Energy Auditing of Induction Motor Based On Life Cycle Cost Comparison

A Thesis submitted in partial fulfilment of the

Requirement for the award of degree of

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in

Power System and Electric Drives

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DECLARATION

I hereby certify that the work which is being presented in thesis entitled **"Energy Auditing of Induction Motor Based On Life Cycle Cost Comparison"** in partial fulfilment of ward of degree of **Master of Engineering in Power System and Electric Drives** submitted in Electrical and instrumentation Engineering department, Thapar University, Patiala is an authentic record of my own work carried under the supervision **Mrs. Suman Bhullar**, Assistant Professor , Department of Electrical and Instrument Engineering, Thapar University Patiala, Punjab

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Abstract

Energy being basic need of a human being, should be utilized efficiently *i.e* minimum wastage of energy should be there. Industries are consuming a major portion of electrical energy in developed as well as developing countries. In industries, 90% above, induction motors are used to perform the various activities.

Induction motors being the major energy consumer in industry offer opportunities of energy saving. In plant many induction motors are rewound. This thesis reports the analysis done on the new and rewound induction motor for its efficiency. Life cycle cost of the new and rewound motor is analysed based upon its efficiency and other parameters. Comparison between new and rewound motors is shown. It is found that rewound motor consume 1.5 to 2 times more energy than new motor.

CHAPTER 1

INTRODUCTION

1.1 Introduction to Energy

Energy is uttermost need of human being .We need energy in every field to perform activities whether it is residential, commercial, industrial, and agricultural. We cannot think our life without energy .Our life would stall without energy because we are totally dependent on energy due to our life style. Energy is the ability to do work and work is the transfer of energy from one form to another. In practical terms, energy is what we use to manipulate the world around us, whether by exciting our muscles, by using mechanical devices such as automobiles, or by using electricity. Energy comes in different forms - heat, light, mechanical, electrical, chemical, and nuclear energy.

There are two types of energy - stored energy and working energy. For example, the food we eat contains chemical energy, and our body stores this energy until we release it when we work or play.

Potential energy is stored energy and the energy of position (gravitational). It exists in various forms.

Chemical energy is the energy stored in the bonds of atoms and molecules. Biomass, petroleum, natural gas, propane and coal are examples of stored chemical energy.

Nuclear energy is the energy stored in the nucleus of an atom - the energy that holds the nucleus together. The nucleus of a uranium atom is an example of nuclear energy.

Stored mechanical energy is energy stored in objects by the application of a force. Compressed springs and stretched rubber bands are examples of stored mechanical energy.

Energy is the basic need. Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them.

Gravitational energy is the energy of place or position. Water in a reservoir behind a hydropower dam is an example of gravitational energy. When the water is released to spin the turbines, it becomes motion energy.

Kinetic energy is energy in motion- the motion of waves, electrons, atoms, molecules and substances. It exists in various forms.

Radiant energy is electromagnetic energy that travels in transverse waves. Radiant energy includes visible light, x-rays, gamma rays and radio waves. Solar energy is an example of radiant energy.

Thermal energy is the internal energy in substances- the vibration and movement of atoms and molecules within substances. Geothermal energy is an example of thermal energy.

Motion-The movement of objects or substances from one place to another is motion. Wind and Hydro power are examples of motion.

Sound is the movement of energy through substances in longitudinal (compression/rarefaction) waves.

1.1.1Electrical energy

It is the most important form of energy used it is the movement of electrons .Now-a-days almost all the machines, equipment etc. operate on electricity. This form of energy is gaining importance because it is cheaper as compared to other forms, flexible, reliable, pollution free at consumer terminals etc. Lightning and electricity are examples of electrical Energy.

Electrical Energy Basics

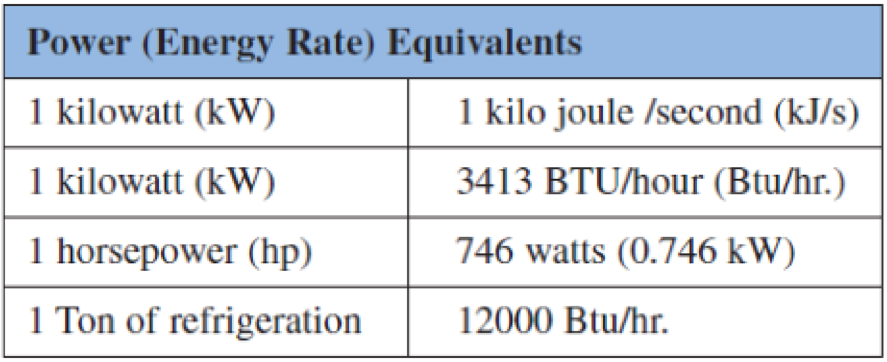
Electric current is divided into two types: Directional Current (DC) and Alternating Current (AC). **Directional Current** A non-varying, unidirectional electric current for example: Current produced by batteries. **Alternating Current** A current which reverses in regularly recurring intervals of time and which has alternately positive and negative values, and occurring a specified number of times per second. For example household electricity produced by generators, electricity supplied by utilities.

Energy Units

Kilowatt-hour is the energy consumed by 1000 Watts in one hour. If 1kW (1000 watts) of a electrical equipment is operated for 1 hour, it would consume 1 kWh of energy that means 1 unit of electricity. For a company, it is the amount of electrical units in kWh recorded in the plant over a month for billing purpose. The company is charged / billed based on kWh consumption.

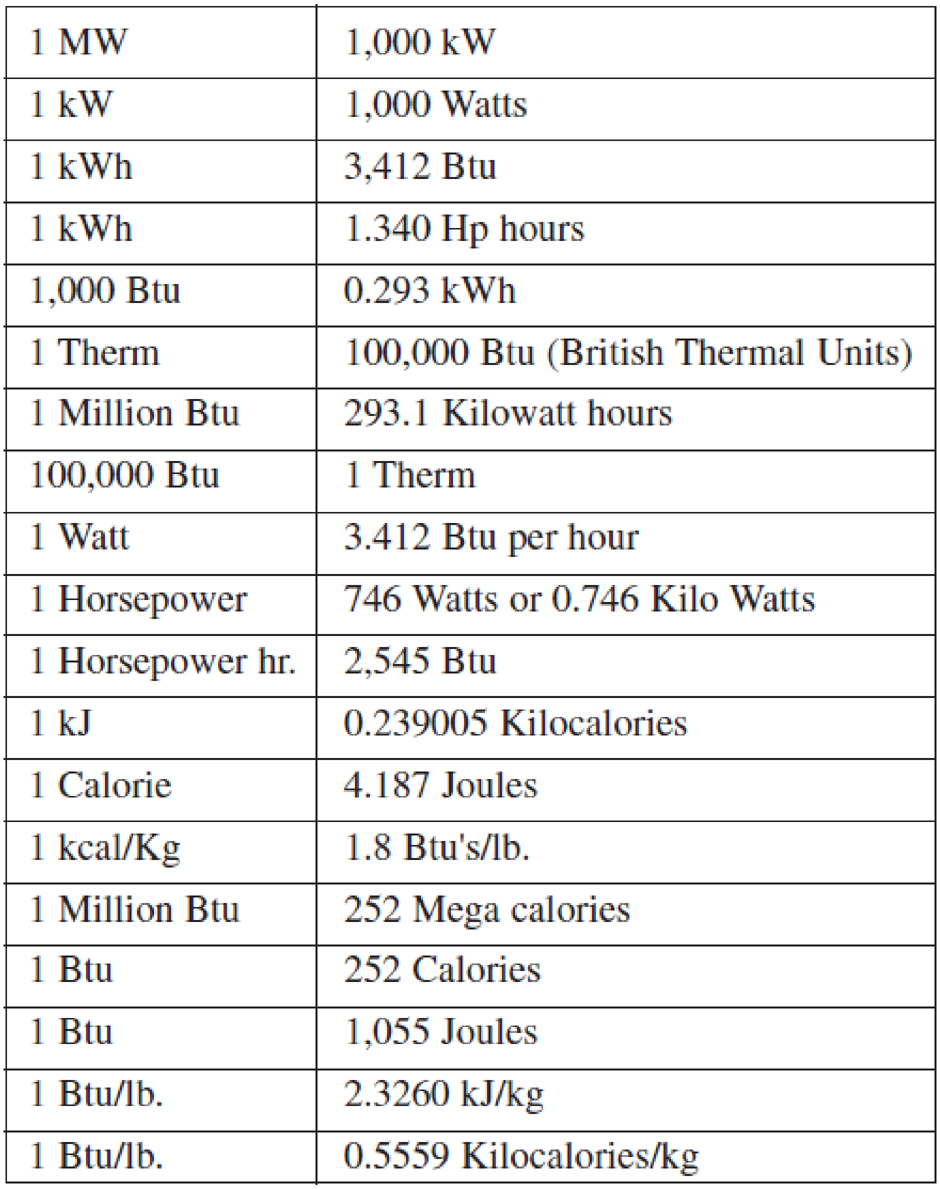
1 barrel of oil = 42 U.S. gallons (gal) = 0.16 cubic meters (m3)

Table 1.1.1 (a) shows Energy Equivalent



Power (Energy Rate) Equivalents	
1 kilowatt (kW)	1 kilo joule /second (kJ/s)
1 kilowatt (kW)	3413 BTU/hour (Btu/hr.)
1 horsepower (hp)	746 watts (0.746 kW)
1 Ton of refrigeration	12000 Btu/hr.

Table 1.1.1 (b) shows Energy units



1 MW	1,000 kW
1 kW	1,000 Watts
1 kWh	3,412 Btu
1 kWh	1.340 Hp hours
1,000 Btu	0.293 kWh
1 Therm	100,000 Btu (British Thermal Units)
1 Million Btu	293.1 Kilowatt hours
100,000 Btu	1 Therm
1 Watt	3.412 Btu per hour
1 Horsepower	746 Watts or 0.746 Kilo Watts
1 Horsepower hr.	2,545 Btu
1 kJ	0.239005 Kilocalories
1 Calorie	4.187 Joules
1 kcal/Kg	1.8 Btu's/lb.
1 Million Btu	252 Mega calories
1 Btu	252 Calories
1 Btu	1,055 Joules
1 Btu/lb.	2.3260 kJ/kg
1 Btu/lb.	0.5559 Kilocalories/kg

1.1.2 Classification

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy

Primary and Secondary Energy

Primary energy sources are those that are either found or stored in nature. Common primary energy sources are coal, oil, natural gas, and biomass. Other primary energy sources available include nuclear energy from radioactive substances, thermal energy stored in earth's interior, and potential energy due to earth's gravity. The major primary and secondary energy sources are shown in Figure 1.1.2 (a) Primary energy sources are mostly converted in industrial utilities into secondary energy sources; for example coal, oil or gas converted into steam and electricity. Primary energy can also be used directly. Some energy sources have non-energy uses, for example coal or natural gas can be used as a feedstock in fertiliser plants.

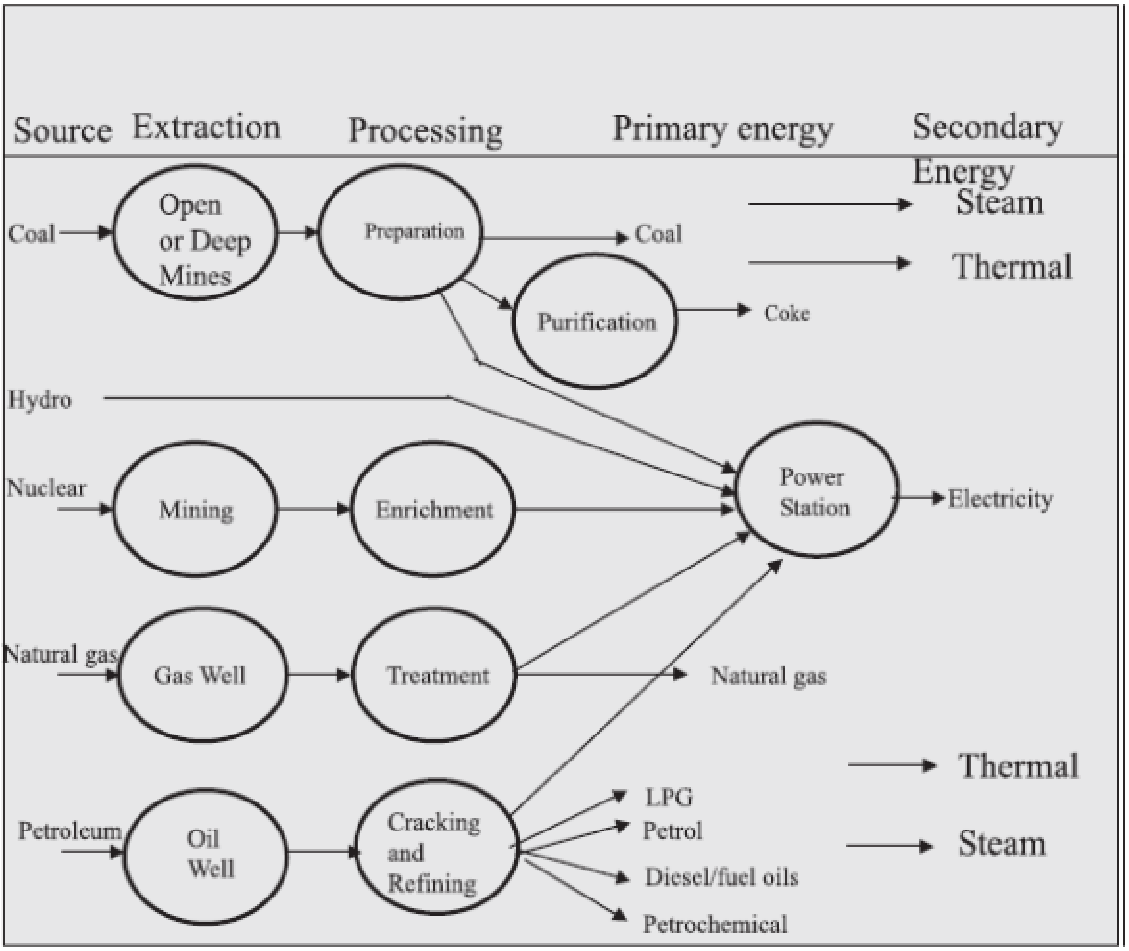


Figure 1.1.2 (a) shows Major Primary and Secondary Sources

Commercial Energy and Non Commercial Energy

The **Commercial energy** sources that are available in the market for a definite price are known as commercial energy. The most important forms of commercial energy are electricity, coal and refined petroleum products. Commercial energy forms the basis of industrial, agricultural, transport and commercial development in the modern world. In the industrialized countries, commercialized fuels are predominant source not only for economic production, but also for many household tasks of general population.

The **Non-Commercial energy** sources that are not available in the commercial market for a price are classified as non-commercial energy. Non-commercial energy sources include fuels such as firewood, cattle dung and agricultural wastes, which are traditionally gathered, and not bought at a price used especially in rural households. These are also called traditional fuels. Non-commercial energy is often ignored in energy accounting.

Renewable and Non-Renewable Energy

Renewable energy is energy obtained from sources that are essentially inexhaustible. Examples of renewable resources include wind power, solar power, geothermal energy, tidal power and hydroelectric power Figure 1.1.2(b). The most important feature of renewable energy is that it can be harnessed without the release of harmful pollutants. **Non-renewable energy** is the conventional fossil fuels such as coal, oil and gas, which are likely to deplete with time.

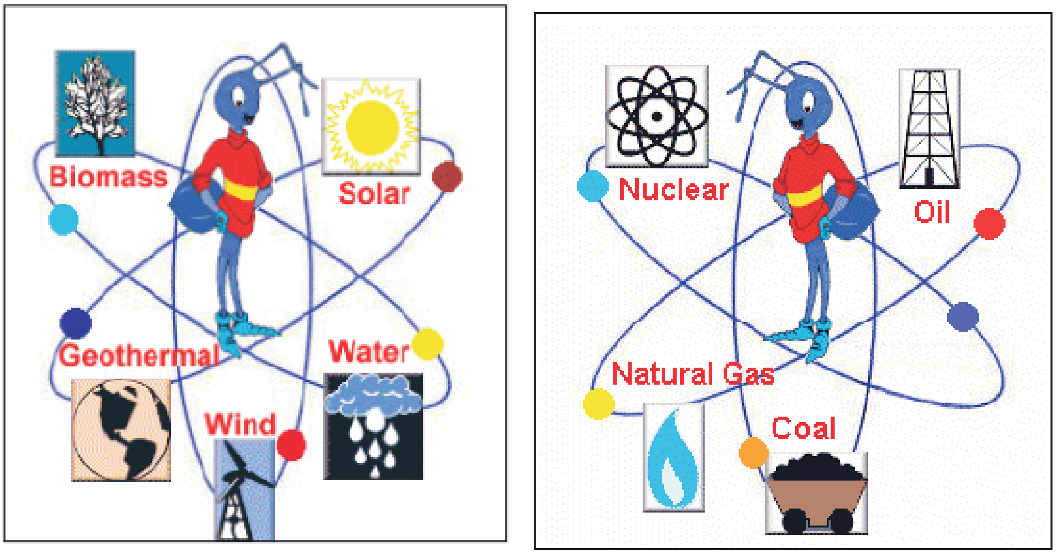


Figure 1.1.2 (b) shows Renewable and Non-Renewable Energy.

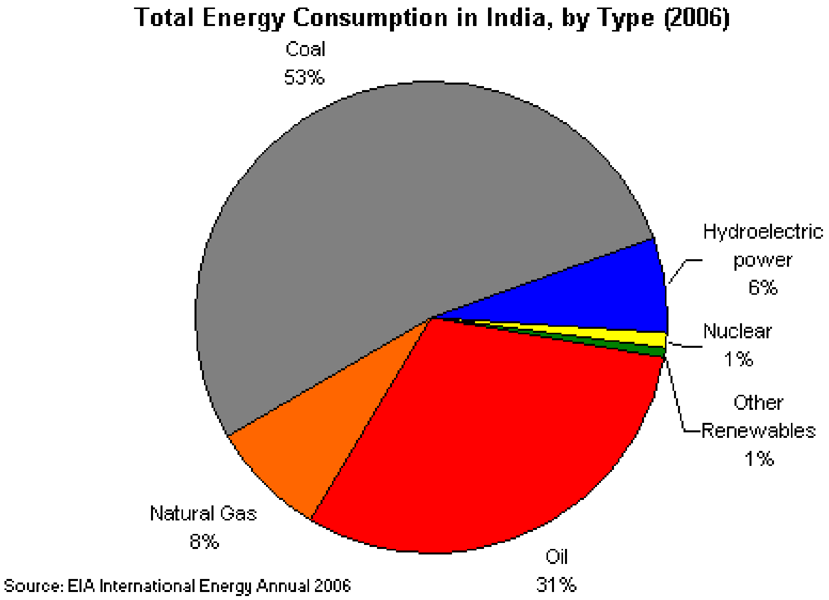
1.2 Economic Aspects

Economic growth is desirable for developing countries, and energy is essential for economic growth. However, the relationship between economic growth and increased energy demand is not always a straightforward linear one. For example, under present conditions, 6% increase in India's Gross Domestic Product (GDP) would impose an increased demand of 9 % on its energy sector. In this context, the ratio of energy demand to GDP is a useful indicator. A high ratio reflects energy dependence and a strong influence of energy on GDP growth. The developed countries, by focusing on energy efficiency and lower energy-intensive routes, maintain their energy to GDP ratios at values of less than 1. The ratios for developing countries are much higher.

1.2.1 Per Capita Energy Consumption

Per capita energy consumption is energy consumed by a person per annum. This is a index which shows the status of living of any nation. It is a measure of prosperity and growth of any nation. The per capita energy consumption is too low for India as compared to developed countries See Figure.1.2.1 it is just 4% of USA and 20% of the world average. The per capita consumption is likely to grow in India with growth in economy thus increasing the energy demand.

Pattern of Energy consumption in India:-



Source: EIA International Energy Annual 2006

Figure 1.2.1 shows Total energy consumption in India

1.2.2 Energy Distribution between Developed and Developing Countries

Although 80 percent of the world's population lies in the developing countries and their energy consumption amounts to only 40 percent of the world total energy consumption. The rapid population growth in the developing countries has kept the per capita energy consumption low compared with that of highly industrialized developed countries. The high standards of living in the developed countries are attributable to high energy consumption levels. In industrialized countries, people use four to five times more than the world average, and nine times more than the average for the developing countries. The world average energy consumption per person is equivalent to 2.2 tonnes of coal. An American uses 32 times more commercial energy than an Indian.

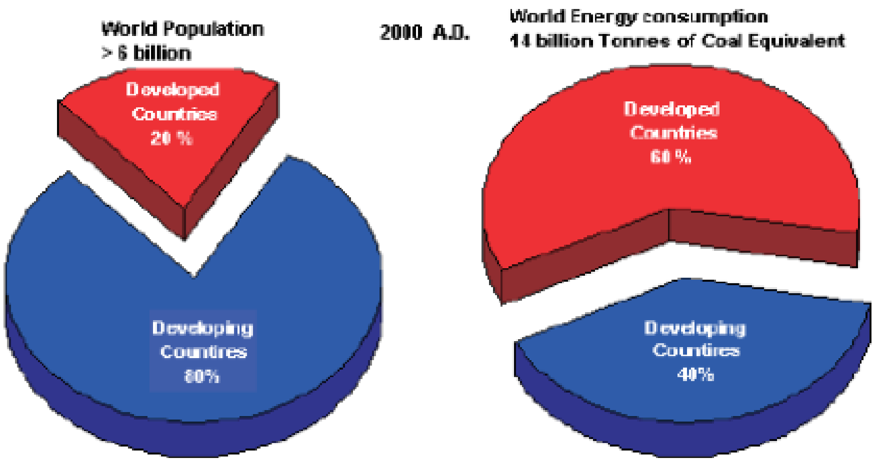


Figure 1.2.2 Scenario of Energy Distribution B/w Developed and Developing Countries

1.2.3 Indian Energy

India is at 6th position in electrical energy consumption in world. So India need more energy in the future which will be meet by various power resources .India has to increase its installed capacity to meet the future energy demand. The total installed capacity for electricity generation in the country has increased from 16,271 MW as on 31.03.1971 to 206,526 MW as on 31.03.2011, registering a compound annual growth rate of 6.4%. Thermal power has the highest rate of annual growth 11.3% from 2009-10 to 2010-11 in installed capacity, followed by Nuclear Power 4.8%.There has been an increase in generating capacity of 18654 MW over the last one year, which is 10% more than the capacity of last year. Hydro power plants come next with an installed capacity of 37.6 thousand MW, accounting for 18.2% of the total installed Capacity. At the end of March 2011, thermal power plants accounted for an overwhelming 64% of the total installed capacity in the country, with an installed capacity of 131.2 thousand MW Besides, non-utilities accounted for 15.9% ,32.9 Thousand MW of the total installed generation capacity. The share of Nuclear energy was only 2.31% (4.78 MW). Over the years, there has been a marked increase in the share of natural gas in primary energy production from 10%. Coal dominates the energy mix in India, contributing to 52% of the total primary energy production. Hydro power contributes with 25% and nuclear power is 3%.Oil share is 1%. Reserve is of the order of 9%.

1.2.4 Role of Energy in Industry

Industrial sector consumes nearly 50% of the total commercial energy. The three main factors that determine the level of energy consumption in an economy are:

-Overall activity or production levels

-Structure of the economy

-Output or activity per unit of energy use

This last component is referred to as energy intensity, and reduction in it occurs when the level of service/activity/output are enhanced for a given amount of energy inputs. Since it is relatively easy to understand the relationship between the amounts of energy needed to produce one physical unit of some good, changes in physical indicators are likely to provide reliable estimates of changes in energy efficiency. Energy intensity is inversely related to efficiency; the greater is the efficiency less the energy required to produce a unit of output or service. A logical conclusion, indicators of improvements in energy efficiencies is that declining energy intensities over time. A more useful indicator of energy intensity may be the ratio of sectoral /sub-sectoral energy use to the output or activity of the sector/ sub-sector.

Indicators that reflect changes in energy intensity have been used in the past few decades, to monitor efficiency changes and cross-country comparisons are made. Prior to mid—80s, the effect of shifting energy consumption on economic growth were primarily concerned with the to the policy makers. As a result, energy policies were often coupled with economic policies that were typically implemented to boost a nation's economic performance.

Efficiency of energy in the present study, manufacturing energy use is disaggregated into five sub-sectors. In the current debate, global warming and climate change shifted the focus, in part with this. They includes; iron and steel, paper and pulp, aluminium, cement and textiles.

(a)Electricity: Commercial and residential sectors are more dependent on purchased electricity than industrial sector since they produces a significant fraction of its own power through direct fuel inputs and some industries, through cogeneration. A form of cogeneration is combined heat and power, which produces thermal and electric energy from a single fuel source.

(b)Natural gas: In the industrial sector, natural gas represents a significant fraction of total than for other sectors. In addition to fuel use, energy consumption of natural gas is also an important raw material in industries applications such as chemical manufacturing and petroleum refining.

(c)Petroleum products: Petroleum products represent a larger fraction of industrial energy inputs than those of the commercial and residential sectors. However, a large fraction of consumption is not for fuel use, but rather as raw material for petroleum refining and chemical manufacturing.

(d)Coal: Despite being an important fuel source for some industries, the use of coal by the industrial sector has relatively small fraction of industrial fuel inputs today as compared to 1950. Over the same period, use of coal in electric power generation has grown rapidly now it supplying more than 60 percent of energy inputs for electric power generation, and thus represents an important, though indirect, source of energy for all three end−use categories except in transportation, particularly commercial and residential sectors.

(v)Renewable: The industrial sector is a significant user of renewable fuels, in part due to the extensive use of biomass fuels in paper and pulp products industry.

1.3 Need of energy conservation and Importance of Energy Conservation

Energy conservation is to conserve the energy or reduce/minimization of wastage of energy without affecting productivity and growth. Energy Conservation and Energy Efficiency are separate, but related concepts. Energy conservation is achieved when for a given amount of work, maximum input is given. Energy Conservation can, therefore, be the result of several processes or developments, such as productivity increase or technological progress. On the other hand Energy efficiency is achieved when energy intensity in a specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels. Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies. Energy efficiency is often viewed as a resource option like coal, oil or natural gas. It provides additional economic value by preserving the resource base and reducing pollution. For example, replacing traditional light bulbs with Compact Fluorescent Lamps (CFLs) means we will use only 1/4th of the energy to light a room.

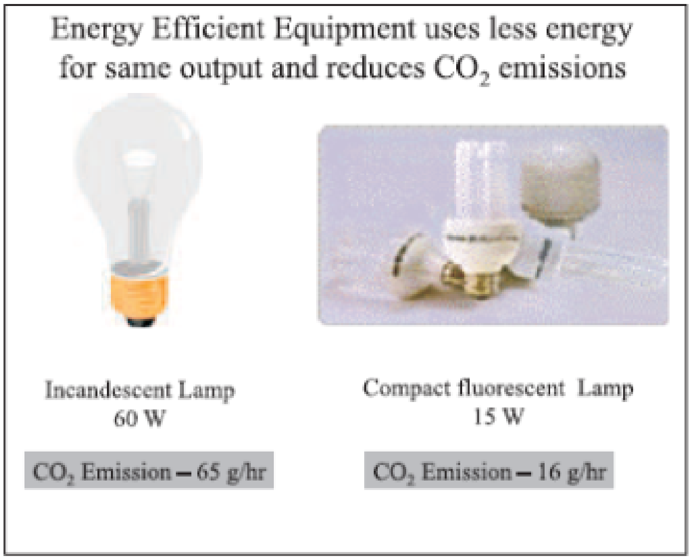
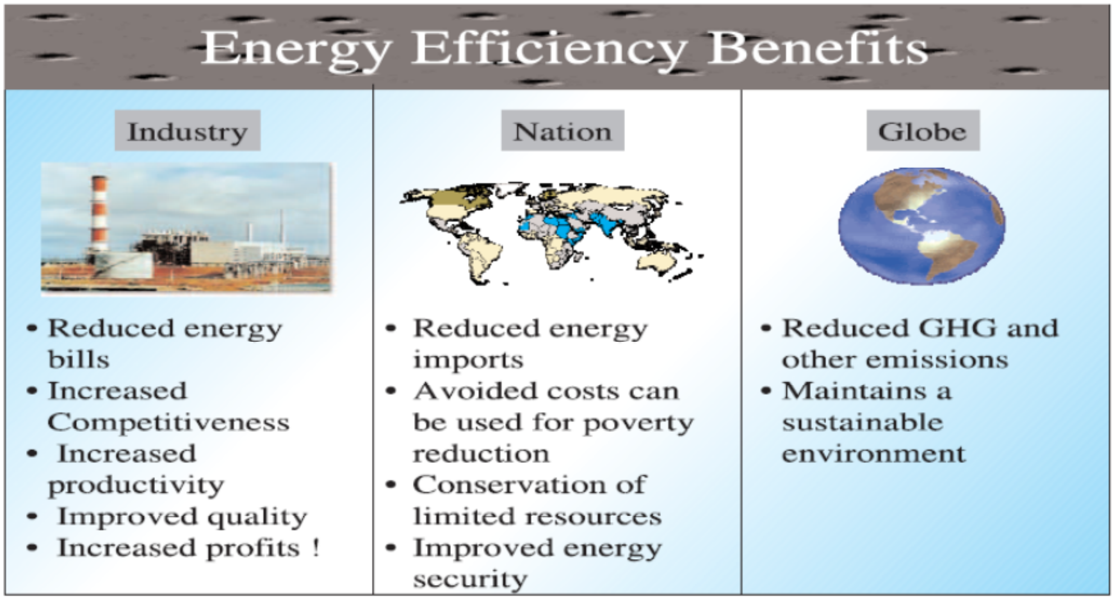


Figure 1.3(a) shows Energy Efficient Equipment

Pollution levels also reduce by the same amount see figure 1.3(a). Although, energy efficiency has been in practice ever since the first oil crisis in 1973, it has today assumed even more importance because of being the most cost-effective and reliable means of mitigating the global climatic change. Recognition of that potential has led to high expectations for the control of future CO_2 emissions even more energy efficiency improvements than have occurred in the past. The industrial sector accounts for some 41 per cent of global primary energy demand and approximately the same share of CO_2 emissions. Coal and other fossil fuels , which have taken three million years to form, are likely to deplete soon.

In the last two hundred years, we have consumed 60% of all resources. For sustainable development, we need to adopt energy efficiency measures. Today, 85% of primary energy comes comes from non renewable, and fossil sources.



Energy Efficiency Benefits

Industry

- Reduced energy bills
- Increased Competitiveness
- Increased productivity
- Improved quality
- Increased profits !

Nation

- Reduced energy imports
- Avoided costs can be used for poverty reduction
- Conservation of limited resources
- Improved energy security

Globe

- Reduced GHG and other emissions
- Maintains a sustainable environment

Figure 1.3(b) shows Energy Efficiency Benefits

These reserves are continually diminishing (see fig 1.3(c)) with increasing consumption and will not exist for future generations.

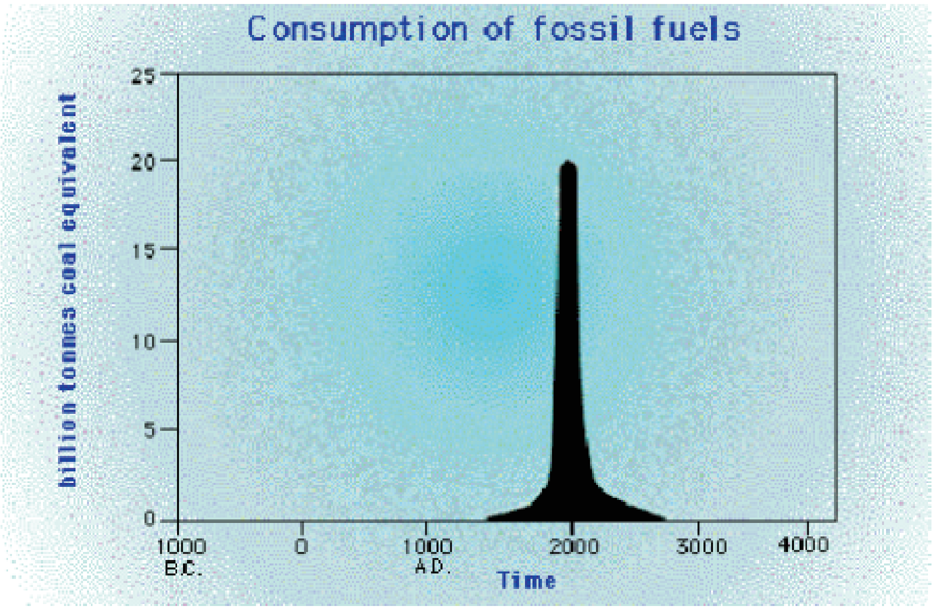


Figure1.3 (c) consumption of Fossil Fuel

1.4 Literature review

Cumming Paul G *et al.* (1981) [8] presented the efficiency testing of induction motors. This paper presented the revised methods and compared this Test Procedure with IEC 34-2 and JEC-37. Each of these specifications included variety of basic methods for determined efficiency based on motor size and availability of test equipment. Ranking of different methods in order of desirability and practicality of use was presented.

Aquila A. Dell *et al.* (1984) [2] proposed a new test method to determine the induction motor efficiency by an equivalent circuit with two rotor loops. This approach was a logical extension of the method of the traditional equivalent circuit. A simple non iterative procedure was used for calculating the two rotor loop parameters.

MONTGOMERY DAVID C *et al.* (1984)[28] discussed that motor users have always been concerned about how long a rewound motor would last but never knew what to do about it. What happens to the efficiency and operating cost of a motor that is rewound two to three tithes during, its lifetime? How motor losses can be changed during the rewind process was reviewed, along with what precautions should be taken to prevent an increase in operating costs and a decrease in motor life.

Schwartzet Thomas F. *et al.* (1985)[34] explored that in the determination of whether to rewind or replace, one factor not mentioned was the degree of burning of the stator iron caused by the insulation fault. If not repaired, this burning could defeat the effect of laminating the iron, raising the eddy current component of core loss in the vicinity of the burn.

RICHTER EIKE *et al.* (1985)[33] considered the design and steady-state performance under normal and abnormal conditions in case of high efficiency induction motor at a 50 percent duty cycle. The study results indicated that a motor with ferrite magnets meets the objectives of the program in ratings of up to 25 hp. A 7.5-hp motor design was carried through the conceptual design stage.

Binns D.F. *et al.* (1987) [3] calculate the present value of losses for a typical operating life and various alternative duty cycles for three performance characteristics (standard motor, high efficiency motor and the present values of the power and energy savings achieved when using the alternatives to the standard motor were shown to be substantial for duty cycles typical of several applications.

Medarametla J. B. *et al.* (1992) [26] described and analyzed the Unity Plus induction motor configuration for three phase motors. The equivalent circuit of the Unity Plus motor for steady-state operation was obtained through standard induction motor analysis methods.

Laboratory experiments on an induction motor, both as a conventional winding machine and a unity plus machine, confirmed the accuracy of the model.

Hsu J. S. *et al.* (1996) [16] separated and compared the basic methods according to their physical natures. This study was useful for field engineers to select or to establish a proper efficiency evaluation method by understanding the theories and error sources of the methods.

Gray Gerald G. *et al.* (1996) [12] presented the current version IEEE Std. 112-1991 Method B containing several requirements for accuracy improvement which have been found to be effective in induction motor. The paper discussed the purpose of these improvements, and also point out some weaknesses in procedure.

Hamer Paul S. *et al.* (1997) [14] discussed the true "control valve loss" factor, taking into account actual speed differences among motor options. A simplified equation and figure were presented to permit quick evaluation of motor purchase alternatives for lowest life-cycle cost based on efficiency and rated-load speed differences.

McCoy Gilbert A *et al.* (1997) [24] discussed Motor Master (DOS format), which was used by many within Pulp & Paper and other industries to evaluate and select motors for energy efficiency and lowest life cycle cost.

Pillay.P. *et al.* (1998) [31] presented the methods existing for determining the efficiency of induction motors. Many of them require a no-load test which was not possible for in-situ determination. An extensive survey of techniques for efficiency measurement was given. A new method was proposed for in-situ induction motor efficiency determined, based on the genetic algorithm. Results were compared with torque-gauge results.

Clarkson Kenneth *et al.* (1998) [6] covered the selection process of a 16,000 HP, 4-pole, Induction Motor driving a centrifugal compressor. Starting considerations, oscillating torque, power factor, mechanical & electrical design issues, first cost, and lifecycle costs were taken into account.

Jalilian A. *et al.* (2000)[17] investigated the behaviour of a 7.5 kW high efficiency cage induction motor fed by distorted supply and shown that a distorted voltage containing low order harmonics causes more losses in the motor as compared with the high order harmonics.

Grantham C. *et al.* (2003) [11] described a novel method of full load testing for temperature rise and efficiency evaluation of three phase Induction motors. A synthetic loading technique was used, without the need to connect a load to the machine's drive. The method proposed considerably reduced the testing time compared with conventional methods of temperature rise and efficiency measurement and the accuracy of the result was maintained. Simulation using a hypothetical machine was used to confirm the technique for efficiency evaluation.

Cowie John G *et al.* (2003) [7] shown that in addition to reduced rotor losses and improvement in overall electrical energy efficiency, an important derivative benefit is reduced motor operating temperature which would lead to longer motor life and reduced maintenance costs in high duty cycle motors.

Haring Tapio *et al.* (2003) [15] development a practical permanent magnet synchronous AC electric motor technology which permitted lower speed and higher torque output as compared to a conventional AC induction motor. This technology permits reduction in the number of mechanical drive components required in many machine applications.

Phumiphak T *et al.* (2004) [30] proposed an economical method that could help the plants to make right decision in replacing the inefficient induction motors with more efficient ones. This method focused on the field efficiency of motors without the needs for removing motors and measuring the output power.

McKinnon Douglas J *et al.* (2005) [25] demonstrated that the synthetic loading methods described were able to be used to evaluate the efficiency of three-phase induction machines. . The total losses for efficiency evaluation were identified by taking the average of the measured input power over each synthetic loading cycle. The measured results gave excellent agreement with the conventional full-load efficiency test method.

Lu Bin *et al.* (2006) [22] proposed a truly nonintrusive method for in-service motor efficiency estimation based on air-gap torque using only motor terminal quantities and nameplate information, with special considerations of motor condition monitoring requirements.

Cao Wenping *et al.* (2006) [5] drawn the conclusions from the study that showed a little impact of rewinding or repeated rewinding on the motor losses and efficiency if “good practice” was followed strictly. The efficiency results presented for most rewind studies apply for the full load condition. The question that then arises whether, there was a chance of improving the energy efficiency by modifying the motor design during rewinding, so that maximum efficiency occurs at the actual load point of the motor when used for its particular application.

Moghani J. S. *et al.* (2006) [27] proposed a drive specifically for washing machine which consists of a buck-boost power factor correction (P.F.C.) circuit, an inverter with selective harmonic elimination (S.H.E.), and a three-phase induction motor. The results showed that the new drive system efficiency was more than 2.5 times higher than efficiency of conventional washing machine single-phase induction motor.

Li Yanfeng *et al.* (2007) [20] introduced an industrial plant electricity consumption management on induction motors. In contrast to the traditional style of energy management that uses walkthrough audit and offline analysis, the proposed approach employed the nonintrusive efficiency estimation, induction motor flux regulation such as the proposed fuzzy energy optimized control, and wireless sensor networks.

Lu Bin *et al.* (2008) [21] proposed a truly nonintrusive method for in-service motor-efficiency estimation based on air-gap torque using only motor terminal quantities and nameplate information, with special considerations of motor condition monitoring requirements. Rotor speed and stator resistance, the stumbling blocks of most in-service testing methods, were extracted from motor input currents instead of being measured.

Koo Dae-Hyun *et al.* (2008) [19] shown the differences among IEC 61972, 34-2 and IEEE 112-methodB were shown and testing results were also compared. The main discrepancies between the various standards were the way of quantification of the stray load losses (SLLs), the stator resistance at the load test and the core losses with the influence of the voltage drop compensation.

Martínez E. *et al.* (2008) [23] presented an analysis of the environmental and life cycle costs of a switched reluctance motor (SRM) drive. The analysis was carried out according to the Energy-Using Product Directive (EuP 2005/32/EC) and followed the Methodology for the Eco-Design of Energy-Using Products (MEEUP methodology).

Kim Jaehyuck *et al.* (2008) [18] developed and presented a high efficiency low cost two-phase switched reluctance motor (SRM) drive system for high speed and large volume applications. The proposed drive can be a strong candidate for a low cost brushless variable (high) speed application in low-cost, mass-production markets, where life cycle and efficiency were valued.

Agamloh B Emmanuel *et al.* (2009) [1] presented a comparison of direct and indirect efficiency comparison methods from a collection of test data of about 1000 induction motors, rated 1-250hp, to show the relative accuracy of the direct method.

Debusschere V *et al.* (2009) [10] optimized the size of the a single phase permanent capacitor induction motors in a transient thermal regime. The optimizations were based on a typical operating cycle of roller shutter. The conclusion was validated when existing motors specifications were used as parameters for the optimization. It appeared that an increase of the diameter reduce the gross energy requirement. Another main result was that the operating cycle definition was fundamental in the design of the motor.

Daut I. *et al.* (2009) [9] presented the parameters calculation of 5hp three phase induction motor. In this paper, the assumed efficiency of an induction motor was 84% and power factor was 0.80. The motor parameters such as the stator resistance, rotor resistance, rotor current, induction motor losses were presented in this paper.

Pang Chee Khiang *et al.* (2011) [29] introduced a novel approach to address the challenge of missing operation context information during in-situ energy data measurement. Finite-State Machines (FSMs) were used to model the engineering processes, and a two stage

Frame work for online classification of real time energy measurement data in terms of machine operation states was proposed for energy audit and machine management.

Cao Wenping *et al.* (2011) [4] discussed that the most significant changes to the loss in induction motors caused by the repair process would be expected to be to stator copper loss, to core loss and to stray load loss. This was shown to be the case but the overall effect was normally less than 0.5% efficiency loss.

1.5 Objective of Thesis

The objective of the thesis is to calculate the efficiency of new and rewound induction motors for the life cycle cost comparison of these motors.

1.6 Organization of the Thesis

This thesis is divided into five chapters-

-The first chapter introduces the concept of energy in various forms role of energy in various sectors, organization of thesis, methodology used and literature survey.

-Second chapter contains the types and methodology of energy audit in industries.

-Third chapter introduces the induction motor its performance, efficiency, its losses, rewound motor issues and load curves.

-Fourth chapter contains data and the result of induction motors comparison of new and rewind motors based upon life cycle cost comparison method.

-Fifth chapter contains results, conclusion and future scope.

1.7 Methodology used:-

Energy audit of induction motor is carried out on life cycle cost comparison .The measured values and calculated values are compared. To compare motor options, A simple approach is proposed based on the purchase price of the motor and the present value of the losses.

Chapter 2

Energy Auditing

2.0 Introduction

The strategy of adjusting and optimizing energy, so as to reduce energy requirements per unit of output while holding constant using systems and procedures or reducing total costs of producing the output from these system or the fundamental goal of energy management is to produce goods and provide services with the least cost and least environmental effect.

The objective of Energy Management is to achieve and maintain optimum energy procurement and utilisation, throughout the organization and:

- To minimise environmental effects.
- To minimise energy costs / waste without affecting production & quality

In any industry, energy, labour and materials are three top operating expenses are often found to be. If one were to relate to the manageability of the cost or potential cost savings in each of the above components, energy would invariably emerge as a top ranker, and thus energy management function constitutes a strategic area for cost reduction.

2.1 Energy Audit: Types and Methodology

In the area of energy management energy Audit is the key to a systematic approach for decision-making. It attempts to balance the total energy inputs with its use, and serves to identify all the energy streams in a facility. Energy Audit will help to understand more about the ways energy and fuel are used in any industry, and help in identifying the areas where waste can occur and where scope for improvement exists. It quantifies energy usage according to its discrete functions. In defining industrial energy audit the pursuing comprehensive energy management programme is an effective tool.

In general, Energy Audit is the translation of conservation ideas into realities, by lending technically feasible solutions with economic and other organizational considerations within a specified time frame. To the energy cost reduction, preventive maintenance and quality control programmes which are vital for production and utility activities, the energy audit would give a positive orientation.

Such an audit programme helps to keep focus on availability and reliability of supply of energy variations which occur in the energy costs, decide on appropriate energy mix, identify energy conservation technologies, retrofit for energy conservation equipment etc

The primary objective of energy audit is to determine ways to reduce energy consumption per unit of product output or to lower operating costs. Energy Audit provides a “bench-mark" for managing energy in the organization and also provides the basis for planning a more effective use of energy throughout the organization.

Type of Energy Audit

The type of Energy Audit to be performed depends on:

- Function and type of industry
- Depth to which final audit is needed, and
- Potential and magnitude of cost reduction desired

Thus Energy Audit can be classified into the following two types.

i) Preliminary Audit

ii) Detailed Audit

2.1.1 Preliminary Energy Audit Methodology

Preliminary energy audit is a relatively quick exercise to:

- Estimate the scope for saving
- Establish energy consumption in the organization
- Set a 'reference point'
- Identify the most likely (and the easiest areas for attention
- Identify immediate (especially no-/low-cost) improvements/ savings
- Identify areas for more detailed study/measurement
- Preliminary energy audit uses existing, or easily obtained data

2.1.2 Detailed Energy Audit Methodology

A detailed energy project implementation plan for a facility is evaluated by a comprehensive audit, since it evaluates all major energy using systems provided. This type of audit offers the most accurate estimate of energy savings and cost. It accounts for the energy use of all major equipment and considers the interactive effects of all projects, and includes detailed energy cost saving calculations and project cost. In a comprehensive audit, one of the key elements is the energy balance. This is based on calculations of energy use and an inventory of energy using systems, assumptions of current operating conditions. This estimated use is then compared to utility bill charges.

Detailed energy auditing is carried out in three phases: Phase I, II and III.

Phase I - Pre Audit Phase

Phase II - Audit Phase

Phase III - Post Audit Phase

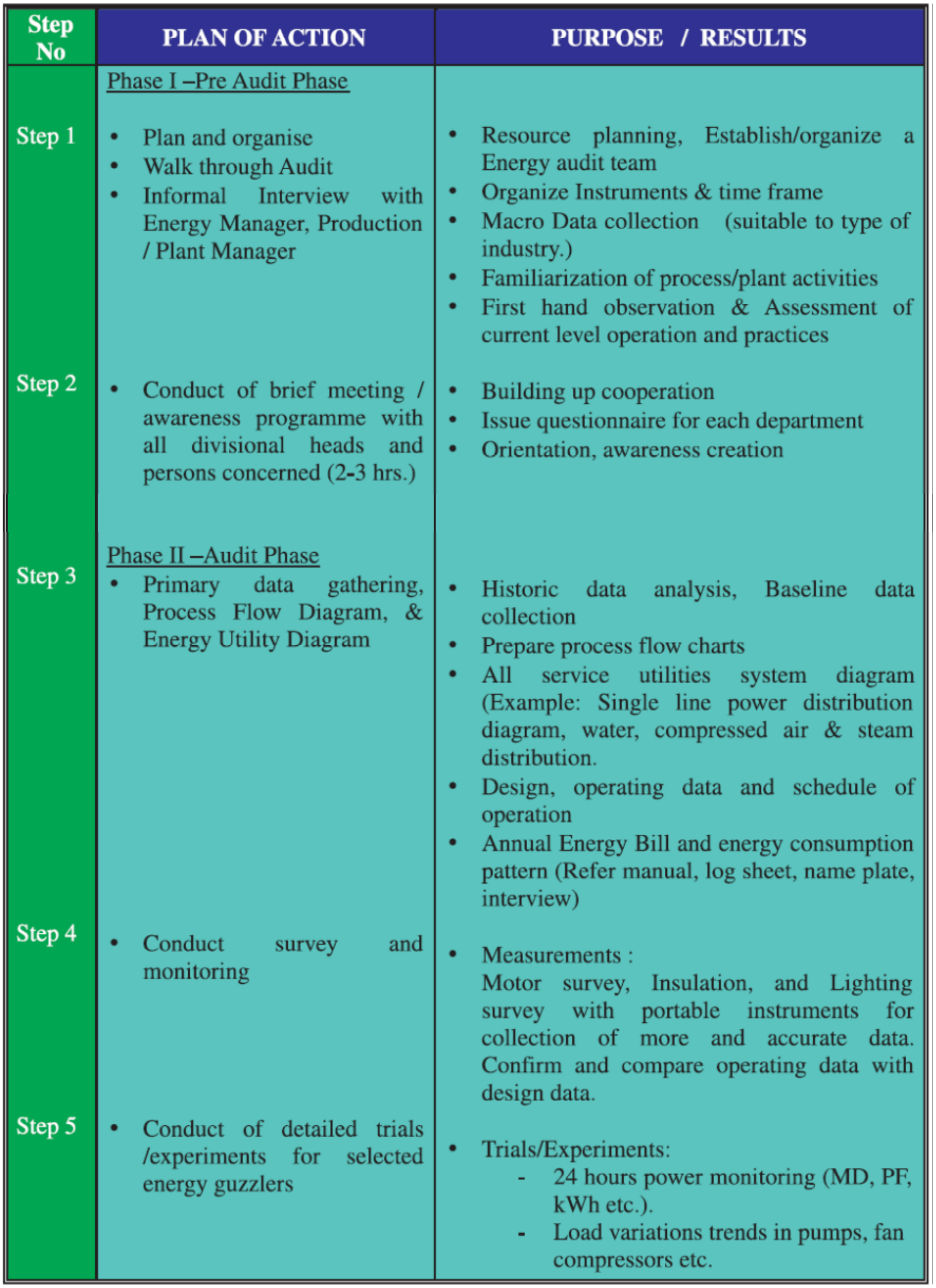
2.2 A Guide for Conducting Energy Audit at a Glance

. A comprehensive ten-step methodology for conduct of Energy Audit at field level is presented below. Industry-to-industry the methodology of Energy Audits needs to be flexible Energy Manager and Energy Auditor may follow these steps to start with and add changes as per their needs and industry types.

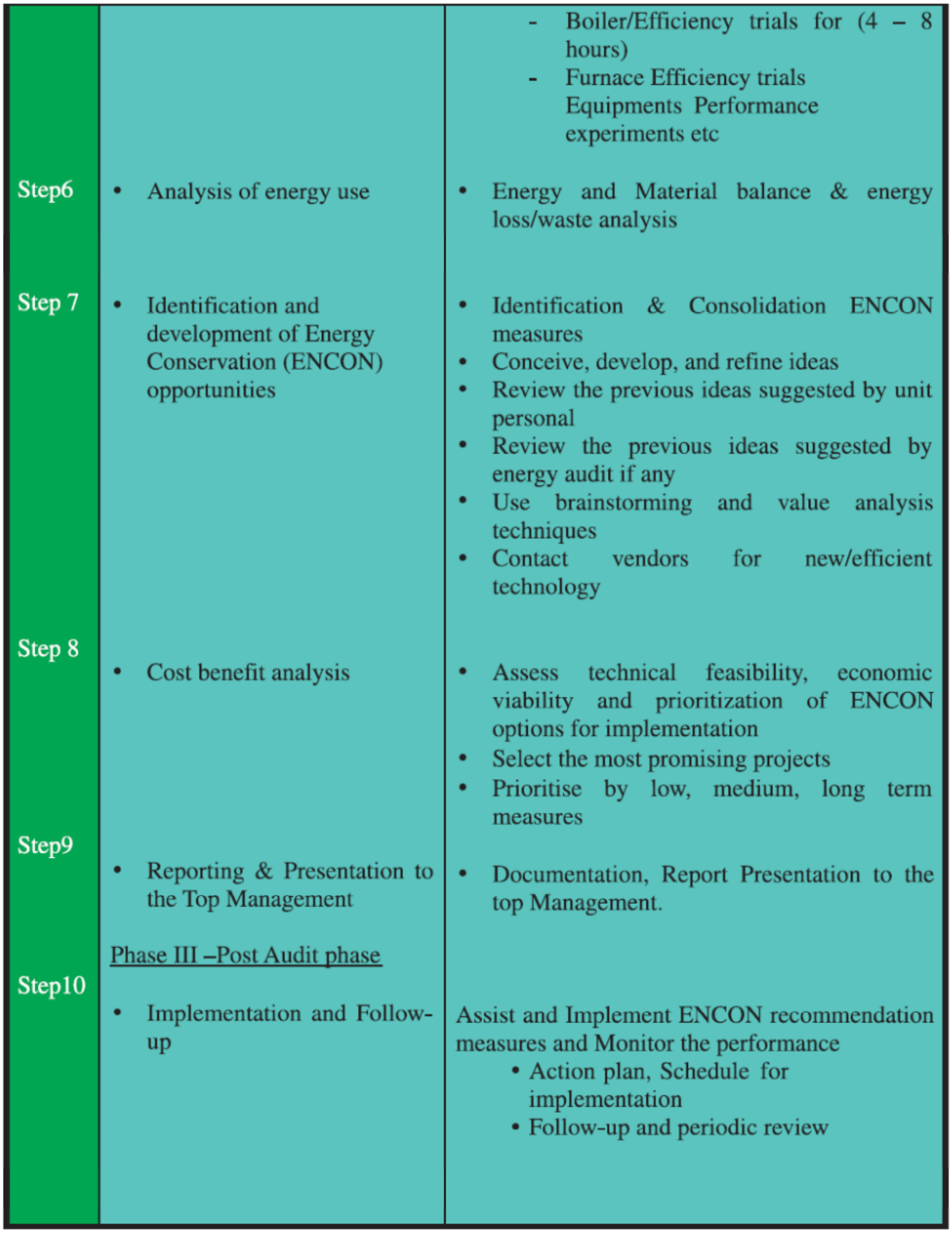
Production cost and productivity levels in terms of product per raw material are useful to get consumption pattern by inputs of existing baseline information and reports. The audit team should collect the following baseline data:

- Electrical energy consumption
- Technology, processes used and equipment details
- Capacity utilisation
- Steam consumption
- Amount & type of input materials used
- Water consumption
- Fuel Consumption
- Other inputs such as compressed air, cooling water etc
- Quantity & type of wastes generated
- Percentage rejection / reprocessing

Table 2.2Pre-Audit and Post Audit Phase



Step No	PLAN OF ACTION	PURPOSE / RESULTS
	Phase I –Pre Audit Phase	
Step 1	• Plan and organise • Walk through Audit • Informal Interview with Energy Manager, Production / Plant Manager	• Resource planning, Establish/organize a Energy audit team • Organize Instruments & time frame • Macro Data collection (suitable to type of industry.) • Familiarization of process/plant activities • First hand observation & Assessment of current level operation and practices
Step 2	• Conduct of brief meeting / awareness programme with all divisional heads and persons concerned (2-3 hrs.)	• Building up cooperation • Issue questionnaire for each department • Orientation, awareness creation
	Phase II –Audit Phase	
Step 3	• Primary data gathering, Process Flow Diagram, & Energy Utility Diagram	• Historic data analysis, Baseline data collection • Prepare process flow charts • All service utilities system diagram (Example: Single line power distribution diagram, water, compressed air & steam distribution. • Design, operating data and schedule of operation • Annual Energy Bill and energy consumption pattern (Refer manual, log sheet, name plate, interview)
Step 4	• Conduct survey and monitoring	• Measurements : Motor survey, Insulation, and Lighting survey with portable instruments for collection of more and accurate data. Confirm and compare operating data with design data.
Step 5	• Conduct of detailed trials /experiments for selected energy guzzlers	• Trials/Experiments: - 24 hours power monitoring (MD, PF, kWh etc.). - Load variations trends in pumps, fan compressors etc.



		- Boiler/Efficiency trials for (4 – 8 hours) - Furnace Efficiency trials Equipments Performance experiments etc
Step6	• Analysis of energy use	• Energy and Material balance & energy loss/waste analysis
Step 7	• Identification and development of Energy Conservation (ENCON) opportunities	• Identification & Consolidation ENCON measures • Conceive, develop, and refine ideas • Review the previous ideas suggested by unit personal • Review the previous ideas suggested by energy audit if any • Use brainstorming and value analysis techniques • Contact vendors for new/efficient technology
Step 8	• Cost benefit analysis	• Assess technical feasibility, economic viability and prioritization of ENCON options for implementation • Select the most promising projects • Prioritise by low, medium, long term measures
Step9	• Reporting & Presentation to the Top Management	• Documentation, Report Presentation to the top Management.
	Phase III –Post Audit phase	
Step10	• Implementation and Follow-up	Assist and Implement ENCON recommendation measures and Monitor the performance • Action plan, Schedule for implementation • Follow-up and periodic review

2.2.1 Phase I -Pre Audit Phase Activities

For efficient working a structured methodology to carry out an energy audit is necessary. An initial study of the site should always be carried out, as the planning of the procedures necessary for an audit is most important.

Initial Site Visit and Preparation Required for Detailed Auditing

To meet the personnel concerned an initial site visit may take one day and gives the Energy Auditor/Engineer an opportunity, to familiarize him with the site and to assess the procedures necessary to carry out the energy audit. The following actions during the initial site visit for the Energy Auditor/Engineer to carry out: -

- Analyse the major energy consumption data with the relevant personnel.
- Discuss with the site's senior management the aims of the energy audit.
- Discuss economic guidelines associated with the recommendations of the audit.
- Tour the site accompanied by engineering/production
- Obtain site drawings where available - building layout, steam distribution, compressed air distribution, electricity distribution etc.

The main aims of this visit are: -

- To identify any existing instrumentation/ additional metering required.
- To finalise Energy Audit team
- To identify the main energy consuming areas/plant items to be surveyed during the audit.
- To decide whether any meters will have to be installed prior to the audit eg. kWh, steam, oil or gas meters.
- To plan with time frame
- To collect macro data on plant energy resources, major energy consuming centres
- To identify the instrumentation required for carrying out the audit.
- To create awareness through meetings/ programme

2.2.2 Phase II- Detailed Energy Audit Activities

A comprehensive audit can take from several weeks to several months to complete depending on the nature and complexity of the site. Detailed studies to establish, and investigate, energy and material balances for specific plant departments or items of process equipment are carried out. Checks of plant operations are carried out over extended periods of time, at nights and at weekends as well as during normal daytime working hours, to ensure that nothing is overlooked whenever possible. The audit report will include a description of energy inputs and product outputs by major department or by major processing function, and will evaluate the efficiency of each step of the manufacturing process. To indicate the expected payback on any capital investment needed to means of improving these efficiencies will be listed, and at least a preliminary assessment of the cost of the improvements will be made. Specific recommendations for detailed engineering studies and feasibility analyses for the audit report should conclude, which must then be performed to justify the implementation of those conservation measures that require investments.

2.2.3 The information to be collected during the detailed audit includes: -

1. Material balance data (raw materials, intermediate and final products, recycled materials, use of scrap or waste products, production of by-products for re-use in other industries, etc.)
2. Energy consumption by type of energy, by department, by major items of process equipment, by end-use.
3. Energy cost and tariff data
4. Process and material flow diagrams
5. Sources of energy supply (e.g. electricity from the grid or self-generation)
6. Generation and distribution of site services (eg. compressed air, steam).
7. Potential for fuel substitution, process modifications, and the use of co-generation systems.
8. Energy Management procedures and energy awareness training programs within the establishment.

Chapter 3

Induction Motor

3.0 Introduction

Motors convert electrical energy into mechanical energy by the interaction between the magnetic fields set up in the stator and rotor windings. Industrial electric motors can be broadly classified as induction motors, direct current motors or synchronous motors. All motor types have the same four operating components: stator (stationary windings), rotor (rotating windings), bearings, and frame (enclosure).

3.1 Induction Motors

The 65% of the total load is industrial load in India and 90% of this industrial load is induction motor load. Compared to other alternatives the induction motor is cheaper and easier to maintain. The induction motor is made up of the stator, or stationary windings, and the rotor. The stator consists of a series of fine wire windings of very low resistance permanently attached to the motor frame. A magnetic field is developed in the windings as a voltage and a current is applied to the stator winding terminals. By the way the stator windings are arranged, the magnetic field appears to synchronously rotate electrically around the inside of the motor housing. Most commonly used prime mover for various equipments in industrial applications is induction motors. In induction motors, the induced magnetic field of the stator winding induces a current in the rotor. It is rugged and reliable, and is by far the most common motor type used in industry.

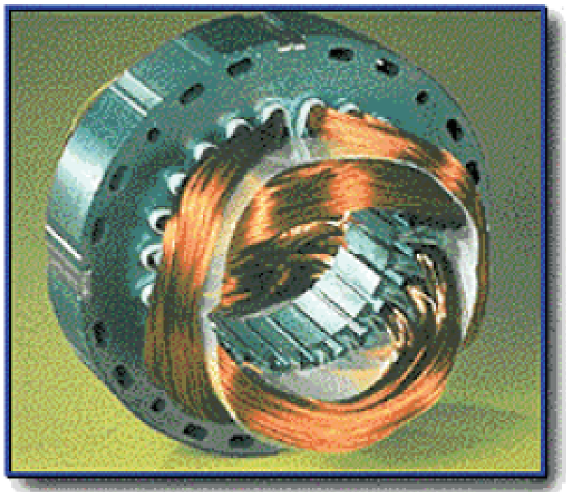


Figure 3.1 Induction Motor Winding

3.1.1 Induction Motors are of mainly two types:

3.1.1.1 Slip ring or wound rotor motors.

3.1.1.1 Slip Ring Motors

Wound rotor motors have brushes and winding on the rotor. Starting torque is more because external resistance can be added in the rotor circuit. We add resistance in rotor circuit at the time of starting.

Figure 3.1.1.1 Slip Ring Induction Motor

Slip ring motors are not commonly used in industry because of their high maintenance cost and they are not rugged.

3.1.1.2 Squirrel Cage Induction Motor

Squirrel cage induction motors rotor is comprised of a number of thin bars, usually aluminium, mounted in a laminated cylinder. The bars are arranged horizontally and almost parallel to the rotor shaft. At the ends of the rotor, the bars are connected together with a “shorting ring.” The rotor and stator are separated by an air gap which allows free rotation of the rotor. The magnetic field generated in the stator induces an EMF in the rotor bars. In turn, a current is produced in the rotor bars and shorting ring and another magnetic field is induced in the rotor with an opposite polarity of that in the stator. The magnetic field, revolving in the stator, will then produces the torque which will “pull” on the field in the rotor and establish rotor rotation.

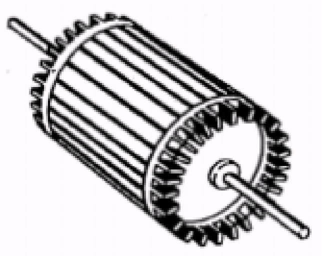


Figure 3.1.1.2 Squirrel Cage Rotor

3.1.2 Synchronous Speed

The speed with which the stator magnetic field rotates, which will determine the speed of the rotor, is called the Synchronous Speed (N_s). The N_s is a function of the frequency of the power source and the number of poles (pole pairs) in the motor. The relationship to calculate the Synchronous Speed of an induction motor is:

$$N_s = (120 \text{ X } f) / P$$

N_s = Synchronous Speed (RPM)
f = frequency (cycles / second) = 50
P = number of poles (pole pairs)

Indian motors have synchronous speeds like 3000 / 1500 / 1000 / 750 / 600 / 500 / 375 RPM corresponding to no. of poles being 2, 4, 6, 8, 10, 12, 16 (always even) and given the mains frequency of 50 cycles / sec.

3.1.3 Motor Slip

The rotor in an induction motor cannot turn at the synchronous speed. In order to induce an EMF in the rotor, the rotor must move slower than the N_s. If the rotor were to somehow turn at N_s, the EMF could not be induced in the rotor and therefore the rotor would stop. However, if the rotor stopped or even if it slowed significantly, an EMF would once again be induced in the rotor bars and it would begin rotating at a speed less than the N_s. The relationship between the rotor speed and the N_s is called the Slip. Typically, the Slip is expressed as a percentage of the N_s. Motor speed (N):

$$N=N_s(1-S)$$

The equation for the motor Slip is:

$$\% \text{ S} = \left(\frac{\text{Synchronous Speed} - \text{Rotor Speed}}{\text{Synchronous Speed}}\right) \text{X} 100$$

%S = Percent Slip
Synchronous Speed (RPM) = N_s
Rotor Speed (RPM) = N_r

3.1.4 Equivalent Circuit

To analyze the operating and performance characteristics of an induction motor, an Equivalent Circuit can be drawn. We will consider a 3–phase, Y connected machine, the Equivalent Circuit for the stator is as shown below:

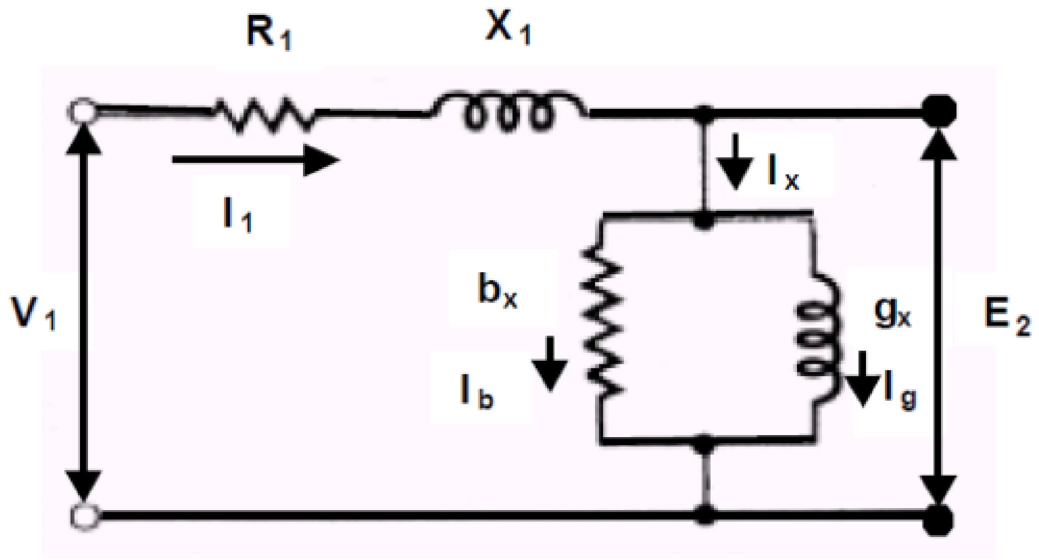


Figure 3.1.4(a) Equivalent Circuit for the stator

Where:

V_1 = Stator Terminal Voltage

I_1 = Stator Current

R_1 = Stator Effective Resistance

X_1 = Stator Leakage Reactance

Z_1 = Stator Impedance ($R_1 + jX_1$)

I_X = Exciting Current (this is comprised of the core loss component = Ig , and a magnetizing current = I_b)

E_2 = Counter EMF (generated by the air gap flux)

The counter EMF (E_2) is equal to the stator terminal voltage less the voltage drop caused by the stator leakage impedance.

$E_2 = V_1 – I_1 (Z_1)$

$E_2 = V_1 - I_1 (R_1 + j X_1)$

In an analysis of an induction motor, the equivalent circuit can be simplified further by omitting the shunt reaction value. The core losses associated with this value can be subtracted from the motor Power and Torque when the friction, windage and stray losses are deducted.

The simplified circuit for the stator then becomes:

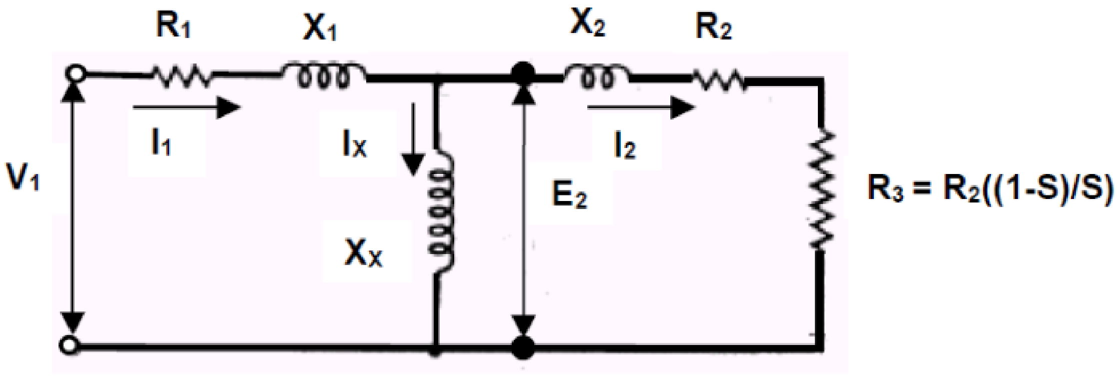


Figure 3.1.4(b) Equivalent Circuit

3.1.5 Motor Speed

The speed of a motor is the number of revolutions in a given time frame, typically revolutions per minute (RPM). The speed of an AC motor depends on the frequency of the input power and the number of poles for which the motor is wound. The synchronous speed in RPM is given by the following equation, where the frequency is in hertz or cycles per second:

$$\text{Synchronous Speed (RPM)} = \frac{120 * \text{Frequency}}{\text{No.of Poles}}$$

The actual speed, with which the motor operates, will be less than the synchronous speed. The difference between synchronous and full load speed is called slip and is measured in percent.

It is calculated using this equation:

$$\%\ \text{slip} = \frac{\text{Synchronous speed} - \text{full load rated speed}}{\text{synchronous speed}}$$

As per relation stated above, the speed of an AC motor is determined by the number of motor poles and by the input frequency. It can also be seen that by changing the frequency speed of an AC motor can be varied infinitely. Manufacturer's guidelines should be referred for practical limits to speed variation. With the addition of a Variable Frequency Drive (VFD), the speed of the motor can be decreased as well as increased.

3.1.6 Power Factor

The power factor of the motor is given as:

$$\text{Cos } \square = \frac{\text{Active Power (kw)}}{\text{Apparent Power (kva)}}$$

It is the angle between phase voltage and phase current or it is the ratio of active power to the apparent power. If current leads the voltage, then p.f is leading if current lags the voltage, then p.f is lagging. It has significant effect on the electrical system if the power factor is low then current in the circuit is more. So, we prefer high p.f but in industry most of the load is inductive because of induction motors. So we have to improve this p.f by installing synchronous condenser or capacitor unit. And another cause of low p.f is as the load on the motor comes down, the magnitude of the **active current** reduces. However, there is no corresponding reduction in the **magnetizing current,** which is proportional to supply voltage with the result that the motor power factor reduces, with a reduction in applied load. Induction motors, especially those operating below their rated capacity, is the main reason for low power factor in electric systems.

3.2 Motor Efficiency

Two important attributes relating to efficiency of electricity use by A.C. Induction motors are power factor (PF) and efficiency (η), efficiency is defined as the ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals. Motors, like other inductive loads, are characterized by power factors less than one.

As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. Resistance losses in wiring upstream of the motor will be higher and important effect of operating with a PF less than one, since these are proportional to the square of the current.

Thus, both a high value for η and a PF close to unity are desired for efficient overall operation in a plant. Squirrel cage motors are normally more efficient than slip-ring motors, and higher-speed motors are normally more efficient than lower-speed motors. Efficiency is also a function of motor temperature. Totally-enclosed, fan-cooled (TEFC) motors are more efficient than screen protected drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity.

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types:

Fixed losses - independent of motor load, and **variable losses** - dependent on load.

Fixed losses consist of magnetic core losses and friction and windage losses. Magnetic core losses (sometimes called iron losses) consist of eddy current and hysteresis losses in the stator. They vary with the core material and geometry and with input voltage. Friction and windage losses are caused by friction in the bearings of the motor and aerodynamic losses associated with the ventilation fan and other rotating parts.

Variable losses consist of resistance losses in the stator and in the rotor and miscellaneous stray losses. Resistance to current flow in the stator and rotor result in heat generation that is proportional to the resistance of the material and the square of the current (I^2R). Difficult to either measure directly or to calculate stray losses arise from a variety of sources, but are generally proportional to the square of the rotor current. Part-load performance characteristics of a motor also depend on its design. Both PF and η fall to very low levels at low loads. The Figures 3.2(a) shows the effect of load on power factor and efficiency. It can be seen that power factor drops sharply at part loads. The Figure 3.2(b) shows the effect of speed on power factor.

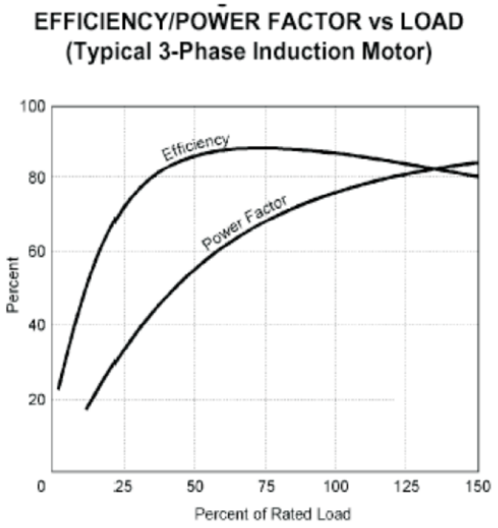


Figure 3.2(a) Load vs. Power factor, Efficiency

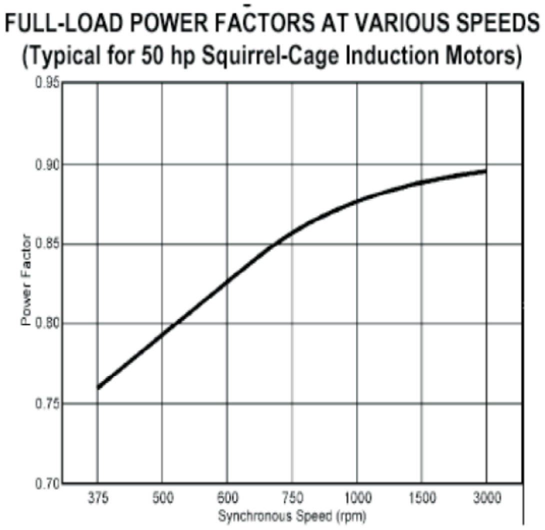


Figure 3.2(b) Speed vs. Power factor

3.2.1 Stator and Rotor I^2R Losses

These losses are major losses and typically account for 55% to 60% of the total losses. Current passing through stator and rotor conductors resulting I^2R losses (heating losses). I^2R losses are the function of a conductor resistance, the square of current. Resistance of conductor is a function of conductor material, length and cross sectional area. The suitable selection of copper conductor size will reduce the resistance. Reducing the motor current is most readily accomplished. This involves possible shortening of air gap and lowering the operating flux density. Rotor I^2R losses are a function of the rotor conductors and the rotor slip. Utilisation of copper conductors will reduce the winding resistance. Motor operation closer to synchronous speed will also reduce rotor I^2R losses.

3.2.2 Core Losses

These losses are independent of load and account for 20 – 25 % of the total losses. Core losses are those found in the stator-rotor magnetic steel and are due to hysteresis effect and eddy current effect during 50 Hz magnetization of the core material. Eddy current losses are generated by circulating current within the core steel laminations. These are reduced by using thinner laminations. The hysteresis losses which are a function of flux density, are be reduced by utilizing low loss grade of silicon steel laminations. The reduction of flux density is achieved by suitable increase in the core length of stator and rotor.

3.2.3 Friction and Windage Losses

These losses are independent of load. Friction and windage losses results from bearing friction, windage and circulating air through the motor and account for 8 – 12 % of total losses. The windage losses also reduce with the diameter of fan leading to reduction in windage losses. The reduction in heat generated by stator and rotor losses permit the use of smaller fan.

3.2.4 Stray Load-Losses

These account for 4 to 5 % of total losses. These losses vary according to square of the load current and are caused by leakage flux induced by load currents in the laminations. These losses are reduced by careful selection of slot numbers, tooth/slot geometry and air gap. Energy efficient motors cover a wide range of ratings and the full load efficiencies are higher by 3 to 7 %. The mounting dimensions are also maintained as per IS1231 to enable easy replacement.

3.3 Comparison Between Conventional and Energy- Efficient Motors

Energy-efficient motors now available in India operate with efficiencies that are typically 3 to 4 percentage points higher than standard motors. Energy-efficient motors (EEM) are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design. Intrinsic motor losses are reduced by design improvements. Improvements include the use of lower-loss silicon steel, a longer core, thicker wires, thinner laminations, smaller air gap between stator and rotor, copper instead of aluminium bars in the rotor, superior bearings and a smaller fan, etc.

This may result in major benefits in varying load applications. The power factor is about the same or may be higher than for standard motors. In keeping with the stipulations of the BIS, energy-efficient motors are designed to operate without loss in efficiency at loads between

75% and 100 % of rated capacity. Furthermore, energy-efficient motors have lower operating temperatures and noise levels, greater ability to accelerate higher-inertia loads, and are less affected by supply voltage fluctuations.

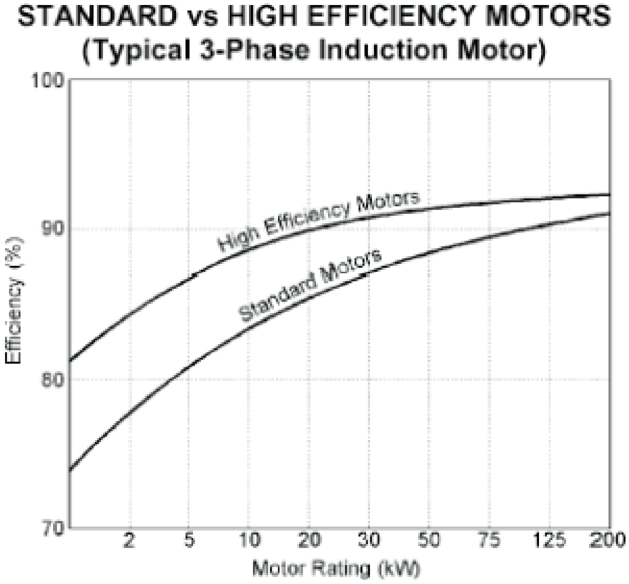


Figure 3.3 Standard v/s High Efficiency Motor

The costs of energy-efficient motors are higher than those of standard motors as a result of these modifications to improve performance. The higher cost will often be paid back rapidly in saved operating costs, particularly in new applications or end-of-life motor replacements. The economics will be less clearly positive in cases where existing motors have not reached the end of their useful life. Because the favourable economics of energy-efficient motors are based on savings in operating costs, there may be certain cases which are generally economically ill-suited to energy efficient motors. These include highly intermittent duty or special torque applications such as, traction drives, hoists and cranes, punch presses, machine tools, and centrifuges.

In addition, energy efficient designs of multi-speed motors are generally not available. Furthermore, energy- efficient motors are not yet available for many special applications, e.g. for flame-proof operation in fire pumps or oil-field or for very low speed applications. Also, most energy-efficient motors produced today are designed only for continuous duty cycle operation. Given the tendency of over sizing on the one hand and ground realities like ; frequency variations ,voltage, efficacy of rewinding in case of a burnout, on the other hand, benefits of EEM's can be achieved only by careful operation ,selection, implementation, and maintenance.

Chapter 4

Life Cycle Cost of Induction Motor

4.0 Introduction

The majority of motors in the field are induction motors. The industry is becoming increasingly concerned about the ability of electric motors to ride through power system disturbances. There may be various reasons for the desire of testing induction motors in the field, such as the consideration of exchanging out of date or worn motors with new, or checking the efficiencies after rewinding.

4.1 Determination of Motor Efficiency for Life Cycle Cost Comparison

The last calculation considered is to determine the motor efficiencies. These can be calculated by comparing the losses to the total power input of the motor.

$$\text{Efficiency} = 1.000 - (\text{Total Losses}) / (\text{Motor Input})$$

The energy crisis has resulted in an increased interest in motor efficiencies. Various reports have claimed large savings in oil usage if high efficiency motors are universally used. While efficiency is a simple ratio of the output to input, precise measurement of these two quantities, particularly when that ratio gets above 0.9, can be difficult.

4.1.1 Description of Motor Losses

Losses in an induction motor can be segregated into no load losses and load losses.

No-Load Losses Windage and friction (Wf) are mechanical losses due to bearing friction and windage Core loss (Wh) constitutes hysteresis and eddy current losses in the iron at no-load.

Load Losses Stator I^2R (W_1) losses are losses in the stator winding. (Note: R is a variable with temperature.) Rotor I^2R or slip loss (W_2) are losses in the rotor winding. (Note: R is a variable with temperature.) Stray-load losses (W_{LL}) are additional fundamental and high frequency losses in the iron, strand and circulating current losses in the stator winding, harmonic losses in the rotor conductors under load. These losses are proportional to the rotor current squared.

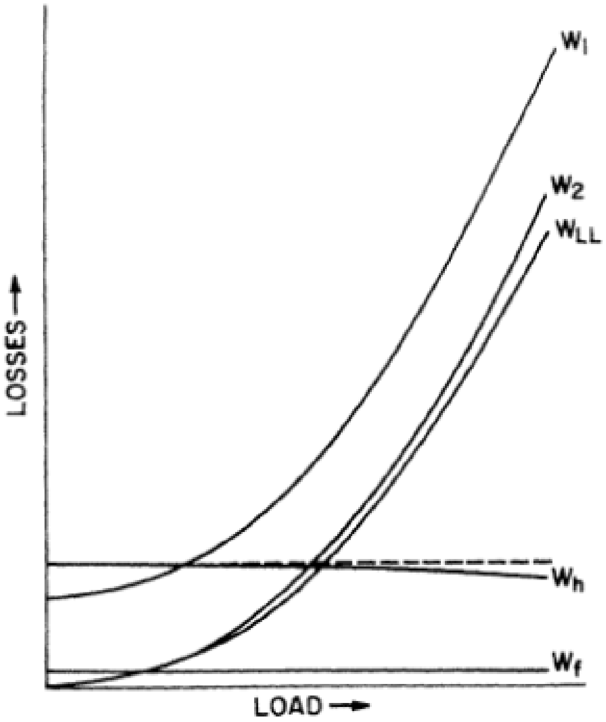
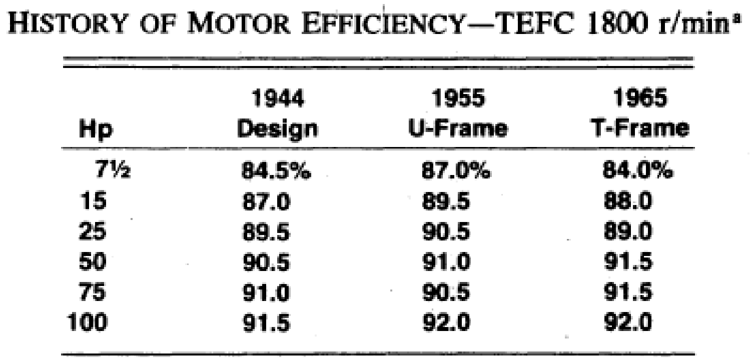


Figure 4.1.1 Motor Losses v/s Load

4.1.2 Determines Motor Efficiency

The operating efficiency of any motor is determined by its original design, the quality of the construction or rewind, how heavily it is loaded and the quality of the power supply. Design value will vary with the motor vintage (Table 4.1.2(a)), hp and speed (Table 4.1.2(b)), enclosure and voltage. "U frame" motors were generally more efficient than "original NEMA" designs and the smaller "T frame" designs. .The most common operating speed motors, 1800 r/min, are generally more efficient than 3600- and 1200-r/min designs.

Table 4.1.2 (a) efficiency of rewound motor will depend upon original design.

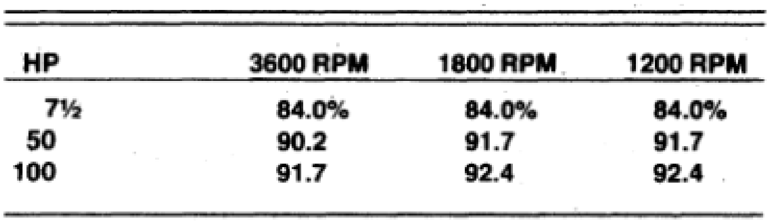


HISTORY OF MOTOR EFFICIENCY—TEFC 1800 r/min[a]

Hp	1944 Design	1955 U-Frame	1965 T-Frame
7½	84.5%	87.0%	84.0%
15	87.0	89.5	88.0
25	89.5	90.5	89.0
50	90.5	91.0	91.5
75	91.0	90.5	91.5
100	91.5	92.0	92.0

Motor efficiency by design parameters

Table 4.1.2(b) Efficiency varies with motor horsepower and speed.



HP	3600 RPM	1800 RPM	1200 RPM
7½	84.0%	84.0%	84.0%
50	90.2	91.7	91.7
100	91.7	92.4	92.4

Although the efficiency curve (Fig. 4.1.2(c)) is relatively flat above 25 percent load, efficiency does vary with load. The peak efficiency occurs where no-load losses equal load losses.

The voltage at the motor terminals also has an effect on efficiency. The exact impact will vary with the flux density of the original design and the motor load. Voltage unbalance can have a dramatic impact on motor efficiency.

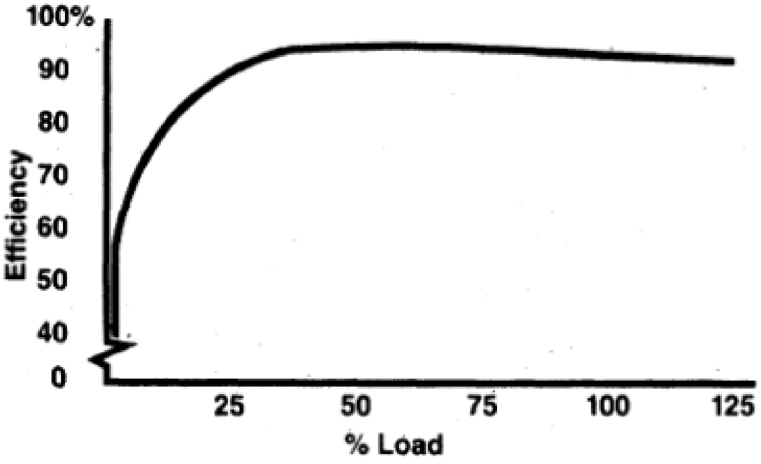


Figure 4.1.2 (c)   Efficiency versus load

4.1.3 Why Be Concerned About Motor Losses?

Although motors are more efficient than any of the equipment they drive, their operating cost is of vital importance because they do account for over 90 percent of the power used by industry. The total annual operating cost for a single 50-hp motor is Rs 1142440, based on continuous operation at Rs4.5/kWh power rates and 89.2 percent efficiency . Useful work represents Rs 1019460 of this total and motor losses Rs 122980. It is essential these losses not be allowed to increase since their increase will reduce profits year after year, and a typical industrial plant may have hundreds of motors.

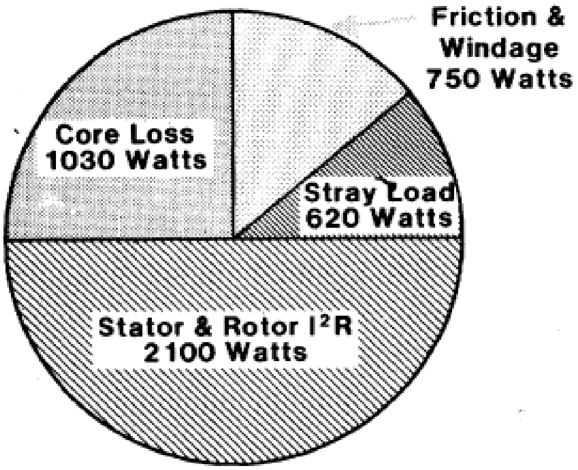


Figure 4.1.3 Losses for 50-hp 3600-r/min drip proof motor at full load

4.2 Life Cycle Cost Comparison of Induction Motor

Indian industry is currently feeling a squeeze on profits due to the rapid rise in power costs. It is no longer practical to consider the monthly power bill as a fixed base cost that cannot be controlled. Power costs have been rising faster than both material and producer good prices. During the 2000's they were increasing at approximately the same rate, and it was generally possible to pass any power increase along to the customer in the form of a price increase. After the energy crunch, power rates increased much faster than the prices for products, so any portion of power posts that could not be passed along came directly out of profits. Since motors account for over 90 percent of power used by industry, they have always had an impact on operating costs. In today's economy, it is more important than ever to keep the cost of motor losses under control.

So for Life cycle cost comparison method first of all we have to calculate the rated speed, Efficiencies, Prices of new and rewind motors.

Life-Cycle Cost (LCC)

$LCC = PP + EF \times K W_e$

LCC life cycle cost

PP motor purchase price

EF evaluation factor

$K W_e$ evaluated loss

$EF = C (N) (PWF)$

where

C	power cost, (Rs/kWh);
N	operating time each year, (h);
PWF	cumulative present worth factor.

$KW_e = L\ (hp)\ (0.746)[(S_e/S_b)^x-1+(100/E_{op})-1]$

where

KW_e	evaluated loss, (kW);
L	load factor= (driven-load rated horsepower)/(motor nameplate horsepower);
Hp	motor nameplate horsepower, (hp);
S_e	rated full-load speed of evaluated motor, (r/min);
S_b	rated full-load speed used as the basis for the evaluation, (r/min); usually the quoted rated speed of the driven equipment;
x	exponent of S_e/S_b
E_{op}	motor nominal efficiency at the rated driven equipment shaft load,(%)

Assume the following:

- power cost of Rs 4.5 per kilowatt hour;
- operating hours of 8000 per year;
- cumulative present worth factor equals 4.

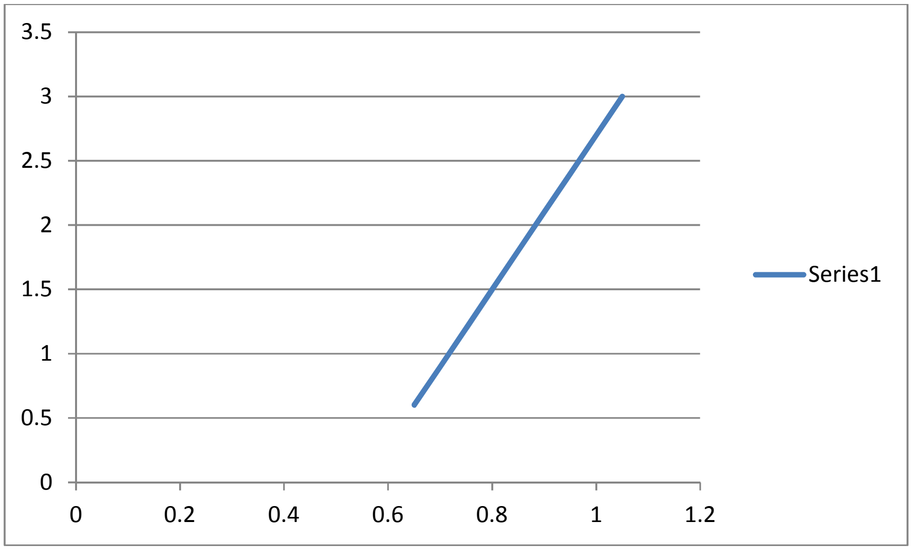


Figure 4.2 Load Factor (L)

4.3 Energy Audit and Life Cycle Cost Comparison of New and Rewound Motors:

Table.4.1 Measured Parameters of 15 H.P Induction Motor

Motor Name	full load rated speed (rpm)	no load speed (rpm)	no load voltage (V)	no load current (I)	no load input power (w)	Still motor temp. (°C)	on load temp. (°C)	full load voltage (v)	full load current (I)	full load input power (w)	full load speed (rpm)	no load motor temp (°C)
New	1460	1480	415	8	523.87	12	140	415	20	13500	1475	34
R.W 1	1460	1480	410	7.5	589	13	142	410	25	13500	1470	43
R.W 2	1460	1480	410	9	550	15	151	410	23	14000	1475	49
R.W 3	1460	1480	410	8	579.89	16	143	410	22	13400	1475	43
R.W 4	1460	1485	415	10	580	20	150	415	30	14100	1480	50

Table.4.2 Calculated Parameters of 15 H.P Induction Motor

Motor Name	synchronous speed (rpm)	no-load stator resistance (Ω)	on-load stator resistance (Ω)	no – load stator cu loss (Ω)	full load stator cu loss (Ω)	Iron friction & windage loss	no-load slip	on-load slip	full load rotor loss	stray loss	p.f At Full Load	Efficiency At Full Load
New	1500	0.38	0.53	24.32	212	500	1.3	1.7	213.1	202.5	0.94	91.65
R.W1	1500	0.89	1.22	50.06	762.5	537.4	1.3	2	244	202.5	0.76	87.06
R.W2	1500	1.36	1.85	110.2	978.7	440	1.3	1.7	209.7	210	0.86	86.87
R.W3	1500	0.86	1.17	55.04	566.3	523	1.3	1.6	205.1	201	0.86	88.84
R.W4	1500	1.34	1.81	134	1629	446	1	1.3	160	211.5	0.66	82.65

Table.4.3 Measured Parameters of 20 H.P Induction Motor

Motor Name	full load rated speed (rpm)	no load speed (rpm)	no load voltage (V)	no load current (I)	no load input power (w)	Still motor temp. (°C)	on load temp. (°C)	full load voltage (v)	full load current (I)	full load input power (w)	full load speed (rpm)	no load motor temp (°C)
New	1460	1490	415	11	615	20	136.6	410	30.2	17000	1475	40
R.W1	1460	1490	410	10	660	24	142	410	31.4	17300	1475	42
R.W2	1460	1490	410	10	660	25	130.7	410	35.7	17200	1475	41
R.W3	1460	1490	410	10.5	680	31	150	415	34	17900	1475	48

Table.4.4 Calculated Parameters of 20 H.P Induction Motor

motor name	synchronous speed (rpm)	no-load stator resistance (Ω)	on-load stator resistance (Ω)	no – load stator cu loss (Ω)	full load stator cu loss (Ω)	Iron friction & windage loss	no-load slip	on-load slip	full load rotor loss	stray loss	p.f At Full Load	Efficiency At Full Load
New	1500	0.29	0.38	32.6	346.6	583	0.67	1.67	268.2	255	0.8	91.46
r.w1	1500	1.30	1.78	127.9	1755.1	533	0.67	1.67	251.6	260	0.79	83.82
r.w2	1500	0.99	1.3	96.8	1656.8	564	0.67	1.67	251.7	258	0.7	84.13
r.w3	1500	0.84	1.1	90.34	1271.6	590	0.67	1.67	269.9	270	0.76	86.58

Table.4.5 Measured Parameters of 50 H.P Induction Motor

motor name	full load rated speed (rpm)	no load speed (rpm)	no load voltage (V)	no load current (I)	no load input power (w)	Still motor temp. (°C)	on load temp (°C)	full load voltage (v)	full load current (I)	full load input power (w)	full load speed (rpm)	no load motor temp (°C)
New	1480	1495	415	21	1290	25	110	415	55	41000	1485	40
r.w1	1480	1495	410	11	6801.7	30	125	415	63	41275	1485	46
r.w2	1480	1495	420	22	2003.5	24	119	410	59.5	41050	1485	44.6
r.w3	1480	1490	415	23.5	1800	36.8	140	415	62.5	43000	1480	43.8
r.w4	1480	1495	410	21.5	1700	37.7	130	410	64	44300	1485	39.9

Table.4.6 Calculated Parameters of 50 H.P Induction Motor

motor name	synchronous speed (rpm)	no-load stator resistance (Ω)	on-load stator resistance (Ω)	no – load stator cu loss (Ω)	full load stator cu loss (Ω)	iron friction & windage loss	no-load slip	on-load slip	full load rotor loss	stray loss	p.f at full load	efficiency at full load
New	1500	0.15	0.13	66.15	393.25	1236.9	.33	1	393.2	612	.99	93.5
r.w1	1500	0.9	1.21	108.9	4802.5	1432.5	.33	1	356.4	620.1	.94	82.53
r.w2	1500	0.75	0.98	363	3469.4	1667.4	.33	1	363.12	616.4	.99	85.1
r.w3	1500	0.9	1.4	497.03	5468.8	1330.1	.67	1.3	492.8	647	.95	81.5
r.w4	1500	0.98	1.3	453	5324.8	1260.2	.33	1	378.5	665.1	.98	82.7

Table.4.7 Measured Parameters of 100 H.P Induction Motor

Motor Name	full load rated speed (rpm)	no load speed (rpm)	no load voltage (V)	no load current (I)	no load input power (w)	Still motor temp. (°C)	on load temp (°C)	full load voltage (v)	full load current (I)	full load input power (w)	full load speed (rpm)	no load motor temp (°C)
New	1480	1495	415	80	2700	36	122	415	113	85000	1485	44
r.w1	1480	1495	415	82	3000	42	135	415	120	85500	1485	45

Table.4.8 Calculated Parameters of 100 H.P Induction Motor

Motor name	synchronous speed (rpm)	no-load stator resistance (Ω)	on-load stator resistance (Ω)	no – load stator cu loss (Ω)	full load stator cu loss (Ω)	iron friction & windage loss	no-load slip	on-load slip	full load rotor loss	stray loss	p.f at full Load	Efficciency at full load
New	1500	0.05	0.06	320	766.14	2497.4	0.33	1	820.3	1272	0.99	93.7
r.w1	1500	0.5	0.65	3362	9360	94.1	0.33	1	775.7	1283	1	86.53

4.4 Life Cycle Cost Comparison of New and Rewind Motors:

A Simple Algorithm to Calculate Life Cycle Cost

Step1 Find Out The Energy Cost.

Step2 Find Out Working Hours.

Step3 Find Out Efficiency.

Step4 Find Out Evaluation Factor (Rated Speed/ Full Load Speed)

Step4 Find Out Motor Rating

Step5 Life Cycle Formula

Step6 Values

Step7 Compare Result

4.4.1For 15 H.P Motors

4.4.1.1 New Motor 15 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\,W_e$

LCC life-cycle cost

PP Rs.56850

EF evaluation factor

$K\,W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_{e}=L\,(hp)\,(0.746)\,[(S_e/S_b)^x-1+(100/E_{op})-1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 15, (hp);

S_e 1475, (r/min);

S_b 1460, (r/min);

x 2.7

E_{op} 91.65, (%)

LCC= Rs 200621

4.4.1.2 Rewound Motor No.1, 15 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\,W_e$

LCC life-cycle cost

PP Rs.44885

EF evaluation factor

$K\,W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF	4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x\text{-}1+(100/E_{op})\text{-}1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	15, (hp);
S_e	1470, (r/min);
S_b	1460, (r/min);
x	2.7
E_{op}	87.06, (%)

LCC= Rs 246949

4.4.1.3 Rewound Motor No.2, 15 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\ W_e$

LCC	life-cycle cost
PP	Rs.44885
EF	evaluation factor
$K\ W_e$	evaluated loss

EF=C (N) (PWF)

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x\ \text{-}1+(100/E_{op})\text{-}1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	15, (hp);
S_e	1475, (r/min);
S_b	1460, (r/min);
x	2.7

E_{op} 86.87, (%)

LCC= Rs 261210

4.4.1.4 Rewound Motor No.3, 15 H.P Motor Life Cycle Cost Comparison:

LCC=PP + EF × K W_e

LCC life-cycle cost

PP Rs.44885

EF evaluation factor

K W_e evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

KW_{e} = L (hp) (0.746)[$(S_e/S_b)^x$-1+(100/E_{op})-1]

where

KW_e evaluated loss, (kW);

L 0.75

Hp 15, (hp);

S_e 1475, (r/min);

S_b 1460, (r/min);

x 2.7

E_{op} 88.84, (%)

LCC= Rs 230820

4.4.1.5 Rewound No.4, 15 H.P Motor Life Cycle Cost Comparison:

LCC=PP + EF × K W_e

LCC life-cycle cost

PP Rs.44885

EF evaluation factor

K W_e evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_{e} = L\ (hp)\ (0.746)[(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 15, (hp);

S_e 1480, (r/min);

S_b 1460, (r/min);

x 2.7

E_{op} 82.65, (%)

LCC= Rs 342092

4.4.2For 20 H.P Motors

4.4.2.1 New Motor, 20 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K\,W_e$

LCC life-cycle cost

PP Rs.70670

EF evaluation factor

$K\,W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_{e} = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 20, (hp);

S_e 1475, (r/min);

S_b 1460, (r/min);

x	2.7
E_{op}	91.46, (%)

LCC= Rs 265644

4.4.2.2 Rewound Motor No.1 20 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\ W_e$

LCC	life-cycle cost
PP	Rs.55795
EF	evaluation factor
$K\ W_e$	evaluated loss

$EF=C\ (N)\ (PWF)$

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x-1+(100/E_{op})-1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	20, (hp);
S_e	1475, (r/min);
S_b	1460, (r/min);
x	2.7
E_{op}	83.82, (%)

LCC= Rs 407071

4.4.2.3 Rewound Motor No.2, 20 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\ W_e$

LCC	life-cycle cost
PP	Rs.55795
EF	evaluation factor
$K\ W_e$	evaluated loss

$EF=C\ (N)\ (PWF)$

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_{e} = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	20, (hp);
S_e	1475, (r/min);
S_b	1460, (r/min);
x	2.7
E_{op}	84.13, (%)

LCC= Rs 390957

4.4.2.4 Rewound Motor No.3, 20 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K\,W_e$

LCC	life-cycle cost
PP	Rs.55795
EF	evaluation factor
$K\,W_e$	evaluated loss

EF=C (N) (PWF)

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_{e} = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	20, (hp);
S_e	1475, (r/min);

S_b 1460, (r/min);

x 2.7

E_{op} 86.58, (%)

LCC= Rs 342617

4.4.3For 50 H.P Motors

4.4.3.1 New Motor 50 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\ W_e$

LCC life-cycle cost

PP Rs.188475

EF evaluation factor

$K\ W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 50, (hp);

S_e 1485, (r/min);

S_b 1480, (r/min);

x 2.7

E_{op} 93.57, (%)

LCC= Rs 498661

4.4.3.2 Rewound Motor No.1, 50 H.P Motor Life Cycle Cost Comparison:

$LCC=PP + EF \times K\ W_e$

LCC life-cycle cost

PP Rs.148874

EF evaluation factor

$K\ W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 50, (hp);

S_e 1485, (r/min);

S_b 1480, (r/min);

x 2.7

E_{op} 82.57, (%)

LCC= Rs 1030935

4.4.3.3 Rewound Motor No.2, 50 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K\ W_e$

LCC life-cycle cost

PP Rs.148874

EF evaluation factor

$K\ W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L	0.75
Hp	50, (hp);
S_e	1485, (r/min);
S_b	1480, (r/min);
x	2.7
E_{op}	85.10, (%)

LCC= Rs 889967

4.4.3.4 Rewound Motor No.3, 50 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K W_e$

LCC	life-cycle cost
PP	Rs.148874
EF	evaluation factor
$K W_e$	evaluated loss

EF=C (N) (PWF)

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_e = L\ (hp)\ (0.746)\ [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	50, (hp);
S_e	1480, (r/min);
S_b	1480, (r/min);
x	2.7
E_{op}	81.54, (%)

LCC= Rs 1059129

4.4.3.5 Rewound Motor No.4, 50 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K W_e$

LCC	life-cycle cost

PP Rs.148874

EF evaluation factor

$K W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_{e} = L (hp) (0.746) [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e evaluated loss, (kW);

L 0.75

Hp 50, (hp);

S_e 1485, (r/min);

S_b 1480, (r/min);

x 2.7

E_{op} 82.78, (%)

LCC= Rs 1022880

4.4.4For 100 H.P Motors

4.4.4.1 New Motor 100 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K W_e$

LCC life-cycle cost

PP Rs.402315

EF evaluation factor

$K W_e$ evaluated loss

EF=C (N) (PWF)

where

C 4.5 (Rs/kWh);

N 8000, (h);

PWF 4

EF= Rs144000/KW

$KW_{e} = L (hp) (0.746) [(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	100, (hp);
S_e	1485, (r/min);
S_b	1480, (r/min);
x	2.7
E_{op}	93.7, (%)

LCC= Rs 1014631

4.4.4.2 Rewound Motor 100 H.P Motor Life Cycle Cost Comparison:

$LCC = PP + EF \times K\,W_e$

LCC	life-cycle cost
PP	Rs.317784
EF	evaluation factor
$K\,W_e$	evaluated loss

EF=C (N) (PWF)

where

C	4.5 (Rs/kWh);
N	8000, (h);
PWF	4

EF= Rs144000/KW

$KW_e = L\,(hp)\,(0.746)\,[(S_e/S_b)^x - 1 + (100/E_{op}) - 1]$

where

KW_e	evaluated loss, (kW);
L	0.75
Hp	100, (hp);
S_e	1485, (r/min);
S_b	1480, (r/min);
x	2.7
E_{op}	86.53, (%)

LCC= Rs 1598815

Chapter 5

Results and Conclusion

5.1 Life Cycle Cost Results of New and Rewound Motors for 8000 working hours

For 15 H.P motors

1. New-Rs.200621
2. Rewound no.1-Rs.246949
3. Rewound no.2-Rs.261210
4. Rewound no.3-Rs.230820
5. Rewound no.4-Rs.342092

For 20 H.P motors

1. New-Rs.265644
2. Rewound no.1-Rs.407071
3. Rewound no.2-Rs.390957
4. Rewound no.3-Rs.342617

For 50 H.P motors

1. New-Rs.498661
2. Rewound no.1-Rs.1030935
3. Rewound no.2-Rs.889967
4. Rewound no.3-Rs.1059129
5. Rewound no.4-Rs.1022880

For 100 H.P motors

1. New-Rs.1014631
2. Rewound no.1-Rs.1598815

5.2 Conclusion

From the calculation done in previous chapter, it is concluded that a new motor consumes always less energy if properly designed, operated and maintained. Rewound motors have less efficiency, low power factor and more energy cost. But in some cases rewound motors can be more efficient than original motors if properly rewound with high quality materials. In the present time energy price goes high day by day as compared to the equipment price such as motors. Even new motors consume 3 to 4 times energy of its initial price in one year and improperly rewound motors consume 5 to 7 time energy in one year as compared to its price and rewound motor consume 1.5 to 2 times more energy than new motor. So we concluded that the difference between prices of new and rewound motor is very small as compared to the electricity consumption of low efficiency rewound motors. So we have to install highly efficient motors.

5.3 Future Scope

In this thesis report the life cycle cost of 16 induction motors is calculated and compared with theoretical values in the future life cycle cost of number of motors (at least 100) can also be calculated and compared.

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