

ELECTRICAL ENERGY AUDIT OF INDUCTION MOTORS IN A TEXTILE PLANT

*A thesis submitted in partial fulfilment of the requirements for the
award of degree of*

Master of Engineering

in

Electronic Instrumentation and Control



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Declaration

I hereby declare that the report entitled "**Electrical Energy Audit of Induction Motors in a Textile Plant**", is an authentic record of my own work carried out as a requirement for the award of degree of M.E. (Electronic Instrumentation & Control) at Thapar University, Patiala, under the guidance of **Dr. Mandeep Singh (AP, EIED)** during January to July 2011.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

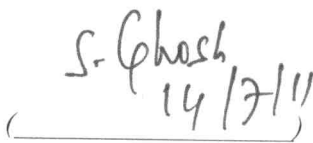


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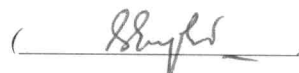
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Abstract

Textile plant being one of the most energy intensive processes holds a good promise of saving electrical energy. This report through one of its preliminary study of a major textile plant identifies the key areas where electrical energy can possibly be saved. The report opens up new vista of saving energy in a textile industry.

Induction motors being the major energy consumer in the plant offer opportunities of energy saving. In the plant many induction motors are in-house rewind. This thesis reports the analysis done on the rewind induction motors for its efficiency. Practical comparisons between rewind motors and the new motors are shown. It is found that rewind motors, if replaced by new ones, have a payback period in the range of 2 years to as less as 6 months.

Organization of Thesis

The complete project thesis is divided into five chapters as follows.

The first chapter introduces the textile industry and energy audit and finally explains the energy audit in detail.

The second chapter gives an overview of the textile industry. It also discusses the basic textile process in the plant under study.

The third chapter tells about the electrical systems in the plant under study and covers almost all the electrical systems where energy can be saved. Also describes the distribution of electrical energy in the plant processes.

The fourth chapter reports the electrical energy saving opportunities in all most all the sections of the plant.

The fifth chapter gives the detailed description of analysis done on the in-house rewound induction motors to determine their efficiencies and their payback if replaced with new motors. It also includes the analysis done on few electrical types of equipments for power factor improvement. Report is concluded in the end.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Textile industry is one of the most important industries in the world. Textile industries suffer from inadequate development planning, which is a typical problem with most of



the textile industries. A typical textile industry structure contains subsections which are occupied by number of different units working independently. One of the sections is shown in figure 1.1. There might be some hidden defects left in the structure that leads to unnecessary (or wastage of) energy use.

Few studies have been conducted in the past, which shows that there are many opportunities in the textile industries to save energy. In 1988, it was estimated that reduction rates of 16 % in process heat and 8 % in power consumption could be achieved in the finish textile industry just like other manufacturing industries by using available technology ^[1].

Figure1.1 Inner view of textile plant According to Franck et al. (1999), the potential for steam reduction is still very high; it has typically been 5 to 10 % in traditional process integration studies where process equipment is accepted ^[2].

Today manufacturers are facing an increasingly competitive global business environment. In public and private companies, rise in energy prices are leading to the rise in cost of the product and decrease the value added at the plant. They seek opportunities to reduce

production costs without reducing the quality and quantity of the product. Successful, cost-effective investment into energy-efficiency technologies and practices meet the challenge of maintaining the output of a high quality product despite reduced production costs. This is especially important in the current age, as energy-efficient technologies also results in some additional benefits, such as increasing the productivity of the company or reducing the water and/or materials consumption.

Energy efficiency plays an important tool in the company's strategy to compete the global challenges. End-of-pipe solutions can be expensive and inefficient while energy efficiency can often be an inexpensive opportunity to reduce emissions of criteria and other pollutants. In short, energy-efficiency investment is a sound business strategy in today's manufacturing environment (Worrell and Galitsky, 2004) ^[3] ^[4]. Government has implied many policies and programs with an aim to improve competitiveness of the industries through increased energy efficiency and reduced environmental impact. However, usually there are only limited information sources available on how to improve energy-efficiency, especially for Small Scaled Industries (SCIs). Energy-efficiency technologies and practices should, therefore, be prepared and disseminated to industrial plants.

This thesis report provides information on energy-efficient technologies and production measures applicable to the textile industry. The report also includes analysis of an audit conducted on motors of different horsepower in a textile plant and includes energy saving and cost information available. For some measures this report also provides a range of savings and payback periods found in under varying conditions. At all times, it must be borne in mind that the values presented in this report are offered as guidelines. Actual cost and energy savings for the measures will vary, depending on plant operating characteristics, plant size production, product characteristics and several other factors.

The other important issue that needs to be highlighted is that the cost values given in this thesis report are presented as nominal costs. Therefore, the time value of the money should be considered while using the cost data from this report. A survey was conducted

to identify different measures; this report is not exhaustive, as new ways to improve energy efficiency are developed continuously.

1.2 ENERGY AUDIT

Energy audit is an important commercial tool to save energy and to improve financial state of an organisation. Almost all the large scaled and many small scaled organisations i.e. industries as well as non-industrial sectors are conducting energy audit to save energy and to minimize the electricity cost. We will discuss about energy audit briefly in the proceeding sections.

1.2.1 Definition of energy audit

An energy audit is an inspection, survey and analysis of energy flow for energy conservation in buildings, processor systems to reduce the amount of energy input(s) into the system without affecting negatively to the output(s).

1.2.2 Principle

When the object of study is an occupied building then reducing energy consumption, while maintaining or improving human comfort, health and safety, are of primary concern. Beyond simply identifying the source of energy use, an energy audit seeks to prioritize the energy uses according to the greatest to least cost effective opportunity for energy savings. An energy audit serves the purpose of identifying where a plant facility uses energy and identifies energy conservation opportunities.

1.2.3 Types of energy audit

The term energy audit is commonly used to describe a broad spectrum of energy studies ranging from a quick walk-through a facility to identify major areas of comprehensive analysis of the implications of alternative energy efficiency measures sufficient to satisfy the financial criteria of sophisticated investors. Numerous audit procedures have been

developed for non-residential (tertiary) buildings (ASHRAE ^[5]; IEA-ECBCS Annex 11 ^[6]; Krarti, 2000). Audit is to identify the most efficient and cost-effective Energy Conservation Opportunities (ECOs) or Measures (ECMs). Energy Conservation Opportunities (or Measures) can consist in more efficient use or of partial or global replacement of the existing installation.

When looking to the existing audit methodologies developed in IEA-ECBCS Annex 11, by ASHRAE and by Krarti (2000), it appears that the main issues of an audit process are:

- The analysis of building and utility data including study of the installed equipment and analysis of energy bills;
- The survey of the real operating conditions;
- The understanding of the building behaviour and of the interaction with the weather, occupancy and operating schedules;
- The selection and the evaluation of energy conservation measures;
- The estimation of energy saving potential;
- The identification of customer concerns and needs.

Common types/levels of energy audits are distinguished below:

- **Level 0 – Benchmarking:** This first analysis consists of a preliminary Whole Building Energy Use (WBEU) analysis based on the analysis of the historic utility use and cost and the comparison of the performances of the building to those of similar building. This benchmarking of the studied installation allows determining if further analysis is required or not;
- **Level 1 – Walk-through audit:** Preliminary analysis is made to assess building energy efficiency to identify simple and low-cost improvements, but makes a list of energy conservation measures (ECMs), or energy conservation opportunities (ECOs) to orient the future detailed audit. This inspection is based on visual verifications, study of installed equipment, operating data and detailed analysis of recorded energy consumption collected during the benchmarking phase;

- **Level 2 – Detailed/General energy audit:** Based on the result of the pre-audit. This type of energy audit consists of survey of energy usage in order to provide a comprehensive analysis of the studied installation, a more detailed analysis of the facility, a breakdown of the energy use and a first quantitative evaluation of the ECOs/ECMs selected to correct the defects or improve the existing installation. This level of analysis can involve advanced on-site measurements and sophisticated computer based simulation tools to evaluate precisely the selected energy retrofits;
- **Level 3 – Investment-Grade audit:** Detailed analysis of Capital-Intensive Modifications focuses on potential costly ECOs, requiring rigorous engineering study.

Level 0 - Benchmarking

The impossibility of describing all possible situations that might be encountered during an audit means that it is necessary to find a way of describing what constitutes good, average and bad energy performance across a range of situations. The aim of benchmarking is to answer this question. Benchmarking mainly compares the measured consumption with reference consumption of other similar buildings or generated by simulation tools to identify excessive or unacceptable running costs.

As mentioned before, benchmarking is also necessary to identify building presenting energy saving potential. An important issue in benchmarking is the use of performance indexes to characterize the building.

These indexes can be:

- Comfort indexes, comparing the actual comfort conditions to the comfort requirements;
- Energy indexes, consisting in energy demand divided by heated/conditioned area, allowing comparison with reference values of the indexes coming from regulation or similar buildings;

- Energy demands, directly compared to “reference” energy demands generated by means of simulation tools.

Level 1 - Walk-through or Preliminary Audit

The preliminary audit (alternatively called a simple audit or walk-through audit) is the simplest and quickest type of audit. It involves minimal interviews with site-operation personnel, a brief review of facility utility bills and other operating data, and a walk-through of the facility to become familiar with the building operation and to identify any glaring areas of energy waste or inefficiency.

Typically, only major problem areas will be covered during this type of audit. Corrective measures are briefly described, and quick estimates of implementation cost, potential operating cost savings, and simple payback periods are provided. A list of energy conservation measures (ECMs) or energy conservation opportunities (ECOs) that require further consideration is also provided. This level of detail is not sufficient for reaching a final decision on implementation proposed measure, but is adequate to prioritize energy-efficiency projects and to determine the need for a more detailed audit.

Level 2 - General Audit

The general audit (alternatively called detailed energy audit or complete site energy audit) expands on the preliminary audit described above by collecting more detailed information about facility operation and by performing a more detailed evaluation of energy conservation measures.

Utility bills are collected for a 12 to 36 months period to allow the auditor to evaluate the facility’s energy/demand rate structures and energy usage profiles. If interval meter data is available, the detailed energy profiles made by this data will be typically analyzed for signs of energy waste. Additional metering of specific energy-consuming systems are often performed to supplement utility data. In-depth interviews with facility operating personnel are conducted to provide a better understanding of major energy consuming

system and to gain insight into short and longer term energy consumption patterns. This type of audit will be able to identify all energy-conservation measures appropriate for the facility, given its operating parameters. A detailed financial analysis is performed for each and every measures based on detailed implementation cost estimates; site-specific operating cost savings, and the customer's investment criteria. Sufficient detail is provided to justify project implementation.

Level 3 - Investment-grade audit

In most corporate settings, upgrades to a facility's energy infrastructure must complete for capital funding with non-energy-related investments. Both energy and non-energy investments are rated on a single set of financial criteria that generally stress the expected Return On Investment (ROI). The projected operating savings from the implementation of energy projects must be developed such that they provide a high level of confidence. In fact, investors often demand guaranteed savings. The investment-grade audit expands on the detailed audit described above and relies on a complete engineering study in order to detail technical and economical issues necessary to justify the investment related to the transformations.

1.2.4 History

Energy audits initially became popular in response to the crisis of 1973 and later years. Interest in energy audits has recently increased as a growing understanding of human impact upon global warming and climate change.

TEXTILE MANUFACTURING PROCESS

2.1 GLOBAL OVERVIEW OF THE TEXTILE INDUSTRY

The textile industry has played an important role in the development of human civilization over several decades. The textile industries fulfil one of the three basic needs of the human being i.e. housing, food and clothing by providing clothes for them. The industrial revolution was based upon the principle materials like coal, iron, steel and cotton. Technological developments from the second part of the eighteenth century onwards led to an exponential growth of cotton output, first starting in the U.K., and later spreading to other European countries. The production of synthetic fibres that started at the beginning of the twentieth century also grew exponentially (Schonberger and Schafer, 2003) [7]. Figure 2.1 shows the relationship between world population and total textile demand. Assuming that world population will grow to 10 billion in 2050, and further to 11.6 billion in 2150 when it is expected to plateau, total textile consumption is forecast to double, even using the relatively conservative 1990's figure of per capita annual average textile consumption (8 kg/person) (UNIDO, 1992) [8].

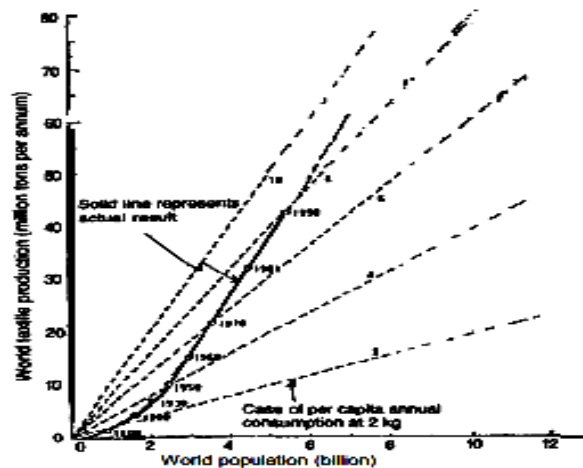


Figure 2.1 Relationship between World Population and Textile Consumption & Production

The textile industry is traditionally regarded as a labour-intensive industry developed on the basis of an abundant labour supply. The number of persons employed in the textile and clothing industry was around 2.45 million in the European Union (EU) in 2006 (European Commission, 2009a) ^[9], around 500,000 in the U.S. in 2008 (USDL, 2010) ^[10], and about 8 million in China in 2005 (Qiu, 2005) ^[11].

China is the world's top textile exporter with 40% of world textile and clothing exports (European Commission, 2009b) ^[12]. The textile and clothing industry is the largest manufacturing industry in China with about 24,000 enterprises. The value of its total output was 1,064 billion Yuan in 2002 (US \$129.8 billion²). China is the largest clothing producer in the world and has the largest production capacity for textile products consisting of cotton, manmade fibers and silk (Qiu, 2005). In 2008, the total export value of China's textile industry was US \$65.406 billion, an increase of 16.6% compared to 2007. With the rising living standard of the Chinese people, local demand for high quality textiles and apparel goods continues to increase (CRI, 2010) ^[13]. China is also the largest importer of textile machinery and Germany is the largest exporter of textile machinery (Textile Exchange, 2009) ^[14]. Figure 2.2-2.3 shows the leading exporters and importers of textiles in 2008 with the amount of exports and imports in billion U.S. dollars. It should be noted that the figures are just for textiles and do not include clothing. As can be seen in the figures, EU, China, and U.S. are the top three textile importers and exporters.

The EU textile and clothing sector represents 29% of the world textile and clothing exports, not including trade between EU Member countries, which places the EU second after China (European Commission, 2009b) ^[12]. In 2000, the European textile and clothing industry represented 3.4% of the EU manufacturing industry's turnover, 3.8% of the added value and 6.9% of the industrial employment (European Commission, 2003) ^[15].

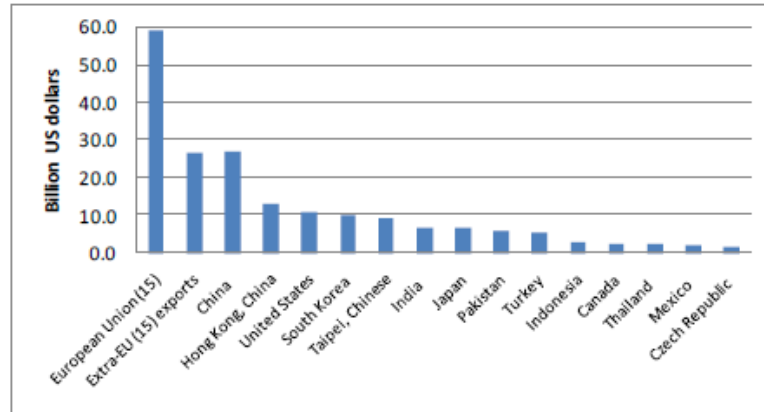


Figure2.2 Leading Exporters of Textile in 2006 (WTO, 2008)

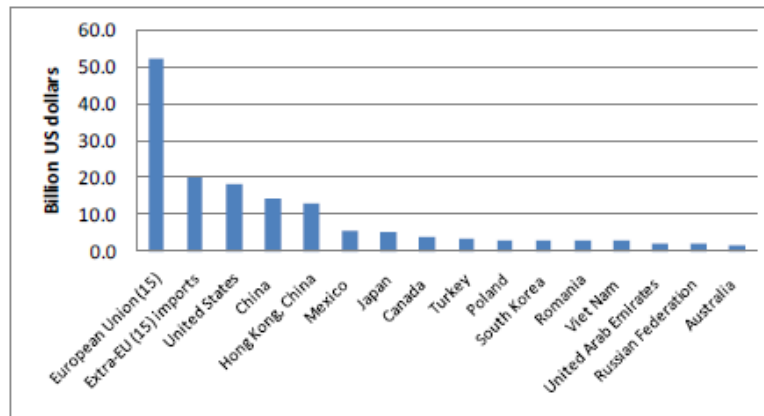


Figure2.3 Leading Importers of Textiles in 2006

2.2 TEXTILE PROCESS

The textile industry has one of the most complicated industrial chains in the manufacturing industry. It is a fragmented and heterogeneous sector dominated by SMEs, with a demand mainly driven by three dominant end-uses: clothing, home furnishing and industrial use. Characterizing the textile, manufacturing is complex because of the wide variety of substrates, processes, machinery and components used, and finishing steps undertaken. Different types of fibers or yarns, methods of fabric production, and finishing processes (preparation, printing, dyeing, chemical/mechanical finishing, and coating), all interrelate in producing a finished fabric. When one of these components is changed, the properties of the end product are affected. There are several properties that can be used to

define a fabric. Some examples of fabric properties include weight, appearance, texture, strength, lustre, flexibility, and affinity to dyestuff.

Figure 2.4 is a flow diagram depicting the various textile processes (or we can say Textile Chain) that are involved in converting raw materials into a finished product. All of these processes do not occur at a single facility, although there are some integrated plants that have several steps of the process all in one plant. There are also several niche areas and specialized products that have been developed in the textile industry which may entail the use of special processing steps that are not shown in Figure 2.4 (US EPA, 1998) ^[16].

Due to the variety of the processes involved in the textile industry, there are too many processes to be explained within the space constraints of this thesis report. Thus, the brief description of the major textile processes for which the energy-efficiency measures are shown in the diagram. Flowcharts of the processes are also given to help the reader better understand manufacturing sequences and process steps. The major textile processes are:

- ❖ Spun Yarn Spinning
- ❖ Weaving
- ❖ Wet-processing (preparation, dyeing and finishing)

Figure 2.4 shows the whole process of making nylon yarn in the form of a flow chart, briefly. In this process, first raw material i.e. caprolactam is polymerised and processed to make sugar sized chips. These chips become the base of fiber manufacturing process.

Now these chips, after extracting and drying, are sent to fiber production unit where these chips are fed to horizontally rotating machine where chips are processed and converted into a highly viscous liquid.

Then the highly viscous liquid is made to pass through a plate having several minute holes. Several fibers are obtained after passing the highly viscous liquid through plates. These fibers are then processed and finishing is done. Finally, fiber is rolled on the bobs. Bobs are the structures that hold the final fiber and are sent to the consumer directly.

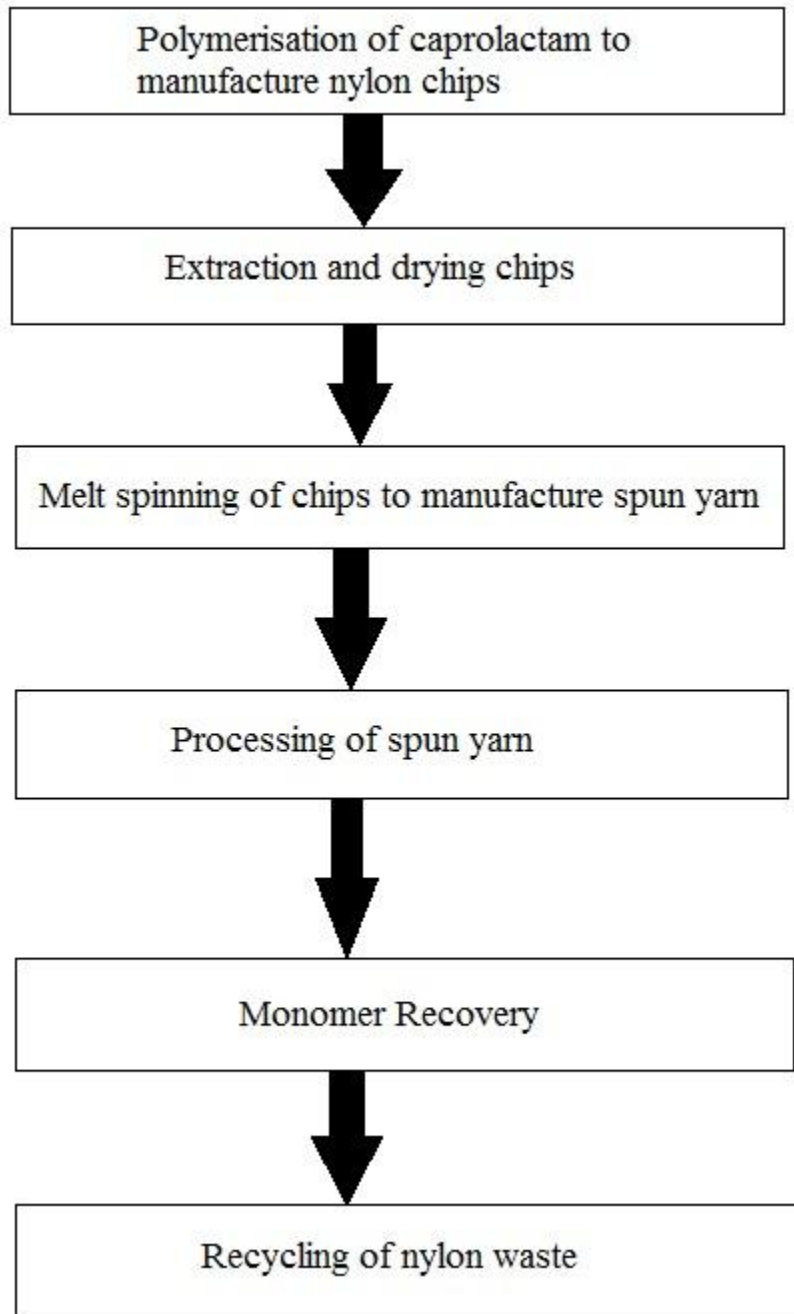


Figure2.4 Textile Process

ELECTRICAL SYSTEM IN TEXTILE PLANT

3.1 INTRODUCTION

Electric power supply system in a country comprises of generating units that produce electricity; high voltage transmission lines that transport electricity over long distances; distribution lines that deliver the electricity to consumers; substations that connect the pieces to each other; and energy control centres to coordinate the operation of the components.

Figure 3.1 shows the plant layout of the textile industry under study.

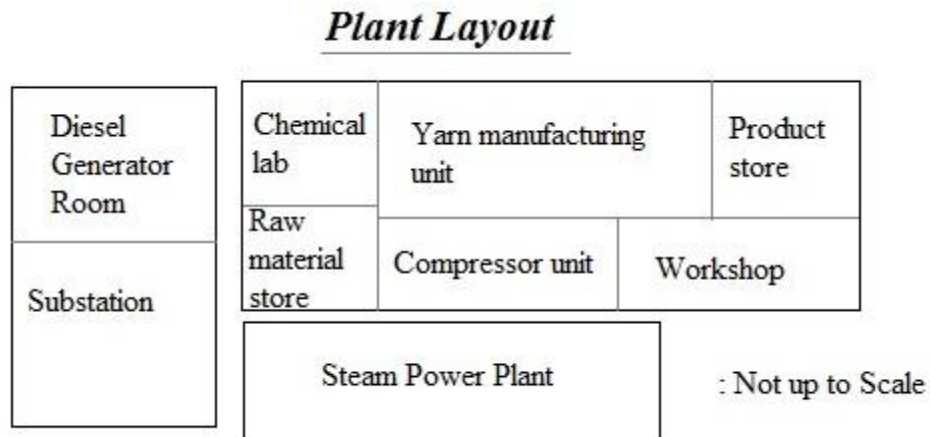


Figure3.1 Electrical Supply System in the Textile plant

3.2 DIFFERENT ELECTRICAL SYSTEMS IN THE PLANT

Different electrical systems are:

1. Substation
2. Steam Power Plant
3. Diesel Power Plant
4. Other Electrical Utilities

Figure 3.2 shows the distribution network of electrical energy in the plant under study.

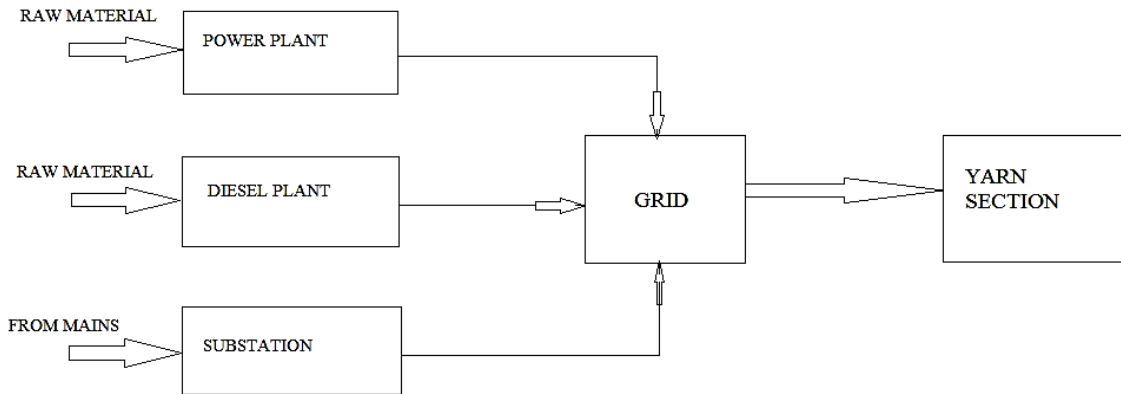


Figure 3.2 Distribution of electrical energy in the plant

3.2.1 Substation

A **substation** is a part of an electrical generation, transmission, and distribution system. Substation in the industries transforms voltage from high to low. Electric power may flow through several substations between generating plant and consumer, and its voltage may change in several steps.

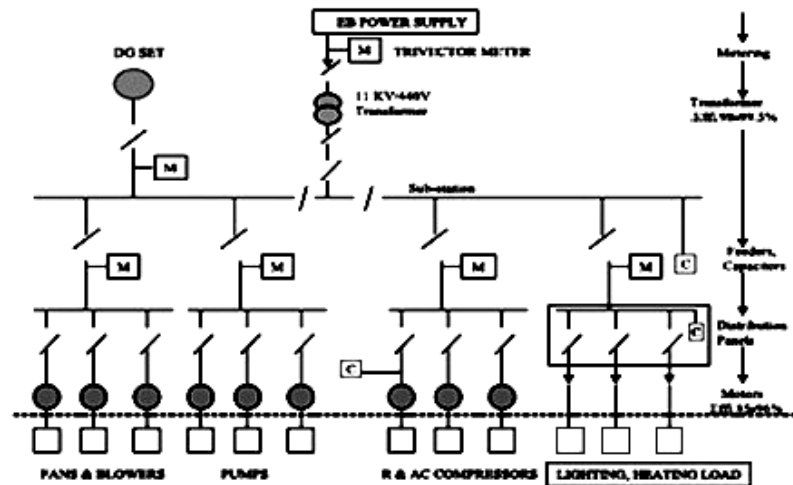


Figure3.3 Substation Layout in the Textile Plant

This is the major electrical system in every industry. It receives electrical energy from mains and processes it and distributes it to different sections of the plant.

A substation that has a step-up transformer increases the voltage while decreasing the current, while a step-down transformer decreases the voltage while increasing the current for domestic and commercial distribution. The word “substation” comes from the days before the distribution system became a grid. First substations were connected to only one power station, where the generators were housed, and were subsidiaries of that power station. Figure 3.3 shows the layout of the substation in a typical textile plant.

Table 3.1 Electrical Components in the sub-station

S.NO.	EQUIPMENT	NUMBERS	RATING
1	Transformer	3	5 MVA
2	Oil Circuit Breaker	3	750 MVA
3	CT	1	33/110 V
4	PT	1	300/5 A
5	Air C.B.	15	630 A
6	Meters	---	---
7	Relays	---	---

Table 3.1 shows the list of electrical equipments present in the substation with their quantity and ratings of some equipment are also listed.

3.2.2 Steam power plant

A **steam power plant** is the cheapest mode of electrical energy in an industry. The fossil fuels such as coal, oil and natural gas, nuclear energy, and falling water (hydel) are commonly used energy sources in the power generating plant.



Figure3.4 steam power plant

A wide and growing variety of unconventional generation technologies and fuels have also been developed, including cogeneration, solar energy, wind generators, and waste materials. About 70 % of power generating capacity in India is from coal based thermal power plants. The electrical energy generation of coal-fired power generation plant is shown in figure 3.4. Steam power plant in the textile plant under study is husk fired not coal fired.

Principle of husk-fired is same as that of coal-fired which is shown in figure 3.5. Energy stored in the husk is converted into electricity in thermal power plant just like coal. Like coal, husk is pulverized to the consistency of talcum powder. First husk is cut into minute pieces and then is blown into the water wall boiler where it is burned at temperature higher than 1300°C. The heat in the combustion gas is transferred into steam. This high-pressure steam is used to run the steam turbine to spin. Finally turbine rotates the generator to produce electricity.

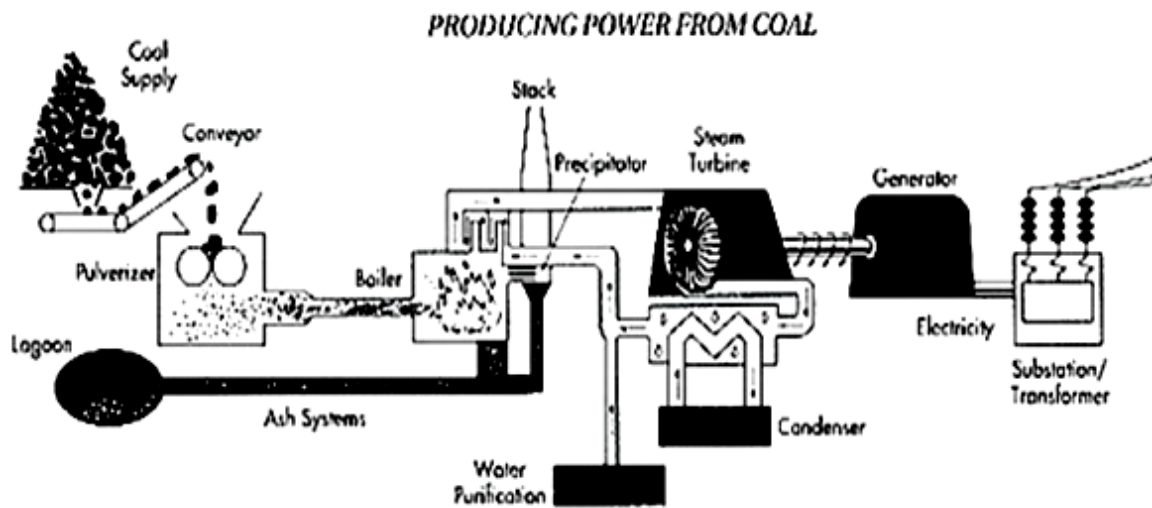


Figure3.5 Coal Fired Power Plant Processes

In India, for the husk based power plants the overall efficiency ranges from 28% to 35% depending upon the size, operational practices and capacity utilization. Where fuels are the source of generation, a common term used is the “HEAT RATE” which reflects the efficiency of generation. “HEAT RATE” is the heat input in kilo Calories or kilo Joules, for generating ‘one’ kilo Watt-hour of electrical output. One kilo Watt hour of electrical energy being equivalent to 860 kilo Calories of thermal energy or 3600 kilo Joules of thermal energy. The “HEAT RATE” expresses in inverse the efficiency of power generation.

3.2.3 Diesel power plant

A **Diesel Power Plant** is series of combination of diesel engines with electrical generators (often called alternators) to generate electric energy. Diesel generating sets are used in places without connection to the power grid or as emergency power-supply if the grid fails. Small portable diesel generators range from about 1 kVA to 10 kVA may be used as power supplies on construction sites, or as auxiliary power for vehicles such as mobile homes.



Figure3.6 Diesel engine power plant

One or more diesel generators operating without a connection to an electrical grid are referred to as operating in "Island Mode" and the setup is shown in figure 3.6. In island mode, several parallel generators provide the advantages of redundancy and better efficiency at partial loads. The plant brings generator sets online and takes them off line depending on the demands of the system at a given time. An islanded power plant intended for primary power source of an isolated community ("Prime Power") will often have at least three diesel generators, any two of which are rated to carry the required load. Groups of up to 20 are not uncommon.

Generators can be electrically connected together through the process of synchronization. Synchronization involves matching voltage, frequency and phase before connecting the generator to a live bus-bar. Failure to synchronize before connection could cause a high current short-circuits or wears and tears on the generator and/or its switchgear. The synchronization process can be done automatically by an auto-synchronizer module. The auto-synchronizer will read the voltage, frequency and phase parameters from the generator and bus-bar voltages, while regulating the speed through the engine governor or Engine Control Module (ECM).

Load can be shared among parallel running generators through load sharing. Load sharing can be achieved by using droop speed control which is controlled by the

frequency at the generator, while it constantly adjusts the engine fuel control to shift load to and from the remaining power sources. A diesel generator will take more loads when the fuel supply to its combustion system is increased, while load is released if fuel supply is decreased.

When the grid or power plant shuts down or stops working under some emergency due to any problem, luckily many power plants opt to use diesel generators as a source of backup or standby power. Most plants will have an entirely separate building that is used to house the backup generators, since they are extremely large. They must provide power to whole of the textile plant, so the generators require a lot of maintenance and care. An experienced engineer will know just how much power is needed and what type of generator should be used for the plant.

In addition to the generators themselves, a supply of diesel must be readily available to feed into the generators so that they work properly. This is usually contained in a very large tank right next to the actual generators themselves. When the power plant experiences a loss, the generators receive a signal to begin powering up, thus providing their own backup source. Leak detection is important, as well as the fact that all environmental standards must be followed when using diesel generators. An inspector frequently checks the power plant to ensure that it is meeting all the proper specifications and safety precautions. These large diesel generators can be a real life saver in the event of a power emergency. While they do not last extremely long, they can maintain power to large areas for several hours. This gives the power plant crew time to work on the main power source and get everything back up and running, while customers do not even experience the blackout.

3.2.4 Breakdown of energy use by textile processes

Breakdown of electrical energy is done on the bases of the part of energy consumed by different sections of the textile plant.

3.2.4.1 Energy use in the spinning process

Electricity is the major type of energy used in spinning plants, especially in cotton spinning systems. If the spinning plant just produces raw yarn in a cotton spinning system, and does not dye or fix the produced yarn, the electrical energy may just be consumed by humidification system in the cold seasons for preheating the fibers before spinning them together.

Therefore, the energy used by a cotton spinning plant would have been less. But in this plant many other processes are done which consume a lot of electrical energy. Figure 3.7 shows the distribution of electrical energy in textile process.

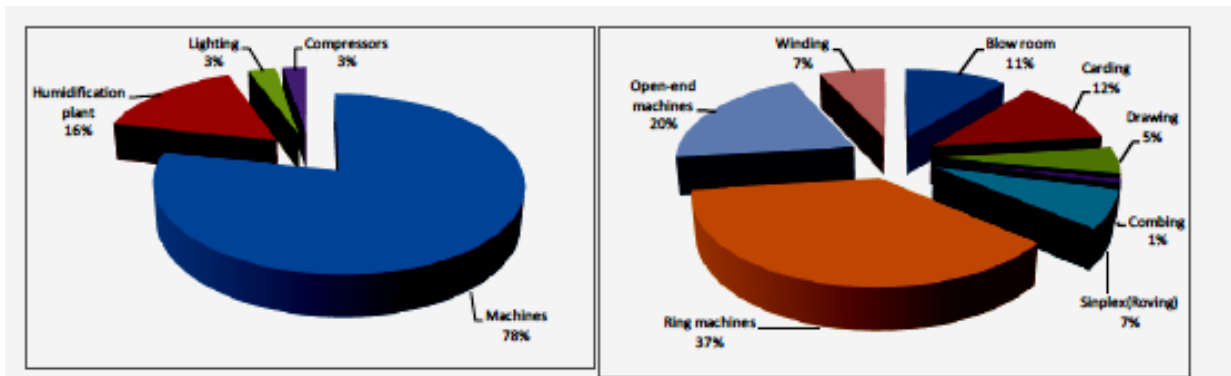


Figure3.7 Pie chart showing Breakdown of Electrical Energy in a typical Textile Process

The energy consumption for spinning different types and counts of yarn and the results are shown in Table 3.2. For all types of fibers, finer yarn spinning consumes more energy. It is said, yarns used for weaving involves more twisting than yarns used for knitting. Also, production speed is low for weaving yarn compared to that of knitting yarn. As a result, with the same yarn count, more energy is consumed for weaving yarn. Also, for the same yarn count, the energy consumption for combed yarn is higher because of the additional production step (combing).

Table3.2 Specific Energy Consumption (kWh/kg) in yarn with different yarn counts

Yarn Count (Tex)	Combed Yarn		Carded Yarn	
	Knitting (KWh/Kg)	Weaving (KWh/Kg)	Knitting (KWh/Kg)	Weaving (KWh/Kg)
37	138	163	134	162
33	158	188	154	186
30	179	212	173	209
25	219	260	211	255
20	306	364	297	357
17	389	462	374	453
15	442	525	423	512
12	552	681	552	672

3.2.4.2. Energy use in wet-processing

Wet-processing is the major energy consumer in the textile industry because it uses a high amount of electrical energy (in the forms of both steam and heat). The energy used in wet-processing depends on various factors such as the form of the product being processed (fiber, yarn, fabric, and cloth), the machine type, the specific process type, the state of the final product, etc.

It can be seen that a significant share of electrical energy in a dyeing plant is lost through re-winding of motors, waste water loss, heat released from equipment, exhaust gas loss, idling, evaporation from liquid surfaces, un-recovered condensate, loss during condensate recovery, and during product drying (e.g. by over-drying). These losses can be reduced by using different energy-efficiency measures explained in the next section of this report.

3.2.4.3. Breakdown of energy in composite textile plants (spinning-weaving-wet processing)

A composite textile plant is a plant that has spinning, weaving/knitting, and wet-processing (preparation, dyeing/printing, finishing) all on the same site.

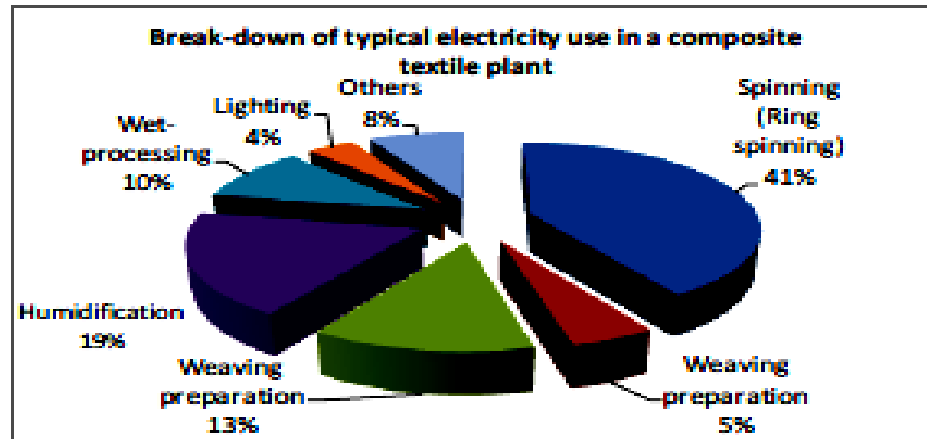


Figure3.8 Breakdown of typical electricity use in a composite

Figure 3.8 shows the breakdown of the typical electricity and thermal energy used in a composite textile plant (Sathaye, et al., 2005) ^[17]. As can be seen, spinning consumes the greatest share of electricity (41%) followed by weaving (weaving preparation and weaving) (18%). Wet-processing preparation (desizing, bleaching, etc) and finishing together consume the greatest share of thermal energy (35%). A significant amount of thermal energy is also lost during steam generation and distribution (35%). These percentages will vary plant to plant.

ELECTRICAL ENERGY SAVING OPPORTUNITIES IN TEXTILE PLANT

4.1 INTRODUCTION

It has been observed that practically in today's world textile plant's electricity consumption is increasing every year, due to prolonged use of the equipments in inefficient operating parameters and also due to increase in production. Textile process comes with a large design safety factor, which has to be optimized after process stabilization for optimum power consumption. The energy cost to production cost is around 15 to 20 % and this comes second to raw material. So our focus area now is energy consumption at load end and by optimizing the energy usage of textile machines, we can have multiple benefits of fewer units per kg of yarn and health of machines enhance.

4.2 AREAS OF ENERGY AUDIT

In the study of energy audit of the running equipment, we first see the visible abnormal symptoms in the inefficient transfer of energy in the system using the II law of thermodynamics. Smooth energy transfer from one form to other like electricity to the output shaft speed, belt transmission etc does not produce abnormal heating, heavy noise, spark etc. where as

- **Lighting** - sparks, in case of contactor switching, loose joints etc
- **Heating** - in motors, other load equipment coupled to motor due to friction, metal-to-metal touch, poor lubrication, misalignment

- **Sound** - from the equipment in form of vibration, mounting on bed, noise from belts, bearings, metal-to-metal contact etc.

If in the running equipment the transfer of energy takes place perfectly and unavoidable losses occur that are acceptable, then the quality and quantity of the output is good and there is less wastage of energy and output. If the transfer is not rightly done i.e. done with more avoidable losses, then productive output reduces, and waste output increases & dissipated in the form of heat, light, sound which is a sign of visible loss in the equipment operating parameters.

4.3 MAJOR AREAS OF ENERGY SAVING POTENTIAL

The major power consuming areas in textile plant that have high energy saving opportunities are:

- Rewound motor efficiency,
- Ring frame parameter,
- Electrical network,
- Man-made fibre production network,
- Cross-cutting energy efficiency measures
- Compressed air distribution.

That is why the plants now have started with power audit, air audit, water audit, lighting audit, capacitor checks, Motor load survey, used oil analysis, condition based performance monitoring. We are discussing the above areas of energy saving opportunities in the following aspects:

- Spot power – balanced voltage across phases at motor terminals
- Spot capacitor –capacitor retrofit where p.f. begins to lag
- Spot humid air – the humidified air received at the premises end

- Spot receiver – mini air receiver at autoconer etc for steady air
- Spot lighting – lumens received at machine end for visual task

4.4 REWOUND MOTOR EFFICIENCY

Rewound motors works at reduced efficiency. The efficiency bell curve indicates peak efficiency of a standard motor at its three quarter loading. Here in rewind motor, the efficiency peaks are at the lower loading level only. And the slippage in the motor increases nearing its full load. Hence keeping an eye on these motors thermal characteristic, we must not fully load the motor, but match our process to its reduced efficiency.

4.4.1 Motor parameters daily measure

- Productive value of the existing motor can be obtained by measuring the no-load parameters like current, power, slip, rpm etc. High temp and high sound generated in abnormal condition at the bearing's location and these parameters are measured by gadgets. Hence instead of all purposes grease application on bearings, high temperature greasing gives longer temperature withstanding capability in this 8760-hour pa run motors. The spindle bolster surface temperature is an indication of the health of spindle, its oil level condition, its bearing's lubrication level and the same can be measured with skin temperature measuring RTD monitor.
- To improve the efficiency of motor for the given motor & load characteristics, we must advise the user to bring down the motor body temperature for better efficiency. Cleanliness of fins, scaling, visible obstructions, starved surroundings, want of air breeze across the fins all-round, do matter.

4.4.2 Improving motor efficiency

- We have to take care of the motor with positive active ventilation all over. For the same, we ensure strong axial air throw along the ribs of motor so the overall surrounding temperature of the motor comes down. Now the motor breathes normally with the shrouded fan effect at its one end and its efficiency improvement is seen in the long run. The loss to the motor due to this retrofit is very minimal, but overall efficiency of the motor improves due to the above force cooling of fins & the motor itself.
- If efficiency of rewind motor is low then best way to save energy is to replace the rewind motor with new motor. Depending upon the horsepower of the motor, payback will vary. As higher as the horsepower of the motor is, payback will be less. Example if we replace the 50hp rewind motor with new motor then the payback will be approximately 1-1.5 years.

4.5 RING FRAME PARAMETERS

- We are aware that the spindle consumes 30 % of power consumed by ring frame. The optimum spindle speed is the ultimate parameter in the plant, which we are targeting to achieve. The optimum spindle speed is the speed at which ring frame gives more output speed with less power input and keeping the prime mover and transmission (by flat belts etc. which minimizes linkage losses) under healthy condition.
- To improve ring frame performance, after looking into the textile-associated savings, let us consider motor and linkage parameters. Condition based monitoring of the motor parameters will definitely enhance its health and productivity & minimizing energy costs.

4.6 ELECTRICAL NETWORK

Transmission Vs Distribution Losses:-

- If we analyze our Indian scenario of T & D Losses, we infer that practically losses are more in distribution than in transmission. If we study the breakup of T & D losses, we find the losses in high voltage transmission are much less as compared to the higher losses in low voltage distribution at 415 volts. Similarly in the plant, the transmission losses in the properly sized conductors are mini-mum from transformer, Motor Control Centre (MCC) to the industry premises; but the losses increase at the auxiliary field distribution boards inside the industry due to tee connections etc. Hence if we can take extra care and measure the hot spots at the field distribution control panels, we can bring down the losses to mini-mum level.
- Now we are aware that voltage unbalance across motor terminals must be $< 1\%$. We should ensure that this is kept mini-mum so that overall motor temperature does not rise; productive output at shaft is more and waste output in the form of heat is reduced.
- Many plants add capacitor to their existing network regularly to keep up to unity PF. Any unbalance in voltage, high/ low voltage, harmonics, etc bring down capacitor efficiency. If the charging current is going less than 75 % of its rated current, it is better to replace the capacitor in consultation with the manufacturer. The symptom of too high skin temperature (say 55°C is the maximum withstanding temperature given by manufacturers) indicates its poor efficiency; as well lower than warm skin temperature indicates its inactivity. Like an ordinary dry cell 1.5V dc rated, when it goes down below 1 volt it is better to throw otherwise its internal resistance increases. Likewise capacitor is also becoming an important industrial tool to improve the efficiency. Good Capacitor is an asset to the network helping to reduce loss; but a bad capacitor is a liability to the network.

- In Regulation Capacitor addition we must insist that the user need not strain much to maintain unity PF at the Motor Control Centre (MCC) to get the fringe benefit of bonus of EB, but maintain higher pf say 0.95 at the load end. Optimally 0.97 is enough for a unit to get the bonus from the EB. Now the industry actually loses more in capacitor compensation more than 0.98 and loses more heavily by addition of more capacitors from 0.99 to unity PF.

Cooling Heavy Loaded Transformer: -

- We are aware that the transformer losses are mini-mum at its half loaded capacity. But if we are making any deviation in any equipment's optimum efficiency vs. loading characteristics, we have to make the surrounding conditions efficient which enable the equipment to keep its losses minimal, even at higher loading levels of operation. For example we see shrouded fan mounted in the side, facing the fins of transformer to bring down the oil temperature and improve the working of the transformer in the long run in the sub stations and this is being tried in the industry's incoming transformer(s) too.
- For Regulation transformer loading, consumer must know his optimum loading of transformer and how much he can deviate from that.

Improvement in Loading of Transformer

- Optimum KVA load of transformer for maximum efficiency

$$= \left(\frac{\textit{iron loss}}{\textit{copper loss}} \right) \times \frac{1}{2} \times \textit{full load KVA of the transformer}$$

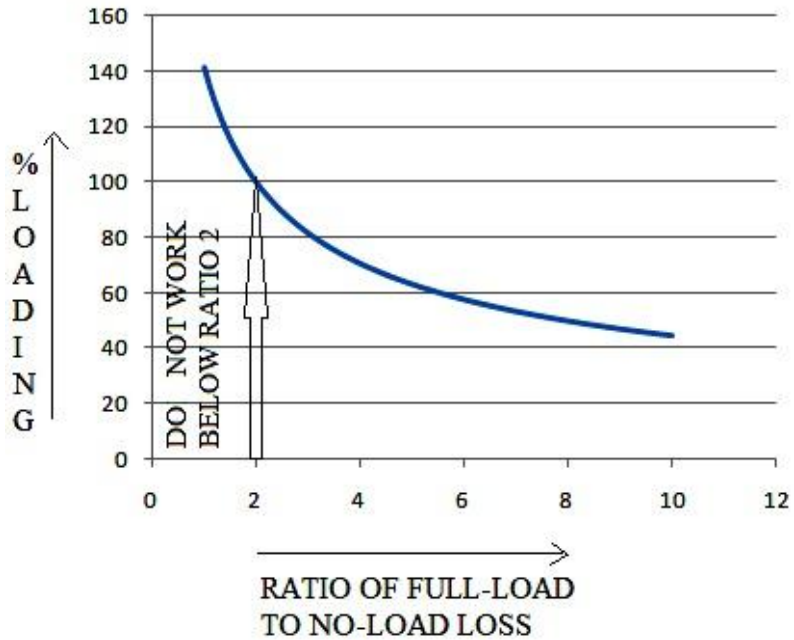


Figure4.1 Percentage loading vs. Ratio of Full-Load loss to No-load loss

Figure 4.1 shows the relation between percentage loading and ratio of full-load loss to no-load loss. As the full-load loss of the transformer increases the percentage by which transformer can be loaded decreases rapidly.

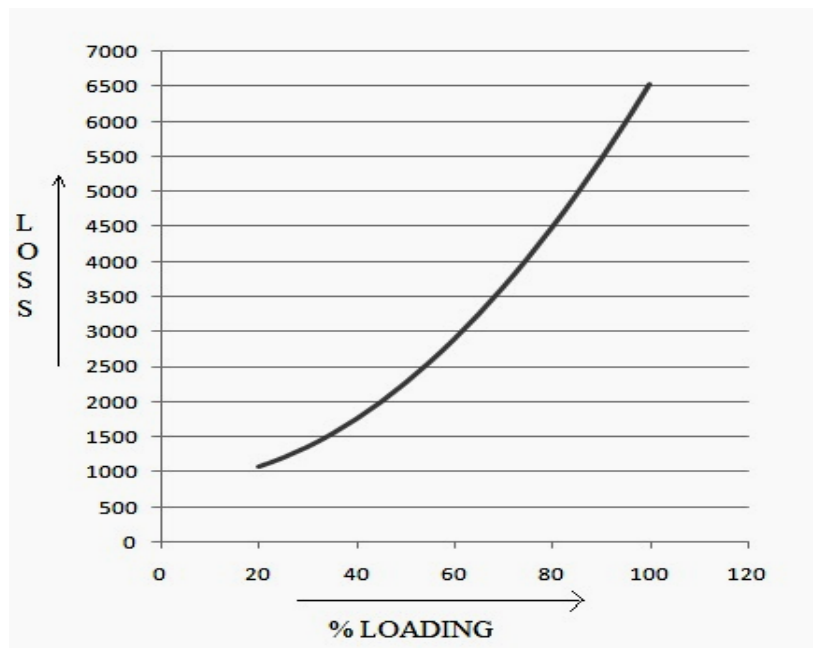


Figure4.2 Percentage loading vs. Total transformer losses

Figure 4.2 shows the relation between percentage loading of the transformer and Total Transformer Loss (TTL). As percentage loading of the transformer increases Total Transformer Loss (TTL) increases. Let us take a fact from figure 4.2, if we load single transformer by 90% the total transformer loss will be 5457 W, but if we load two transformers of same type each by 45% then total transformer loss will be 3989. So a total loss of $(5457 - 3989)$ 1468 W is reduced. Hence proper loading of transformers saves a lot of electrical energy.

Capacitor retrofit to improve efficiency

Losses in the electrical equipments also depend on how close is the power factor to the unity. As the power factor keeps on going far from unity the efficiency goes on decreasing. By connecting capacitors we can improve the power factor of the equipment thus reducing the losses resulting in increase in energy saving.

Fixed power input to plant: -

On-load Tap Changer (OLTC) concept provides benefit to the user. OLTC is more beneficial for those users who are using transformers of 500KVA and higher ratings; because he will be feeding steady regulated uniform voltage to his equipments and his assessment of daily energy consumption does not vary due to varying input voltage from EB say from 380 to 430 volts etc. The consumer will understand to regulate his volt input because this voltage variation affects his productive output badly.

Spot Power: -

The industry management wants the staff to be pro-active. If the subordinates are reactive but not pro-active, then the industry does not progress faster but dillydallies. Similarly, the plant wants its electrical input, say from the incoming transformer to the machine end, to be active and not reactive. So it is better if we correct the circuit p.f. by adding capacitor at motor terminals i.e. improve the p.f. at where it lags i.e. Spot Power Correction (SPC) at load where the lagging originates, thereby reducing the distribution losses in the plant and the amount of p.f. correction is also less when done at load end.

Lighting:-

Now lighting trends are changing from general application to visual task oriented. Let us highlight the first priority of setting lower voltage of say 200 V AC to lamps for reduced consumption and longer probable burning hours.

Alternative approaches can also be mentioned whether power-consuming servo stabiliser can be used, or parallel inductance hooked on to circuit type lighting controller can be used.

For example, in the Telephone Exchanges (TE), task lighting in the switch room is now installed at about 2.4 meter (8 feet) above the ground as against the earlier practice of 3 meter (10 feet) above the ground. It has been seen during their Lighting Study (LS) that illumination level increase by 1.7 times when the mounting height is reduced. This is very much applicable to the plant. From aesthetic sense of fixing at 14 feet height, many plants have brought down to 10 and 8 feet height. Ultimately the worker is more benefited with the convenient visual tasking.

When measured with lux meter, the existing T 12 tube loses light output say by 30 % in 2000 hours; this is very bad deterioration of lumens, and this poor lighting affects the worker's visual task. Unless he complains of poor lighting and his quality of work is poor, the manager does not replace lighting. CII bulletin March 2002 says regular human performance, 1 % increase in lighting improves productivity by 6 % ^[18]. So let the user to opt for T 8, T 5 lightings which do not reduce in lighting levels after prolonged use. So lighting has to be frequently checked by lux meter and not to be complained by worker i.e. grievance feedback & corrective action.

4.7 MAN-MADE FIBER PRODUCTION NETWORK

In man-made fibre production network, opportunities are in large number to save energy because this network contains a large number of motors and other electrical equipments.

Few of the opportunities and techniques are discussed below:

- 1) Installation of Variable Frequency Drives (VFD) on hot air fans in after treatment dryers in viscose filament production.
- 2) Installation of Variable Frequency Drives (VFD) in fresh air fans of humidification system in man-made fiber spinning plants.
- 3) Installation of Variable Frequency drives on motors of dissolvers.
- 4) Adoption of pressure control system with VFD on washing pumps in after treatment process.
- 5) Energy-efficient High Pressure steam-based Vacuum Ejectors in place of Low Pressure steam-based Vacuum Ejectors for Viscose De-aeration.
- 6) Improving motor efficiency in draw false-twist texturing machines

4.8 CROSS-CUTTING ENERGY EFFICIENCY MEASURES

This opportunity consists of measures that can be taken to save energy by controlling the demand of the supply, improving the efficiency and p.f of the equipments etc.

Some of the measures that can be done are:

4.8.1 Electrical demand control

Demand control is a follow-up analysis that is normally conducted after the demand/load profile has been developed by energy auditors. Demand control is nothing more than a technique for levelling out the load profile, i.e. shaving the peaks and filling the valleys. The main advantage of demand control and load management is the reduction of electricity costs. In practice the demand limit of a plant is higher than the average electricity requirement since it is rarely possible to operate with constant power consumption. The first step in demand control analysis is to analyze a plant's electricity utility tariff structure and past history of power demand. The load factor is a useful tool in demand control analysis.

Calculating the load factor (LF):

The load factor is the ratio of the energy consumed during a given period (the period of an electricity bill) to the energy which would have been consumed if maximum demand had been maintained throughout the period.

$$\text{Load factor (\%)} = \frac{\text{energy used during the period(kWh)}}{\text{maximum demand(kW)} \times \text{time consideration(hr)}} \times 100$$

Maximum demand and total kilowatt-hours are easily obtained from past electricity bills. Normally the load factor is less than 100%. That is, the energy consumed is less than the maximum power demand at any time in the period multiplied by the total period time. In general, if the load factor in a plant is reduced, the total cost of electricity will be higher (Morvay and Gvozdenac 2008) ^[19]. In other words, the load factor is a useful method of determining if a plant is utilizing its energy consuming equipment on a consistent basis (higher LF), or using the equipment for a shorter duration (lower LF), thereby paying a demand penalty.

The simplest method for reducing peak loads is to schedule production activities in a way that the big electrical power users do not operate at the peak time at all, or at least some of them do not operate at the same time, if possible. *Machine scheduling* is the practice of turning equipment on or off depending on the time of day, day of week, day type, or other variables and production needs.

4.8.2 Energy-efficiency improvement opportunities in electrical motors

When planning to improve the efficiency of the motor system in an industry, a system's approach incorporating pumps, compressors, and fans must be used in order to attain optimal savings and performance. Considerations with respect to energy use and energy saving opportunities for a motor system are discussed below.

Monitoring and management of electric motors

It is very important to introduce monitoring and management systems for your motors to maximise your energy saving initiatives.

A. Monitoring

For long-term energy savings accurate and precise monitoring should be done, so that wastage of energy can be detected. When you introduce motor monitoring, it is a good idea to take the following steps:

- Make an inventory of your motor systems - this will provide a clear framework for identifying and prioritising actions and also give history of each motor, which is useful for deciding whether to repair or replace when problems occur.
- Measure the power consumed by each motor using an “hours-run” meter, a clamp-on ammeter and a portable power logging device, as well as permanent kilowatt-hour metering.
- Analyse and monitor the condition of each component to predict the risk of failure by using vibration analysis, oil analysis and thermo graphic surveys.

Modern monitoring systems can carry out the analysis automatically and flag up any problems by sending an email or text message to the relevant operative. More advanced systems will automatically shut down a process if a fault is detected.

B. Motor management plan

With well-designed motor management plan, effective cost savings can be done on every motor in the plant. This plan will provide a systematic approach to repair and maintenance, resulting in reduced system down-time.

Your motor management policy will generally include a:

- schedule and procedure for motor maintenance

- plan for repairing, or replacing, failed motors
- plan for purchasing new and more efficient motors

Maintenance

Motor maintenance is one of the most important ways of ensuring that motor continues to work efficiently. Motor maintenance measures can therefore be categorized as either preventative or predictive. Preventative measures, include voltage imbalance minimization, load consideration, motor alignment, lubrication and motor ventilation. Note that some of them aim to prevent increased motor temperature which leads to increased winding resistance, shortened motor life, and increased energy consumption. The predictive motor maintenance is required to observe ongoing motor temperature, vibration, and other operating data to identify when it becomes necessary to overhaul or replace a motor before failure occurs (Barnish et al., 1997) ^[20].

The savings associated with an ongoing motor maintenance program could range from 2% to 30% of total motor system energy use (Efficiency Partnership, 2004) ^[21].

Energy-efficient motors

Energy-efficient motors are the motors with high efficiency, low losses. These motors are made by improving the design, better materials, tighter tolerances, and improved manufacturing techniques. With proper installation, energy-efficient motors can also stay cooler, may also have many advantages like reduced facility heating loads, and higher service factors, longer bearing life, longer insulation life, and less vibration.

The criteria or choice of employing an energy new motor strongly depends on motor operating conditions and the payback period associated with the investment. In general, new motors are most economically attractive when replacing old motors with annual operation exceeding 2,000 hours/year or rewind motors. Sometimes, even replacing an operating motor with a premium efficiency model may have a low payback period. According to data from the Copper Development Association, the upgrade to high-

efficiency motors, as compared to motors that achieve the minimum efficiency as specified by the Energy Policy Act of 1992 can have paybacks of less than 15 months for 50 hp motors (CDA, 2001) ^[22].

Proper motor sizing

Lightly-loaded motors are less efficient than fully-loaded ones, so it is much better that they are loaded as near to their full capacity as possible. There are different ways that you can achieve this, including:

- Replacing larger, partially-loaded motors with smaller, fully-loaded ones,
- Optimising a system or process so that the motor is running at full capacity for shorter time periods instead of running continually with a partial load.

If it is not practical to change your existing motors or optimise existing systems you can still make energy savings on motors running with very light loads by:

- Fitting motor optimisers that reduce the average voltage and current
- Running the motor continually using a different connection mode - for example, star/delta, which reduces starting current and starting torque.

Power factor correction

Power factor is defined as the ratio of the real power flowing to the load to the apparent power in the circuit ^{[23] [24]}. It measures how effectively electrical power is being used. A load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred i.e. a high power factor signals are efficient for utilization of electrical power, while a low power factor indicates poor utilization of electrical power. Inductive loads like transformers and electric motors may cause a low power factor. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with energy-efficient motors, or installing capacitors in the AC circuit to reduce the magnitude of reactive power in the system (U.S. DOE, 1996) ^[25].

Minimizing voltage unbalances

The performance and the life of motors (especially 3- ϕ motors) are badly affected by voltage unbalancing. A voltage unbalance causes a current unbalance, which results in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which causes the reduction in the life of a motor's winding insulation. Voltage unbalances may be caused by faulty operation of power factor correction equipment, an unbalanced transformer bank, or an open circuit. A rule of thumb is that the voltage unbalance at the motor terminals should not exceed 1% although even a 1% unbalance will reduce motor efficiency at part load operation. A 2.5% unbalance will reduce motor efficiency at full load operation.

By regularly monitoring the voltages at the motor terminal and through regular thermographic inspections of motors, voltage unbalances may be identified. It is also recommended to verify that single-phase loads are uniformly distributed and to install ground fault indicators as required. Another indicator for voltage unbalance is a 120 Hz vibration, which should prompt an immediate check of voltage balance (U.S. DOE-OIT, 2005b) ^[26]. The typical payback period for voltage controller installation on lightly loaded motors in the U.S. is 2.6 years (U.S. DOE-IAC, 2006) ^[27].

4.9 COMPRESSED AIR SYSTEM

Compressed air is widely recognized as industries fourth utility. It is the only utility for which end-user has the sole responsibility to produce and maintain in-house. Compressed air is a very costly utility; it is not "free". Developing an understanding of the dynamics of a compressed air system (CAS) is advantageous to the end user for two main reasons.

First, a Compressed Air System (CAS) is inherently inefficient. Due to heat loss during the heat of compression, only approximately 10% of the input energy is usable energy at the point of use. Therefore, significant opportunities exist to reduce the input energy consumed to meet the compressed air demand, sometimes in the neighbourhood of 35-40%.

Secondly, the CAS can be a source of numerous problems that bring about added costs, product rejection and unnecessary downtime due to the erratic and inefficient performance of the CAS.

More than 85% of the electrical energy input to an air compressor is lost as waste heat, leaving less than 15% of the electrical energy consumed to be converted to pneumatic compressed air energy (U.S. DOE-ITP EM, 2008) ^[28]. It is with these facts in mind that industry owners, managers and engineers must recognize that industrial compressed air systems can represent the most insidious form of industrial waste in a plant, and therefore, offer great opportunities for efficiency improvements.

In the following, few energy saving opportunities for compressed air systems are presented.

1. Reduction in demand

Because of the relatively expensive operating costs of compressed air systems, the minimum quantity of compressed air should be used for the shortest possible time, constantly monitored and reweighed against alternatives.

2. Maintenance & monitoring

Inadequate maintenance can lower compression efficiency, increase air leakage or pressure variability and lead to increased operating temperatures, poor moisture control and excessive contamination. Better maintenance will reduce these problems and save energy.

3. Controlling inlet air temperature

By reducing the inlet air temperature, wastage of energy can be reduced by the compressor. In many plants, it is possible to reduce this inlet air temperature by taking suction from outside the building. Importing fresh air has paybacks of up to 5 years, depending on the location of the compressor air inlet (CADDET, 1997)

^[29]. As a rule of thumb, each 3°C reduction will save 1% compressor energy use (CADDET, 1997; Parekh, 2000) ^[30].

4. Matching the compressor to its load

Compressors consume more energy during part-load operation; this is something that should be avoided. Some plants have installed systems with several smaller compressors to match compressed air needs in a structured way (Cergel *et al.*, 2000) [31]. In some cases, the pressure required is so low that the need can be met by a blower instead of a compressor which allows considerable energy savings.

4.10 PUMPING SYSTEM

In most industrial networks, energy consumed by pumping systems is responsible for a major part of the overall electricity bill. In some cases, the energy is used quite efficiently; in others, it is not. Facility operators may be very familiar with pumping system equipment controllability, reliability, and availability, but only marginally aware of system efficiency.

The cost of energy consumed by pumps usually dominates the pump life cycle cost. But many end users, already stretched to support day-to-day facility operations, lack the time and resources to perform a methodological engineering study, in some cases, hundreds of pumps within their facilities to understand the energy costs and the potential opportunity for reduction.

Under the auspices of the Department of Energy's (DOE) Best Practices Program, pre-screening guidance documents and a computer program called PSAT (Pumping System Assessment Tool) have been developed to help end users, consultants, and equipment distributors recognize, both qualitatively and quantitatively, pumping system efficiency improvement opportunities.

In the following, few energy saving opportunities for pumping systems are presented.

Maintenance

Inadequate maintenance lowers pump system efficiency, causes pumps to wear out more quickly and increases costs. Better maintenance will reduce these problems and save energy. Proper maintenance includes the following (Hydraulic Institute, 1994; U.S. DOE, 1999) ^[32] ^[33]:

- Replacement of worn impellers, especially in caustic or semi-solid applications.
- Bearing inspection and repair.
- Bearing lubrication replacement, once annually or semi-annually.
- Inspection and replacement of packing seals.
- Inspection and replacement of mechanical seals.
- Wear ring and impeller replacement.
- Pump/motor alignment check.
- The largest opportunity is usually to avoid throttling losses.

Generally speaking, the best strategy for pumping systems optimization is to begin at the end of the line and work backwards through the pump, motor, and back to the transformer. The elements and the order of review contemplated are:

1. Ultimate goal or purpose
2. Piping system
3. Pump
4. Gear or coupling
5. Motor
6. Adjustable speed drive (if applicable)
7. Motor starter
8. Transformer

4.11 FAN SYSTEM

Efficiencies of fan systems vary considerably across impeller types. The average energy saving potential in these systems in the U.S. Manufacturing industry is estimated at 6% (Xenergy, 1998) ^[34]. For optimal savings and performance, it is recommended that a systems approach is used. In the following, energy saving opportunities for fan system is presented.

Fan efficiency

The key to any design is proper fan selection. The design of the fan and its blade type can affect efficiency and power requirements significantly. Laboratory-measured peak fan efficiency may not be the most stable point of operation.

If peak efficiency coincides with the peak of the pressure curve then there may be operational problems as volumetric flow rates vary with small changes in system pressure. The designer must consider both curves when selecting the best fan and operating point to optimize reliability and power usage. Fan type may dictate proper selection. Airfoil wheels, while more efficient, may not be a good choice when handling particulate laden air. (Lanham, 2007) ^[35].

Proper fan sizing

Most of the fans are oversized for the particular application, which can result in efficiency losses of 1-5% (Xenergy, 1998) ^[34]. However, it may be more cost-effective to control the speed than to replace the fan system.

4.12 POWER FACTOR IMPROVEMENT

The power factor of an AC electric power system is defined as the ratio of the real power flowing to the load to the apparent power in the circuit, and is dimensionless number between 0 and 1. In an electrical power system, a load with low power factor draws more current than a load with a high power factor for the same amount of useful power

transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

Power factor improvement is widely implemented in many commercial as well as non-commercial buildings now-a-days. And it is proving to be one of the best methods to save electrical energy.

4.12.1 Analysis: Power factor improvement

The analysis of power factor improvement is done as a small exercise. In this exercise, we are analysing few electrical types of equipment for power factor improvement and is shown below.

Table4.1 Parameters for power factor improvement.

S.NO.	EQUIPMENT POWER (KW)	PRESENT PF	REQUIRED PF	REQUIRED CAPACITOR SIZE (KVA _r)	REDUCTION IN LOSSES (%)
1	27	0.72	0.95	17.15	42.56
2	12	0.7	0.94	7.89	44.55
3	24	.64	.9	17.19	49.43
4	17.36	.9	.95	2.7	10.24
5	60	.8	.95	25.28	29.09

Table 4.1 shows the list of parameters required for power factor improvement, size of the capacitor bank required and the resulted reduction in the losses after improving power factor. Listed losses reduction shows that power factor improvement can save the electrical energy to a great extent.

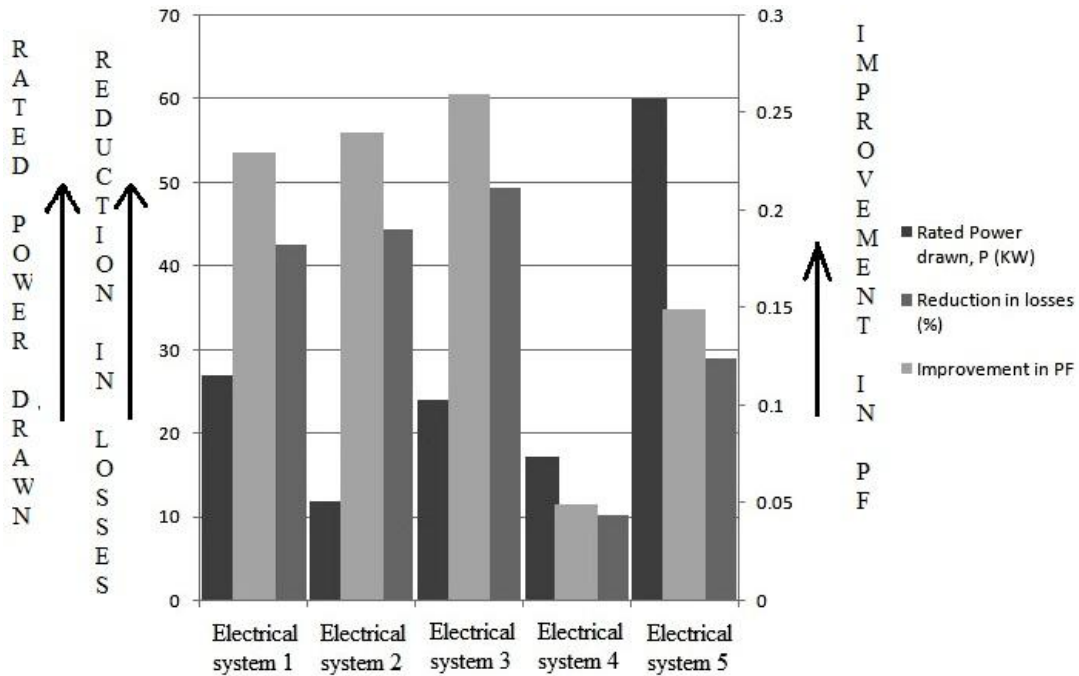


Figure4.3 Power factor improvement analysis

Figure4.3 shows the analysis done on few electrical systems for their power factor improvement.

Figure 4.3 and table 4.1 shows that by connecting a capacitor bank of a determined size, power factor of the system can be improved. Improvement of p.f. can thus lead to large reduction in distribution loss of the system and save large amount of electrical energy.

This analysis also shows that power factor improvement finds a great scope to save electrical energy. Because it is not restricted to one type of electrical system but can be implemented to every type of electrical system i.e. motors, transmission and distribution system, generators etc.

CHAPTER 5

ELECTRICAL EFFICIENCY OF ELECTRICAL MOTOR

5.1 INTRODUCTION

This chapter aims to analyze the efficiencies of the in-house rewind induction motors in the textile plant under study and to minimize (or conserve) energy usage by improving the efficiencies of these motors. The electrical energy audit process in rewind induction motors is evaluated in process stages. The choice of stages is due to the nature of the process and as well, the details of rewind induction motors in the textile plant. As far as possible the same structure will be used for all the different rated motors to facilitate comparison between the rewind induction motor and new motor.

At the end of this chapter, we will also show the analysis done on power factor improvement of few electrical types of equipments. This analysis is done as a small exercise to facilitate the future scope of the power factor improvement strategy.

5.2 METHODOLOGY

The methodology adopted for conducting the detailed energy audit is:

- Basic data collection on:
 1. List of electrical motors of different horsepower and
 2. Operating parameters.

- Measurement of operating parameters of various equipments under different conditions, to estimate their operating efficiency.

- Analysis of data collected to develop specific energy saving proposals.
- Presentation on the findings of the detailed energy audit.

5.3 DESCRIPTION OF THE PLANT

The textile plant considered for the study comes under large scale category. Some important details of the plant are:

- Yarn manufacturing is carried out using state-of-art textile equipment.
- Daily spinning capacity is 10,000 kg of yarn and number of spindles are 45,072.
- The plant operates continuously throughout the year.
- Major energy sources are electricity from substation, steam power plant and High Speed Diesel (HSD).
- Contract demand with Electricity Board.
- Also supply the electrical energy to the residential colony of the industry itself.

5.4 ENERGY AUDIT PROCESS

Figure 5.1 shows the flow diagram depicting the energy audit process.

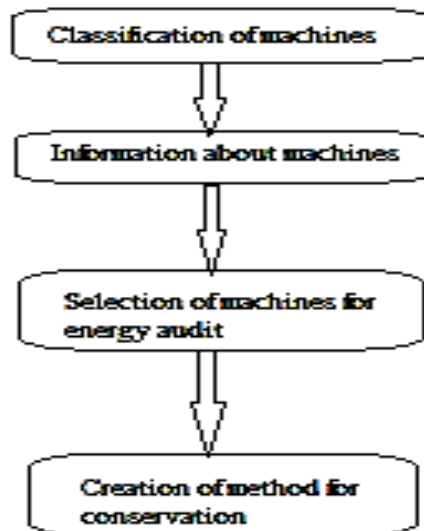


Figure5.1 Energy audit process

The details of the energy audit processes are:

- ✓ Classification of machines is carried out from the power rating of the load and type of load for which they are used.
- ✓ Information about the machines is collected which includes method of power transmission, loading sequence, sources of energy wastage and method of control.
- ✓ Energy against power rated data is used for the selection of machines for detailed energy audit.
- ✓ To identify the methods for energy conservation, following points are considered.
 1. alternate to reduce/avoid energy losses
 2. alternate to reduce down time
 3. alternate to optimum selection

5.5 NECESSITY OF AN INFORMATION SYSTEM FOR BETTER ENERGY CONSERVATION PRACTICES

Energy cost is one of the largest components of conversion cost incurred by the textile plants. At present, energy related data are collected manually in the textile plant which involves considerable amount of time, cost and possible inaccuracies. Online information, on the other hand, provides quick, continuous and accurate results, which will be very much useful in decision making.

5.6 DATA ANALYSIS AND RECOMMENDATIONS

Analysis done on motors to conserve energy is explained in following stages:

5.6.1 Energy usage inventory in rewound induction motors

The first step is to perform the energy usage inventory which will basically end up as method to reduce the energy consumption. The ways of deriving this method will be

different for different types of motor. The analysis (or electrical energy audit under going on rewind motors) is described below.

5.6.2 Work Flow

First the possibilities of each rewind motor have to be determined i.e.

- Which information exists?
- Which is the best way to determine the energy consumption of the different motors working at different areas?

There are a number of different ways to determine energy consumption.

The next step is to actually derive the energy consumption of each stage and to calculate the percentage of the total energy consumption (or to calculate the efficiency of the rewind motor).

The last thing to do is to estimate the payback that will determine that whether to replace the rewind motor with new motor or to make some changes in the motor itself to improve the efficiency if payback is large.

5.6.3 Method

When the energy consumption is not measured, ways to calculate must be found. How this can be done depends on the circumstances. All methods calculate efficiency according to the definition of:

$$\text{Efficiency}(\%) = \frac{\text{Shaft output power}}{\text{Electrical input to drive system}} \times 100$$

The shaft output power is the input power minus the losses. How to assess losses and evaluate output power give rise to fundamental differences among the various methods. Consequently, the accuracies of methods are different.

The degree of intrusiveness of a field evaluation method is determined by what data are required to be measured in the field and the difficulty of performing the measurements.

One or more of the following measurements may be involved:

- Nameplate reading;
- Speed measured by tachometer;
- Currents measured by clamp-on transducer;
- Voltages measurement;
- Input power measurement;
- Stator winding resistance reading;
- Winding temperature data;
- Investment calculation.

The data may be acquired in the format of R.M.S. meter readings or digitally sampled waveforms. The cost associated with the labour, material, and downtime for implementing safety requirements for data collections can be used as a gauge to weigh intrusiveness. For example, using an optical tachometer for rotating speed measurement normally has a lower intrusion level than a voltage measurement, since it requires making connections in a terminal box. Intrusiveness can vary from plant to plant. For the same example, if the voltage transducer is permanently installed and wired to proper connectors, the intrusiveness is significantly lower.

Planning may also affect intrusiveness. If a decoupled no-load test is required and the motor power supply is available during scheduled downtime, it may be possible to conduct this kind of test without affecting production. If, however, the data are to be taken during production time, the cost and intrusion level would be very high.

A. Nameplate Method

The least intrusive field evaluation method is to obtain motor information from the nameplate. In this method, rated parameters of the motor are obtained. These rated

parameters are written on the nameplate (fitted on the motor cage) by the manufacturer after testing the motor when it was newly built. Motor nameplates are provided by virtually all manufacturers to allow users to accurately identify the operating and dimensional characteristics of their motors years after installation. The nameplate is usually a metal plate, secured by a pair of screws or rivets, and is generally located on the side of the motor.

We have note down all the parameters listed on nameplate. These parameters help us in determining the efficiency of the new motor that is of same ratings and will be replacing the rewind motor to save energy if required. Parameters listed on the nameplate are shown in table 5.1:

Table 5.1 Motor nameplate parameters

S.NO	PARAMETER	UNITS
1	Motor Manufacturer	-----
2	Model	-----
3	Type	-----
4	Serial Number	-----
5	Power	HP(horsepower) or KW
6	Speed	RPM
7	Voltage	V
8	Current	A(Ampere)
9	Phases	ϕ
10	Frequency	Hz
11	Armature	V
12	Field	V

Rewound motors introduce additional uncertainty, since the nameplate data may no longer be valid. Core loss of a rewind motor may or may not be increased, depending upon the lamination insulation and the cleaning process of the stator. The copper loss depends on the new coil extension and wire gauges. Certain engineers suggest that, after

each rewinding to the same horsepower and same number of poles, a two percentage point reduction of efficiency should be considered.

B. Speed measured by tachometer

The most conventional unit of measuring the speed of a motor is in RPM. This stands for revolutions per minute, or the number of times the motor's shaft will rotate in one minute. The typical RPM range of most motors, running in industries, is from 1500 to 8000. To get a rough estimation of a motor's RPM speed, one method is to attach a piece of tape of coloured disc to the motor shaft, and count the number of rotations a minute. This depends much on your ability to focus on the moving object, and so accuracy declines as RPM increases.

A more accurate and conventional method of measuring RPM is using a device called a tachometer, which can precisely measure the speed of up to thousands of RPM. There are namely two types of tachometers, the "contact" and "non-contact" tachometers.



Figure5.2 Opto-tachometer for measuring speed

The contact tachometer shown in figure 5.2, is physically attached to the motor shaft, thereby reducing the speed, and providing an inaccurate RPM reading. The non-contact tachometer utilizes a brightness sensor that detects rotations.

We are using non-contact type tachometer to measure speed of the motor. For measuring speed, we are attaching a black-white coloured disc to the shaft, when the motor shaft spins the tachometer flashes the rotating disc with an LED and detects the varying light reflection from light to dark, through its brightness sensor. A chip integrated to the

tachometer is measuring the time for a light to dark to light progression, and thus the RPM speed is measured.

C. Currents measured by clamp-on transducer

The clamp-on current transducer is a non-contact current transducer for use in 50/60 Hz AC current measuring applications. Installation is easy; the transducer is clamped over the wire carrying the current to be measured and the two transducer secondary wires are connected to the monitoring instrument.



Figure5.3 Clamp-on current transducer

The transducer consists of a split ferrite ring, shown in figure 5.3 that, when clamped together over a current carrying AC wire, forms a simple transformer, with the ferrite forming the transformer core and the clamped wire (the wire through which current is measured) being the primary winding of the transformer. A 750 turn secondary winding is integral to the transducer and provides the output signal. Based on this turns ratio, a one amp current flowing in the clamped wire produces a 1.333 milliamp current in the secondary winding if the secondary is terminated into the recommended 75 ohm load. A voltage of 100 milli-volts per sensed amp is developed across the load resistor.

Procedure applying to measure current:

1. Turn on the clamp meter and set the function for measuring current. There is also a selection knob or button to select whether you are measuring alternating current

(AC) or direct current (DC) flow. As we are measuring current in induction motors, so we set the knob on AC.

2. Clamp the meter onto the power cord. The ends of the clamp meter arms, which resemble pincers, will have a recessed area through which the power cord should be placed. Ensures that the clamp meter arms are stable with the cord between them.
3. Now we read the current flow on the clamp meter display. Most clamp meters have automatic range finders, but our meter is not automatic one, so we increase the range of the meter until we get a reading. Write down the reading, which will be numbers that represent the amount of amperes, or amps, flowing through the cable.
4. Now we measure the amount of current flow through a motor by turning the motor on and loading it once with partial load and then full load. The current flow keeps on rising when the motor is being loaded from no-load to full-load.
5. We adjust the position of the clamp meter to ensure that we are getting accurate current flow readings. Note down all the readings.
6. Remove the clamp meter from the power cord.

D. Voltages measurement

Voltage is a differential parameter; it is always measured between two points. There are two ways to measure three-phase voltage—between two of the three lines or between a line and neutral or ground. Service and motor voltages are quoted as line to line, unless otherwise noted. Because of the phase difference, line-to-line readings are 1.73 times line-to-neutral readings.

Instruments for measuring voltages include the voltmeter, the potentiometer, and the oscilloscope. The voltmeter works by measuring the current through a fixed resistor, which, according to Ohm's Law, is proportional to the voltage across the resistor. The potentiometer works by balancing the unknown voltage against a known voltage in a bridge circuit. The cathode-ray oscilloscope works by amplifying the voltage and using

it to deflect an electron beam from a straight path, so that the deflection of the beam is proportional to the voltage.

Figure 5.4 shows the typical instrument that is used to measure voltage across motor. Voltages on all the three phases are measured and average voltage is computed. Voltage is measured using “power analyser” with an error of 0.5%. At the time of measurement, voltage is nearly but not absolutely balanced. So the arithmetical average of the line voltages is used.



Figure5.4 power analyzer

Line to line R.M.S. voltages across R-Y, R-B and Y-B are measured and average of line-to-line R.M.S voltage is calculated as follows.

In motors, where stator winding is connected in Δ (delta),

Phase voltage, $V_{ph} = \text{Line voltage}$

In motors, where stator winding is connected in Y (star),

Phase voltage, $V_{ph} = \text{Line voltage} \div \sqrt{3}$

E. Input power measurement

For no-load power measurement, a low power factor corrected power analyser having full-scale error of not more than 0.5% is used. It is noted that energy meters, which are used usually in measurements where p.f. might be above 0.7, indicate errors of 5 to 10%

when used in low p.f. (0.1 to 0.3) load conditions. Hence it is important to have power analysers with CT's calibrated for various load currents and p.f. ranging from 0.1 to 1.0.

Measurement of energy consumed during a known period is done using a power analyser and power is estimated from energy measurement and time duration. The CT ratios is selected to read preferably above 50% or above of the input current. For example, for measurement of 100 A current, a 200/5 A CT is more desirable than using a 500/5 A CT.

F. Stator resistance measurement

Measurement of winding resistance is done across line to line i.e. R & Y, Y & B and R & B phases. The average value of line-to-line resistance obtained is designated as R_{ll}

To convert the measured value of line-to-line resistance to phase resistance, the following relationships are used.

In 'Star' connection, phase resistance, **$R_{ph} = 0.5 \times R_{ll}$**

In 'Delta' connection, phase resistance, **$R_{ph} = 1.5 \times R_{ll}$**

The resistance must be corrected to the operating/full load temperature by using following relationship

$$\frac{R_2}{R_1} = \frac{235 + T_2}{235 + T_1}$$

Where, R_2 = unknown resistance at temperature T_2

R_1 = resistance measured at temperature T_1

G. Winding temperature measurement

The stator winding temperature detector i.e. *Resistance Temperature Detector (RTD)* is used to measure temperature of the Motor windings. These sensors are sandwiched

between the windings of Motors. Unlike on/off devices, it allows continuous measurement of winding temperature. The NEMA recognizes this kind of sensor as a standard protection for motor and generator Insulation. Normally, these RTDs are of wire wound and sensing element extends through the length of the detector. These features will provide average temperature reading. Normally six sensors are recommended for each motor, two per phase.

These models are intended for use in hazardous areas in which explosive gas atmospheres, caused by mixtures of air and gases, vapours or mists, exist under normal atmospheric conditions. Due to special design guidelines, it prevents arcing. This RTD are generally flat type in construction and are available in various sizes.

RTDs gives us temperatures at different conditions like at no-load, at full-load or at partial-load. These reading are then used to calculate stator resistances at various loading conditions with the help of equation mentioned in previous section.

H. Investment Calculation

The success of the project (or audit) depends on a perfect decision rule that will determine whether to accept the investment project or reject it. This section presents the financial decision rules for increasing the success rate of the investment project. And the decision rules are: the net present value, payback period, and the internal rate of return.

1. Net present value (NVP)

The Net Present Value (NVP) of investment proposal is derived by discounting the net cash receipts at a rate which reflects the value of the alternative use of the funds, summing them over the life of the proposal and deducting the initial outlay ^[36].

The Net Present Value (NPV) can be defined as follows ^[37]:

$$NPV = \frac{CF_0}{(1+k)^0} + \frac{CF_1}{(1+k)^1} + \dots + \frac{CF_n}{(1+k)^n}$$

$$= \sum_{t=0}^n \frac{CF_t}{(1+k)^t}$$

Where NPV = Net Present Value

CF_t = Cash flow occurring at the end of year, t (where, t=0, 1,...n)

n = life of the project

k = Discount rate

The discount rate (k) employed for evaluating the present value of the expected future cash flows should reflect the risk of the project.

If the outcome of the net present value is positive, the investment is acceptable. Net present value is the most reliable feasibility indicator since it reflects the absolute magnitude of the project. The larger the value is the better the profits [36].

2. Payback period

The payback period gives the number of years required to recover the initial investment outlay from a project's future cash flows. The payback can be calculated using the formula [36]:

$$\text{Payback period} = \frac{\text{Initial investment outlay}}{\text{Annual cash receipts}}$$

The payback period is often used as an argument for rejecting profitable energy conservation investments. For example, Diesen (1998) suggests that the

payback time should be less than 3 - 4 years to accept an investment. The reason for this is that a higher output provided by the implementation cannot be achieved due to limitations, complications, and bottlenecks that the implemented investment reveals elsewhere in the production line ^[38]. In other words, Diesen's recommendation includes a certain margin for an unknown risk.

Investment calculations should emphasise the importance of a thorough evaluation and understanding of the possible consequences of the investment. If the risks are fully examined and no justified reasons for rejecting the investment are found, a long payback time should never prevent from making profitable investments.

3. Internal Rate of Return

The internal rate of return (IRR) is defined as the rate of discount, which equates the net present value of the cash flow to zero. If the internal rate of return is greater than the required rate of return of the investment, the investment is acceptable ^[36].

The internal rate of return can be compared with the cost of funds to yield a 'margin of profit'. Mutually exclusive decisions should be dictated by differences between the alternative proposals' net present values and not by their internal rates of return.

5.7 SUBJECT ANALYSIS

In this study the subject of investigation (or say under study) is a major textile plant. This plant includes a 33KV substation, 6MW steam power plant, diesel plant and a fiber manufacturing plant. The installed capacity is 43,000 Tonnes Per Annum (TPA). The plant produces Nylon Filament Yarn (NFY), using caprolactam as its raw material. Caprolactam is the major raw material required and its requirement is 99.5%.

Textile plant under study, consumes large amount of electrical energy because this plant is very old and electrical equipments are not maintained properly. Like, in this plant many motors, which are working, are in-house rewind motors, and parameters of the rewind motor always differ from that of new motor. So we have aimed to study the rewind motors to save electrical energy as they are the major consumer of the electrical energy also.

In the subject, the saving in electrical energy is found by analysing few of the rewind motors and looking for alternative options to increase the efficiency of the motors. The current study focuses not only on energy saving but as well as on financial saving opportunities also that will be analysed by investigating the rewind motors in the plant.

To evaluate the feasibility of the opportunities, it is necessary to analyse the efficiency of the rewind motors and the duration for which motors run in the plant. After analysing the different parameters of the rewind motors, a proposal will be made, according to which investment project will be proposed and will be implemented, which will decide that whether to replace the rewind motor with new motor or to keep working with the rewind motor, after some changes have been done to improve its efficiency.

There are three types of parameters which are collected during analysing the rewind motors. And these three parameters types are:

1. Rated parameters; that are printed on the name plate and given in the manual by manufacturer.
2. Measured parameters; that are measured using different instruments under different conditions. Conditions are like no-load, partial-load and full-load.
3. Calculated parameters; that are determined (or computed) from rated and measured parameters using standard formulas.

Tables 5.2 to 5.13 contain parameters of all the three parameter types of the analysed rewind motors of different powers:

Table5.2 Rated Parameters of 15HP Rewound Motors

MOTOR IDENTIFIER	MOTOR MODEL	MOTOR TYPE	NO. OF PHASES	NO. OF POLES	RATED POWER (W)	RATED POWER (HP)	RATED VOLTAGE (V)	RATED CURRENT (A)	FULL-LOAD RATED SPEED (RPM)	SUPPLY FREQUENCY (Hz)
NEW	NEW	15HP	3	4	12000	15	415	19	1460	50
R.M. 1	OLD		3	4	12000	15	415	19	1460	50
R.M. 2			3	4	12000	15	410	19	1460	50
R.M. 3			3	4	12000	15	415	19	1460	50
R.M. 4			3	4	12000	15	415	19	1460	50
R.M. 5			3	4	12000	15	415	19	1460	50

Table5.3 Measured Parameters of 15HP Rewound Motors

MOTOR IDENT.	N.L. VOLT (V)	N.L. CURR. (A)	N.L. I/P POWER (W)	N.L. SPEED (RPM)	TEMP. OF STILL MOTOR (°C)	RESIS. AT ROOM TEMP. (Ω)	TEMP. OF N.L. MOTOR (°C)	TEMP. OF LOADED MOTOR (°C)	F.L. VOLT. (V)	F.L. CURR. (A)	F.L I/P POWER (W)	F.L. SPEED (RPM)
New	415	8	523.87	1480	12	0.35	34	140	415	20	13500	1475
R.M. 1	410	7.5	589	1480	13	0.8	43	142	410	25	13500	1470
R.M. 2	410	9	550	1480	15	1.2	49	151	410	23	14000	1475
R.M. 3	410	8	579.89	1480	16	0.78	43	143	410	22	13400	1475
R.M. 4	415	10	580	1485	20	1.2	50	150	415	30	14100	1480
R.M. 5	415	8.5	591	1480	14	0.91	44	145	410	25	14000	1475

Table5.4 (a) Calculated Parameters of 15HP Rewound Motors

MOTOR IDENTIFIER	SYNCHRONOUS SPEED (RPM)	STATOR RESIST. OF NO-LOAD RUNNING MOTOR (Ω)	STATOR RESIST. OF LOADED MOTOR (Ω)	STATOR CU. LOSS AT NO-LOAD (W)	STATOR CU. LOSS AT FULL-LOAD (W)	IRON AND F&W LOSSES (W)	NO-LOAD SLIP (%)	LOAD SLIP (%)	FULL-LOAD ROTOR LOSSES (W)
NEW	1500	0.38	0.53	24.39	212.5	499.47	1.33	1.67	213.13
R.M. 1	1500	0.89	1.22	50.44	760.08	538.56	1.33	2	244.027
R.M. 2	1500	1.36	1.85	110.42	980.13	439.58	1.33	1.67	209.67
R.M. 3	1500	0.86	1.17	55.29	568.54	524.6	1.33	1.67	205.1
R.M. 4	1500	1.34	1.81	134.12	1630.59	445.89	1	1.33	160.3
R.M. 5	1500	1.02	1.39	73.67	867.97	517.33	1.33	1.67	210.25

Table5.4 (b) Calculated Parameters of 15HP Rewound Motors

MOTOR IDENTIFIER	STRAY LOSSES (W)	FULL-LOAD O/P POWER (W)	PERCENTAGE LOADING (%)	P.F. AT FULL-LOAD	EFFICIENCY AT FULL-LOAD, η_{FL} (%)	RATED EFFICIENCY (%)
NEW	202.5	12372.34	103.10	0.94	91.65	91.8
R.M. 1	202.5	11754.83	97.96	0.76	87.07	91.8
R.M. 2	210	12160.62	101.34	0.86	86.86	91
R.M. 3	201	11900.75	99.17	0.86	88.81	91.8
R.M. 4	211.5	11651.72	97.1	0.66	82.64	91.8
R.M. 5	210	12194.45	101.62	0.79	87.10	91.8

Table5.5 Rated Parameters of 20HP Rewound Motors

MOTOR IDENTIFIER	MOTOR MODEL	MOTOR TYPE	NO. OF PHASES	NO. OF POLES	RATED POWER (W)	RATED POWER (HP)	RATED VOLTAGE (V)	RATED CURRENT (A)	FULL-LOAD RATED SPEED (RPM)	SUPPLY FREQUENCY (Hz)
NEW	NEW	20HP	3	4	15000	20	415	27	1460	50
R.M. 1	OLD		3	4	15000	20	415	27	1460	50
R.M. 2			3	4	15000	20	415	27	1460	50
R.M. 3			3	4	15000	20	415	27	1460	50

Table5.6 Measured Parameters of 20HP Rewound Motors

MOTOR IDENTIFIER	N.L. VOLT. (V)	N.L. CURR. (A)	N.L. I/P POWER (W)	N.L. SPEED (RPM)	TEMP. OF STILL MOTOR (°C)	RESIS. AT ROOM TEMP. (Ω)	TEMP. OF N.L. MOTOR (°C)	TEMP. OF LOADED MOTOR (°C)	F.L. VOLT. (V)	F.L. CURR. (A)	F.L I/P POWER (W)	F.L. SPEED (RPM)
NEW	415	11	615	1490	20	0.25	39	137	410	30	17000	1475
R.M. 1	410	10	660	1490	24	1.2	41	141	410	31	17300	1475
R.M. 2	410	10	660	1490	23.5	0.91	40	131	410	34.5	17200	1475
R.M. 3	410	10.5	680	1490	30	0.77	47	150	415	33	18000	1475

Table5.7 (a) Calculated Parameters of 20HP Rewound Motors

MOTOR IDENTIFIER	SYNCHRONOUS SPEED (RPM)	STATOR RESIST. OF NO-LOAD RUNNING MOTOR (Ω)	STATOR RESIST. OF LOADED MOTOR (Ω)	STATOR CU. LOSS AT NO-LOAD (W)	STATOR CU. LOSS AT FULL-LOAD (W)	IRON AND F&W LOSSES (W)	NO-LOAD SLIP (%)	LOAD SLIP (%)	FULL-LOAD ROTOR LOSSES (W)
NEW	1500	0.27	0.36	32.50	328.24	582.5	0.67	1.67	268.15
R.M. 1	1500	1.28	1.74	127.88	1674.14	532.12	0.67	1.67	251.56
R.M. 2	1500	0.97	1.29	96.81	1533.56	563.19	0.67	1.67	251.72
R.M. 3	1500	0.82	1.12	90.34	1218.24	589.66	0.67	1.67	269.87

Table5.7 (b) Calculated Parameters of 20HP Rewound Motors

MOTOR IDENTIFIER	STRAY LOSSES (W)	FULL-LOAD O/P POWER (W)	PERCENTAGE LOADING (%)	P.F. AT FULL-LOAD	EFFICIENCY AT FULL-LOAD, η_{FL} (%)	RATED EFFICIENCY, η (%)
NEW	255	15566.11	103.77	0.8	91.57	91.9
R.M. 1	259.5	14582.67	97.22	0.79	84.29	91.9
R.M. 2	258	14593.53	97.29	0.70	84.85	91.9
R.M. 3	270	15652.23	104.35	0.76	86.96	91.9

Table5.8 Rated Parameters of 50HP Rewound Motors

MOTOR IDENTIFIER	MOTOR MODEL	MOTOR TYPE	NO. OF PHASES	NO. OF POLES	RATED POWER (W)	RATED POWER (HP)	RATED VOLTAGE (V)	RATED CURRENT (A)	F.L. RATED SPEED (RPM)	SUPPLY FREQUENCY (Hz)
NEW	NEW	50HP	3	4	37000	50	415	62	1480	50
R.M. 1	OLD	50HP	3	4	37000	50	415	62	1480	50
R.M. 2			3	4	37000	50	415	62	1480	50
R.M. 3			3	4	37000	50	415	62	1480	50
R.M. 4			3	4	37000	50	415	62	1480	50
R.M. 5			3	4	37000	50	415	62	1480	50
R.M. 6			3	4	37000	50	415	62	1480	50

Table5.9 Measured Parameters of 50HP Rewound Motors

MOTOR IDENT.	N.L. VOLT. (V)	N.L. CURR. (A)	N.L. I/P POWER (W)	N.L. SPEED (RPM)	STILL MOTOR (°C)	RESIS. AT ROOM TEMP. (Ω)	N.L. MOTOR TEMP. (°C)	LOADED MOTOR (°C)	F.L. VOLT. (V)	F.L. CURR. (A)	F.L I/P POWER (W)	F.L. SPEED (RPM)
NEW	415	21	1290	1495	25	0.11	39	110	415	57	41000	1485
R.M. 1	415	1020.5	6601500	1495	28	0.79	43	120	415	62	41900	1485
R.M. 2	415	1022	6601690	1495	2305	0.99	47	132	415	62.5	42000	1485
R.M. 3	410	10.519	6801750	1495	29	0.83	45.5	127	415	61.5	41275	1485
R.M. 4	420	21.5	2003.5	1495	23	0.67	45	119	410	58	41050	1485
R.M. 5	415	23	1800	1490	37	0.87	43	141	415	63	43000	1480
R.M.6	410	21.5	1700	1495	38	0.91	40	130	410	63.5	44300	1485

Table5.10 (a) Calculated Parameters of 50HP Rewound Motors

MOTOR IDENT.	SYNC. SPEED (RPM)	ST. RESIST. OF N.L. RUNNING MOTOR (Ω)	ST. RESIST. OF LOADED MOTOR (Ω)	ST. CU. LOSS AT N.L. (W)	ST. CU. LOSS AT F.L. (W)	IRON AND F&W LOSSES (W)	N.L. SLIP (%)	F.L. SLIP (%)	F.L. ROTOR LOSSES (W)
NEW	1500	0.12	0.15	51.12	474.23	1238.88	0.33	1	392.87
R.M. 1	1500	0.84	1.07	350.93	4099.05	1149.07	0.33	1	366.52
R.M. 2	1500	1.05	1.37	509.9	5355.69	1180.10	0.33	1	354.64
R.M. 3	1500	0.88	1.14	318.36	4304.6	1431.64	0.33	1	355.39
R.M. 4	1500	0.73	0.92	336.12	3092.53	1667.38	0.33	1	362.9
R.M. 5	1500	0.89	1.2	470.38	4773.31	1329.62	0.67	1.33	491.96
R.M. 6	1500	0.95	1.26	439.84	5092.44	1260.16	0.33	1	379.47

Table5.10 (b) Calculated Parameters of 50HP Rewound Motors

MOTOR IDENTIFIER	STRAY LOSSES (W)	F.L. O/P POWER (W)	PERCENTAGE LOADING (%)	P.F. AT F.L.	EFFICIENCY AT F.L., η_{FL} (%)	RATED EFFICIENCY, η (%)
NEW	615	38279.03	99.46	0.99	93.36	93.9
R.M. 1	628.5	35656.87	96.37	0.94	85.1	93.9
R.M. 2	630	34479.57	93.19	0.94	82.1	93.9
R.M. 3	619.13	34564.25	93.42	0.94	83.74	93.9
R.M. 4	615.75	35311.43	95.44	0.99	86.02	93
R.M. 5	645	35760.12	96.65	0.95	83.16	93.9
R.M. 6	664.5	36903.43	99.74	0.98	83.3	93

Table5.11 Rated Parameters of 100HP Rewound Motors

MOTOR IDENT.	MOTOR MODEL	MOTOR TYPE	NO. OF PHASES	NO. OF POLES	RATED POWER (W)	RATED POWER (HP)	RATED VOLTAGE (V)	RATED CURRENT (A)	F.L. RATED SPEED (RPM)	SUPPLY FREQUENCY (Hz)
NEW	NEW	100HP	3	4	75000	100	415	122	1480	50
R.M. 1	OLD	100HP	3	4	75000	100	415	122	1480	50

Table5.12 Measured Parameters of 100HP Rewound Motors

MOTOR IDENT.	N.L. VOLT. (V)	N.L. CURR. (A)	N.L. I/P POWER (W)	N.L. SPEED (RPM)	TEMP. OF STILL MOTOR (°C)	RESIS. AT ROOM TEMP. (Ω)	TEMP. OF N.L. MOTOR (°C)	TEMP. OF LOADED MOTOR (°C)	F.L. VOLT. (V)	F.L. CURR. (A)	F.L I/P POWER (W)	F.L. SPEED (RPM)
NEW	415	81	2700	1495	35	0.03	43	120	415	110	85000	1485
R.M. 1	415	79.5	3000	1495	40	0.45	46	132	415	115	85500	1485

Table5.13 (a) Calculated Parameters of 100HP Rewound Motors

MOTOR IDENT.	SYNCHRONOUS SPEED (RPM)	STATOR RESIST. OF NO-LOAD RUNNING MOTOR (Ω)	STATOR RESIST. OF LOADED MOTOR (Ω)	STATOR CU. LOSS AT NO-LOAD (W)	STATOR CU. LOSS AT FULL-LOAD (W)	IRON AND F&W LOSSES (W)	NO-LOAD SLIP (%)	LOAD SLIP (%)	FULL-LOAD ROTOR LOSSES (W)
NEW	1500	0.03	0.04	202.67	477.28	2497.34	0.33	1	820.25
R.M. 1	1500	0.46	0.6	2906.17	7942.21	93.84	0.33	1	774.64

Table5.13 (b) Calculated Parameters of 100HP Rewound Motors

MOTOR IDENTIFIER	STRAY LOSSES (W)	FULL-LOAD O/P POWER (W)	PERCENTAGE LOADING (%)	P.F. AT FULL-LOAD	EFFICIENCY AT FULL-LOAD, η_{FL} (%)	RATED EFFICIENCY, η (%)
NEW	1275	79930.13	101.5	0.99	94.03	91.9
R.M. 1	1282.5	75406.81	100	1	88.2	91.9

Tables 5.2 to 5.13 show the practically collected parameters of the in-house rewind induction motors needed to determine the efficiency. Here we are also determining the actual efficiency of the new motor because actual efficiency of new motor differs from its manufacturer's rated efficiency. Difference may be of very low value. Now we are using these parameters to make comparisons of rewind motors with new induction motor of same rating.

After comparing the efficiencies of the rewind induction motors with that of new motors, we are estimating the payback period of the rewind induction motors to make the decision easy regarding the replacement of the rewind induction motors with the new ones.

After analyzing the rewind motors, a recommendation is made to save electrical energy. The comparisons between rewind motor and new motor of different ratings (or result) are shown below in the form of figures. These figures also include the payback period of individual analysed rewind induction motor.

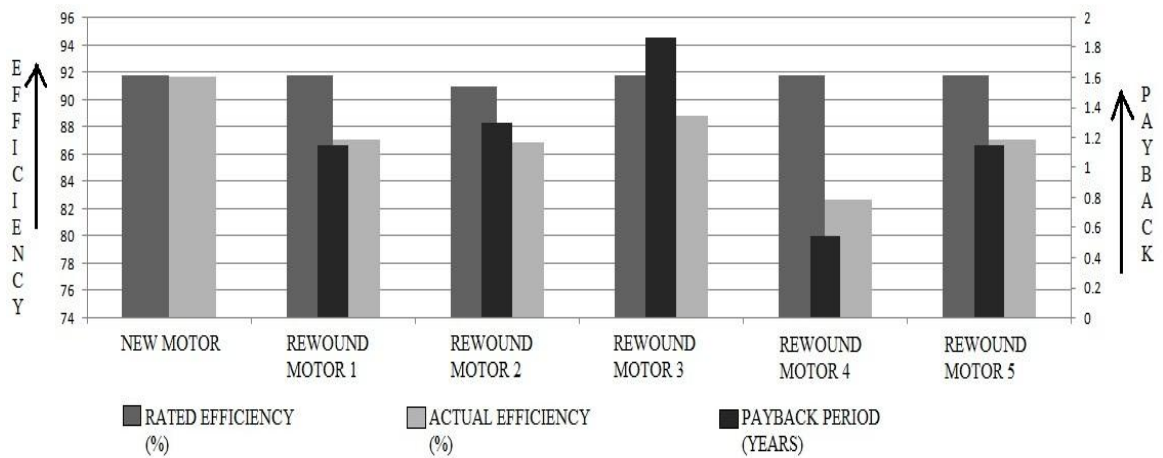


Figure 5.5 15HP Motor Analysis

Figure 5.5 shows the result of analysis done on 15HP motors. Efficiencies of five 15HP rewind motors are determined and compared with efficiency of new induction motor. Then payback periods are calculated which is resulting in very less payback period i.e. near about 2 years to 6 months. In the analysis of 15HP motors shown in the above figure, first comparison is between rated efficiency and actual efficiency of the new motor. Then are the comparisons between efficiency of the new motor and

actual efficiencies of the in-house rewind induction motors. Each comparison of the rewind motor also include its payback period in the Figure .

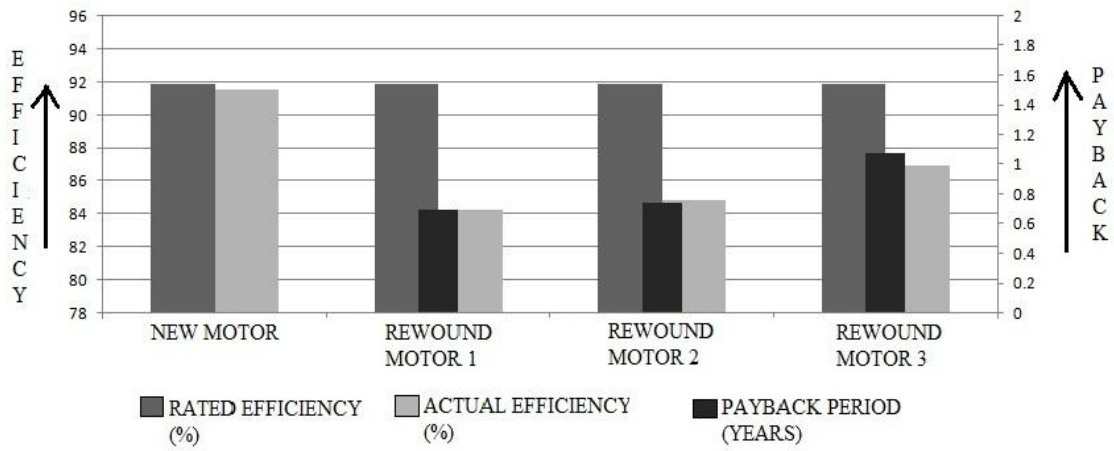


Fig5.6 20HP Motor Analysis

Figure 5.6 shows the result of analysis done on 20HP motors. This figure includes first comparison of rated and actual efficiency of the new motor, then between efficiency of the new motor and rewind motors of 20HP rating. Then payback periods are also calculated for 20HP rewind motors, which is resulting in an average of very less payback period i.e. near about 6months to 1.5 year. Similarly next figures include the comparisons in the same fashion.

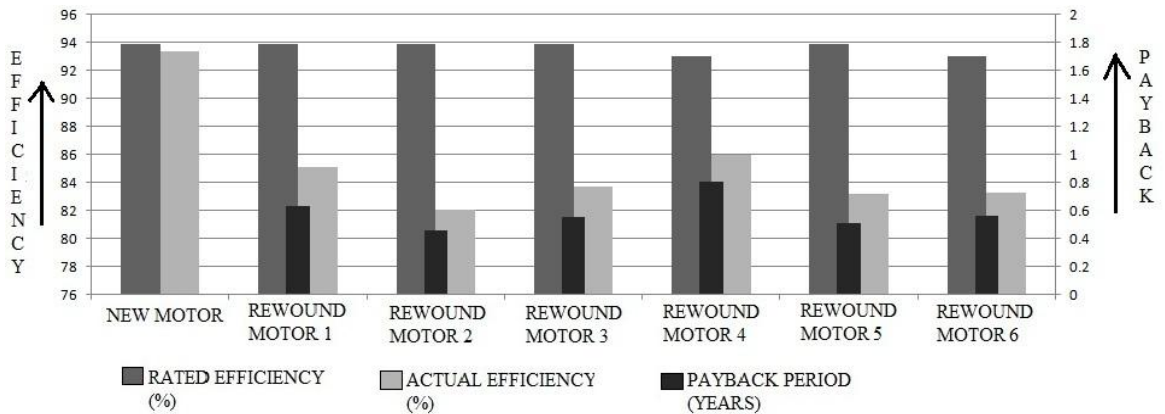


Figure 5.7 50HP Motor Analysis

Figure 5.7 shows the result of analysis done on 50hp motors. Efficiencies of six 50hp rewind motors have been calculated and after comparing them with efficiency of industrial wound induction motor, we are getting an average payback of very less period, which ranges from 6months to 9months. Comparison and payback period is shown in the Figure 5.7.

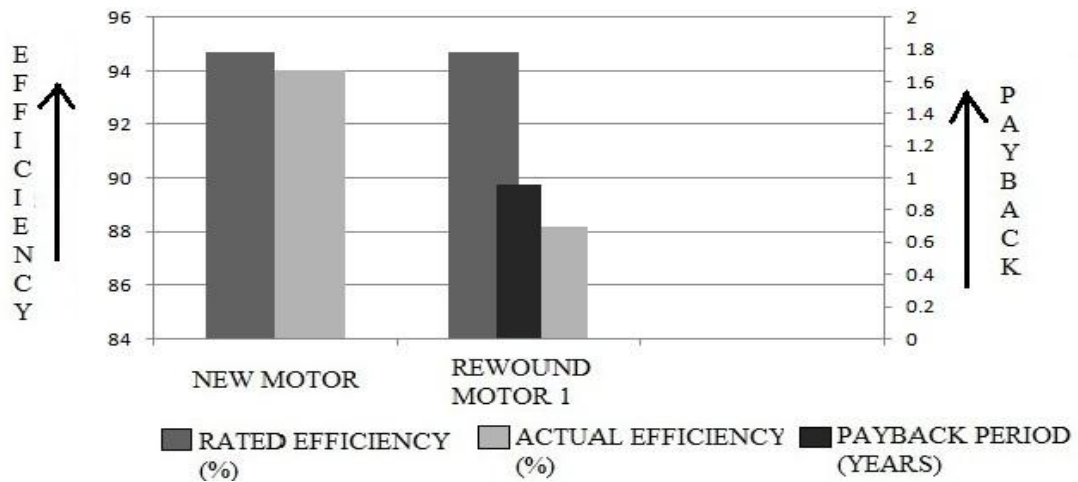


Figure 5.8 100HP Motor Analysis

Figure 5.8 shows the similar analysis done on 100hp rewind motor as done on previous rewind motors. Similarly payback period is calculated which is resulting in payback period of nearly around 9 months.

According to analysis done on the in-house rewind induction motors, it is recommended to replace these rewind induction motors with new motors.

After analysis is done, we are noticing that there is relationship between motor power and its payback period. The relationship is stating that as large as the motor is, the lower is its payback period.

Average Payback Period

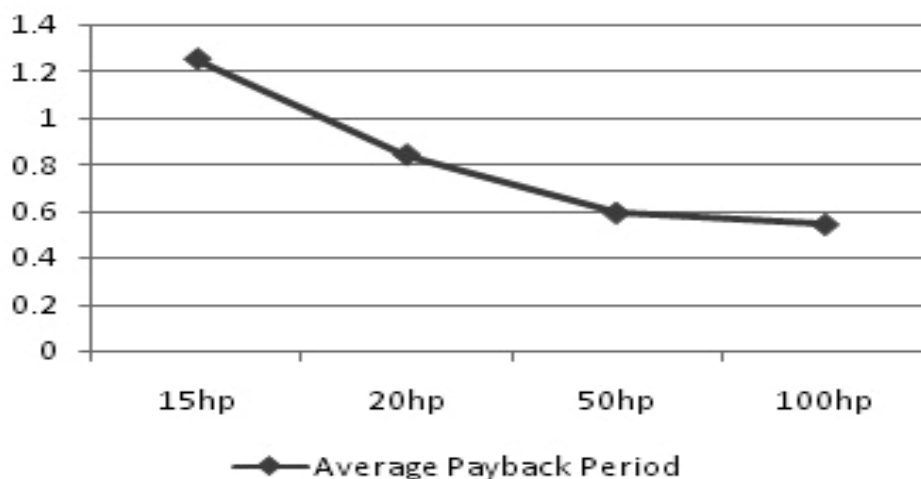


Figure 5.9 Motor Power vs. Payback Period

Figure 5.9 shows the relationship between motor power and its payback period. It can be analysed from the Figure 5.9 that payback period decreases with the decrease in the motor power. So it is highly recommended to replace the high power motor with new motors instead of repairing them.

Table 5.14 Relationship between motor power and its payback period

MOTOR HORSE POWER	AVERAGE PAYBACK PERIOD
15HP	1.25
20HP	0.84
50HP	0.59
100HP	0.54

Different induction motor powers and their corresponding payback periods are shown in table 5.14. From this table, we are also understanding the relationship between motor power and its payback period as understood by Figure 5.9.

5.8 CONCLUSIONS AND SCOPE FOR FUTURE WORK

Electrical energy is the most flexible type of energy since it can be converted to any form and can be transferred with equal ease. With every passing year the demand of electrical energy rises much higher than its supply. And therefore the only way to plug this gap is to identify the places where it can be conserved.

The preliminary study of textile plant has explored the possible energy saving areas such as in induction motors, p.f. improvement and optimised parallel loading of transformer. Analysis of some has been done to save energy. It has been seen in this study that a huge chunk of energy can be saved in replacing in-house rewind induction motors by new motors.

After doing a thorough analysis on the rewind induction motors for its efficiency, it is found that rewind motors, if replaced by new ones, have a payback period in the range of 2 years to as less as 6 months. It is therefore recommended that the rewind motors be analysed for its efficiency and if the efficiencies are found inadequate, these be replaced by the new motors.

This report reflects upon the preliminary study done on a typical textile plant with regard to conservation of electrical energy only. Scope for further study exists in doing a detailed energy audit covering not only the electrical energy but thermal and other sources of energy as well.

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PUBLICATIONS

1. Dr. Mandeep Singh and Jatin Gupta, “Electrical Energy Audit in Textile Plant: A Study,” paper accepted to be published in International Journal of Electronics Engineering.
2. Dr. Mandeep Singh and Jatin Gupta, “Efficiency of Rewound Induction Motors in a Textile Plant: An Analysis,” paper accepted to be published in International Journal of Electronics Engineering.