2.6	32.8
5/3/2010 16:46	44670	31340	0.7	49.5	510.9	51.6	513.1	51.2	512
5/3/2010 16:46	44220	30850	0.7	49	510.7	51.1	512.9	50.7	511.8
5/3/2010 16:46	44550	31300	0.7	49.4	510.4	51.6	512.6	51.2	511.5
5/3/2010 16:46	44550	31320	0.7	49.4	510.2	51.6	512.5	51.2	511.3
5/3/2010 16:46	44870	31670	0.7	49.7	510.3	52	512.6	51.5	511.5
5/3/2010 16:46	44960	31770	0.7	49.8	510.3	52	512.5	51.7	511.4
5/3/2010 16:46	44220	30860	0.7	49	510.6	51.1	512.9	50.8	511.7
5/3/2010 16:46	44040	30670	0.7	48.8	510.5	50.9	512.7	50.6	511.6
5/3/2010 16:46	44020	30670	0.7	48.8	510.4	50.9	512.7	50.6	511.6
5/3/2010 16:46	44220	30900	0.7	49	510.3	51.2	512.6	50.8	511.4
5/3/2010 16:46	44220	0	-1	0	0	0	0	0	0

Annexure B: HE-motor test results at low product level

Date & Time	Power (VA)	Power (W)	Pf	Current (Red)	Voltage (Red)	Current (White)	Voltage (White)	Current (Blue)	Voltage (Blue)	
5/3/2010 16:25		518.4	518.4	1	2.4	7.3	2.4	7.4	2.3	0
5/3/2010 16:25	46760	34530	0.7	53	511.7	54.9	514.1	53.7	512.9	
5/3/2010 16:25	41800	33440	0.8	45.6	515.3	47.1	517.5	46.4	516.4	
5/3/2010 16:25	41700	33350	0.8	45.6	515.2	47.1	517.3	46.3	516.2	
5/3/2010 16:25	41590	33220	0.8	45.5	514.9	47	517	46.2	516	
5/3/2010 16:26	41560	33170	0.8	45.5	515.1	47	517.2	46.1	516.2	
5/3/2010 16:26	41410	33050	0.8	45.3	515.1	46.9	517.3	46	516.2	
5/3/2010 16:26	41070	32690	0.8	44.9	515.1	46.5	517.4	45.7	516.3	
5/3/2010 16:26	41020	32620	0.8	44.8	515.4	46.4	517.8	45.6	516.6	
5/3/2010 16:26	41120	32720	0.8	44.9	515.5	46.5	517.8	45.7	516.7	
5/3/2010 16:26	41050	32670	0.8	44.8	515.5	46.3	517.8	45.6	516.7	
5/3/2010 16:26	41170	32780	0.8	44.9	515.7	46.4	517.9	45.7	516.8	
5/3/2010 16:26	41350	32970	0.8	45.1	515.4	46.5	517.7	46	516.6	
5/3/2010 16:26	41460	33080	0.8	45.2	515.3	46.7	517.7	46.1	516.5	
5/3/2010 16:26	41420	33040	0.8	45.1	515.1	46.7	517.6	46.1	516.4	
5/3/2010 16:26	41440	33070	0.8	45.2	515.3	46.7	517.6	46.1	516.4	
5/3/2010 16:26	41500	33110	0.8	45.2	515.2	46.7	517.5	46.2	516.3	
5/3/2010 16:27	41310	32950	0.8	45	515	46.5	517.4	46	516.2	
5/3/2010 16:27	41350	32980	0.8	45	515.4	46.6	517.8	46.1	516.6	
5/3/2010 16:27	41350	32970	0.8	45	515.1	46.5	517.4	46.1	516.3	
5/3/2010 16:27	41530	33160	0.8	45.2	515	46.8	517.4	46.3	516.2	
5/3/2010 16:27	41390	33020	0.8	45.1	515.1	46.7	517.5	46.1	516.3	
5/3/2010 16:27	41220	32850	0.8	44.9	515.3	46.4	517.6	45.9	516.4	
5/3/2010 16:27	41190	32810	0.8	44.9	515.1	46.5	517.4	45.8	516.2	
5/3/2010 16:27	41110	32740	0.8	44.8	515	46.4	517.5	45.8	516.3	
5/3/2010 16:27	41170	32810	0.8	44.9	514.9	46.4	517.2	45.8	516.1	
5/3/2010 16:27	41150	32780	0.8	44.8	514.9	46.4	517.3	45.9	516.1	
5/3/2010 16:27	41290	32940	0.8	45	514.8	46.5	517.3	46	516.1	
5/3/2010 16:27	41030	32650	0.8	44.7	515	46.2	517.3	45.8	516.1	

5/3/2010 16:28	41020	32630	0.8	44.7	515.2	46.2	517.5	45.7	516.4
5/3/2010 16:28	41000	32640	0.8	44.7	515.1	46.2	517.5	45.7	516.3
5/3/2010 16:28	40970	32630	0.8	44.7	514.8	46.2	517.2	45.7	516
5/3/2010 16:28	41460	33080	0.8	45.2	515.3	46.7	517.7	46.1	516.5
5/3/2010 16:28	41420	33040	0.8	45.1	515.1	46.7	517.6	46.1	516.4
5/3/2010 16:28	41440	33070	0.8	45.2	515.3	46.7	517.6	46.1	516.4
5/3/2010 16:28	41500	33110	0.8	45.2	515.2	46.7	517.5	46.2	516.3
5/3/2010 16:28	41310	32950	0.8	45	515	46.5	517.4	46	516.2
5/3/2010 16:29	41350	32980	0.8	45	515.4	46.6	517.8	46.1	516.6
5/3/2010 16:29	41460	33080	0.8	45.2	515.3	46.7	517.7	46.1	516.5
5/3/2010 16:29	41420	33040	0.8	45.1	515.1	46.7	517.6	46.1	516.4
5/3/2010 16:29	0	0	-1	0	0	0	0	0	0

Annexure C: SE-motor test results at high product level

Date & Time	VA	KW	PF	I (Red)	V	I (White)	V	I (Blue)	V (Blue)
11/10/2010 17:38	0	0	-1	0	0	0	0	0	0
11/10/2010 17:38	20580	9533	0.6	34.2	246.6	36.4	246.4	35.4	246.4
11/10/2010 17:38	33940	22290	0.7	48.7	438.1	51.8	636.7	50.2	512.7
11/10/2010 17:38	33820	22130	0.7	48.5	513.1	51.5	512.7	50	512.7
11/10/2010 17:39	33780	22090	0.7	48.5	513	51.5	512.8	49.9	512.8
11/10/2010 17:39	33600	21840	0.6	48.2	513.1	51.3	512.7	49.7	512.7
11/10/2010 17:39	33590	21820	0.6	48.2	513.1	51.3	512.8	49.7	512.8
11/10/2010 17:39	33580	21830	0.6	48.2	513.1	51.3	512.8	49.6	512.8
11/10/2010 17:39	33460	21750	0.6	48.1	513.1	51.1	512.7	49.4	512.7
11/10/2010 17:39	33620	21930	0.7	48.3	513.1	51.4	512.6	49.6	512.6
11/10/2010 17:39	33620	21980	0.7	48.3	513	51.4	512.6	49.6	512.6
11/10/2010 17:39	33510	21850	0.7	48.1	513	51.3	512.7	49.5	512.7
11/10/2010 17:39	33580	21900	0.7	48.2	513	51.3	512.8	49.6	512.8
11/10/2010 17:39	33520	21860	0.7	48.2	513.1	51.2	512.7	49.5	512.7
11/10/2010 17:39	33410	21720	0.6	48	513.1	51	512.8	49.4	512.8
11/10/2010 17:39	33500	21800	0.6	48	513.1	51.2	512.8	49.5	512.8
11/10/2010 17:40	33530	21890	0.7	48.2	513.1	51.3	512.8	49.5	512.8
11/10/2010 17:40	33390	21720	0.6	47.9	513.1	51.1	512.8	49.3	512.8
11/10/2010 17:40	33550	21920	0.7	48.2	513.1	51.3	512.8	49.5	512.8
11/10/2010 17:40	33450	21780	0.7	48	513.1	51.1	512.9	49.4	512.9
11/10/2010 17:40	33470	21830	0.7	48	513.1	51.2	512.7	49.4	512.7
11/10/2010 17:40	33450	21800	0.7	48	513	51.2	512.7	49.4	512.7
11/10/2010 17:40	33410	21750	0.7	47.9	512.9	51.1	512.7	49.3	512.7
11/10/2010 17:40	33410	21770	0.7	47.9	512.9	51.2	512.6	49.3	512.6
11/10/2010 17:40	33270	21610	0.6	47.7	513	51	512.7	49.2	512.7
11/10/2010 17:40	33360	21720	0.7	47.9	513	51.1	512.7	49.3	512.7
11/10/2010 17:40	33460	21830	0.7	48	513	51.3	512.7	49.4	512.7
11/10/2010 17:40	33470	21860	0.7	48	512.9	51.2	512.6	49.5	512.6
11/10/2010 17:41	33520	21890	0.7	48	513.1	51.3	512.7	49.5	512.7
11/10/2010 17:41	33530	21890	0.7	48	513.2	51.2	512.8	49.6	512.8

11/10/2010 17:41	33500	21840	0.7	47.9	513.3	51.2	512.9	49.6	512.9
11/10/2010 17:41	33590	21910	0.7	48.1	513.4	51.3	512.8	49.7	512.8
11/10/2010 17:42	33520	21820	0.6	48.1	513.5	51.3	512.9	49.5	512.9
11/10/2010 17:42	33570	21900	0.7	48.1	513.4	51.3	512.8	49.6	512.8
11/10/2010 17:42	33510	21830	0.7	48	513.4	51.2	512.9	49.5	512.9
11/10/2010 17:42	33490	21840	0.7	48	513.5	51.2	512.9	49.5	512.9
11/10/2010 17:44	33450	21780	0.7	47.8	513.5	51.2	513.1	49.4	513.1
11/10/2010 17:44	33390	21720	0.6	47.7	513.5	51.2	513	49.4	513
11/10/2010 17:44	33350	21670	0.6	47.7	513.5	51	513.1	49.4	513.1
11/10/2010 17:44	33350	21660	0.6	47.7	513.5	51	513.1	49.4	513.1
11/10/2010 17:45	33530	21900	0.7	48.1	513.2	51.3	512.8	49.5	512.8

Annexure D: HE-motor test results at high product level

Date & Time	VA	kW	PF	I (Red)	V	I (White)	V	I (Blue)	V
11/10/2010 17:13	0	0	-1	0	125	0	125	0	125
11/10/2010 17:13	4561	4561	1	7.4	144.4	7.7	144.3	7.3	144.3
11/10/2010 17:13	31390	22560	0.7	44.7	512.6	47.6	512.3	46.5	512.3
11/10/2010 17:13	29090	21820	0.8	40.9	513	43.7	512.7	42.8	512.7
11/10/2010 17:13	28900	21610	0.7	40.6	513.3	43.4	513	42.5	513
11/10/2010 17:13	28980	21680	0.7	40.8	513.2	43.5	512.8	42.6	512.8
11/10/2010 17:13	29070	21760	0.7	40.8	513.3	43.6	513	42.7	513
11/10/2010 17:13	28950	21660	0.7	40.7	513.2	43.5	512.9	42.5	512.9
11/10/2010 17:14	28620	21320	0.7	40.2	513.3	43	513	42.1	513
11/10/2010 17:14	28640	21360	0.7	40.2	513.3	43	512.9	42.1	512.9
11/10/2010 17:14	28850	21580	0.7	40.5	513.2	43.2	512.9	42.4	512.9
11/10/2010 17:14	28900	21640	0.7	40.6	513.2	43.2	512.9	42.5	512.9
11/10/2010 17:14	28870	21600	0.7	40.5	513.2	43.2	512.8	42.4	512.8
11/10/2010 17:14	28610	21360	0.7	40.2	513.1	42.8	512.7	42.1	512.7
11/10/2010 17:14	28720	21450	0.7	40.3	513.3	43	512.9	42.2	512.9
11/10/2010 17:14	28820	21550	0.7	40.4	513.3	43.1	512.9	42.4	512.9
11/10/2010 17:14	28940	21670	0.7	40.6	513.2	43.3	512.8	42.6	512.8
11/10/2010 17:14	28800	21540	0.7	40.4	513.3	43	512.8	42.4	512.8
11/10/2010 17:14	28830	21570	0.7	40.4	513.2	43.1	512.9	42.4	512.9
11/10/2010 17:14	28590	21330	0.7	40.1	513.3	42.8	512.9	42.1	512.9
11/10/2010 17:15	28590	21330	0.7	40.1	513.3	42.8	512.8	42	512.8
11/10/2010 17:15	28520	21270	0.7	40	513.2	42.7	512.9	42	512.9
11/10/2010 17:15	28820	21570	0.7	40.4	513.2	43.1	512.8	42.4	512.8
11/10/2010 17:15	28820	21560	0.7	40.4	513.2	43.1	512.8	42.4	512.8
11/10/2010 17:15	28650	21380	0.7	40.2	513.3	42.8	512.9	42.1	512.9
11/10/2010 17:15	28590	21320	0.7	40.1	513.4	42.8	513	42	513
11/10/2010 17:15	28680	21410	0.7	40.2	513.5	42.9	513	42.2	513
11/10/2010 17:15	28880	21610	0.7	40.4	513.5	43.1	513	42.5	513
11/10/2010 17:15	28670	21400	0.7	40.2	513.4	42.9	513	42.2	513
11/10/2010 17:15	28720	21430	0.7	40.3	513.5	42.9	513.1	42.2	513.1

11/10/2010 17:15	28820	21530	0.7	40.4	513.4	43	513	42.4	513
11/10/2010 17:15	28740	21450	0.7	40.2	513.4	42.9	513	42.3	513
11/10/2010 17:16	28720	21450	0.7	40.1	513.4	43	513.1	42.3	513.1
11/10/2010 17:16	28980	21710	0.7	40.5	513.4	43.3	513.1	42.7	513.1
11/10/2010 17:16	28860	21590	0.7	40.3	513.3	43.1	513	42.6	513
11/10/2010 17:16	28880	21610	0.7	40.4	513.4	43.1	513	42.6	513
11/10/2010 17:16	28970	21700	0.7	40.5	513.4	43.2	513.1	42.7	513.1
11/10/2010 17:22	28870	21590	0.7	40.2	513.3	43.2	513	42.8	513
11/10/2010 17:22	28950	21680	0.7	40.3	513.2	43.3	512.9	42.9	512.9
11/10/2010 17:23	16470	10940	0.8	26.7	390.5	28.7	390.1	28.5	390.1

Annexure E: Comparison of result measured on the motor test – Low Product level

Time	Power (kW) HE-Motor	Power (kW) SE-Motor	PF HE-Motor	PF SE-Motor	Current HE-Motor	Current SE-Motor
0	0	0	0	0	0	0
5	4.6	9.533	1	0.6	7.3	35.4
10	22.56	22.29	0.7	0.7	46.5	50.2
15	21.82	22.13	0.8	0.7	42.8	50
20	21.61	22.09	0.7	0.7	42.5	49.9
25	21.68	21.84	0.7	0.6	42.6	49.7
30	21.76	21.82	0.7	0.6	42.7	49.7
35	21.66	21.83	0.7	0.6	42.5	49.6
40	21.32	21.75	0.7	0.6	42.1	49.4
45	21.36	21.93	0.7	0.7	42.1	49.6
50	21.58	21.98	0.7	0.7	42.4	49.6
55	21.64	21.85	0.7	0.7	42.5	49.5
60	21.60	21.9	0.7	0.7	42.4	49.6
65	21.36	21.86	0.7	0.7	42.1	49.5
70	21.45	21.72	0.7	0.6	42.2	49.4
75	21.55	21.8	0.7	0.6	42.4	49.5
80	21.67	21.89	0.7	0.7	42.6	49.5
85	21.54	21.72	0.7	0.6	42.4	49.3
90	21.57	21.92	0.7	0.7	42.4	49.5
95	21.33	21.78	0.7	0.7	42.1	49.4
100	21.33	21.83	0.7	0.7	42	49.4
105	21.27	21.8	0.7	0.7	42	49.4
110	21.57	21.75	0.7	0.7	42.4	49.3
115	21.56	21.77	0.7	0.7	42.4	49.3
120	21.38	21.61	0.7	0.6	42.1	49.2
125	21.32	21.72	0.7	0.7	42	49.3
130	21.41	21.83	0.7	0.7	42.2	49.4
135	21.61	21.86	0.7	0.7	42.5	49.5
140	21.40	21.89	0.7	0.7	42.2	49.5
145	21.43	21.89	0.7	0.7	42.2	49.6

150	21.53	21.84	0.7	0.7	42.4	49.6
155	21.45	21.91	0.7	0.7	42.3	49.7
160	21.22	21.69	0.7	0.6	42	49.5
165	21.47	21.64	0.7	0.6	42.3	49.4
170	21.45	21.74	0.7	0.6	42.3	49.5
175	21.71	22.01	0.7	0.7	42.7	49.8
180	21.59	21.83	0.7	0.6	42.6	49.6
185	21.61	21.81	0.7	0.6	42.6	49.6
190	21.70	21.8	0.7	0.6	42.7	49.5
195	21.38	21.9	0.7	0.7	42.3	49.5
200	21.55	21.89	0.7	0.7	42.5	49.5
205	21.66	21.76	0.7	0.6	42.7	49.4
210	21.64	21.82	0.7	0.6	42.7	49.5
215	21.56	21.9	0.7	0.7	42.6	49.6
220	21.40	21.83	0.7	0.7	42.3	49.5
225	21.52	21.84	0.7	0.7	42.5	49.5
230	21.53	21.83	0.7	0.7	42.5	49.6
235	21.59	21.68	0.7	0.6	42.6	49.3
240	21.60	21.78	0.7	0.7	42.7	49.4
245	21.39	21.72	0.7	0.6	42.3	49.4
275	21.54	21.76	0.7	0.6	42.5	49.5
280	21.56	21.66	0.7	0.6	42.5	49.2
285	21.61	21.7	0.7	0.6	42.5	49.4
290	21.73	21.76	0.7	0.6	42.7	49.4
305	10.37	6.82	0.7	0.7	28.5	49.4
310	0	0	0	0	0	0
Average	**21.53**	**21.80**	**0.70**	**0.65**	**42.41**	**49.48**

Annexure F: **Comparison of result measured on the motor test** - High product level

Time	Power (kW) HE-Motor	Power (kW) SE-Motor	PF HE-Motor	PF SE-Motor	I (A) (Blue) HE-Motor	I (A) (Blue) SE-Motor
0	0	0	0	0	0	0
5	5.184	32.31	0.7	0.7	53.7	11.1
10	34.53	31.72	0.7	0.7	46.4	52.4
15	33.44	31.81	0.8	0.7	46.3	51.6
20	33.35	31.8	0.8	0.7	46.2	51.8
25	33.22	31.72	0.8	0.7	46.1	51.7
30	33.17	31.42	0.8	0.7	46	51.7
35	33.05	31.49	0.8	0.7	45.7	51.4
40	32.69	31.36	0.8	0.7	45.6	51.4
45	32.62	31.65	0.8	0.7	45.7	51.2
50	32.72	31.52	0.8	0.7	45.6	51.5
55	32.67	31.79	0.8	0.7	45.7	51.4
60	32.78	31.72	0.8	0.7	46	51.6
65	32.97	31.79	0.8	0.7	46.1	51.5
70	33.08	31.62	0.8	0.7	46.1	51.7
75	33.04	31.68	0.8	0.7	46.1	51.5
80	33.07	31.34	0.8	0.7	46.2	51.6
85	33.11	30.85	0.8	0.7	46	51.2
90	32.95	30.86	0.8	0.7	46.1	50.7
95	32.98	30.67	0.8	0.7	46.1	50.8
100	32.97	30.67	0.8	0.7	46.3	50.6
105	33.16	30.9	0.8	0.7	46.1	50.6
110	33.02	31.3	0.8	0.7	45.9	50.8
115	32.85	31.32	0.8	0.7	45.8	51.2
120	32.81	31.67	0.8	0.7	45.8	51.2
125	32.74	31.77	0.8	0.7	45.8	51.5
130	32.81	31.58	0.8	0.7	45.9	51.7
135	32.78	31.77	0.8	0.7	46	51.5
140	32.94	31.79	0.8	0.8	45.8	51.7

145	32.65	31.62	0.8	0.7	45.7	51.7
150	32.63	31.68	0.8	0.7	45.7	52.4
155	32.64	31.34	0.8	0.7	45.7	51.6
160	32.63	30.85	0.8	0.7	53.7	51.8
165	32.69	30.86	0.8	0.7	46.4	51.7
170	32.62	30.67	0.8	0.7	46.3	51.7
175	32.72	30.67	0.8	0.7	46.2	51.4
180	32.67	30.9	0.8	0.7	46.1	51.4
185	32.78	31.3	0.8	0.7	46	51.2
190	32.97	31.32	0.8	0.7	45.7	51.5
195	33.08	31.67	0.8	0.7	45.6	51.4
200	33.04	31.77	0.8	0.7	45.7	51.6
205	33.07	31.58	0.8	0.7	45.6	51.5
210	33.11	31.77	0.8	0.7	45.7	51.7
215	32.95	30.9	0.8	0.7	46	51.5
220	32.98	31.3	0.8	0.7	46.1	51.6
225	32.97	31.32	0.8	0.7	46.1	51.2
230	33.16	31.67	0.8	0.7	46.1	50.7
235	32.69	31.77	0.8	0.7	46.2	50.8
240	32.62	31.58	0.8	0.7	46	50.6
245	32.72	31.77	0.8	0.7	46.1	50.6
250	32.67	31.79	0.8	0.7	46.1	50.8
255	32.78	31.62	0.8	0.7	46.3	51.2
260	32.97	31.68	0.8	0.7	46.1	51.2
265	33.08	31.34	0.8	0.7	45.9	51.5
290	32.98	30.9	0.8	0.7	46	51.2
295	32.97	31.32	0.8	0.7	45.8	50.7
310	15.62	29.32	0.8	0.7	45.7	50.6
315	0	0	0	0	0	0
Average	**32.94389831**	**31.37728814**	**0.798305085**	**0.701694915**	**46.08983051**	**51.37288136**

Annexure G: Motor test results

Motor test	Power (kW)		Power factor		Current (R)		Voltage (R)		Current (Y)		Voltage (Y)		Current (B)		Voltage (B)	
	Rated	Actual	Rated	Actual	Rated	Actual	Rated	Actual	Rated	Actual	Rated		Rated	Actual	Rated	Actual
At low product level																
SE-motor	45	31.4	0.80 (75% load)	0.7	65.3	49.5	500	510	65.3	51.7	500	513.1	65.3	51.3	500	512
HE-motor	45	32.9	0.83 (75% load)	0.8	62.9	45	500	515	62.9	46.6	500	517.5	62.9	46	500	516
At high product level																
SE-motor	45	21.8	0.71 (50% load)	0.7	65.3	48.1	500	511	65.3	51.2	500	516	65.3	49.5	500	512.8
HE-motor	45	21.6	0.76 (50% load)	0.7	62.9	40.5	500	513.3	62.9	43.2	500	512.9	62.9	42.5	500	513

Annexure H: Motor speed rpm test

Time (seconds)	SE-motor	HE-motor
1	1471	1487
5	1470	1488
10	1480	1481
15	1489	1479
20	1483	1482
25	1476	1475
30	1488	1480
35	1483	1482
40	1481	1485
45	1479	1476
50	1481	1484
55	1479	1489
60	1475	1485
65	1473	1485
70	1482	1485
75	1489	1489
80	1483	1485
85	1479	1480
90	1488	1489
95	1480	1479
100	1487	1489

Annexure I: HE-motor Data sheet

WEG Indústrias S.A.	Nr.: 21349/2009
	Date: 16-MAR-2009

DATA SHEET

Three-phase Induction Motor - Squirrel Cage

Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Premium Efficiency Plus

Frame	: 225S/M
Output	: 45 kW
Frequency	: 50 Hz
Poles	: 4
Rated speed	: 1480 rpm
Slip	: 1.33 %
Rated voltage	: 500V
Rated current	: 62.9 A
L. R. Amperes	: 465 A
Il/In	: 7.4
No load current	: 20.8 A
Rated torque	: 291 Nm
Locked rotor torque	: 240 %
Breakdown torque	: 300 %
Design	: N
Insulation class	: H
Temperature rise	: 80 K
Locked rotor time	: 19 s (hot)
Service factor	: 1.15
Duty cycle	: S1
Ambient temperature	: -20°C to +40°C
Altitude	: 1000 m.a.s.l
Enclosure	: IP66 (TEFC)
Mounting	: B3L(E)
Rotation	: Both
Aprox. weight*	: 385 kg
Moment of inertia	: 0.76986 kgm²
Sound Pressure Level	: 70.0 dB(A)

	Front	Rear
Bearing	6314-C3	6314-C3
Regreasing int.	11638 h	11638 h
Grease amount	27 g	27 g
Grease - Polyrex EM - ESSO		

Load	Power factor	Efficiency (%)**
100%	0.88	93.9
75%	0.83	93.9
50%	0.76	93.6

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS. Noise level with tolerance of +3 dB(A).

Performed	Checked	Revision	Approved
c-lionelb	AUTOMATICO	Nr.: 0 Date: 16-MAR-2009	

*Weight value can be changed without previous notification.

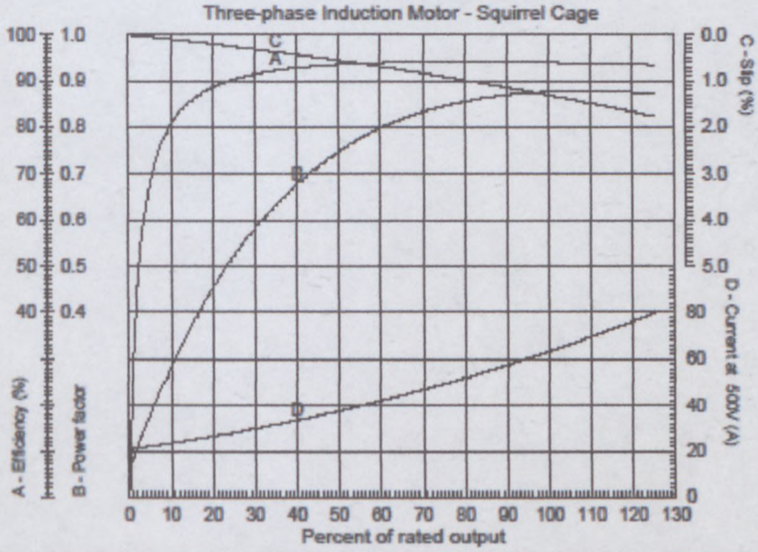
**Determining losses and efficiency according to IEC 34-2 A.

Annexure J: HE-motor performance under load characteristic curves

weg	**WEG Indústrias S.A.**	Nr.: 21349/2009 Date: 16-MAR-2009

PERFORMANCE UNDER LOAD

Three-phase Induction Motor - Squirrel Cage



Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Premium Efficiency Plus

Output	: 45 kW	Duty cycle	: S1
Frame	: 225S/M	Service factor	: 1.15
Rated speed	: 1480 rpm	Design	: N
Frequency	: 50 Hz	Enclosure	: IP66 (TEFC)
Rated voltage	: 500 V	Locked rotor torque	: 240 %
Insulation class	: H	Pull up torque	: 200 %
Rated current	: 62.9 A	Breakdown torque	: 300 %
Il/In	: 7.4		

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS.

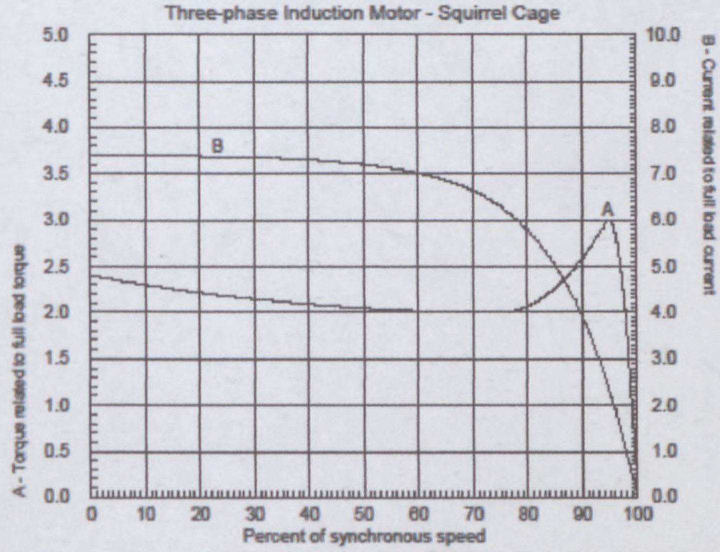
Performed	Checked	Revision	Approved
c-lionelb	AUTOMATICO	Nr.: 0 Date: 16-MAR-2009	

Annexure K: SE-motor performance curves related to speed

weg	**WEG Indústrias S.A.**	Nr.: 21349/2009
		Date: 16-MAR-2009

PERFORMANCE CURVES RELATED TO SPEED

Three-phase Induction Motor - Squirrel Cage



Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Premium Efficiency Plus

Output	: 45 kW	Duty cycle	: S1
Frame	: 225S/M	Service factor	: 1.15
Rated speed	: 1480 rpm	Design	: N
Frequency	: 50 Hz	Enclosure	: IP66 (TEFC)
Rated voltage	: 500 V	Locked rotor torque	: 240 %
Insulation class	: H	Pull up torque	: 200 %
Rated current	: 62.9 A	Breakdown torque	: 300 %
Il/In	: 7.4		

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS.

Performed c-lionelb	Checked AUTOMATICO	Revision Nr.: 0 Date: 16-MAR-2009	Approved

Annexure L: SE-motor data sheet

WEG Indústrias S.A.	Nr.: 19552/2009
	Date: 10-MAR-2009

DATA SHEET

Three-phase Induction Motor - Squirrel Cage

Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Standard Efficiency

Frame	: 225S/M
Output	: 45 kW
Frequency	: 50 Hz
Poles	: 4
Rated speed	: 1475 rpm
Slip	: 1.67 %
Rated voltage	: 500V
Rated current	: 65.3 A
L. R. Amperes	: 457 A
Il/In	: 7.0
No load current	: 25.6 A
Rated torque	: 292 Nm
Locked rotor torque	: 240 %
Breakdown torque	: 300 %
Design	: N
Insulation class	: F
Temperature rise	: 80 K
Locked rotor time	: 12 s (hot)
Service factor	: 1.00
Duty cycle	: S1
Ambient temperature	: -20°C to +40°C
Altitude	: 16 m.a.s.l
Enclosure	: IP55 (TEFC)
Mounting	: B3L(E)
Rotation	: Both
Aprox. weight*	: 361 kg
Moment of inertia	: 0.66488 kgm²
Sound Pressure Level	: 70.0 dB(A)

	Front	Rear
Bearing	6314-C3	6314-C3
Regreasing int.	11638 h	11638 h
Grease amount	27 g	27 g
Grease - Polyrex EM - ESSO		

Load	Power factor	Efficiency (%)**
100%	0.86	92.6
75%	0.80	92.4
50%	0.71	91.5

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS. Noise level with tolerance of +3 dB(A).

Performed	Checked	Revision	Approved
c-lionelb	AUTOMATICO	Nr.: 0 Date: 10-MAR-2009	

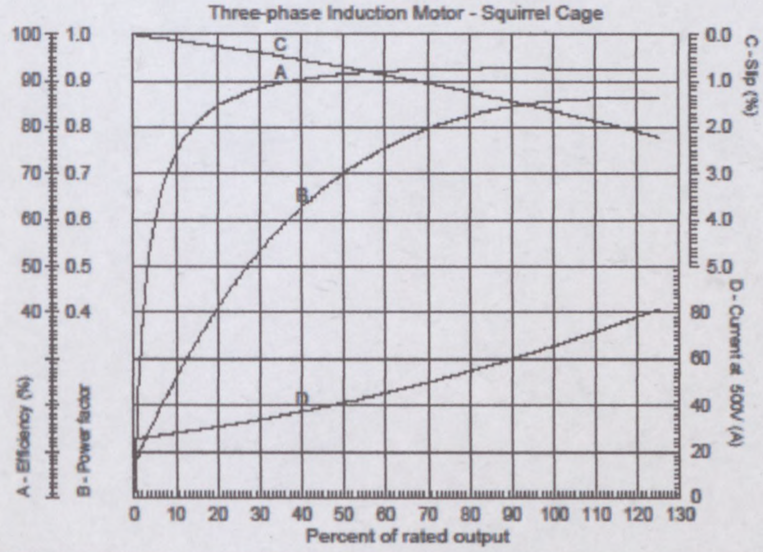
*Weight value can be changed without previous notification.
**Determining losses and efficiency according to IEC 34-2 A.

Annexure M: SE-motor performance under load characteristic curves

WEG Indústrias S.A.	Nr.: 19552/2009
	Date: 10-MAR-2009

PERFORMANCE UNDER LOAD

Three-phase Induction Motor - Squirrel Cage



Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Standard Efficiency

Output	: 45 kW	Duty cycle	: S1
Frame	: 225S/M	Service factor	: 1.00
Rated speed	: 1475 rpm	Design	: N
Frequency	: 50 Hz	Enclosure	: IP55 (TEFC)
Rated voltage	: 500 V	Locked rotor torque	: 240 %
Insulation class	: F	Pull up torque	: 200 %
Rated current	: 65.3 A	Breakdown torque	: 300 %
Il/In	: 7.0		

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS.

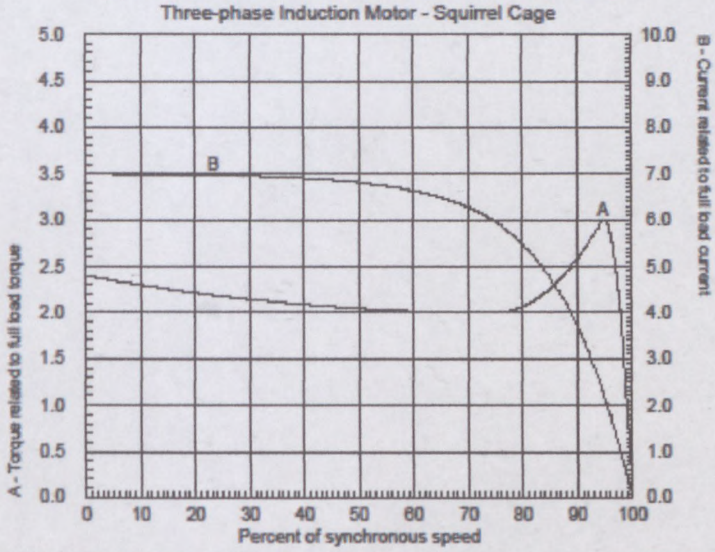
Performed	Checked	Revision	Approved
c-lionelb	AUTOMATICO	Nr.: 0 Date: 10-MAR-2009	

Annexure N: SE-motor performance curves related to speed

WEG	WEG Indústrias S.A.	Nr.: 19552/2009 Date: 10-MAR-2009

PERFORMANCE CURVES RELATED TO SPEED

Three-phase Induction Motor - Squirrel Cage



Customer	: J.T. BLAKEMORE SERVICES PTY LTD
Product code	:
Product line	: Standard Efficiency

Output	: 45 kW	Duty cycle	: S1
Frame	: 225S/M	Service factor	: 1.00
Rated speed	: 1475 rpm	Design	: N
Frequency	: 50 Hz	Enclosure	: IP55 (TEFC)
Rated voltage	: 500 V	Locked rotor torque	: 240 %
Insulation class	: F	Pull up torque	: 200 %
Rated current	: 65.3 A	Breakdown torque	: 300 %
Il/In	: 7.0		

Notes:

The figures given herewith are regarded as estimated values based on calculation and applied to sinusoidal power supplied motors, within permissible tolerances under SABS.

Performed	Checked	Revision	Approved
c-lionelb	AUTOMATICO	Nr.: 0 Date: 10-MAR-2009	

SABS

COMMERCIAL

Permit to Apply Certification Mark

Subject to the provisions of the Standards Act 1993 (Act 29 of 1993), the relevant regulations made thereunder and the conditions contained in the above-mentioned schedules, this permit authorizes

WEG MOTORES LTDA
SANTA CATARINA,
BRAZIL

to apply the certification mark

"n" SABS

In respect of the mark specification:

SANS 60079-15/SABS IEC 60079-15:2006
TO: ELECTRICAL APPARATUS FOR EXPLOSIVE GAS ATMOSPHERES PART 15: CONSTRUCTION, TEST AND MARKING OF TYPE OF PROTECTION "n" ELECTRICAL APPARATUS

[illegible]

Serial Number	4754/9784
Effective date	27 June 2007
Valid Until	27 June 2010
Date of Original Certification	18 February 2000
Director	Martin Kuscus

SABS COMMERCIAL (Pty) Ltd

GLOSSARY

CPUT	Cape Peninsula University of Technology
DSM	Demand Side Management
EFF1	Energy efficiency 1
EFF2	Energy efficiency 2
EFF3	Energy efficiency 3
ESKOM	South African Electricity Supply Authority
FLC	Full Load Current
Fuel Storage tanks	15m tall by 54m diameter cylindrical steel structure used to store petroleum products.
Fuel Storage tanks	cylindrical steel structure used to store petroleum products.
GHGes	Green House Gasses
HE-motor	High efficient Motor
HP	Horse Power
IIEC	International Institute of Energy Conservation
kW	Kilowatts
kWH	Kilowatts Hours
Load-factor	Ratio of actual load to possible load
LRC	Locked Rotor Current
MCC	Motor Control Centre
Mega-flex	An electricity billing system used by ESKOM on industries
MTTF	Mean Time To Failure
NERSA	National Electricity Regulation of South Africa
Refineries	The word refineries in this document is used to mean petroleum refineries
RSA	Republic of South Africa
SE-motors	Standard Efficiency Motors
SOPAC	South Pacific Applied Geosciences Commission
VSD	Variable Speed Drives

INDEX