



**ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
ENERGY CENTER**

**ELECTRICAL ENERGY AUDIT OF WALIA STEEL  
INDUSTRY**

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**Energy Audit of Walia Steel Industry**

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**CERTIFICATION**

I, the undersigned, certify that I have read and hereby recommend for the acceptance by Addis Ababa University a thesis entitled, ‘Electrical Energy Audit of Walia Steel Industry’ in partial fulfillment of a degree of Masters of Science in Energy Technology with my approval as a university advisor.

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## **DECLARATION**

I, the undersigned, declare that this thesis is my own work, has not been presented for any degree in this or any other university, and all sources of materials used for this thesis work have been fully acknowledged .

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Signature

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## **ABSTRACT**

As the energy demands rise and the pollution levels grow, it becomes imperative to save the energy in all fields in which it is used therefore the subject of energy conservation is a big concern for industries in general and steel industries in particular where energy is intensively used but not properly managed.

And when it comes to the energy usage of Walia Steel Industry the inefficient energy usage of the factory can be seen from the average power factor value of 0.48, from its poor monthly average load factor of 31.80%, high specific energy consumptions as compared with international benchmarks, under-loaded motors, transformer, and cable losses, oversized installed capacities of distribution transformers and from the monthly average penalties for maximum demand and power factor which is of 81,564.67ETB.

Hence the purpose of this thesis is to address the energy inefficiency problems of the industry through conducting detailed energy audits of the factory and recommend energy conserving measures to alleviate the identified inefficiency reasons for the factory.

Accordingly, the energy audit of the major energy-consuming systems of the factory has been done and for the analysis of the audit historical data of energy consumption and production data of 23 months, measurement data of motors, power distribution lines data has been collected for analysis, modeling, and simulation work using motor master+ international and ETAP 16.0.0 software packages.

From the detailed audit by replacing the under loaded motors with proper sizes of motors can save 705,210.25ETB annually, and by correcting the power factor of the system and reconfiguring the network the energy loss has decreased by 69.1% and the annual cost saving of 167,690.43ETB can be gained from the avoided loss, from avoided demand charge is of 84,253.80ETB and from the avoided power factor penalty is 2,835,000.00ETB.

Finally to mitigate the energy inefficiency of the factory resizing the motors and installing power factor correctors in the power system of the factory has been recommended.

**Keywords:** Energy Audit, energy Conserving Measures, Inefficient energy usage, motor loading.

## **ACRONYMS, ABBREVIATIONS AND SYMBOLS**

ETB	Ethiopian Birr
€	Euro
ETAP	Electrical Transient Analyzer Program
GHG	Greenhouse Gas
EEU	Ethiopian Electric Utility
EEM	Energy Efficiency Measures
HP	Horse Power
IM	Induction Motors
PF	Power Factor
IEC	International Electrotechnical Commission
SF	Service Factor
NEMA	National Electrical Manufacturers Association
WSI	Walia Steel Industry
ISO	International Organization For Standardization
UAE	United Arab Emirates
RHS	Rectangular Hollow Section
SHS	Square Hollow Section
CHS	Circular Hollow Section
WAA	West Addis Ababa
GCV	Gross Calorific Value
KW	Kilowatt
MW	Megawatt
KVAR	Kilovolt Ampere Reactive
AC	Alternating Current
KVA	Kilovolt Ampere
P	Real Power
Q	Reactive Power
S	Apparent Power
KWh	Kilowatt Hour
MWh	Megawatt Hour
Kvarh	Kilovolt Ampere Reactive Hour
MJ	Mega Joule
SEC	Specific Energy Consumption
SLD	Single Line Diagram

DC	Direct Current
$N_s$	Synchronous Speed
$n$	Shaft Speed
$f$	Frequency
$p$	The Number Of Magnetic Poles
IMSSA	International Motor Selection and Savings Analysis
RPM	Revolutions Per Minute
$\emptyset$	Power Factor Angle
GUI	Graphical User Interface
HF	High Frequency
PFC	Power Factor Corrector
MWh/yr.	Mega Watt Hour Per Year
EA	Energy Auditing
KV	Kilovolt
F5	Feeder5
MW	Mega Watt
MVA	Megavolt Ampere
MVAR	Megavolt Ampere Reactive
Amp	Ampere
$P_m$	Mechanical Power
$P_i$	Input Power
$P_{ir}$	Input Power At Full-Rated Load
$I_n$	Rated Current
$P_{rated}$	Rated Power
IP	Ingress Protection
$PF_{Av}$	Average Power Factor
$P_{MAX}$	Maximum Demand Of The Month
<i>D. Charge</i>	Demand Charge
$\rho$	density
MFC	Monthly Fuel Consumption
DF	Diesel Fuel
MSP	Monthly Steel Production
MEEC	Monthly Electrical Energy Consumption
EE	Electrical Energy
REC	Real Energy Consumed
MDC	Maximum Demand Charge

PLC	Per Liter Cost
<i>MFC</i> *	Monthly Fuel Cost
<i>MEEC</i> *	Monthly Electrical Energy cost
MD	Maximum Demand
ECM	Energy Consumed Per Month
OT	Operation Time
$\eta_{dg}$	Efficiency of Diesel Generator
$m_w$	Motor Wattage
CB	Circuit Breaker

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## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1. Background**

As to the energy consumption, the industrial sector is the major commercial energy consuming sector in Ethiopia; where electrical energy is the most common and widely used type of energy and in industries energy accounts the highest share of production cost. This is, indeed, a significant cost factor accounting 15-20% of the total steel production costs therefore the subject of energy conservation is a big concern for industries in general and steel industries in particular and since industries are highly energy intensive judicious use of energy becomes imperative for developing countries like Ethiopia where power generation requires huge sum of money for project implementation of generating power plants[1].

And energy efficiency is the most cost-effective way to reduce energy consumption and industrial greenhouse gas (GHG) emissions in the short-to mid-term. Energy efficiency is also considered necessary to reduce GHG by 60–80%, which is required to stabilize climate change[2]. Hence, focusing on energy efficiency is not only good for the environment but also profitable for industries; as it increases competitiveness and productivity. Thus, energy audits assist industrial companies or facilities in understanding how they use energy and help to identify the areas where waste occurs and where opportunities for improvement exist[3].

It is also known that electrical motors account to consume more than 71% of the global total electric power produced[4]. Thus, ever-increasing imbalance of energy supply, energy demand and energy intensiveness of industries is driving towards energy audit and energy management[5]. Thus, the increasing in energy supply and demand imbalance is urging countries to focus on energy audit and energy management. It is also becoming hot topic for researchers around the world, though there is little or almost no attention to energy audit and energy management in Ethiopia.

Having said this all on energy demand, supply gap and energy efficiency problems in industries in general and Walia Steel Industry(WSI) in particular this paper will be focusing on energy audit of WSI where source of energy for steel production is both electricity from the national grid and diesel fuel. But the share of energy from electricity is by far higher than the diesel. Thus, as per the per unit energy usage, further analysis using measured data and

analysis software energy efficiency opportunities that can improve the energy management and economic benefits by implementing some energy saving measures on the industry are identified[6].

This paper tried to show the benefits of energy efficiency improvement in WSI are beyond cost-saving that is it also increases productivity, competitiveness and can merit the investment in many cases.

Thus, the objective of this paper is to perform energy audit for WSI and identify energy conserving measures to be implemented in the industry and increase the overall energy efficiency of the industry in general and of the electrical motors in particular by proper sizing of the motors as per the actual loads on it and by improving the power factor value of the industry from 0.48 to 0.9 through incorporating power factor corrector capacitor banks in the system to reduce the reactive component of the power drawn by the electrical motors there by improve the distribution line losses, transformer losses and motor losses of the industry.

### **1.2. Problem Statement**

As a result of expansion of industries in Ethiopia, the electric energy demand is growing high and the government is currently trying to meet the demand through constructing power generation plants. Nevertheless, almost no or little attention is given to the energy management and it is known that constructing generation plants alone cannot mitigate the energy demand of the country.

Thus, energy should be managed, efficiently used and demand side management should be given a due attention to alleviate the currently existing power supply reliability issues and meet the demand and supply gap of the country there by increases the competitiveness and profitability of industries.

As industries are the most energy intensive sector, energy auditing on industries can be a starting measure and crucial means of energy management for better industrial energy efficiency.

It is known that inefficient energy usage is common in industries and the inefficiency greatly affects the environmental pollution, production cost, the profitability and competitiveness of industries; and this can demerit investment.

In industries in general steel industries in particular, significant portion of energy is wasted because of inefficient usage of energy thus conducting energy audit to identify the reasons of

inefficiency and recommend possible energy conserving measures to be implemented is mandatory. When it comes to WSI, the poor averaged power factor value, load factor value and the monthly penalty paid to EEU are the good indications for inefficient energy usage of the factory.

Hence, this thesis evaluates the energy performance of WSI, identify reason of inefficiency and recommend possible energy conserving measures to be taken or to be implemented by the industry.

### **1.3. Objectives**

#### **General objective**

The main objective of this thesis is to perform energy audit for WSI, identify the potential energy efficiency opportunities and recommend the possible energy conserving measures to be taken.

#### **Specific objectives**

The specific objectives of this thesis are:-

- I. To identify energy consuming equipments in the factory.
- II. To identify the types of energy sources used in the factory
- III. To identify where energy is inefficiently used/consumed
- IV. To identify the reasons of energy inefficiency in the industry
- V. To identify the possible energy conserving measures to be taken and perform technical and economic feasibility analysis on the selected energy conserving measures to be taken.

### **1.4. Limitation of the study**

This study has the following limitations:

- Has not incorporated lighting system of the factory in the detailed energy auditing work.
- Has excluded motors whose wattage is less than 5KW in the conducted measurement and in the detail energy performance analysis for their wattage is follows: 16 are in the range of  $0.18 \geq m_w \leq 0.75$ , 53 are between  $1.1 \geq m_w \leq 3.5$  and 11 are  $4 \geq m_w \leq 4.5$  Kw wattages.

- In designing the Power Factor Corrector (PFC) the total harmonic distortion content of the power system of the factory is not analyzed.
- The measurements made are transient in nature and yearly operation hours data of the motors used for the analysis purpose are averaged values which were taken from the production manager's office of the factory.

### **1.5. Significance of the Study**

Energy audits assist industrial companies on how energy was being used, helps to identify the areas where energy waste occurs and where opportunities for improvement exist[7]. In a country where professional consultancy and knowledge are not valued, only initial cost of a product or service is aimed to be least priced and life cycle cost is overlooked conducting energy auditing is mandatory. And besides where procurements have no professional advices and involvement and where there is poor regulatory body in the country it is inevitable that there will be inefficient energy usage across the country in general and in industries in particular where the usage is more intensive.

In industries like WSI, where energy is poorly managed this study can serve as an eye-opener for the owner, the management, all staffs and other concerned stakeholders to see seriously for the options available for mitigating energy wastage, cost saving benefits and other beyond cost saving benefits that can be achieved through implementing the identified energy conserving opportunities.

### **1.6. Scope of the study**

This study focused on collecting historical energy and production data and took measurements on the electrical motors to conduct the detail energy audit of the factory. In this thesis work, the first step was to investigate and get a clue for the existence of energy inefficiency through the preliminary audit work using historical energy and production data. Then conducting the detail energy to identify inefficiency reasons and quantify the losses thereby identifies the saving potentials. To evaluate the energy performance of the motors for proper sizing of the motors and identify the saving potential, both in terms of energy and cost were analyzed using MotorMaster+International software package.

Meanwhile, to investigate the losses found in the distribution power cables and the transformers of the existing power distribution system of the factory Electrical Transient Analyzer Program (ETAP) software was used and then investigating the saving potentials of the system after PFC has been incorporated in the designed and reconfigured power distribution system of the factory as per designed values for each power supplying lines were done using ETAP.

Finally, the outputs from preliminary audit work, MotorMaster+International and ETAP software packages were analyzed, discussed and the findings were used as inputs for the conclusions and recommendations of the thesis work for the betterment of the energy performance of the factory.

### **1.7. Methodology**

The necessary data that helps to carry out the research work has been collected through the following methodologies, so that both quantifying and qualifying the energy wasted in the factory could be possible.

#### **Literature Review**

Literature review on previously conducted energy audit works of industries, on steel industries in general and more specifically on rolling and forming steel industries has been made. Moreover, reviews on typical industrial detailed energy audit format of reporting, manuals and guidelines on energy efficiency, benchmarking reports on steel sector has been made.

#### **Energy Audit Procedures**

The audit procedures followed in conducting this thesis are as follows:

- Define the scope and plan of the audit.
- Prepare check list.
- Factory visit/ initial walk-through visit.
- Understand the manufacturing process and layout of the machines
- Prepare manufacturing process flow diagram and machine layouts.
- Collect historical energy and production data.
- Perform preliminary analysis, as per the data collected.

- Analysis on the energy usage pattern of the factory and do the comparative analysis and benchmarking.
- Name plate data collection and measurements on the electrical motors
- Perform the analysis using ETAP 16.0.0 and MotorMaster + international software packages
- Identify energy efficiency potentials from the analysis
- Perform the cost benefit analysis
- Write the audit report with the possible energy conserving potential recommendations

### **Energy Audit Instruments**

For the electrical parameter measurement, handheld power meter (watt meter) was used to measure input power of the electrical motors and handheld infrared tachometer was used to measure the shaft speed of the electrical motors.

## **1.8. Organization of the thesis**

This thesis is organized in seven chapters and the content of each chapter is presented as follows:

**Chapter 1:** Depicts about the general introduction of the thesis, the need to conduct the thesis, statement of the problem, objectives of the thesis, limitation, significance of the study and the methodology used.

**Chapter 2:** Describes about a review of different literatures from general to specific for conducting the audit work.

**Chapter 3:** Deals about factory overview, manufacturing processes, flow diagram and machine layouts.

**Chapter 4:** Presents about the preliminary energy audit of the factory which includes analysis of the historical energy and production data then comparison with international bench marks of similar industries which are having similar products and production processes.

**Chapter 5:** Presents about energy audit of electric motors in the factory by doing motor loading and evaluate the energy performance of the motors using MotorMaster+International analysis software package and the energy conserving opportunities are also presented here.

**Chapter 6:** Deals about systemic load flow analysis and optimum placement of power factor corrector by quantifying the systemic energy loss of the factory and the corrective measures that shall be taken to mitigate the losses are also analyzed using ETAP software and presented. And besides the technical and economic feasibility of the identified energy conservation opportunities are summarized.

**Chapter 7:** Describes about the conclusions and recommendations of the research as per findings of the thesis. Finally, the references and appendices that has been used for this thesis work are presented at the end of the thesis.

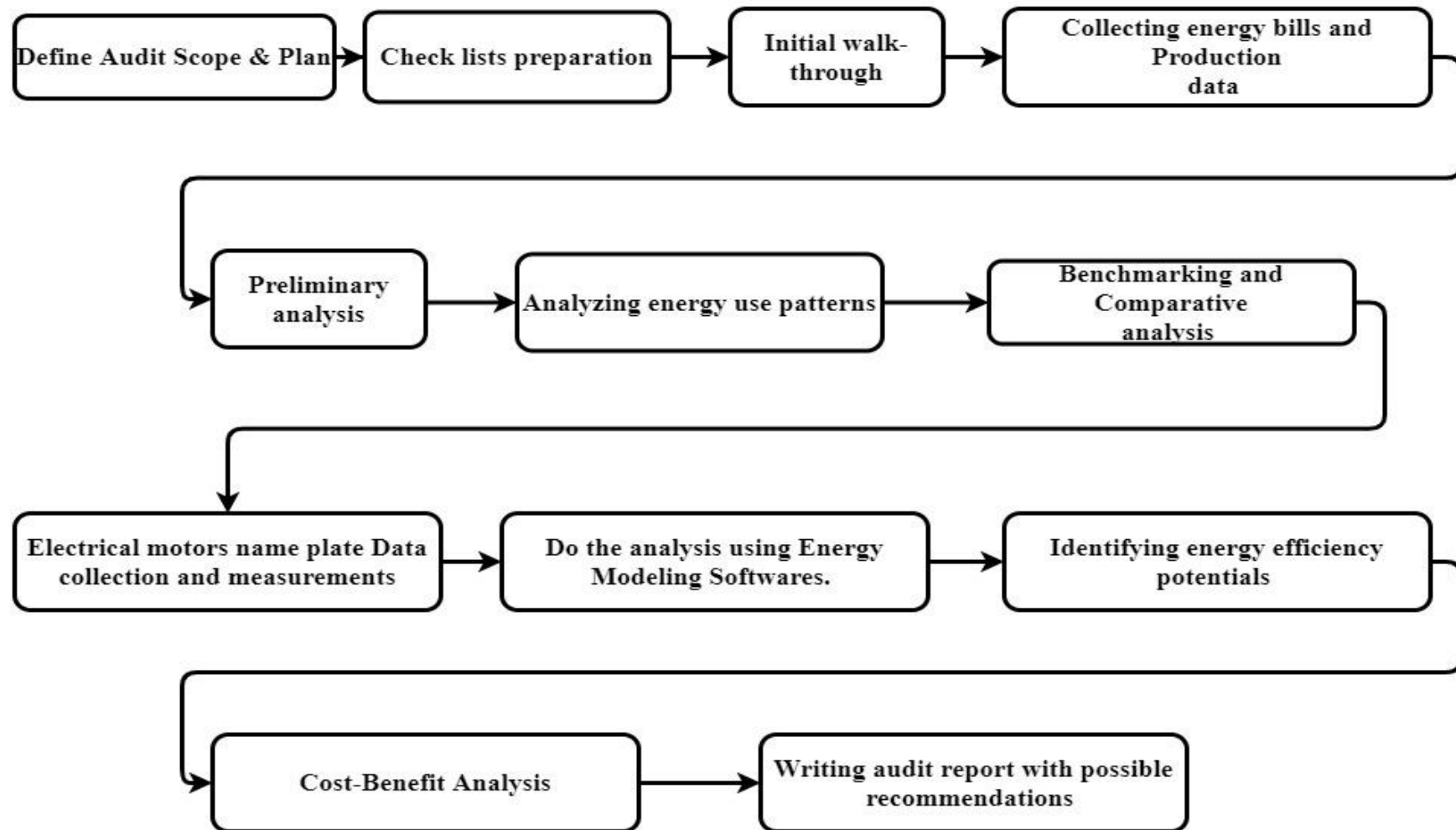


Figure 1-1 : Overview of the energy audit methodology used for WSI

## **CHAPTER TWO**

### **LITERATURE REVIEW**

To address the energy inefficiency problems of industries, researchers have tried different approaches to identify where the inefficiency is; so that they can recommend possible Energy Conservations (ECONs) to save energy or increase efficiency, save energy cost, increase both productivity and competitiveness thereby merit investment by improving the energy management of industries. And the following are literatures reviewed for this thesis of energy auditing work.

O.A.Oyelaran *et al* (2016) have demonstrated on their paper that energy is one of the major inputs for the economic development of any country.

In case of developing countries, the energy sector assumes a critical importance in view of the ever-increasing energy needs which requires huge investment. A management to achieve and maintain optimum energy procurement and utilization throughout the organization which minimizes energy costs and wastage without affecting production and quality is utmost important. Thus, for a systematic approach for decision-making in the area of energy management; conducting energy audit to determine energy wastage/losses, provide techniques and ways to minimize the losses is inevitable.

O.A.Oyelaran *et al* (2016) have also highlighted on their paper that energy is one of the largest controllable costs in most organizations (especially manufacturing and processing industries) and there is considerable scope for reducing energy consumption and cost. The benefits are also reflected directly in an organization's profitability while also making a contribution to global environmental improvement in terms of energy conservation.

Meanwhile, O.A.Oyelaran *et al* (2016) have also presented in their article that the concept of energy auditing was born shortly after the oil energy crisis in the early 1970s. Since there were many inefficient uses of energy, an auditor had a relatively easy job in identifying opportunities for saving energy. Over the years, facility management became more energy conscious and as a result, energy efficiency of industrial processes increased dramatically and energy audit concept is a measure of energy utilization efficiency in a manufacturing process that leads to interest in energy performance of machines and plants directly associated with production process[8].

Sunday Olayinka *et al* (2013) defined energy audit as the verification, monitoring and analysis of energy use including submission of technical report containing recommendations for improving energy efficiency with cost analysis and an action plan to reduce consumption.

The authors have demonstrated that energy audit is the fundamental and most significant step for implementation of any effective energy management program. It tries to answer how, where and how much energy is used in a system and recommends ways and means of eliminating losses and improving the efficiency of the system. The immediate advantages obtained through energy audit are improved maintainability, reliability features coupled with reduction losses. Long term energy saving can be through the use of energy efficient equipment.

Detailed energy audit, on the other hand, is a comprehensive audit which provides a detailed energy project implementation since it evaluates all major energy using systems. It is an accurate method for energy saving and audit. In this audit, three-phases are involved; pre audit phase, audit phase and post audit phase and the objective of energy audit is to promote the idea of energy conservation in the company.

The work eligible for energy audit study should be directed towards the following:

- Identifying the areas of energy wastage
- Estimating of energy saving potential in the company facilities and
- Suggesting cost-effective measures that will improve the efficiency of energy use, estimating the costs and payback period.

The increasing role of energy efficiency as a catalyst for sustainable industrial development is realism in the industrialized countries of the world. The whole purpose of energy efficiency is to minimize the amount of energy used to get a desired effect[9].

T. B. Patel and K. D. Panchal (2015) have highlighted that an audit encourages a detailed study of how facility uses energy, what the facility pays for that and finally recommending various Energy Efficiency Measures (EEM) that will save huge amount of money in bills and it also includes the identification of areas of energy wastage and estimation of energy saving potential. As per this article, the purpose of energy auditing is to recommend steps to be taken for improving the energy efficiency, reduce energy cost and saving the money on the energy bills. Besides, this paper highlights the efficient use of available energy requirement

per unit of output and audit is the only feasible way to handle energy crisis apart from capacity addition

T. B. Patel and K. D. Panchal (2015) have also put in their article that various studies in different countries have shown significant energy-efficiency improvement opportunities exist in the industrial sector. Many of which are cost-effective and these energy-efficiency options include both cross-cutting as well as sector-specific measures.

In this paper, it is concluded that energy audit is an effective tool in identifying and perusing a comprehensive energy management program. A careful audit of any type will give the industry a plan with which it can effectively manage the industrial energy system at minimum energy cost and is useful for an industry in combating essential energy cost and also raps several other benefits like improved production, better quality, higher profit and most important satisfaction of heading towards contributing in world energy saving [10].

Munguia *et al* (2020) have stated the significance of energy audit that is the first step of any energy management programs and it is also an activity that serves the purposes of assessing energy use pattern of a factory or energy consuming equipment and identifying energy saving opportunities thus energy audit identifies and in detail quantifies effective possibilities of energy savings tailored to the object being analyzed. Besides, Munguia *et al* (2020) presented in this paper that it is a preliminary activity towards instituting energy efficiency programs in an establishment and consists of activities that seek to identify conservation opportunities preliminary to the development of an energy savings program.

Meanwhile, they have also put the role of an energy audit as follows:

- I. To identify where energy is being consumed and assesses energy saving opportunities
- II. To minimize costs for energy
- III. To minimize operational costs
- IV. To minimize costs for repairs and reconstruction
- V. To increase quality of environment that contributes to increase work productivity
- VI. To increases awareness of energy issues among plant personnel, to make them more knowledgeable about proper practices that will make them more productive and
- VII. In the factory, doing an energy audit in effect gauges the energy efficiency of a plant against “best practices”. When used as a “baseline” for tracking yearly progress against

targets. Therefore, energy audit becomes the best first step towards saving money in the production plant[11].

R. Uriarte-Romero *et al* (2017) have also highlighted the contents of an energy audit as follows :

I. Important points to consider when collecting site load data are:

Operating hours - This can be gathered from plant personnel and is important to ensure the accuracy of this data because much of the potential for energy savings lies on correct estimation of the equipment's operating hours. Duty cycle –machines, such as large electric motors have varying loads and hence, different power requirements. Actual power consumed for electric power users is based on either three-phase current/voltage readings or power analyzer measurements; like direct kW which incorporates power factor.

II. Analysis of energy use

To identify where energy is being used and areas where the audit should focus on to raise awareness on energy usage and its cost implication. This is done by listing all energy consuming equipment used and the corresponding operating hours. Hence, spreadsheet and charts information which are useful for analysis are generated based on the above information.

III. Identification of energy projects

Opportunities for energy savings can range from the simplest, such as lighting retrofits, to the most complex such as the installation of a cogeneration plant. The important thing to remember is to focus on major energy users and areas. Applying the 80/20 rule, focuses on opportunities that provide 80% of the saving but require 20% input. And after the preliminary identification of opportunities, spend more time on those which have shorter payback periods.

IV. Cost benefit analysis

The identified energy conservation opportunities should be analyzed in terms of the costs of implementing the project versus the benefits that can be gained. If installation of heat plate exchanger to recover waste heat is wanted, calculating the total cost of installation and comparing with the savings which will be derived from recovered waste heat is needed. This makes sense to go on with the project if there is a net positive benefit from the project.

#### V. Action plan to set implementation priority

After passing the cost benefit test, an action plan should be developed to ensure that the opportunities identified are implemented [2].

Zachariadis *et al* (2018) presents ways of how a list of cost-effective energy conservation measures can be determined using both energy savings and economic analysis and the tasks to be performed as follows:

- Prepare a comprehensive list of energy conservation measures using the information collected.
- Determine the energy savings due to the various energy conservation measures pertinent to the plant using the baseline energy use
- Based on the evaluation of the energy use pattern of the industry, several energy conservation opportunities for the industry shall be analyzed.
- Estimate the initial costs required to implement the energy conservation measures.
- Evaluate the cost-effectiveness of each energy conservation measure using an economic analysis method like simple payback or life-cycle cost analysis.
- Among the ECONs considered in the study, identify from the list of them which can bring significant and successful reduction in energy consumption of the industry

Zachariadis *et al* (2018) have also demonstrated further that in most applications initial investments are required to implement energy conservation measures. Thus, initial costs generally must be justified in terms of a reduction in the operating costs due to energy cost savings. The article has also highlighted for an energy retrofit project to be economically worth and the initial expenses have to be lower than the sum of savings obtained by the reduction in the operating costs over the lifetime of the project. To compare the various cash flows over the lifetime of a project, a life-cycle cost analysis is typically used but the parameters and the concepts that significantly affect the economic decision making shall be considered which include:

- The time value of money and interest rates including simple and compounded interest
- Inflation rate and composite interest rate
- Taxes including sales, local, state, and federal tax charges
- Depreciation rate and salvage value[12].

G. S. Grewal and B. S. Rajpurohit(2016) have presented in their article that electric motors in various countries account to consume more than 71% of the total electric power produced and the ever-increasing imbalance of energy supply and demand is driving towards energy audit and energy management. In this article, it also demonstrated that in the industrial sector; steel rolling mills are the major absorbers of electrical power thus incremental rise in efficiency of installed induction motors results in great savings.

PF can be observed as useful parameter of non-useful energy drawn from supply reactive volt–amperes rather than watts. Hence, lesser power factor means more non useful energy drawn.

Meanwhile, they have also demonstrated that mills with poor power factor draws greater currents which results in overloading the equipment at times of full load and also, operation at poor power factor results in higher penalties from public utility.

Machines are designed for maximum efficiency at rated loads. As load factor decreases, efficiency declines and this results in reduction of power factor. Partially loaded motors of higher Horse Power (HP) ratings can be replaced by induction motors of suitable ratings to achieve correct amount of power for each portion of duty cycle. For voltage drop of 6%, running torque and starting torque decreases by 11% and results in full load current by more than 5% of its rated value. With the rise in voltage drop, there is an increase of temperature in the windings. Besides, without keeping voltage rise to its limits; machine windings may burn out. Voltage variation in any of the phases of machine causes varying currents in the machine winding. Therefore, this increases the losses by inappropriate margin which has to be avoided by all means.

Induction motors are the largest harmonic producing load on the plant's electrical system and problems develop when nonlinear loads vary over a wide range. They cause sudden inrush of currents causing greater harmonics and unwanted tripping of higher horse power Induction Motors( IMs) takes place and due to heavy inrush of current on sudden rise of load urges to draw maximum power suddenly from electric utility [1].

A. Aderibigbe *et al* (2017) present in their article that electric motors in industries contribute a major percentage of electrical loads, and by implication, a major portion of the generated electrical energy is consumed by electric motors. It is, therefore, vital to ensure that these motors operate with negligible energy loss. In operational environment, many factors can be

responsible for a reduction in motor performance. One of the major factors is a regime of voltage unbalance that affects the motor, the load and supply network. This paper has established the risk of unbalance voltage conditions on the performance of three-phase induction motors. Voltage unbalance is an undesirable operational condition that should be proactively monitored and mitigated using appropriate methods such as motor de-rating, line load inspection, and line voltage unbalance detection devices. Globally, a reduction in energy wastage as a result of voltage unbalance related issues; particularly in industries will help save several millions of dollars spent yearly on unproductive energy dissipation predominantly as heat. This results in expedient energy conservation and increase in operational efficiency and effectiveness.

A. Aderibigbe *et al* (2017) have highlighted that motor-driven systems use more than 66% of the total electrical energy consumption of industries, and this makes electric motor a major support for industrial operations. To guarantee that energy is efficiently utilized by these motors, it is vital to ensure that all form of losses are identified and at least reduced if not completely eliminated and it has been established that there are energy losses associated with voltage unbalance.

Meanwhile, this article has also demonstrated the common attendant consequences of unbalance voltage includes decline in motor efficiency, early motor failure due to excess heat and de-rating of poly-phase induction motors[13].

P. Hayamin (2018) presents the effect of voltage unbalance on temperature, performance, efficiency and life time of the motors based on the results and analysis from functional test found an increasing of motor temperature which operated under imbalanced voltage as well as decreased of its performance and the continued operation of electric motor in such conditions caused the deteriorated insulation and short circuit in tested motor.

P. Hayamin (2018) highlights that imbalanced voltage can directly affects the machine, conveyor system or tools that were operated under three-phase unbalanced voltages as well as affect to entire electric system of whole plant for example an imbalanced electrical power from increased current flow in electric wire and these effects also affect to efficiency, performance and shorten life time of three-phase motors as well as machine have to stop operating for fixing, maintenance or replacing damaged motor[14].

R. A. Shnibha and A. S. Albarabar (2012) presented a method of determining the operating PF of the induction motors using only the measured current and the manufacturer data that are typically available from the nameplate and/or data sheet for IM monitoring. Therefore, it is very important to clarify the effect of voltage variation in the supply voltage on the characteristics of the IM. The unbalance voltage is caused by asymmetrical transformer windings or transmission impedances, unbalanced loads, or large single phase loads. Voltage unbalance exists in almost all three-phase power system networks and the level of unbalance is considerably large in weak power systems and those supplying large single phase loads.

As unbalance in the voltage source can cause excessive losses, heating, noise, vibration, torsional pulsations, slip, and motor accelerating torque detecting an unbalance of even a few percentage in the voltage supply is important.

Traditionally, to monitor the operating Power Factor (PF) of the IM, one would require both the voltage and the current measurements, and then apply the displacement method. However, that would require both voltage and current sensors but the PF can be determined from only the measured current and manufacturer's data and this method requires no voltage measurement and so can provide a low-cost solution [15].

A.Goyal (2015) demonstrates efficiency of motors in industrial terms that efficiency is the ratio of shaft output power to the input power. It represents the success of machine in converting electrical power to mechanical power and this can be expressed by the following equation:

$$Efficiency = \frac{P_m}{P_m + \sum Losses} \quad (2.1)$$

The difference between the electrical (input) and mechanical (output) power is the sum of motor losses and these losses are directly related with the heat generated inside the motor and winding resistance is directly related to the motor's temperature and it is proved that with increase in temperature due to heat and losses, the efficiency of motor degrades. When the stator and core temperature of three-phase induction motor is increased, stator resistance also increases as a result of which efficiency decreases. So, it is required to maintain the stator temperature by adopting cooling method in order to improve the efficiency.

A.Goyal(2015) also highlights mechanisms of heat generation inside an induction motor as a result of electrical and mechanical losses inside the machines, all rotating electrical machines

dissipate heat. Losses are higher during the process of starting of motor, dynamic braking and increase with loading. The mechanism of heat generation in induction motors are classified into four groups, mainly related to the places where losses occur. These are joule losses, iron losses, stray losses and mechanical losses which corresponds to the conversion of electrical energy into thermal energy, the conversion of electric energy into thermal energy in the iron, the skin effect, high frequency among others that are unknown or not easily quantified and the conversion of the mechanical energy into thermal energy due to mechanical friction respectively[16].

World Energy Group(WEG) (2016) demonstrates that the insulation materials and insulation systems determines its useful lifetime of the motor and depends almost exclusively on the life of the winding insulation. However, the lifetime of a motor is affected by many factors, such as moisture, vibration, corrosive environments and others. Among all these factors, the most important is the working temperature of the employed insulation materials. An increase from 8 to 10 degrees above the rated temperature class of the insulation system can reduce the motor lifetime by half. When speaking about decreasing the useful lifetime of the motor, we are not talking about high temperatures where the insulation system burns and the winding is suddenly destroyed. For the insulation lifetime this means a gradual ageing of the insulation material which becomes dry, losing its insulation properties until it cannot withstand the applied voltage. This result in a breakdown of the insulation system and a consequent short-circuit of the windings. Experience shows that the insulation system has practically an unlimited lifetime if the temperature is kept below a certain limit if this temperature limit is exceeded, the insulation lifetime will shorten as the temperature increases. This temperature limit is well below the “burning” temperature of the insulation system and depends on the type of used insulation material. This temperature limit refers to the hottest spot in the insulation system, but not necessarily to the whole winding. A weak point in the inner part of the windings will be enough to destroy the insulation system.

WEG has highlighted insulation class impact on temperature rise withstand and life time of an electrical motor. As previously mentioned the temperature limit depends on the type of used material. In order to comply with the standards the insulation material and insulation systems (each one formed by a combination of several materials) are grouped in insulation classes. Each one is defined by the particular temperature limit, i.e. by the highest

temperature that the insulation material or system can withstand continuously without affecting its useful life. The insulation classes used for electrical machines and their respective temperature limits are in accordance with International Electrotechnical Commission (IEC) 60034-1 are as follows: class A (105 °C), class E (120°C), class B (130°C), class F (155 °C) and class H (180 °C).

Moreover, WEG has dealt with electric motor application with regard to the temperature rise limit for different insulation classes of motors that the hottest spot temperature in the winding should be maintained below the maximum allowed temperature for the insulation class and the total temperature is the sum of the ambient temperature, plus temperature rise ( $\Delta T$ ), plus the difference existing between the average winding temperature and the hottest spot. Motor standards specify the maximum temperature rise  $\Delta t$ , so the temperature of the hottest spot remains within the allowable limit based on the following considerations:

- a) Ambient temperature should not exceed 40 °C, as per the standard. Above this value, working conditions are considered as special operating conditions.
- b) The difference between the average temperature of the winding and the hottest spot does not vary very much from motor to motor and its value specified by standard, is 5 °C for classes A and E, 10 °C for class B and F and 15 °C for class H. Therefore, motor standards specify a maximum allowed ambient temperature, as well as a maximum allowed temperature rise for each insulation class. Thus, the temperature of the hottest spot is indirectly limited. The figures and the allowable temperature composition for the hottest spot are shown in Table 2-1 below.

Table 2-1 Temperature composition as function of the insulation class[17]

Insulation Class		A	E	B	F	H
Ambient temperature	°C	40	40	40	40	40
$\Delta T = \text{temperature rise}$ ( <i>resistance method</i> )	°C	60	75	80	105	125
Difference between the hottest spot and average temp	°C	5	5	10	10	15

Total: temperature of the hottest spot	°C	105	120	130	155	180
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Besides, in this WEG electrical specification for electrical motors thermal protection of electric motors is highlighted as follows:

- The motors used for continuous duty must be protected against overloads by a device integrated to the motor,
- An independent device, usually fitted with a thermal relay having rated or setting current equal to or below the value obtained by multiplying the rated motor power supply current ( $I_n$ ) by the Service Factor (SF), as shown in Table 2-2 below[17].

Table 2-2 Power supply current x Service Factor[17]

Motor Service Factor(SF)	Relay current setting
1.0 to 1.15	$I_n \cdot SF$
$\geq 1.15$	$(I_n \cdot SF) - 5\%$

US Department of Energy (2012) has set a method/formula for quantifying the temperature rise because of unbalanced voltage on electrical motors and described through examples that a motor will run hotter when operating on a power supply with voltage unbalance. The additional temperature increase is estimated with the following equation:

$$Total\ Temperature\ Rise = \frac{Balanced\ Temperature\ Rise \times (1 + 2(\%Voltage\ Unbalance)^2)}{100} \quad (2.2)$$

A motor with an 80°C temperature rise caused by resistance would experience a temperature increase of 6.4°C when operated under conditions of 2% voltage unbalance and winding insulation life is reduced by one-half for each 10°C increase in operating temperature[18]

M. S. H. Lipu (2013) also highlights that during unbalanced voltage supply to electrical motors although generally not desirable, another corrective action may be to de-rate a motor. When voltage unbalance exceeds 1%, a motor must be de-rated for it to operate successfully. The de-rating curve, shown below, indicates that at the 5% limit established by NEMA for unbalance, a motor would be substantially de-rated, to only about 75% of its nameplate horsepower rating[19].

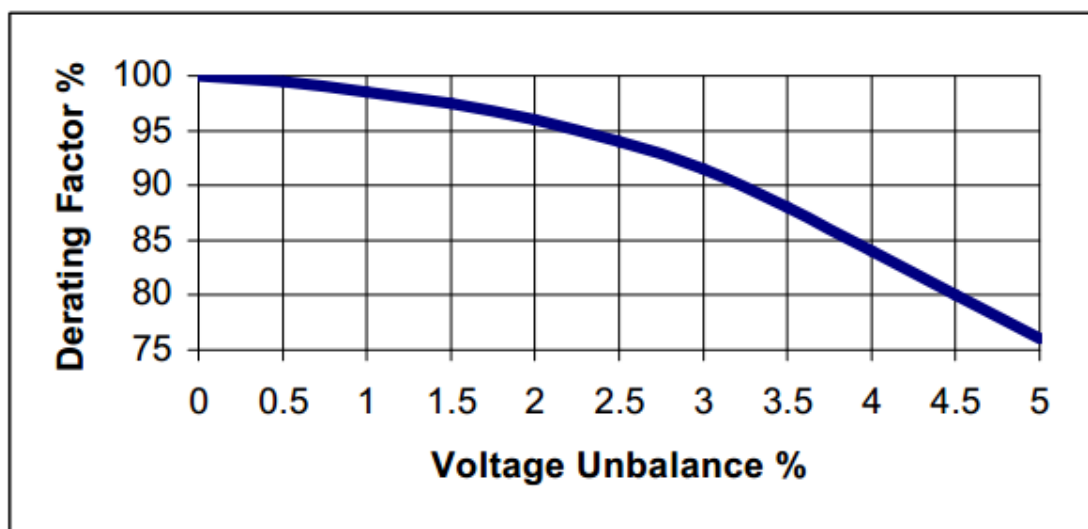


Figure 2-1 Voltage unbalance versus derating Factor[19]

O. A. Oyelaran *et al* (2016) have shown in their article the inefficiency causes in the food processing industry and distillation & bottling company, where they conducted energy auditing and have forwarded the following recommendations:

1. To maintain a high power factor all over sized motors must be replaced by properly sized and energy efficient motors and additional capacitor bank should be connected across the load
2. Optimum use of natural light has to be used in combination with electric lighting and the maximum use of sunlight can be get by means of transparent roof sheets and besides have recommended replacing incandescent lamps by Compact Fluorescent Lamps (CFL's), conventional fluorescent lamp by energy efficient fluorescent lamp and replacement of conventional ballast by electronic ballast to improve the efficiency in the lighting system of the industries[8].

## **CHAPTER THREE**

### **FACTORY OVERVIEW, MANUFACTURING PROCESSES, FLOW DIAGRAM AND MACHINE LAYOUTS**

#### **3.1. Factory Overview**

WSI is a private limited company established in 2006 at Alemgena town of the Oromia regional state, which is 20km away from Addis Ababa. It was established with an initial capital of Birr200, 000,000 (Two Hundred Million Birr) and, in the years to follow, has increased its capital. The company was established with the objective of manufacturing and marketing of steel products. Additionally, the industry is built on a total land area of 53,000 square meters [m<sup>2</sup>]. WSI was established with the view of alleviating the acute shortage of construction materials in Ethiopia and to support the national endeavor of achieving the economic development by contributing in the harnessing of social problems through job creation to citizens. When WSI was established, it was the first private Steel industry at that time. Being one of the steel industries in the country and having demonstrated impressively a swift growth, WSI has rapidly reshaped Ethiopia's Steel sector and taken initiatives that will expand its operation to the wider African market. It is customer's comfort, confidence and peace of mind to bring to their attention that WSI has been certified with the ISO 9001:2015 by an international certifying company which endorses its seal of approval for operation and product quality and reliability.



Figure 3-1 Part of Walia Steel Factory



Figure 3-2 Raw Materials and products of Walia Steel Industry

### **3.1.1. Raw Materials**

WSI imports raw materials (steel coils) from Ukraine, China, India, Russia, Taiwan, United Arab Emirates (UAE) and other countries. The raw materials imported by WSI include cold rolled, hot rolled, galvanized and color coated steel sheets. The total raw material required exceeds 800,000MT per annum.

### **3.1.2. Production**

The Company is currently one of the major suppliers of steel products to the domestic market, with a dominant market share. WSI's product offerings can be classified into three major product categories:

- Hollow section products,
- LTZ profiles, and
- Cut-to-length sheet metals

The products range also includes rectangular square and hollow sections, LTZ profiles and sheet

metals. WSI began its operation in the production of steel reinforcement bars and, in the years to follow, expanded its operation by investing in steel pipe making technologies and producing rectangular square and circular hollow sections, LTZ profiles and sheet metals of various size and thickness.

### **3.1.3. Facilities**

WSI has well equipped facilities across a total land area of 53,000 m<sup>2</sup> which makes the regular

loading and unloading processes extremely convenient and which creates easy movement of heavy duty trucks and machinery.

### **3.1.4. Marketing and Sales**

WSI has always placed greater emphasis on providing an effective and efficient sales and distribution network that cater to the changing needs of the market for its products and services all over the country. Combined with the success and consumer confidence built over years of experience in the steel industry, WSI has established a countrywide network of years of experience in the steel industry. Moreover, WSI aims to continuously improve and build

itself as a remarkable local and regional steel manufacturer. Thus, it becomes a trusted supplier to many of infrastructural projects under way by government agencies; in addition, WSI acts with the best interests of its domestic market achieving dominant market share and is also seeking to expand its operation to encompass neighboring African nations.

Few years after its establishment in 2006, WSI started manufacturing steel products as its flagship of the product line. Despite the fact that WSI was established to involve in many sectors, as per its memorandum of association, the main focus has been on the manufacturing of steel products for the last 12 years. For this reason, its focus of attention in recent years has been increasing with further product diversification to satisfy the ever escalating demands of its customers and to meet this demand WSI has been expanding its operation:

- By increasing its production capacity for the existing products through adding additional manufacturing lines
- Diversifying the product types towards wider RHS, thinner and thicker sheet metals, checkered plate, corrugated sheet and roofing profile

### **3.2. Manufacturing processes**

The input materials for WSI are cold rolled and hot rolled iron sheets having thicknesses of 0.5-0.9mm and 1-10mm respectively and the products of WSI from the cold and hot rolled iron sheets are Rectangular Hollow Section (RHS), Square Hollow Section (SHS), Circular Hollow Section (CHS), LTZ, chequered plate and sheet metal plate.

Meanwhile, for the production of the above mentioned products the factory does have Twenty production lines and 3/three/ production processes in five production shades of WSI compound which is located at Alemgena.

And the production processes in the factory are:

1. Hollow section process which produces RHS,SHS,CHS and LTZ products
2. Cut-to-length process which produces sheet metal plate and chequered plate products
3. And slitting process that produces silted sheets of iron which is used as inputs to hollow section process and cut-to-length process.

Overall, of all the production lines five of them are silting lines, ten are hollow section lines, four are cut-to-length lines and one is Chequered plate line.

Table 3-1 Production lines, Factory name and the type of products in WSI

<b>S.No</b>	<b>Production Line's Name</b>	<b>Factory Name</b>	<b>Product Type</b>
1	Line 38(1)	Factory 1	Hollow section
2	Line 38(3)	Factory 1	Hollow section
3	Line 76(1)	Factory 1	Hollow section
4	Slitting(1)	Factory 1	Silted sheet of iron
5	Cut-to-size(1)	Factory 1	Sheet metal
6	Cut-to-size(3)	Factory 1	Sheet metal
7	Line 76(2)	Factory 2	Hollow section
8	Slitting(2)	Factory 2	Silted sheet of iron
9	Line 60(1)	Factory 3	Hollow section
10	Line 60(2)	Factory 3	Hollow section
11	Line 38(2)	Factory 3	Hollow section
12	Slitting(3)	Factory 3	Silted sheet of iron
13	Cut-to-size(2)	Factory 3	Sheet metal
14	Cut-to-size(4)	Factory 3	Sheet metal
15	Line 60(3)	Factory 4	Hollow section
16	Slitting(4)	Factory 4	Silted sheet of iron
17	Chequered plate line	Factory 4	Chequered plate
18	Line 200(1)	Factory 5	Hollow section
19	Line 200(2)	Factory 5	Hollow section
20	Slitting(5)	Factory 5	Silted sheet of iron

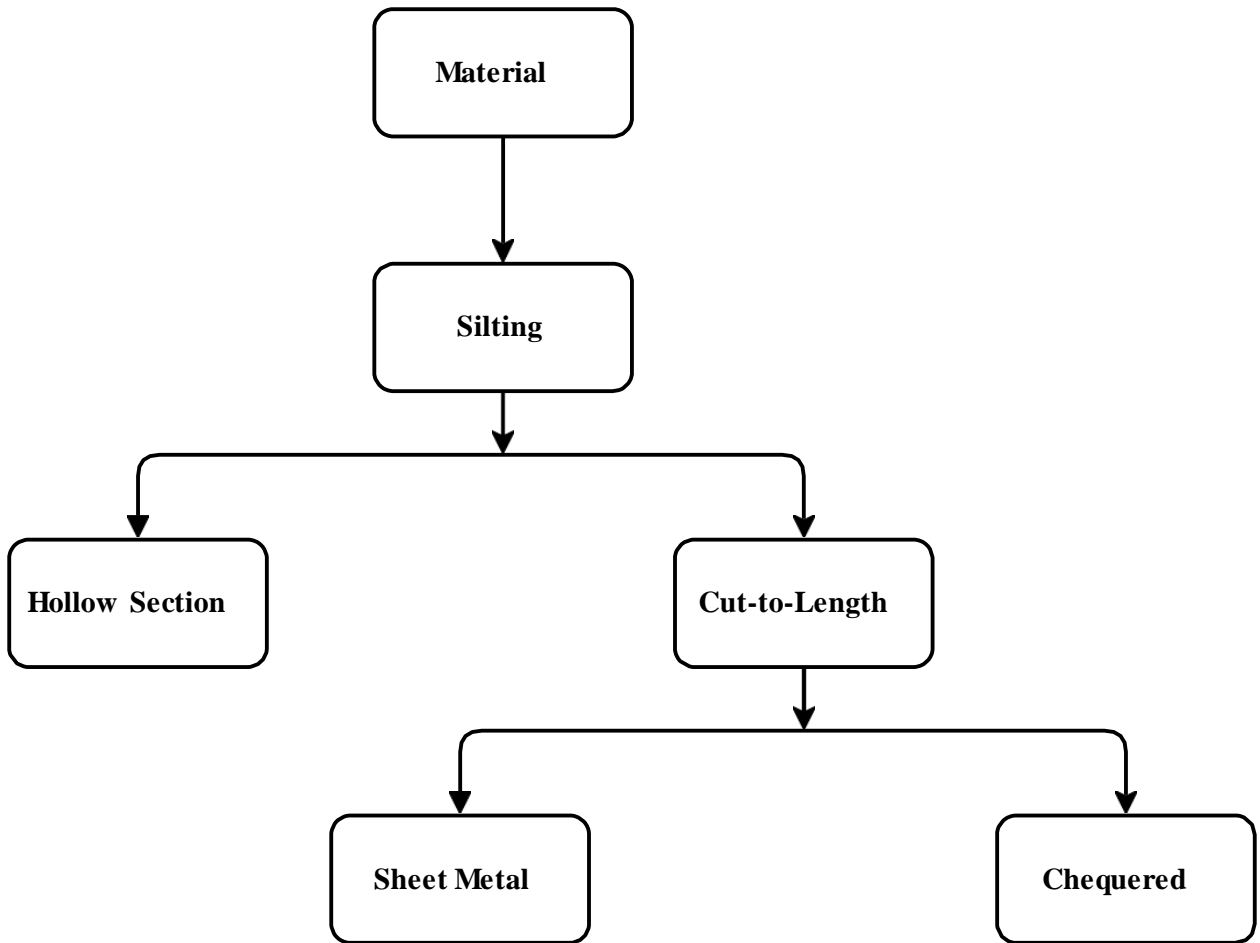


Figure 3-3 General Picture of the production Process of the Factory

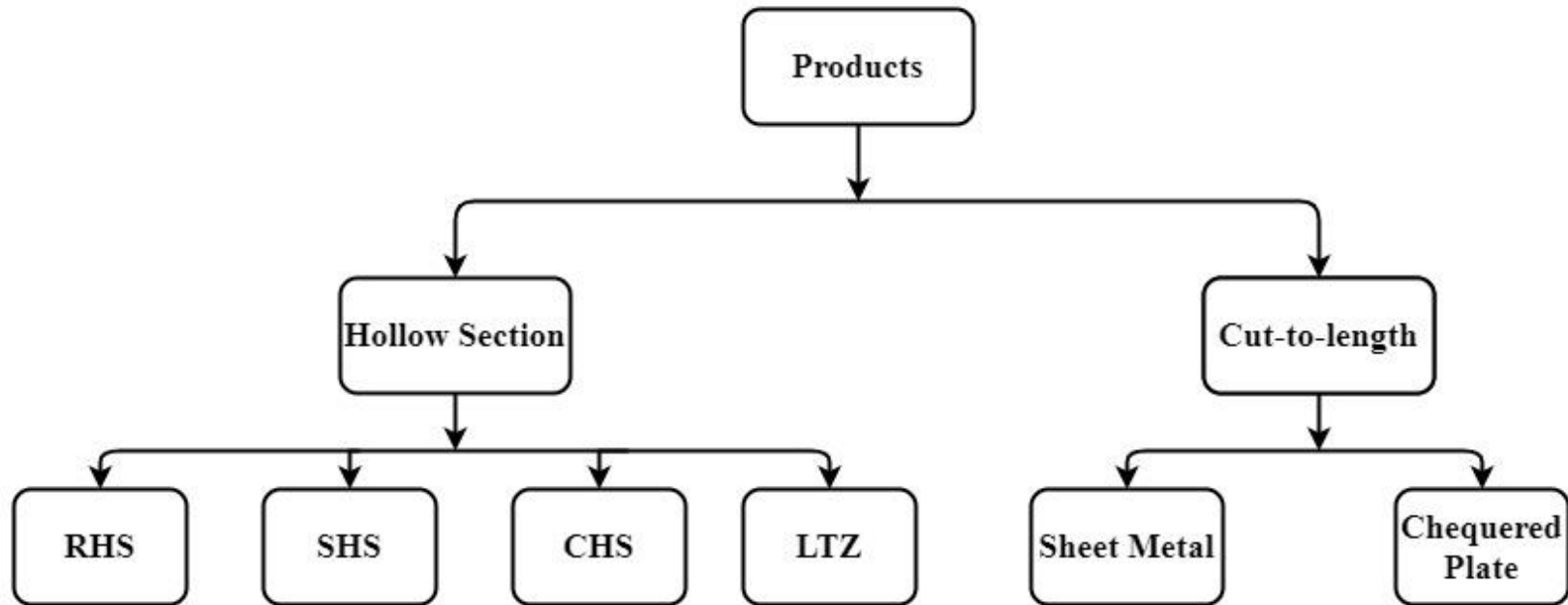


Figure 3-4 Main Products of WSI and Main production processes in the factory

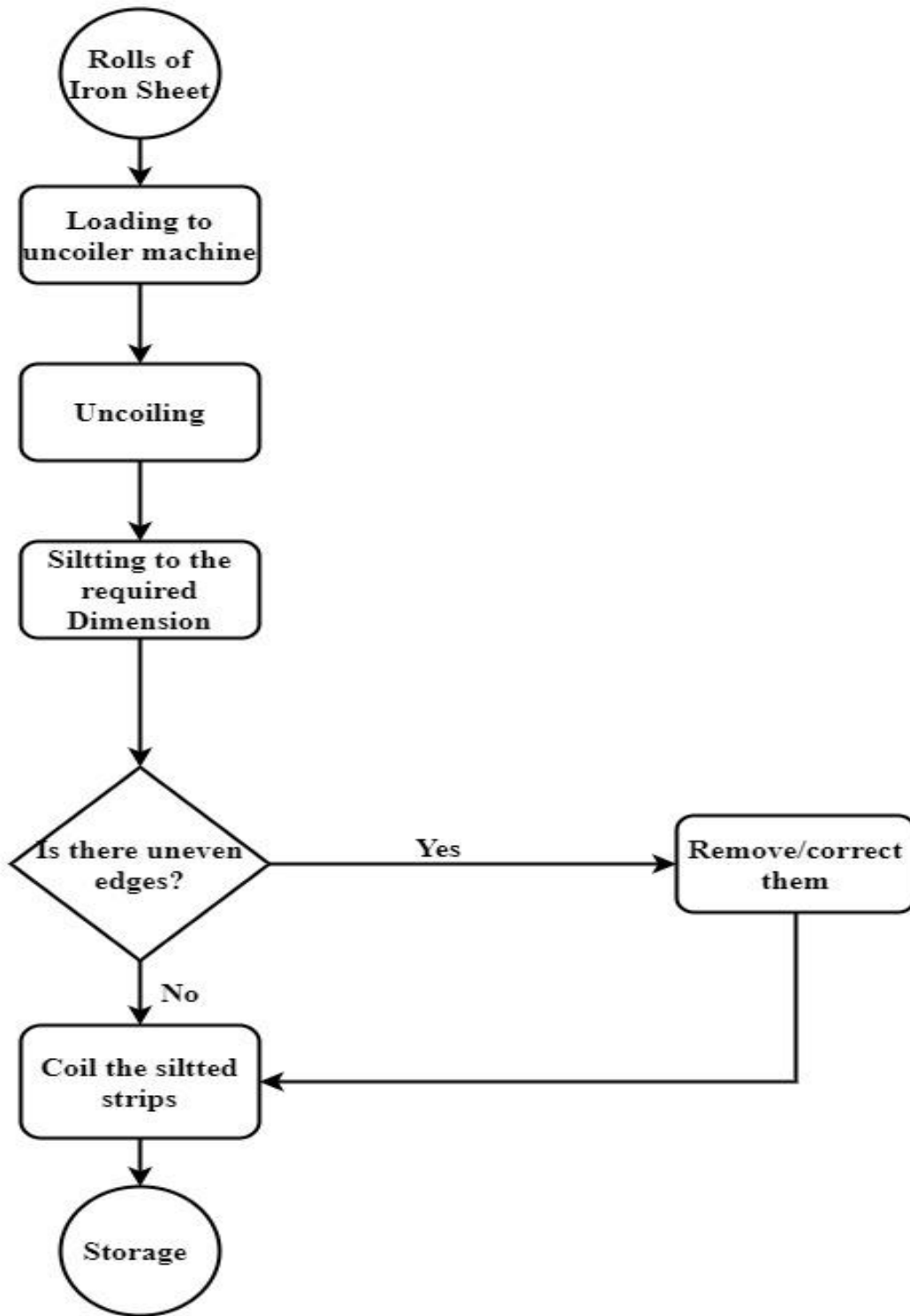


Figure 3-5 Slitting Manufacturing Process

Table 3-2 Descriptions of slitting manufacturing process

<b>Process steps</b>	<b>Process Description</b>
1	First load the rolls of sheet iron on the uncoiler by the overhead crane and check whether it is firmly hold by the uncoiler jaws and check also whether it is centrally placed or not.
2	If properly placed proceed the uncoiling if not do the corrections and then do the uncoiling.
3	Remove uneven edges before slitting process is carried out
4	Then lead the uncoiled sheet of metal from the uncoiler to the Cutter machine by the roller.
5	Then here starts the slitting process by the cutter.
6	Before recoiling process while slitting is done check for uneven edges and remove if there exists.
7	At last, check if recoiler's jaw has firmly and properly hold the slitted sheet of iron ends
8	Then Recoiling is done here for the slitted sheet of iron by the recoiler.
9	The final product is dispatched to store and made ready for the next other production processes that is for hollow section and cut-to-length manufacturing processes.

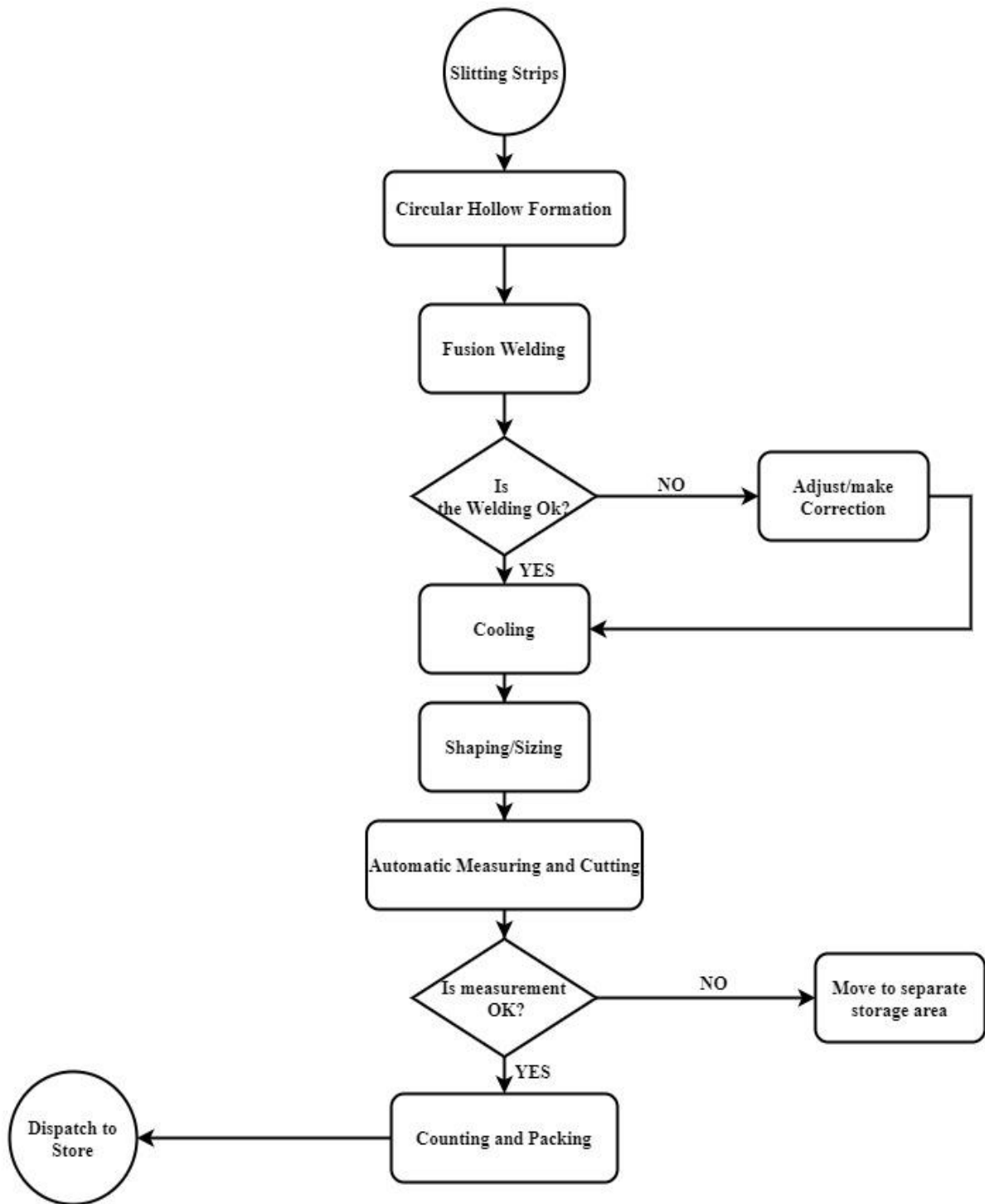


Figure 3-6 Hollow Section Manufacturing Process

Table 3-3 Descriptions of hollow section manufacturing process

<b>Process steps</b>	<b>Process Description</b>
1	Based on the order given issue, the raw material is unpacked and made ready for loading
2	Prepare the slitting line for blades, spacers and guides for the given order and load the material, slit it and recoil to produce the stripes
3	Change the dies sets on to the specific line, adjust them and insert the stripes in the line to form circular section to make it ready for welding.
4	Insert the appropriate impeder (carbide) for welding the circular section which reached on welding device by balancing the speed and current for sound welding
5	Visually inspect the soundness of the weld after chips are removed
6	Adjust the speed and current if there is a problem of welding
7	Allow the welded circular hollow section to pass through coolant bath on the line to sink the heat generated during welding
8	Continue the process by passing welded circular hollow section through the shaping (sizing) die sets to achieve shape and size required by adjusting these dies
9	After achieving appropriate shape and size, the straight product will be cut to the required by automatic cutting machine aided by computer
10	The measurements, shape and size shall be inspected
11	The rejects , if any shall be collected , segregated and identified by appropriate means
12	After checking all the parameters and adjustments the final product will be counted and packed as appropriate
13	Then the final product is dispatched to store

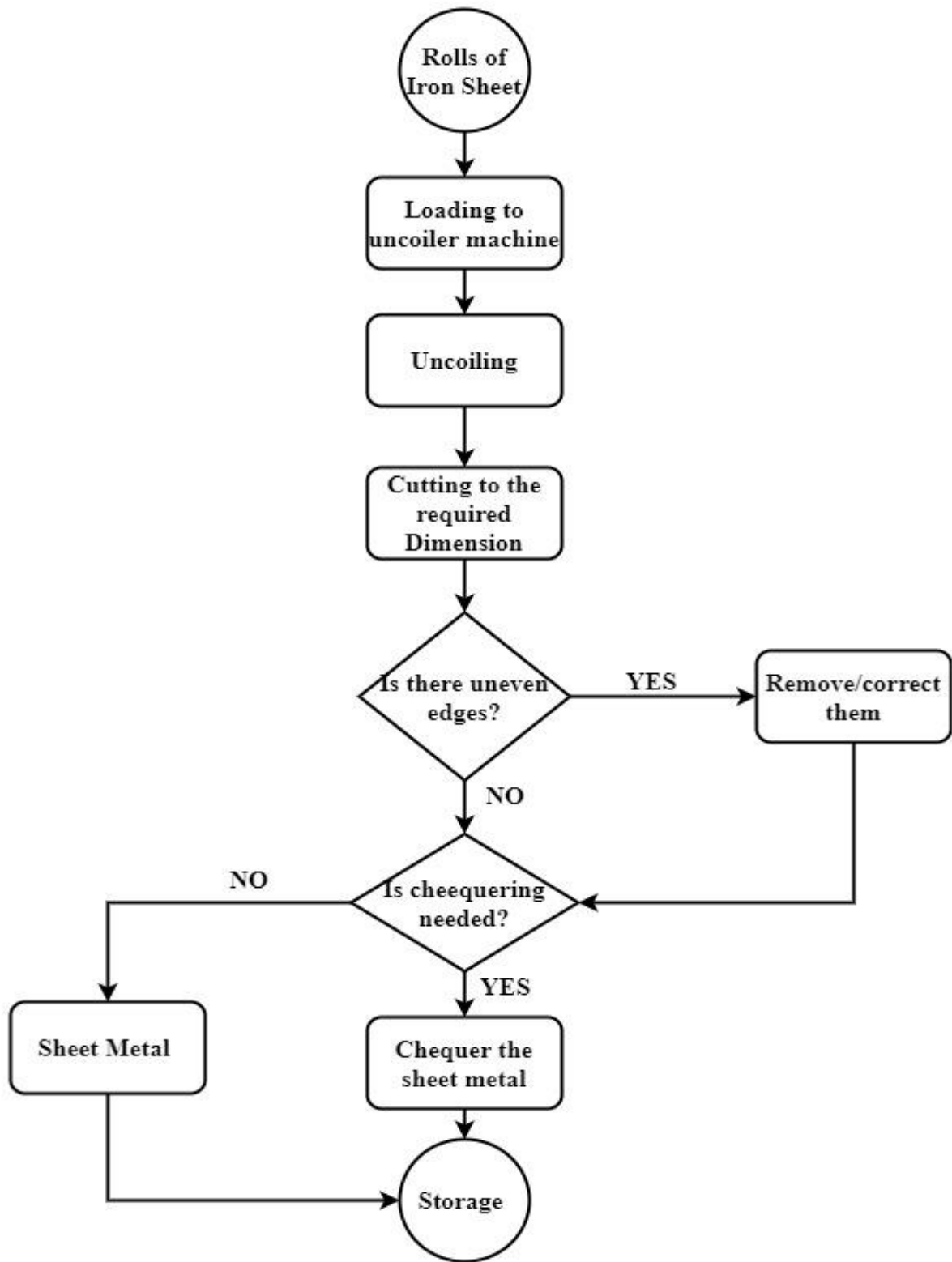


Figure 3-7 Cut-to-length manufacturing process

Table 3-4 Descriptions of cut-to-length manufacturing process

<b>Process steps</b>	<b>Process Description</b>
1	First load the rolls of sheet iron on the uncoiler by the overhead crane and check whether it is firmly hold by the uncoiler jaws and check also whether it is centrally placed or not placed.
2	If ok proceed the uncoiling if not do the corrections and then do the uncoiling.
3	Remove uneven edges before cutting process is carried out
4	Then lead the uncoiled sheet of metal from the uncoiler to the Cutting /shearing machine by the straight or leveling roller.
5	Then here starts the cutting process to the required dimension by the cutter.
6	Again check and remove any uneven edges of the cut sheets of metal
7	If chequering is needed chequer the sheet of metal with the chequering machine
8	The final product is dispatched to store

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### 3.3. Machines Layout

In this factory, the plant (machines) layouts are mainly of 4/four/ namely slitting, hollow section, sheet metal (cut-to-length) and chequered layouts. And the layouts are shown in the following figures [Figure 3-8- Figure 3-10].

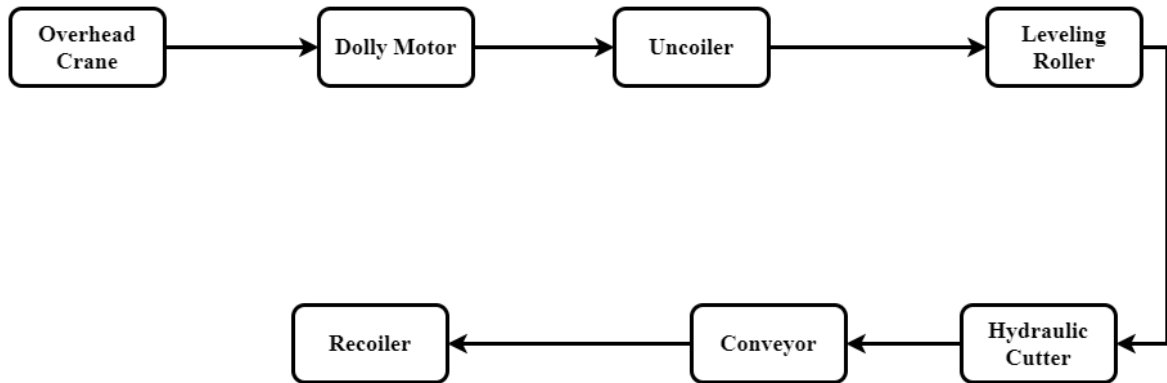


Figure 3-8 Slitting Machines Layout

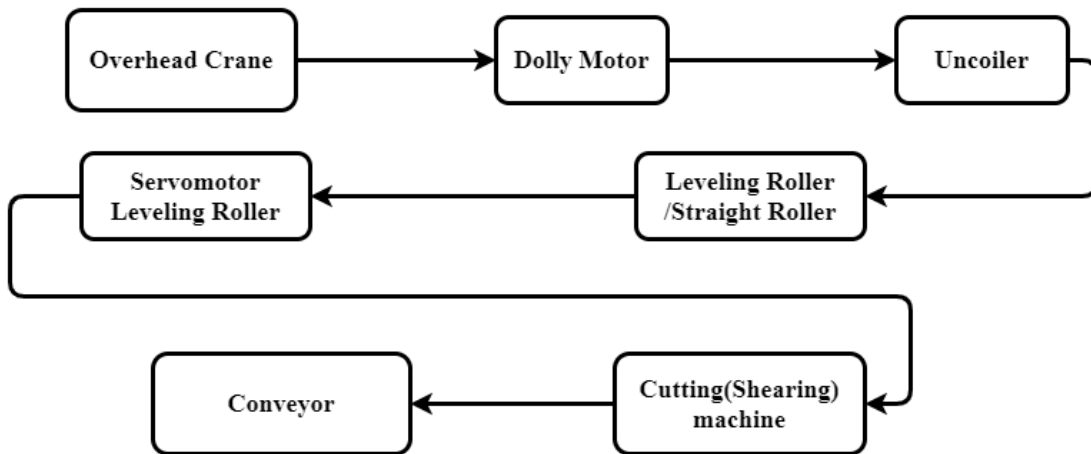


Figure 3-9 Cut-to-Size Machines Layout

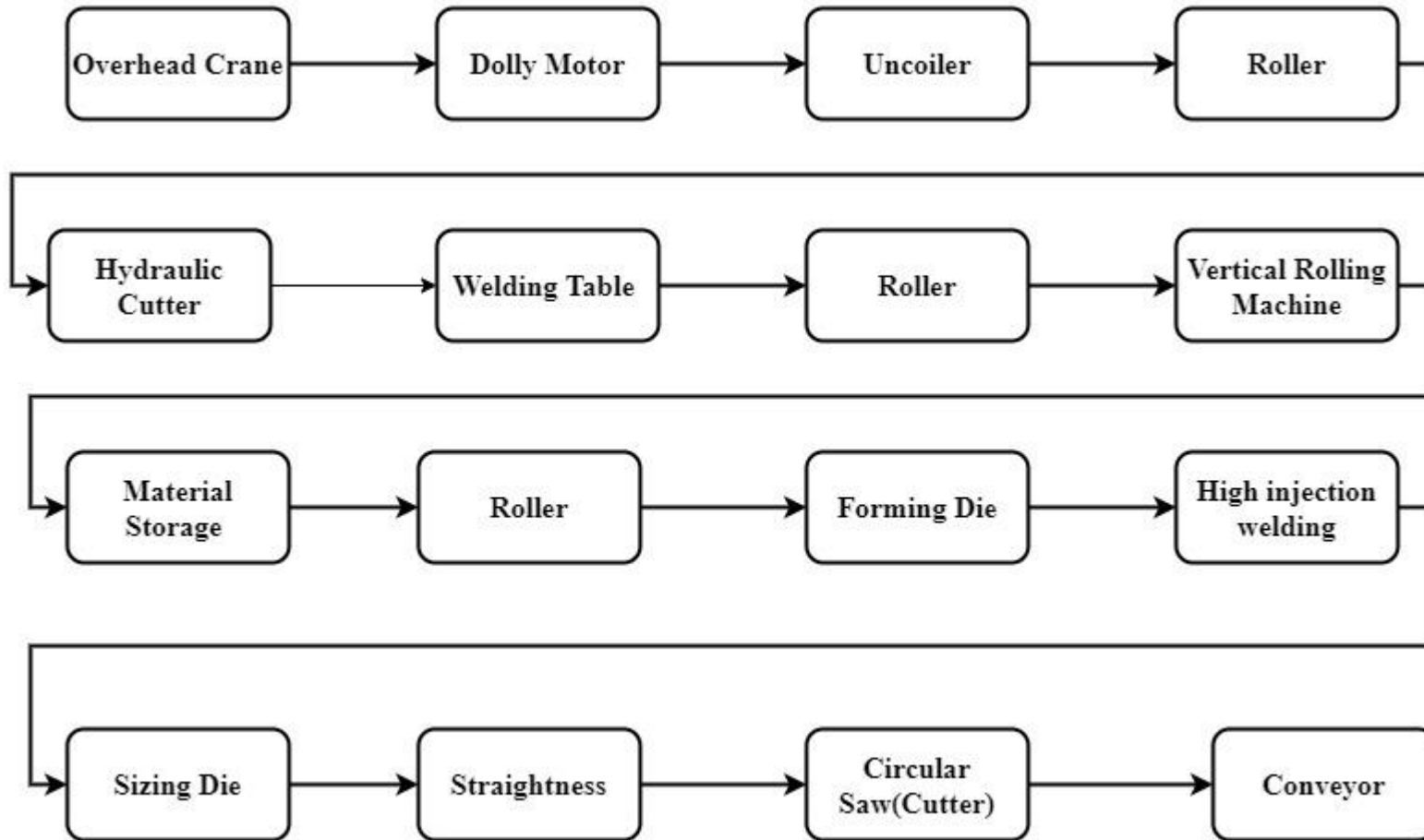


Figure 3-10 Hollow Section Machines Layout

## **CHAPTER FOUR**

# **PRELIMINARY ENERGY AUDIT OF WALIA STEEL INDUSTRY**

### **4.1. Introduction**

WSI is one of the most energy intensive factories in Ethiopia. The factory uses both electrical energy and diesel fuel oil as sources of energy for its manufacturing process. The factory mainly depends on the main grid for its electrical energy supply during manufacturing process. For loading and unloading activity, it consumes diesel fuel oil when power supply is interrupted from the main grid.

The monthly energy consumptions data of electrical energy bills and the monthly liters of diesel fuel of WSI consumption data were collected, summarized and tabulated in Appendix A and Appendix B.

As per the energy data (April 2018-February 2020) taken from Ethiopian Electric Utility-West Addis Ababa (EEU-WAA) district office and diesel data from the factory, monthly average energy bill payment for electrical energy and diesel fuel oil is 142,461.61ETB and 33,469.77ETB respectively.

For the analysis of the historical energy consumption pattern of the factory, to calculate average specific energy of the industry and to compare with other factories worldwide which are having similar product type and production process and then to give conclusion as per the analysis made energy consumption and production data of 23 months has been collected. And as per the data collected the average specific energy of the factory has been calculated, compared with benchmarks to check the energy usage status and the conclusions are discussed as per the findings of the analysis made.

### **4.2. Data collection**

#### **4.2.1. WSI energy consumption bill data**

Twenty three months (April 2018-February 2020) of energy data from the energy bills obtained from EEU, monthly steel production data and diesel fuel oil data from the factory's production department and electrical department were collected for analysis.

#### **4.2.2. WSI structural steel production data collected**

The Structural Steel production of WSI of 23 months ranging from April 2018 to February 2020 (GC) was collected from WSI production office and the data is summarized and tabulated in the Appendix B.

#### **4.2.3. Analysis of the factory's energy consumption and production data**

Here, the historical data collected of energy consumption and production data are analyzed using the specific gravity (density of fuel) of diesel fuel is  $837 \pm 8 \text{ kg/m}^3$  which is  $0.837 \pm 8 \text{ kg/L}$  and gross calorific value is  $45.6 \pm 0.49 \text{ MJ/kg}$  [20] but took  $0.845 \text{ kg/L}$  and  $45 \text{ MJ/kg}$  for the density and for the gross calorific value (GCV) of the diesel oil respectively. Besides, the efficiency taken for the diesel generator is 0.55

#### **4.2.4. WSI energy cost data**

The energy cost data of the factory is collected from the factory and from EEU-WAA District office.

$$MEEC^* = REC(kWh) \times \text{per kWh cost} + PF \text{ charge} + MDC \quad (4.1)$$

$$MFC^* (ETB) = MFC(L) \times PLC (ETB) \quad (4.2)$$

As per the collected data, the cost of diesel fuel per liter ranges from 17.85ETB to 18.75ETB and the real electrical energy consumed multiplying factor ranges from 0.4086ETB up to 0.8008ETB.

### **4.3. Monthly load factor and power factor values**

#### **4.3.1. Load Factor**

The load factor is a measure of the utilization rate, or efficiency of electrical energy usage; a high load factor indicates that load is using the electric system more efficiently, whereas consumers that underutilize the electric distribution will have a low load factor [21].

And its value is always less than one because maximum demand is never lower than average demand, since facilities likely never operate at full capacity for the duration of an entire day. A high load factor means power usage is relatively constant. Low load factor shows that occasionally a high demand is set. To service that peak, capacity is sitting idle for long

periods, thereby imposing higher costs on the system. Electrical rates are designed so that customers with high load factor are charged less overall per Kilo Watt hour (KWh).

The monthly load factor is the ratio of the energy consumed during a month to the energy which would have been consumed, if maximum demand had been maintained throughout the period[22].

$$\text{Load factor (\%)} = \frac{ECM(KWh)}{MD(KW) \times OT(hr)} \times 100 \quad (4.3)$$

#### **4.3.2. Power Factor**

Power dissipated by a load is referred to as true power. True power is symbolized by the letter P and is measured in the unit of Kilo Watts (KW), Power merely absorbed and returned in load due to its reactive properties is referred to as reactive power and is symbolized by the letter Q and is measured in the unit of Kilo-Volt-Amps-Reactive (KVAR) and the total power in an Alternating Current (AC) circuit, both dissipated and absorbed/returned is referred to as apparent power and is symbolized by the letter S and is measured in the unit of Kilo-Volt-Amps (KVA)[23]. Besides, the angle between the true power and apparent power is phi [Ø]. And these three types of power are trigonometrically related to one another as shown in Figure 4-1.

Hence, low power factor in an electrical system often occur when inductive loads are operated below their full load capacity especially motors. Consistently operating electrical loads at low power factor will result in higher utility bills because of the poor utilization of electrical energy. In fact, a higher power factor means less KVA and KVAR components and a more efficient utilization of electrical energy while a low power factor implies the presence of more KVA and reactive (KVAR) power components and less efficient electrical energy utilization.

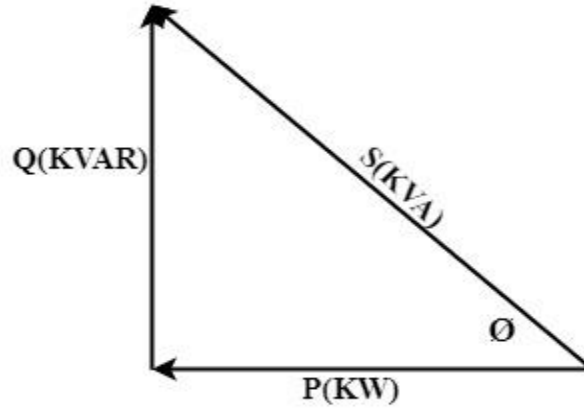


Figure 4-1 Power Triangle

Hence, the monthly power factor is the ratio between true power and apparent power of the month in consideration.

$$S = P + jQ \quad (4.4)$$

$$\text{Power factor}(\text{Cos}\phi) = \frac{P}{\sqrt{P^2 + Q^2}} \quad (4.5)$$

Thus, monthly power factor is calculated as follows for the monthly true energy and reactive energy of the factory is known.

$$\text{Power factor}(\text{Cos}\phi) = \frac{kWh}{\sqrt{(kWh)^2 + (kvarh)^2}} \quad (4.6)$$

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Table 4-1 Monthly Power factor and Load factor values of WSI (April 2018-February 2020)

<b>Month(Billing Period)</b>	<b>KWh/Month</b>	<b>Kvarh/Month</b>	<b>Maximum Demand (KW)</b>	<b>Monthly Power Factor (Cos Ø)</b>	<b>Load Factor (%)</b>
April 2018	144,000	234,000	1350	0.52	41.03
May 2018	90,000	216,000	1350	0.38	25.64
June 2018	252,000	333,000	1350	0.6	71.79
July 2018	63,000	117,000	1350	0.47	17.95
August 2018	126,000	216,000	1350	0.5	35.9
September 2018	108,000	189,000	1350	0.5	30.77
October 2018	81,000	153,000	1350	0.47	23.08
November 2018	117,000	207,000	1350	0.49	33.33
December 2018	117,000	207,000	1350	0.49	33.33
January 2019	72,000	99,000	1350	0.59	20.51
February 2019	90,000	189,000	1350	0.43	25.64
March 2019	81,000	135,000	1350	0.51	23.08
April 2019	162,000	279,000	1350	0.5	46.15
May 2019	99,000	180,000	1350	0.48	28.21
June 2019	108,000	207,000	1350	0.46	30.77
July 2019	108,000	207,000	1350	0.46	30.77
August 2019	108,000	207,000	1350	0.46	30.77
September 2019	108,000	207,000	1350	0.46	30.77
October 2019	108,000	207,000	1350	0.46	30.77
November 2019	108,000	207,000	1350	0.46	30.77
December 2019	108,000	207,000	1350	0.46	30.77
January 2020	108,000	207,000	1350	0.46	30.77
February 2020	135,000	252,000	1800	0.47	28.85

From Table 4-1, the monthly average power factor value is 0.48 but the minimum power factor requirement of EEU is 0.9 and the monthly average load factor of the factory is 31.80% which is low load factor. And the monthly average Power Factor (PF) value depicts the useful full power drawn from the grid is less than the non-useful power drawn. Thus, there is inefficient energy usage in the factory and the low load factor value shows energy

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consuming equipment are not using energy in a proper manner thus underutilizing the system.

Table 4-2 Electrical Energy and Penalty Costs Break Down (April 2018-February 2020)

<b>Month(Billing Period)</b>	<b>Monthly Energy Cost(ETB)</b>	<b>PF Charge (ETB)</b>	<b>Maximum Demand Cost(ETB)</b>	<b>Total Electrical Energy Cost</b>
April 2018	58,838.40	31,277.31	-	90,115.71
May 2018	36,774.00	42,883.04	-	79,657.04
June 2018	102,967.20	24,675.32	-	127,642.52
July 2018	25,741.80	35,437.41	-	61,179.21
August 2018	51,483.60	32,960.27	-	84,443.87
September 2018	44,128.80	33,603.62	-	77,732.42
October 2018	33,096.60	35,954.29	-	69,050.89
November 2018	47,806.20	33,943.24	-	81,749.44
December 2018	47,806.20	33,943.24	-	81,749.44
January 2019	43,538.40	26,399.46	49,794.75	119,732.61
February 2019	53,423.00	54,442.92	49,794.75	157,660.67
March 2019	48,980.70	37,310.49	49,794.75	136,085.94
April 2019	97,961.40	39,454.61	49,794.75	187,210.76
May 2019	59,865.30	82,077.48	94,610.03	236,552.81
June 2019	65,307.60	12,557.15	13,278.60	91,143.35
July 2019	65,307.60	47,089.31	49,794.75	162,191.66
August 2019	65,307.60	47,089.31	49,794.75	162,191.66
September 2019	65,307.60	47,089.31	49,794.75	162,191.66
October 2019	65,307.60	47,089.31	49,794.75	162,191.66
November 2019	65,307.60	47,089.31	49,794.75	162,191.66
December 2019	65,307.60	47,089.31	49,794.75	162,191.66
January 2020	82,956.60	86,330.41	91,290.38	260,577.39
February 2020	108,108.00	120,288.93	132,786.00	361,182.93

From Table 4-2, it is observed that the monthly average electrical energy cost was 142,461.61ETB; of which 60,896.93ETB was the monthly average real energy cost, 45,481.52 ETB was the power factor penalty cost and 36,083.15ETB was the maximum demand penalty cost thus the factory was paying 81,564.67ETB monthly on average for penalty of inefficient energy usage which is 57% of the monthly average electrical energy cost and annually paying 978,776.04ETB for penalty only.

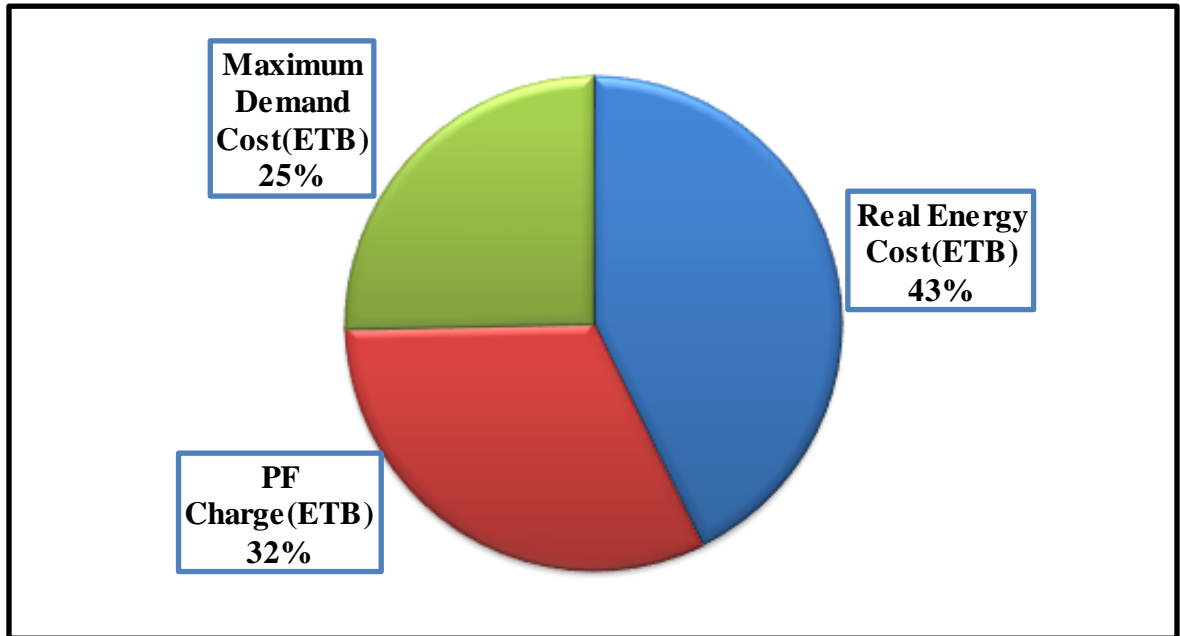


Figure 4-2 Monthly Average Electrical Energy Consumption Cost Breakdown

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Table 4-3 Energy Cost and Production Data of the Factory (April 2018-February 2020)

<b>Billing Period (G.C)</b>	<b>Electricity Cost (ETB)</b>	<b>Fuel Cost (ETB)</b>	<b>Electricity and Fuel Cost (ETB)</b>	<b>Monthly Production of Steel (tone)</b>
April 2018	90,115.71	3,570.00	93,685.71	1415.7
May 2018	79,657.04	3,570.00	83,227.04	1505.6
June 2018	127,642.52	7,500.00	135,142.52	839
July 2018	61,179.21	54,375.00	115,554.21	978.02
August 2018	84,443.87	11,250.00	95,693.87	654.94
September 2018	77,732.42	9,375.00	87,107.42	809.57
October 2018	69,050.89	7,500.00	76,550.89	856.88
November 2018	81,749.44	7,500.00	89,249.44	699.84
December 2018	81,749.44	249,375.00	331,124.44	956.96
January 2019	119,732.61	9,375.00	129,107.61	987.97
February 2019	157,660.67	7,500.00	165,160.67	861.06
March 2019	136,085.94	3,750.00	139,835.94	816.52
April 2019	187,210.76	7,500.00	194,710.76	542.3
May 2019	236,552.81	11,250.00	247,802.81	425.6
June 2019	91,143.35	3,570.00	94,713.35	473.6
July 2019	162,191.66	3,750.00	165,941.66	2511.91
August 2019	162,191.66	15,000.00	177,191.66	2161.71
September 2019	162,191.66	52,500.00	214,691.66	1298.63
October 2019	162,191.66	249,375.00	411,566.66	1311.65
November 2019	162,191.66	3,750.00	165,941.66	729.63
December 2019	162,191.66	3,750.00	165,941.66	1177.07
January 2020	260,577.39	11,250.00	271,827.39	1218.5
February 2020	361,182.93	-	361,182.93	1192.09

As we can observe from Table 4-3, though it is known that energy consumption is expected to increase linearly with increase in production volume of the factory but this not working in WSI because of the poor energy performance that can be evidenced from the PF and the loading factor values and that is why the PF charge (reactive energy cost) and maximum demand charge costs are greatly affecting the monthly electrical energy cost of the factory almost in all the months.

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And as per Table 4-4, the monthly average total energy consumption of the factory was 442,848.28 MJ of which 407,113.04MJ was electrical and 35,735.23MJ was energy from diesel fuel. From this it is observed that the share of electrical energy is huge which is 92% of the total energy consumed and whereas the energy from the diesel fuel is by far less which is 8% of the total energy consumed in the production process of the factory.

Table 4-4 Total Monthly Energy Consumption of the Factory (April 2018-February 2020)

<b>Billing Period (G.C)</b>	<b>Electrical Energy consumed (MJ)</b>	<b>Fuel Energy Consumed(MJ)</b>	<b>Total Energy Consumed (MJ)</b>	<b>Production of Steel structures(tonne)</b>
April 2018	518,400.00	4,182.75	522,582.75	1415.7
May 2018	324,000.00	4,182.75	328,182.75	1505.6
June 2018	907,200.00	8,365.50	915,565.50	839
July 2018	226,800.00	60,649.88	287,449.88	978.02
August 2018	453,600.00	12,548.25	466,148.25	654.94
September 2018	388,800.00	10,456.88	399,256.88	809.57
October 2018	291,600.00	8,365.50	299,965.50	856.88
November 2018	421,200.00	8,365.50	429,565.50	699.84
December 2018	421,200.00	278,152.88	699,352.88	956.96
January 2019	259,200.00	10,456.88	269,656.88	987.97
February 2019	324,000.00	8,365.50	332,365.50	861.06
March 2019	291,600.00	4,182.75	295,782.75	816.52
April 2019	583,200.00	8,365.50	591,565.50	542.3
May 2019	356,400.00	12,548.25	368,948.25	425.6
June 2019	388,800.00	4,182.75	392,982.75	473.6
July 2019	388,800.00	4,182.75	392,982.75	2511.91
August 2019	388,800.00	16,731.00	405,531.00	2161.71
September 2019	388,800.00	58,558.50	447,358.50	1298.63
October 2019	388,800.00	278,152.88	666,952.88	1311.65
November 2019	388,800.00	4,182.75	392,982.75	729.63
December 2019	388,800.00	4,182.75	392,982.75	1177.07
January 2020	388,800.00	12,548.25	401,348.25	1218.5
February 2020	486,000.00	0.00	486,000.00	1192.09

#### **4.4. Specific energy consumption of the factory**

Factory's production capacities vary throughout the year. Therefore, the variation of energy use with the variation in production is inevitable but variation in energy usage alone may not truly show the condition of energy efficiency in a factory. Thus, it is much better and more accurate to calculate the average value and conduct graphical analysis of a factory's Specific Energy Consumption (SEC), which is the energy use per unit of production. And the specific energy consumption of a plant can be calculated by using monthly energy consumption data obtained from energy bills and the monthly production data.

$$\text{Specific Energy (kWh or MJ/tonne)} = \frac{\text{Energy Consumption (KWh or MJ)}}{\text{Production(tonne)}} \quad (4.7)$$

##### **4.4.1. Monthly specific energy**

Thus the monthly specific energy consumption of a factory is the total energy consumed divided by the total production in that month which is average energy required to produce a unit of a product in this thesis the energy required for one tone of steel production.

##### **Monthly specific energy of electrical and diesel fuel**

$$\text{SEC of DF(MJ/tonne)} = \frac{\rho \left(\frac{\text{Kg}}{\text{L}}\right) \times \text{GCV} \left(\frac{\text{MJ}}{\text{Kg}}\right) \times \text{MFC(L)} \times \eta_{\text{dg}}}{\text{MSP(tonne)}} \quad (4.8)$$

$$\text{SEC of EE} \left(\frac{\text{MJ}}{\text{tonne}}\right) = \frac{\text{MEEC (KWh)} \times 3600(\text{s/hr})}{\text{MSP(tonne)} \times 1000} \quad (4.9)$$

Thus by using the collected data of monthly energy consumption both electrical energy and energy from diesel fuel, monthly production data of the factory and using equation(4.8) and equation(4.9) the corresponding monthly specific energy consumptions of the two energy sources is calculated and tabulated in Table 4-5 and Figure 4-3.

#### **4.5. Specific energy of the factory and comparison with international benchmark**

From the Table 4-5 below, the monthly average specific energy consumption of electrical energy is 465.2MJ/tonne, energy from diesel fuel is 34.24MJ/tonne and the total average specific energy consumption of the factory is 499.44MJ/tonne. And to compare with the

specific energy consumption of other steel factories available worldwide that are having the following parameters in common like that produces the same product type, have the same production processes to produce the product, have the same technology in use and use relatively same energy sources for the manufacturing process of their product Egypt's and Indonesia's steel industries best practices which are having 98kWh/tonne[24] and 125kWh/tonne[25] specific energy consumptions values respectively are taken.

Accordingly, the least specific energy consumption value of the best practices is that of steel industry in Egypt which has specific energy consumption of 98kWh/tonne which is 352.8MJ/tonne (for 1kWh= 3.6MJ) thus taken as benchmark in this thesis work and when it is compared with the specific energy consumption of Walia steel which is 499.44MJ/tonne the specific energy of Walia steel is higher than the benchmark by 146.64MJ/tonne.

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Table 4-5 Monthly Specific Energy Consumption of the Factory (April 2018-February 2020)

<b>Billing Period (G.C)</b>	<b>SEC of Electrical Energy (MJ/tonne)</b>	<b>SEC of Fuel Energy (MJ/tonne)</b>	<b>Total Monthly SEC (MJ/tonne)</b>
April 2018	366.18	2.95	369.13
May 2018	215.20	2.78	217.98
June 2018	1,081.29	9.97	1091.26
July 2018	231.90	62.01	293.91
August 2018	692.58	19.16	711.74
September 2018	480.25	12.92	493.17
October 2018	340.30	9.76	350.06
November 2018	601.85	11.95	613.8
December 2018	440.14	290.66	730.8
January 2019	262.36	10.58	272.94
February 2019	376.28	9.72	386
March 2019	357.13	5.12	362.25
April 2019	1,075.42	15.43	1090.85
May 2019	837.41	29.48	866.89
June 2019	820.95	8.83	829.78
July 2019	154.78	1.67	156.45
August 2019	179.86	7.74	187.6
September 2019	299.39	45.09	344.48
October 2019	296.42	212.06	508.48
November 2019	532.87	5.73	538.6
December 2019	330.31	3.55	333.86
January 2020	319.08	10.3	329.38
February 2020	407.69	0	407.69

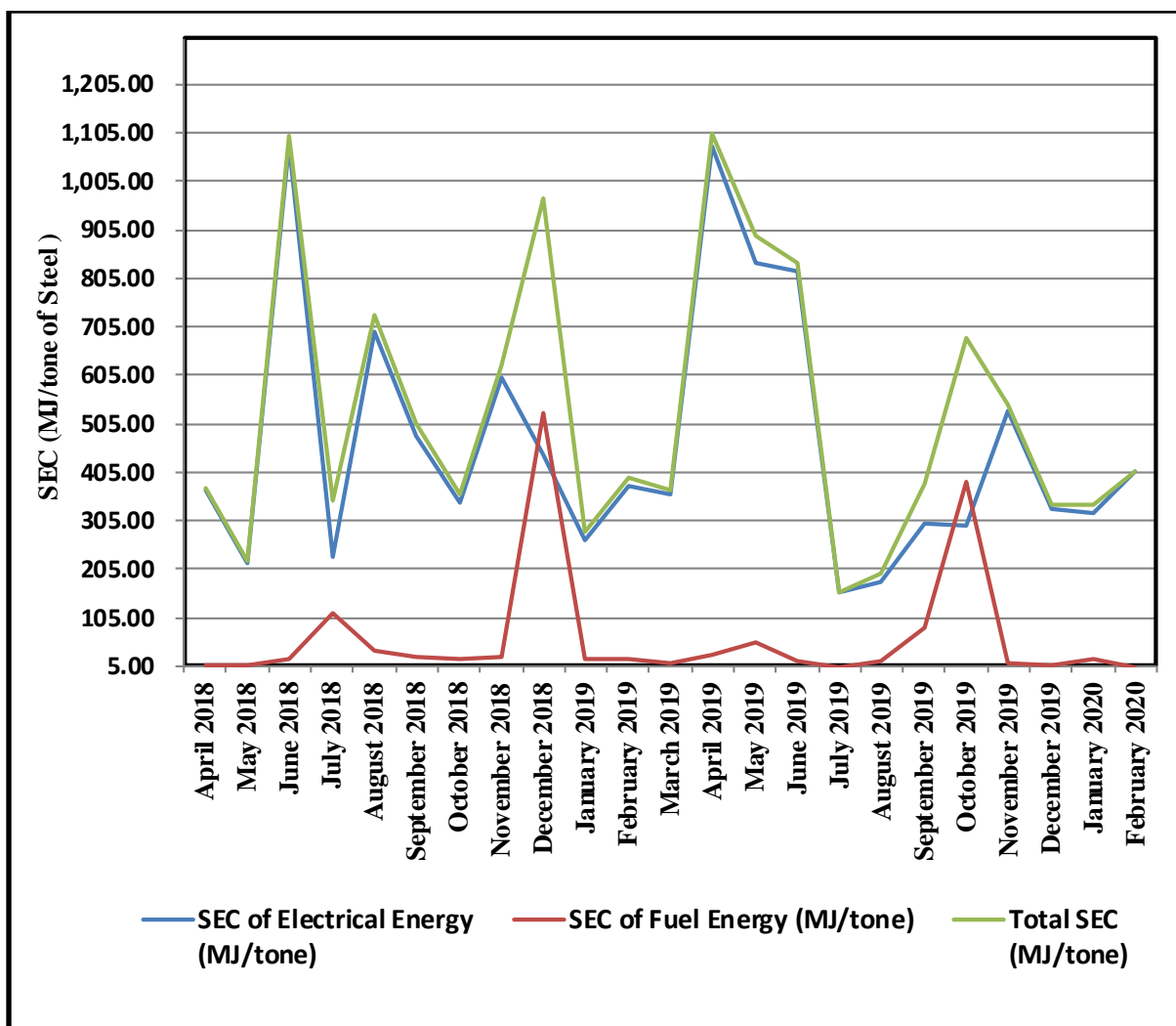


Figure 4-3 Monthly Specific Energy Consumption of the Factory

#### **4.6. Concluding Remarks of the Preliminary Energy Audit**

As per the discussions made above, the specific energy consumption of WSI is 499.44MJ/tonne and that of the benchmark factory is 352.8MJ/tonne hence WSI's SEC is higher than the benchmark factory by 146.64MJ/tonne and the difference is significant and is a good indication for inefficient energy usage in the factory.

Besides to the factory's higher average specific energy consumption value as compared with international benchmarks, the Poor PF value, and the Poor load factor value are also the compelling evidences that the factory does have energy inefficiency thus conducting detail energy auditing on the factory shall be done for better energy management of the factory, to find where the inefficiency is and to know the reasons of inefficiency there by recommend the possible energy conserving measures.

## **CHAPTER FIVE**

# **ENERGY AUDIT OF ELECTRIC MOTORS IN THE FACTORY**

### **5.1. Introduction**

As it is known electrical motor are used to convert electrical energy into mechanical energy. In WSI, motors are used to cut, coil and uncoil, silt, form required shapes, drive conveyors, pumps and cranes. The wattage, power factor and efficiency for the motors found in factory ranges from 0.18kW to 200kW , 0.76 to 0.89 and 72.9% to 94.9% respectively.

Motors are found in all the manufacturing processes of WSI that is they are the prime movers for all the machines for cutting, silting, hollow section manufacturing processes of the factory. A motor having a nameplate rating of some value does not mean it actually delivers that horsepower to its load rather the load itself determines the horsepower required to drive it, and whatever motor is connected to that load will try to deliver the power that load demands. If the motor is called upon to deliver more power than it is designed to deliver, it will overheat, possibly stall and eventually burnout. If it is called to deliver much less than rated power, it will operate inefficiently, wasting energy and energy dollars[26]. The evaluation of motors focuses on the operating efficiency and motor load to identify energy efficiency gains and possible reliability improvements. Thus, improving the efficiencies of motors, replacing with energy efficient motors or proper sizing of motors can save significant amount of electrical energy from being wasted.

To analyze and evaluate the energy performance of the motors, the following data were collected nameplate data of rated power, rated power factor, rated efficiency, rated speed, rated voltage and rated current. And measured data of input power and shaft speed of the motors are also taken as input data for the performance analysis. Besides to the above data for power distribution of the factory has been collected and Single Line Diagram (SLD) has been prepared that can used for the analysis for the systemic energy performance of the factory. In the nameplate data collection and measurement only motors whose wattage is greater than 5kW has been taken into account for it covers 96.7% of the total load of the factory. In the factory, there are about 180 motors of which 100 are having greater than 5kW and 80 are having less than 5kW wattage.

And as per the computations made for the motors, 25 motors have been found with percentage loading of less than cutting value and by replacing these motors with energy efficient motors an annual energy cost saving of 16,075.00Euro which is 705,210.25ETB can be saved. Thus, in this chapter the energy usage performances, the possible energy conservation opportunities and measures for the motors found in the factory are discussed.

## **5.2. Motor survey and data collection**

To do the analysis and evaluate the energy performance of the motors and know the systemic performance of the factory data required for the analysis made on the factory has been collected through survey and measurement.

### **5.2.1. Data collected by survey and interviews**

During the survey of WSI, the following data were collected by visual inspection and interviews.

- Rated power 0.18 kW to 200 kW,
- Rated power factor ranges from 0.76 to 0.89 and
- Rated efficiency ranges from 72.9% to 94.9%
- The service time (age) of the motors ranges from 4 years to 12 years
- The averaged operating hours of the motors in the factory is 3,120 hours per year.
- Awareness status checking on the energy management issue of the factory for managers and all staffs of the factory.

### **5.2.2. Data collected by measurement**

In addition to survey, visual inspection and interviews, data needed for the analysis of motor energy performance were collected using instruments like handheld Watt meter and infrared tachometer to measure input power to motor and shaft speed of the motor respectively. The following Table 5-1 contains motor's description, collected data of rated power(kW), rated efficiency, measured input electric power(kW),calculated percentage motor loading, service years of motors, motor location in the factory and specific production line of the motor.

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Table 5-1 Motors nameplate, measured and calculated data

S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (kW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
1	DC machine	1	75	84.9	15.44	1497	20.6	12	Factory 1	Cut to size(3)
2	Belt motor	1	15	81.3	4.14	1490	27.6	12	Factory 1	Cut to size(3)
3	Cutting motor	1	11	89.6	7.37	2958	67	12	Factory 1	Cut to size(3)
4	Air pump	1	11	89.8	8.57	1472	77.9	12	Factory 1	Cut to size(3)
5	Saw motor	1	5.5	87	3.54	2944	64.4	12	Factory 1	Line 38(1)
6	Cart motor	1	7.5	86	5.32	1482	70.9	12	Factory 1	Line 38(1)
7	Material motor	1	55	85	34.29	1486	62.3	12	Factory 1	Line 38(1)
8	Hydraulic motor	1	7.5	88.7	6.34	1466	84.5	12	Factory 1	Line 38(3)
9	Material feeding motor	2	37	92.2	27.29	990	73.8	12	Factory 1	Line 38(3)
10	Cutting motor	1	22	86	14.58	2932	66.3	12	Factory 1	Line 76(1)
11	DC motor for cutting home	1	15	83	13.37	1478	89.1	12	Factory 1	Line 76(1)
12	DC master	1	132	91.4	36.65	1496	27.8	12	Factory 1	Line 76(1)
13	Coil store motor	1	15	85	12.18	1472	81.2	12	Factory 1	Line 76(1)
14	Distilled water pump motor	1	11	87	9.23	2927	83.9	12	Factory 1	Line 76(1)
15	Coolant water pump motor	1	7.5	84	6.7	2925	89.3	12	Factory 1	Line 76(1)
16	Cutting motor	1	22	80.2	5.69	2973	25.9	9	Factory 2	Line 76(2)

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S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (kW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
17	DC motor for cutting home	1	15	86	9.94	1472	66.3	9	Factory 2	Line 76(2)
18	DC master	1	132	85	100.94	1484	76.5	9	Factory 2	Line 76(2)
19	Coil store motor	1	11	88.4	9.21	1485	83.7	9	Factory 2	Line 76(2)
20	Coolant water motor	1	7.5	89	6.4	2924	85.3	9	Factory 2	Line 76(2)
21	Cutting motor	1	18.5	77.7	5.65	2981	30.5	8	Factory 3	Line 60(1)
22	DC motor for cutting home	1	22	86	16.63	1481	75.6	8	Factory 3	Line 60(1)
23	DC master	1	132	85	86.96	980	65.9	8	Factory 3	Line 60(1)
24	Coil storage motor	1	11	79	2.71	1496	24.6	8	Factory 3	Line 60(1)
25	Servo motor	1	11	81.1	3.3	1489	30	8	Factory 3	Cut to size(2)
26	DC master	1	75	89	47.19	1489	62.9	8	Factory 3	Cut to size(2)
27	Cutting motor	1	11	89.8	8.33	1473	75.7	8	Factory 3	Cut to size(2)
28	Uncoiler roller motor	1	5.5	90	4.4	2928	80	8	Factory 3	Cut to size(2)
29	Cutting motor	1	18.5	90	10.89	2963	58.9	8	Factory 3	Line 60(2)
30	DC motor for cutting home	1	22	88	16.5	1485	75	8	Factory 3	Line 60(2)
31	DC master	1	132	89	105.3	991	79.8	8	Factory 3	Line 60(2)
32	Coil storage motor	1	11	88.4	9.71	1484	88.3	8	Factory 3	Line 60(2)
33	Uncoiler motor	2	7.5	85	6.53	1456	87.1	8	Factory 3	Line 38(2)
34	DC motor	1	55	84	42.56	1477	77.4	8	Factory 3	Line 38(2)

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S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (kW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
35	Saw motor	1	11	72.9	2.94	2983	26.7	8	Factory 3	Line 38(2)
36	Cart motor	1	15	80.7	3.79	1498	25.3	8	Factory 3	Line 38(2)
37	Material feeding motor	1	15	81.9	4.52	1490	30.1	8	Factory 3	Silting(3)
38	DC motor	1	37	85.8	9.43	1495	25.5	8	Factory 3	Silting(3)
39	Hydraulic motor	1	11	88	7.88	1475	71.6	8	Factory 3	Silting(3)
40	DC motor	1	110	86	71.63	1483	65.1	8	Factory 3	Silting(3)
41	DC motor	1	132	87	104.69	1486	79.3	8	Factory 3	Silting(3)
42	Coil transport	1	55	89	39.55	1487	71.9	8	Factory 3	Cut to size(4)
43	Air pump	1	11	88	9.63	1469	87.5	8	Factory 3	Cut to size(4)
44	Leveling motor	1	110	86	88.26	1479	80.2	8	Factory 3	Cut to size(4)
45	Cutting motor	1	30	88.1	7.66	1492	25.5	8	Factory 3	Cut to size(4)
46	Saw motor	1	18.5	76.1	4.73	2984	25.6	7	Factory 4	Line 60(3)
47	DC motor for cutting home	1	22	87.1	6.01	1477	27.3	7	Factory 4	Line 60(3)
48	DC master	1	132	90.9	45	985	34.1	7	Factory 4	Line 60(3)
49	Coil storage motor	1	11	81.4	3.39	1489	30.8	7	Factory 4	Line 60(3)
50	Air storing motor	1	7.5	87	5.17	1464	68.9	7	Factory 4	Line 60(3)
51	Coolant pump motor	1	7.5	89	4.72	2944	62.9	7	Factory 4	Line 60(3)
52	DC motor	1	55	83.5	11.61	1495	21.1	7	Factory 4	Silting(4)
53	Hydraulic pump motor	1	11	88	8.13	1474	73.9	7	Factory 4	Silting(4)

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S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (kW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
54	Up and down motor	1	5.5	90	4.28	1458	77.8	7	Factory 4	Silting(4)
55	Cutter motor	1	132	89.4	36.41	2988	27.6	7	Factory 4	Silting(4)
56	Strips recoiler motor	1	200	86	123.26	996	61.6	7	Factory 4	Silting(4)
57	Hydraulic motor	1	7.5	90	5.25	1462	70	7	Factory 4	Silting(4)
58	Hydraulic motor	1	15	81.4	4.19	1490	27.9	8	Factory 5	Line 200(1)
59	Roller motor	1	22	85.3	6.81	992	31	8	Factory 5	Line 200(1)
60	Material storage motor	1	90	89.6	26.59	996	29.5	8	Factory 5	Line 200(1)
61	Roller motor	1	55	86	43.49	750	79.1	8	Factory 5	Line 200(1)
62	Forming die motor	2	90	87	74.48	989	82.8	8	Factory 5	Line 200(1)
63	Shaping die motor	1	160	85	118.59	750	74.1	8	Factory 5	Line 200(1)
64	Hydraulic motor	1	22	90.5	18.23	1478	82.9	8	Factory 5	Line 200(1)
65	Coolant return motor	1	15	89	13.31	2921	88.7	8	Factory 5	Line 200(1)
66	Saw motor	1	160	94.9	109.59	1487	68.5	8	Factory 5	Line 200(1)
67	Distilled water pump motor	1	11	89.4	9.23	2948	83.9	8	Factory 5	Line 200(1)
68	Carriage motor	1	45	86	29.3	989	65.1	8	Factory 5	Line 200(1)
69	Conveyor motor	4	5.5	84.9	4.79	970	87.1	8	Factory 5	Line 200(1)
70	Hydraulic motor	1	15	90.6	10.6	1481	70.7	8	Factory 5	Line 200(2)
71	Roller motor	1	37	92.7	29.54	1482	79.8	8	Factory 5	Line 200(2)

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S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (kW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
72	Material storage motor	11	5.5	87.7	4.7	1466	85.5	8	Factory 5	Line 200(2)
73	Forming die motor	2	132	94.6	86.51	994	65.5	8	Factory 5	Line 200(2)
74	Shaping die motor	1	90	87.7	20.11	998	22.3	8	Factory 5	Line 200(2)
75	Hydraulic motor	1	22	84.1	4.33	1496	19.7	8	Factory 5	Line 200(2)
76	Coolant return motor	1	15	89.5	11.4	2932	76	8	Factory 5	Line 200(2)
77	Jaw uncoiler motor	2	30	88.8	9.43	1491	31.4	8	Factory 5	Silting(5)
78	Cutter motor	1	110	92.3	79.85	743	72.6	8	Factory 5	Silting(5)
79	Hydraulic motor	1	22	91.6	17.53	1482	79.7	8	Factory 5	Silting(5)
80	Material straightness motor	1	11	89.8	9.92	1472	90.2	8	Factory 5	Silting(5)
81	Uncoiler motor	1	110	94.3	76.99	987	70	8	Factory 5	Silting(5)
82	Chips uncoiler motor	1	11	89.8	9.31	1473	84.6	8	Factory 5	Silting(5)

### 5.3. Motor loading and efficiency

Motors are typically most efficient around 75% of their rated load and their efficiency decreases slightly as the load increases to 100% of the rated load. Going the other way, the efficiency starts dropping off a little more rapidly, down to around 50% load. Beyond that, motor efficiency drops off precipitously. Although the exact part-load efficiency curve of a motor will vary with size, type, manufacturer and other factors[27] and the following graph provide a general overview of part-load efficiency curves.

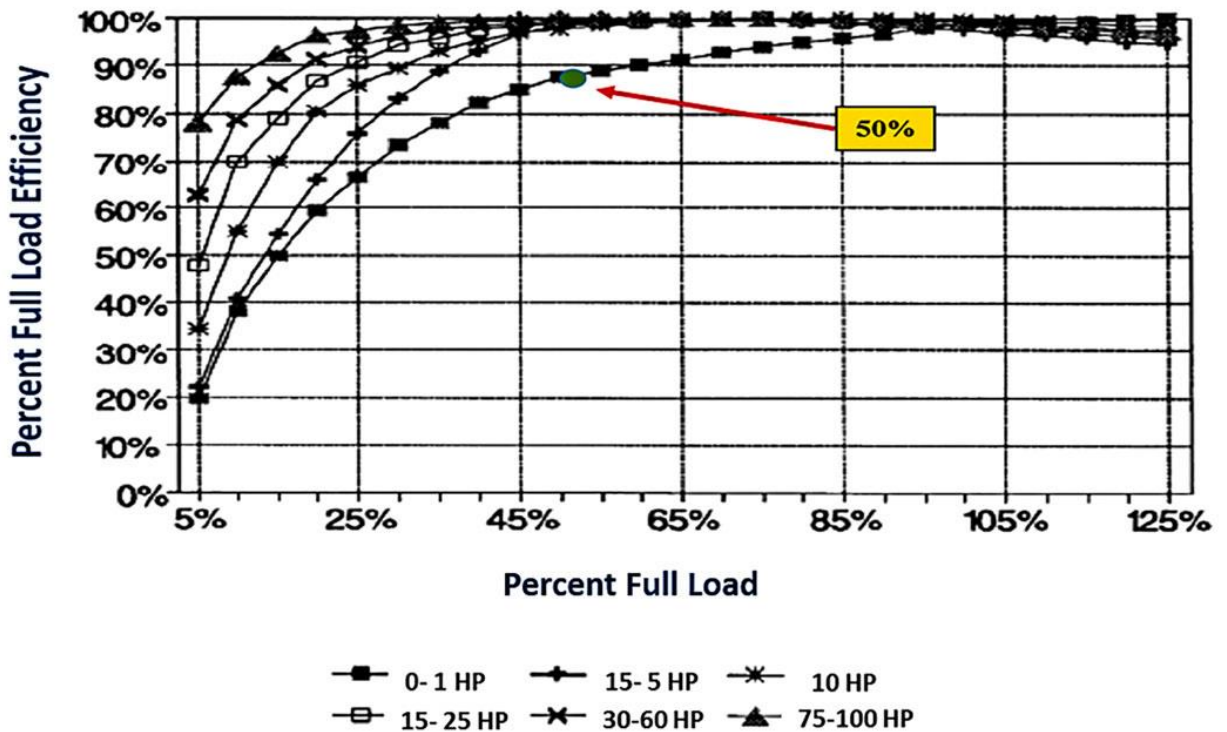


Figure 5-1 Percent Full Load Efficiency and Percent Full Load of Electrical motors[28]

### 5.4. Energy performance assessment of motors

The two most important parameters in assessing energy performance of a motor are efficiency and power factor. These parameters are mainly affected by the motor loading status of a motor. The efficiencies of motors remain almost constant between 50% to 100% loading as it can be seen in the Figure 5-1. When a motor has a higher rating than that required by the equipment, motor operates at part load. In this state, the efficiency of the motor is reduced. Replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for motors, and only when they are operating at less than one-third to one-half capacity, depending on their size[17].

Hence, motor loading and part load efficiency are mandatory while doing motor's performance assessment. However, aged motors may not have detailed nameplate data, and measurement of every parameter could be time taking and unmanageable thus using documentation of drawings and part load versus efficiency graphs of motors is advisable.

#### **5.4.1. Determining Motor Loading**

After the necessary data for analysis of performance assessment of motors has been collected, determining the motor loading shall be done to know whether the motor is properly loaded or not and the rated load of a motor describes the capacity of the motor to do work and most electric motors are designed to operate at 50%-100% rated load, and operate most efficiently at 75% load[29]. And there are three methods for determining the percentage motor loading namely input power measurements method, line current measurements method and the slip method. Of those methods measuring the motor's actual input power method provides a convenient and accurate way to determine the loading of a motor for the others does have accuracy limitations. In this case, the motor's measured power in KW (or V, I and PF) is required[30].

In determining percentage loading by input power measurements, first measure input power  $P_i$  with a hand held power meter, using the rated power  $P_{ir}$  of the motor along with the measured input power value the percentage loading of the motor can be computed as follows.

The percentage loading of a motor can now be calculated as follows:

$$\% \text{ Loading} = \frac{P_i}{P_{ir}} \times 100\% \quad (5.1)$$

Thus, when direct –read power measurements are available, can be used to estimate motor part load and the motor's part load can be quantified by comparing the measured input power under load to the power required when the motor operates at rated capacity.

$$\text{Motor Loading \%} = \frac{\text{Actual operating load of the motor}}{\text{Rated capacity of the motor}} \times 100\% \quad (5.2)$$

$$\text{Efficiency(\%)} = P_{rated} \times \left( \frac{0.746 \text{ Kw}}{\text{HP}} \right) \times \left( \frac{\% \text{ Motor Loading}}{P_{in}} \right) \quad (5.3)$$

$$\text{Torque}(Nm) = \frac{P_m(w) \times 9.549}{n(\text{rpm})} \quad (5.4)$$

The output power (mechanical power) is equal to the product of the operational efficiency and the input power to the motor.

$$N_s = \frac{120f}{p} \quad (5.5)$$

#### **5.4.2. Choosing the right motor size**

After the loading of motor's has been done, sizing the under loaded ones shall be done. And motor sizing refers to the process of picking the correct motor for a given load. It is important to size a motor correctly for the following two reasons:

- If a motor is too small for an application, it may not have sufficient torque to start the load and run it up to the correct speed. Even if it does get the load up to speed the motor will overheat and burnout if it is too small for the application.
- If a motor is too large for an application, then money has been wasted in purchasing such a large motor. Also motors typically operate inefficiently when they are run well below rated load. So money is also wasted in running costs[26].

At its simplest, if the load is constant then sizing the motor consists of choosing a motor whose rated torque is slightly above the torque required by the load. The load torque should be between 75%-100% of the rated motor torque with 95% being an ideal choice.

For constant speed applications where the motor will run continuously at rated speed you do not need to work out torque. You can simply look at load power and motor power and use the same 75%-100% rule. This is the case for standard induction motors without a variable speed drive[31].

#### **5.4.3. General Comment of the Energy Performance of Electric Motors in WSI**

As it can be seen in Table 5-1 the percentage loading of all motors considered for the detailed energy auditing has been calculated using the above equation and tabulated in Table 5-1. As per Table 5-1 the percentage loading of the 75 motors ranges from 58.9% to 90.2% and in this range of loading efficiency does not reduce significantly whereas the remaining 25 motor's percentage loading lies between 19.7% to 34.1% and this range is where efficiency decreases significantly thus further analysis and evaluation of those under loaded motors for replacement of with new ones of better efficiency and up to the size of the loading has been done using the MotorMaster+International analysis software.

And as per the computation made, 25 motors are found having their percentage loading less than one-third of their capacity and 75 motors are found having percentage loading of greater than one third their capacity. Thus, from the cutting value of loading of large motors it can be said that those 25 motors are the sources of energy inefficiency of the factory.

Thus, replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size.

And of the 100 motors considered for the detail audit work only the 25 motors whose loading value is less than the cutting value are sorted out and tabulated in Table 5-2 for further analysis using the MotorMaster + international software to evaluate the energy performance of the motors, recommend and draw conclusions on the energy conserving measures to be taken for the factory.

### **5.5. MotorMaster + international software**

MotorMaster + international software is an international motor selection and savings analysis (IMSSA) software tool and is designed to support energy consultants, motor distributors, and industrial end users in planning and carrying out energy management and motor efficiency improvement actions. IMSSA provides the energy and cost savings obtainable through selection and use of high efficiency or improved efficiency motors in three scenarios: new purchase, repair versus replace, and replacement of existing operable motors.

The electricity consumed by a motor-driven system over its operating life may cost over forty times the purchase price of the motor. Motors last for many years—even decades—so a smart choice at the time of purchase will produce long lasting energy efficiency benefits. High efficiency motors may cost slightly more than improved efficiency or standard efficiency motors but they can quickly repay their incremental cost in energy savings, reliability improvements, and lower maintenance requirements. Even a small efficiency gain makes a significant difference over the life of the motor.

IMSSA simplifies comparison for high efficiency motors as the software contains an internal database containing price and performance information for over 18,000 motors that are sold throughout the world. Enter motor specifications—kilowatt rating, synchronous speed, degree of protection, and operating voltage and the software will list

available motors, ranked in descending order of full load efficiency. And can also compare the operating costs of motor alternatives, taking into account the motor efficiency at the selected load point, annual operating hours, and electrical energy and demand charges.

The IMSSA motor selection tool was funded and developed to support end users in their selection of energy efficient motor systems. Energy efficiency saves money for our business. Businesses that operate economically are more competitive. The efficient use of energy also minimizes the need for new generating facilities, which in turn reduces greenhouse gas and other priority pollutant emissions and other environmental damages connected with energy production.

A Performance and price database containing information on more than 18,000 IEC metric motors. The motors range from 0.03 to 1,100 kW, with synchronous speeds of 500, 600, 750, 1000, 1500, and 3,000 Revolution Per Minute (RPM), and with enclosures featuring varying degrees of protection. Motors rated to operate at 190, 240, 380-420, 500, 550, 690, and 1900/3000 volts are included.

IMSSA has the analysis features that calculate the energy savings, money savings, greenhouse gas emission reductions, simple payback, cash flows, and after-tax rate of return on investment from using a particular high efficiency motor in a new purchase or retrofit application. Variables such as motor efficiency, purchase price, energy costs, hours of operation and motor load factor are taken into account.

Furthermore, MotorMaster + international software contains a database of new motor price and performance, and features many motor energy management capabilities including replacement analysis, maintenance logging, energy and dollar savings tracking, simple payback period and life cycle cost analysis.

The input parameters to this software are motor nameplate and measured data; like power in kilowatts, speed in revolutions per minute, percentage loading, efficiency, annual operating hours, and energy purchase price in €/kWh.

And the output parameters of the software are energy and demand savings, simple payback period, purchase price of the energy efficient motor, greenhouse gas emissions reduction report.

### **5.5.1. Accessing IMSSA's motor selector and motor savings analysis features**

Motor Selector destination button software module uses information entered from the keyboard to create a list of all available motors meeting specifications, along with their

performance and purchase data. Available motors are listed in descending order of full-load efficiency. High efficiency and improved efficiency motor standard bars appear, so motors that equal or exceed either efficiency standard are readily apparent

The Motor Selector screen contains parameters for selecting and sorting lists of all purpose, definite purpose, or special purpose motors from the motor manufacturer's database or catalog. For instance, the user may wish to create a list of all available 37kW, 1500 RPM, 400-volt motors with an IP55 degree of protection. The available motors are sorted in descending order of the motor's full-load efficiency, and display the motor's model and catalog numbers, full-load speed, power factor and manufacturer's list price.

Additionally, Motor Savings Analysis destination button heads to access IMSSA's energy savings analysis capabilities. Motor Savings Analysis allows you to calculate the annual energy consumption and energy costs for using particular motors in a specific application. It predicts expected energy and cost savings for replacing an existing motor with a specific motor model, and shows the simple payback based on the motor purchase price and energy-cost savings.

The motor savings analysis module produces an analysis of potential energy and Euro savings and computes the simple payback on the investment in the more efficient motor. Note that the simple payback period in years is the incremental cost of the high efficiency motor divided by the monetary value of the annual efficiency benefits[32].

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Table 5-2 Under Loaded Motors in WSI

S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (KW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
1	DC machine	1	75	84.9	15.44	1497	20.6	12	Factory 1	Cut to size(3)
2	Belt motor	1	15	81.3	4.14	1490	27.6	12	Factory 1	Cut to size(3)
3	DC master	1	132	91.4	36.65	1496	27.8	12	Factory 1	Line 76(1)
4	Cutting motor	1	22	80.2	5.69	2973	25.9	9	Factory 2	Line 76(2)
5	Cutting motor	1	18.5	77.7	5.65	2981	30.5	8	Factory 3	Line 60(1)
6	Coil storage motor	1	11	79	2.71	1496	24.6	8	Factory 3	Line 60(1)
7	Servo motor	1	11	81.1	3.3	1489	30	8	Factory 3	Cut to size(2)
8	Saw motor	1	11	72.9	2.94	2983	26.7	8	Factory 3	Line 38(2)
9	Cart motor	1	15	80.7	3.79	1498	25.3	8	Factory 3	Line 38(2)
10	Material feeding motor	1	15	81.9	4.52	1490	30.1	8	Factory 3	Silting(3)
11	DC motor	1	37	85.8	9.43	1495	25.5	8	Factory 3	Silting(3)
12	Cutting motor	1	30	88.1	7.66	1492	25.5	8	Factory 3	Cut to size(4)
13	Saw motor	1	18.5	76.1	4.73	2984	25.6	7	Factory 4	Line 60(3)
14	DC motor for cutting home	1	22	87.1	6.01	1477	27.3	7	Factory 4	Line 60(3)
15	DC master	1	132	90.9	45	985	34.1	7	Factory 4	Line 60(3)
16	Coil storage motor	1	11	81.4	3.39	1489	30.8	7	Factory 4	Line 60(3)
17	DC motor	1	55	83.5	11.61	1495	21.1	7	Factory 4	Silting(4)

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S.No	Motor Description	Quantity	Name plate data		Measured Data		Calculated	Motor Service year(Age)	Factory No	Production line
			Rated power (KW)	Rated Efficiency (%)	Input Power (KW)	Shaft Speed (Rpm)	% loading			
18	Cutter motor	1	132	89.4	36.41	2988	27.6	7	Factory 4	Silting(4)
19	Hydraulic motor	1	15	81.4	4.19	1490	27.9	8	Factory 5	Line 200(1)
20	Roller motor	1	22	85.3	6.81	992	31	8	Factory 5	Line 200(1)
21	Material storage motor	1	90	89.6	26.59	996	29.5	8	Factory 5	Line 200(1)
22	Shaping die motor	1	90	87.7	20.11	998	22.3	8	Factory 5	Line 200(2)
23	Hydraulic motor	1	22	84.1	4.33	1496	19.7	8	Factory 5	Line 200(2)
24	Jaw uncoiler motor	1	30	88.8	9.43	1491	31.4	8	Factory 5	Silting(5)
25	Jaw uncoiler motor	1	30	88.8	9.43	1491	31.4	8	Factory 5	Silting(5)

### 5.6. Motors performance analysis using MotorMaster + international software

Under Loaded Motor's performance evaluation using MotorMaster + international software for all the 25 motors whose percentage loading is less than cutting value for large motors has been evaluated using the software and the motor purchase price data, utility cost per use data of energy, demand charge, power factor and motor saving analysis of replacing the existing motor using IMASS are shown in Figure 5-2 and Figure 5-3 below, which is sample output of the analysis software. Moreover, similar simulation has been also done for all the 25 motors in the factory and the motor energy savings, total cost savings and simple payback analysis are summarized in Table 5-3 and Table 5-4 below.

As a result, the detailed motor saving analysis output that includes mainly annual energy savings, total energy cost savings and simple payback years from replacing existing under loaded motors is summarized in Appendix E.

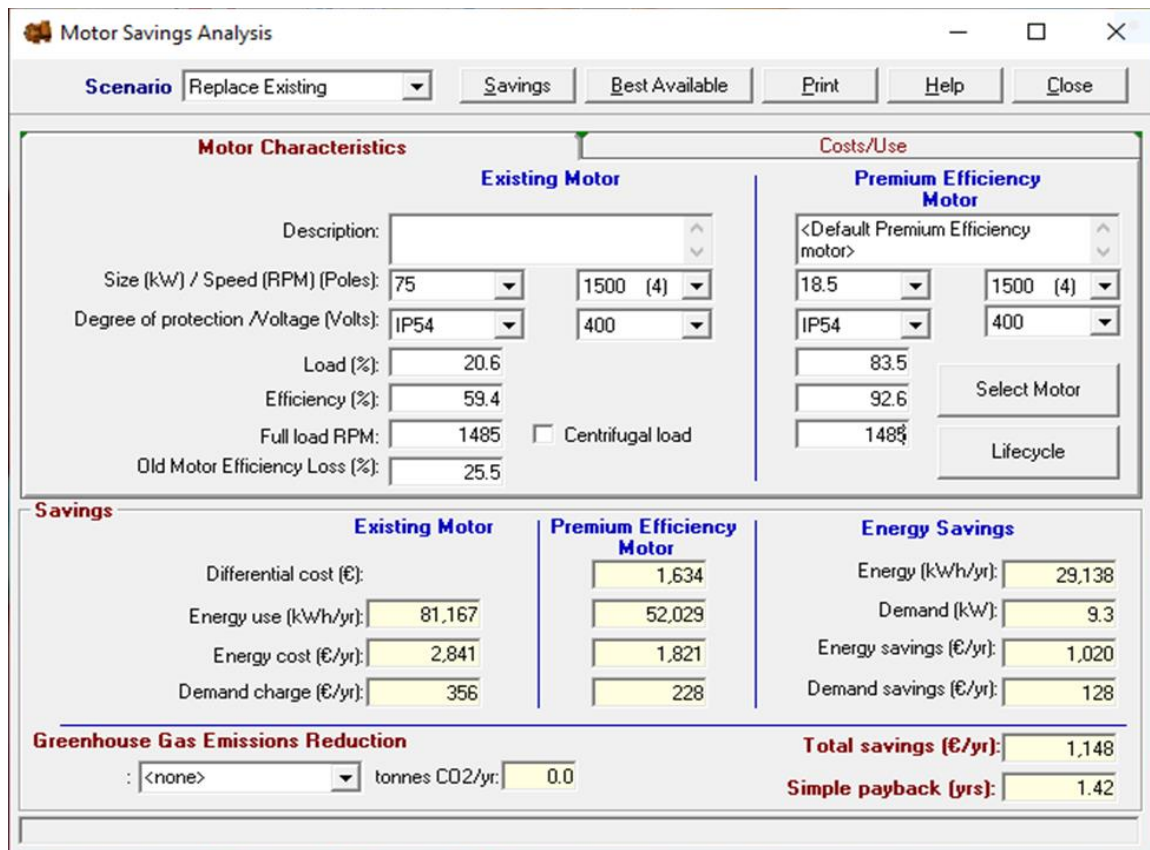


Figure 5-2 Motor Saving analysis of replacing the existing motor using IMASS

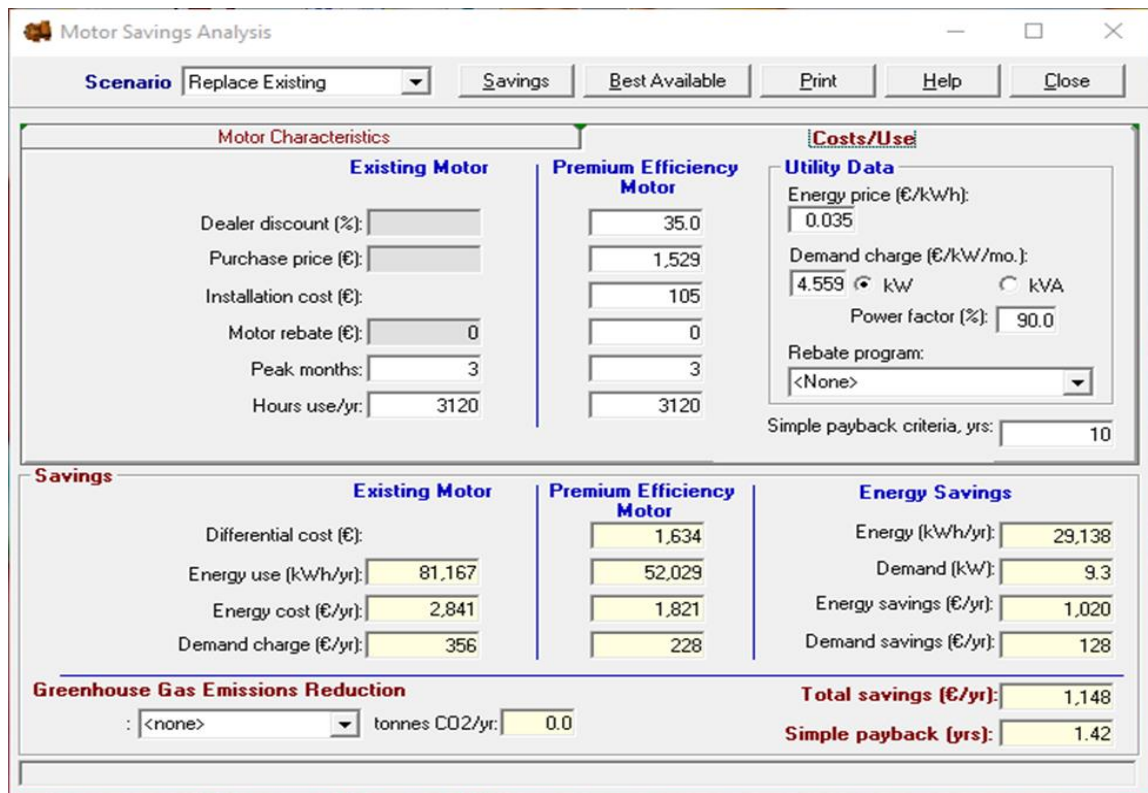


Figure 5-3 Utility cost per use data of energy, demand Charge and power factor

## 5.7. Energy conservation opportunities in electric motors

Energy conservation opportunity identified for WSI electrical motors as per the analysis made is replacing the under loaded inefficient motors found in the factory with appropriate size and energy efficient motors as per the motor's size in Table 5-3 of column replacing motor rated power(KW).

### 5.7.1. Technical evaluation of replacing the existing motors

As discussed above, there are 25 motors with percentage loading below cutting value. Due to this, the factory is wasting significant amount of energy. This energy loss can be mitigated by proper sizing of the motors as per the loading found using the measurement data. As we can see from Table 5-3, the replacement of the existing under loaded motors with proper size ones and of better efficiencies can save 408.15MWh of energy annually which is significant amount of energy. Thus, replacing these motors is technically feasible.

Table 5-3 The Annual Energy Savings from replacing Existing Under loaded and inefficient Motors with energy efficient motors

<b>Existing Motor Rated power (KW)</b>	<b>Measured input power (KW)</b>	<b>Replacing Motor Rated Power (KW)</b>	<b>Existing Motor Energy use (KWh/yr.)</b>	<b>Replacing Motor Energy use (KWh/yr.)</b>	<b>Energy Savings (KWh/yr.)</b>
75	15.44	18.5	81167	52029	29138
15	4.14	5.5	22161	14385	7776
132	36.65	37	163140	121771	41369
22	5.69	7.5	30364	19676	10688
18.5	5.65	7.5	31874	19484	12390
11	2.71	3	14836	9663	5173
11	3.3	3.7	17429	11619	5810
11	2.94	3	18041	10498	7543
15	3.79	4	20240	13352	6888
15	4.52	5.5	23199	15687	7512
37	9.43	11	45444	32171	13273
30	7.66	11	36686	26119	10567
18.5	4.73	5.5	27568	16529	11039
22	6.01	7.5	28579	20672	7907
132	45	55	191624	150318	41306
11	3.39	3.7	17570	11936	5634
55	11.61	15	64092	39265	24827
132	36.41	37	167904	121240	46664
15	4.19	5.5	22108	14541	7567
22	6.81	7.5	33946	24300	9646
90	26.59	30	122482	89999	32483
90	20.11	22	97584	68715	28869
22	4.33	5.5	23865	15058	8807
30	9.43	11	44756	32119	12637
30	9.43	11	44756	32119	12637

### 5.7.2. Economical evaluation of replacing the existing motors

As we can see from Table 5-4 below, the energy cost savings gained annually through proper sizing of motors for those lightly loaded 25 motors is 16,075 Euro which is 705,210.25ETB and the payback periods of replacing these 25 energy inefficient motors with better energy efficient motors ranges from 0.92 years to 2.74 years. Besides, it is known that the average life time of motors is assumed to be 10 to 15 years where as all those motors have served seven up to twelve years in the factory thus replacing the 25

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existing energy inefficient motors is also economically feasible energy conservation opportunity for WSI.

Table 5-4 Total Cost Savings and the Simple Payback Periods of Replacing the Existing Motors

Existin g Motor Rated power (KW)	Measure d input power (KW)	Replacin g Motor Rated Power (KW)	Existin g Motor Total Energy Cost (€/yr.)	Replacing Motor		Total Energy Cost Savings (€/yr.)	Simple Paybac k (yrs.)
				Differentia l Cost (€)	Total Energy Cost (€/yr.)		
75	15.44	18.5	3197	1634	2049	1148	1.42
15	4.14	5.5	873	675	566	307	2.2
132	36.65	37	6425	2429	4796	1629	1.49
22	5.69	7.5	1196	823	775	421	1.95
18.5	5.65	7.5	1256	823	767	489	1.68
11	2.71	3	584	440	380	204	2.16
11	3.3	3.7	686	279	458	228	1.22
11	2.94	3	710	331	413	297	1.11
15	3.79	4	797	540	526	271	1.99
15	4.52	5.5	914	675	618	296	2.28
37	9.43	11	1790	913	1267	523	1.75
30	7.66	11	1445	913	1028	417	2.19
18.5	4.73	5.5	1086	402	651	435	0.92
22	6.01	7.5	1125	849	815	310	2.74
132	45	55	7547	3827	5920	1627	2.35
11	3.39	3.7	692	279	470	222	1.26
55	11.61	15	2524	1300	1546	978	1.33
132	36.41	37	6613	2896	4774	1839	1.57
15	4.19	5.5	871	675	573	298	2.27
22	6.81	7.5	1337	625	958	379	1.65
90	26.59	30	4824	2208	3545	1279	1.73
90	20.11	22	3843	1835	2706	1137	1.61
22	4.33	5.5	940	675	593	347	1.95
30	9.43	11	1762	913	1265	497	1.84
30	9.43	11	1762	913	1265	497	1.84

Though the percentage loading of the 75 electrical motors is in a range where loading efficiency does not reduce significantly the following general recommendation for better energy-efficiency improvement opportunities shall be considered:

1. Motor management plan: creation of a motor survey and tracking program, development of guidelines for proactive repair/replace decisions, preparation for motor failure by creating a spares inventory, development of a purchasing

specification and development of a repair specification and development and implementation of a predictive and preventive maintenance program

2. Maintenance program: the maintenance measures can be as either preventative or predictive. The purpose of predictive motor maintenance is 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. And the preventative measures, include voltage imbalance minimization, load consideration, motor alignment, lubrication and motor ventilation.
3. Rewinding of old motors: for it is cost-effective to rewind an existing energy-efficient motor, instead of purchasing a new motor
4. Minimizing idling of electric motors : for a motor that is turned off consumes no energy
5. Minimizing voltage unbalances: a voltage unbalance degrades the performance and shortens the life of three-phase motors. This causes a current unbalance, which will result in torque pulsations, increased vibration and mechanical stress, increased losses, and motor overheating, which can reduce the life of a motor's winding insulation

## CHAPTER SIX

### SYSTEMIC LOAD FLOW ANALYSIS AND OPTIMUM PLACEMENT OF POWER FACTOR CORRECTOR

#### 6.1. Introduction

Systemic Load Flow Analysis is intended to be done to evaluate the systemic energy performance of the factory and to optimally place the PFC. This compensates reactive component of the energy drawn by the system from the grid which currently is the main source of penalty with huge sum of money for the factory.

As we can see from the energy consumption data of 23 months in Table 4-1, the averaged power factor of the factory was found to be 0.48; which is very low value and shall be corrected to EEU's target power factor value that is 0.9. Besides, the average power consumption of the factory is 0.5MW and the operating load found during measurement was 0.55MW.

As shown in Table 6-1 below, the total installed load of the factory is 5.02MW thus the diversity factor of the factory is 10.97%. As per the average load, operating load and data taken from substation, the maximum apparent power required and the maximum demand of the factory is 1688KVA and 1350KW respectively.

In the systemic load flow analysis of power distribution system of the factory the power analysis software ETAP 16.0.0 is used. The installed loads, operating loads, power cable data and transformer technical data of the factory are considered for load flow analysis by doing so the cables and distribution transformer power losses were quantified and converted to energy losses using the annual operating hours of the factory, thereby to evaluate the systemic energy performance of the factory.

#### 6.2. Power factor

Before starting defining what power factor is, let us define some basic terms, the active power (KW) is working power that actually powers the equipment and performs useful work whereas the reactive power (KVAR) is the power that magnetic equipment (transformer, motor and relay) needs to produce the magnetizing flux and the apparent power (KVA) is the vectorial summation of KVAR and KW. Thus, PF is the ratio of Working Power to Apparent Power.

$$PF(\cos \phi) = \frac{kW}{kVA} \quad (6.1)$$

$$PF(\cos \phi) = \frac{KW}{KW + jKVAR} \quad (6.2)$$

$$PF \text{ Charge} = \left( \frac{0.9}{PF_{Av}} - 1 \right) \times P_{MAX} \times D. \text{ Charge} \quad (6.3)$$

Based on the above definitions, the active power is the real power delivered to the loads and the reactive power is used for the purpose of producing magnetic field for the flow of active power. Besides, apparent power is the combination of the active and reactive power.

The load current of any motor consist of the resistive component and inductive component. The inductive component consists of leakage current and magnetizing current. The leakage current is totally dependent on the load current but the magnetizing component is nearby 20 to 60% of the full load current. Thus power factor is a measure of how efficiently electrical power is converted into useful work output. The ideal power factor is unity, or one[33].

### **6.3. Power Factor Corrector**

Inductive loads constitute a major portion of the power consumed in industrial complexes and the reactive power (KVAR) required by inductive loads increases the amount of apparent power (KVA) in the distribution system. This increase in reactive and apparent power results in a larger angle (measured between KW and KVA). As  $\phi$  increases, cosine of  $\phi$  or power factor decrease thus electrical power distribution system of the industry could have a power factor much less than one.

Thus, capacitors are employed to reduce inductive reactance in the inductive load if inefficient conversion is available in the system under consideration that is if the power factor value is found low. In order to have an efficient system the power factor shall be corrected using power factor correctors of capacitor banks and the value shall be brought a little in excess of 0.9 but shall not be too close to unity, to avoid the leading current in the electrical system .

And the following are benefits that can be gained through improving the power factor of a system:

- Lower utility fees by reducing peak KW billing demand and eliminating the power factor penalty.
- Increased system capacity and reduced system losses in the electrical system

- Increased voltage level in your electrical system and cooler, more efficient motors[34].

#### **6.4. Electrical Transient Analyzer Program (ETAP 16.0.0)**

ETAP is a modeling and simulation software package that can be used for power flow analysis of the power distribution system for a factory based on the input data of the primary data and one-line diagram of power distribution system of the factory; moreover, the system's annual technical energy loss is analyzed and investigated as well.

Furthermore, ETAP is the most popular and powerful electrical engineering analysis and management tools established as a world leader in power system design, analysis, and monitoring.

##### **6.4.1. One-Line Diagrams**

ETAP provides an easy to use, fully Graphical User Interface (GUI) for constructing one-line

diagrams. Here, one can graphically add, delete, relocate, connect elements, zoom in or out, display grid off or on, change element size, change element orientation, change symbols, change equipment/device color, create personalized viewing themes, hide or show protective devices, enter properties and set operating status [35].

#### **6.5. Input Data to ETAP power flow analysis software**

The input data for the ETAP 16.0.0 power analysis software are cable data of 25 power lines, installed loads in each power line, operating loads for the individual power lines, six distribution transformers data and the systemic average power factor value of the factory. Besides, the SLD of power distribution system of the factory which is prepared using the data collected from the factory as shown in Table 6-1 and Figure 6-1 were used as input for the analysis software.

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Table 6-1 Power Lines of WSI Power Distribution System and their detailed data

<b>S.No</b>	<b>Power Lines Name</b>	<b>Cable Size (mm<sup>2</sup>)</b>	<b>Cable length (m)</b>	<b>Conductor Material</b>	<b>Installed Load (KW)</b>	<b>Operating Load (KW)</b>
1	Line 60(1) HF	3x180/120	40	Copper	167.5	18.14
2	Line 60(1) Saw	3x120/70	40	Copper	77.5	9.45
3	Crane and Office	3x70/35	75	Copper	106.7	10.72
4	Cut to Size(1)	3x120	75	Copper	70.85	8.72
5	Cut to Size(3)	3x120	75	Copper	121.1	14.3
6	Line 38(1) HF	3x120	30	Copper	150	16.25
7	Line 38(1) Saw	3x70	30	Copper	85.7	10.48
8	Line 76(2) HF	3x300/120	50	Copper	167.5	18.14
9	Line 76(2) Saw	3x120/70	45	Copper	77.5	9.45
10	Slitting (1)	3x120/70	20	Copper	257.86	27.86
11	Line 38(3) HF	3x150/70	35	Copper	75.46	9.19
12	Line 38(3)Saw	3x120/70	35	Copper	50.31	6.28
13	Line 60(3)	3x180	200	Copper	245	26.48
14	Line 38(2)	3x150	200	Copper	258.6	27.94
15	Cut to Size(4)	3x120	150	Copper	206	22.28
16	Line 200(1) HF	3x240/120	50	Copper	600	64.51
17	Line 200(1) DC motor	3x240/120	50	Copper	150	16.25
18	Silting(5)	3x240/120	60	Copper	324	34.96
19	Line 200(1) Storage motor	3x240/120	40	Copper	90	11.03
20	Line 200(1) Saw motor	3x120/70	15	Copper	535.4	57.6
21	Line60(1)	3x300/120	200	Copper	245	26.48
22	Line60(2)	3x300/120	200	Copper	245	26.48
23	Silting(3)	3x150/70	200	Copper	214.9	23.24
24	Cut to Size(2)	3x120/70	200	Copper	54.59	6.85
25	Slitting (4)	3x180	150	Copper	444.1	47.83

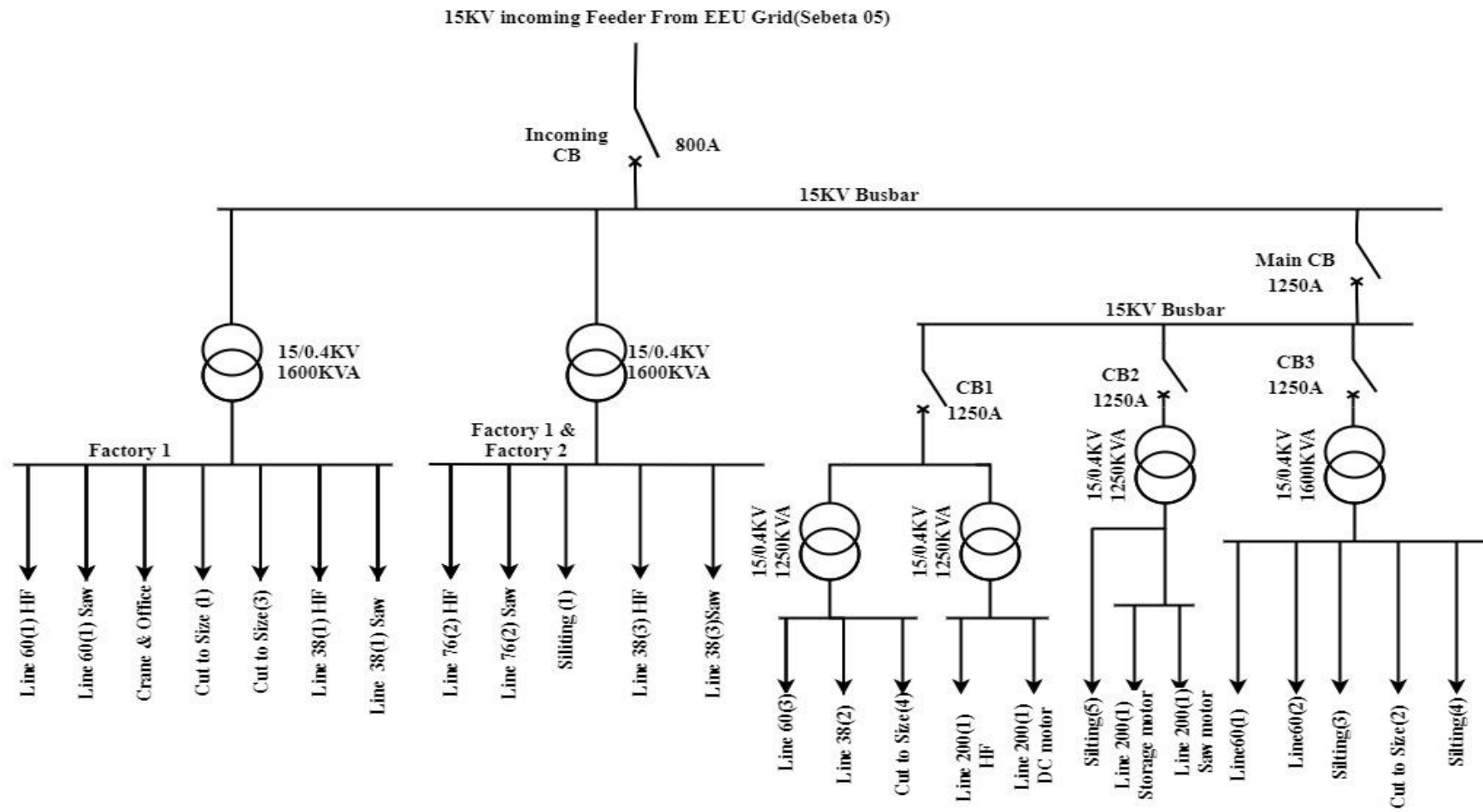


Figure 6-1 Single Line Diagram (SLD) of WSI Power Distribution System

## 6.6. ETAP power flow analysis out puts

In the factory, there are about 25 power supplying lines of different cable sizes which distributes power to different parts of the factory. Additionally, there are about three distribution transformers of 1250KVA capacity each and three other distribution transformers of 1600KVA capacity each totally in the factory the installed capacity is of 8550KVA. As per the load flow analysis carried out using ETAP, in the existing power distribution networks of the factory losses found on the cables and the transformers are summerized in the Table 6-2 below.

Table 6-2 Distribution Transformers and Power Cables Energy Losses of the existing network

Description	Type of Loss		Total Losses (MWh/yr)
	No Load Losses (MWh/yr)	Load Losses (MWh/yr)	
Distribution Transformers	137.38	4.88	142.26
Power Cables		16.23	16.23
Grand Total Losses(Transformer and Cables)			158.49

As per Table 6-2, the annual energy losses of the six distribution transformers found in the factory is 142.26MWh and of the 25 power cables is 16.23MWh which is 158.49MWh total annual energy losses both in the transformers and cables.

When this sum of energy loss is converted into monetary terms using the revised tariffs of EEU, the annual financial losses because of the energy losses of the factory mainly due to the transformer and cable energy losses is 5,531Euro which is 242,648ETB.

### 6.6.1. Determine Amount of KVAR Required

Let  $\phi_1$  is the original power factor angle,  $\phi_2$  is the final or the corrected power factor angle and P is the active operating power then the required capacitor KVAR to improve the power factor of the system from  $\phi_1$  to  $\phi_2$  is :

$$KVAR\ required = P(\tan \phi_1 - \tan \phi_2) \quad (6.4)$$

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Accordingly, the capacitor KVAR required to improve the power factor from 0.48 to 0.9 for all the 25 power lines in factory is summarized in Table 6-3 below and the total KVAR required is 752KVAR.

Table 6-3 Capacitor KVAR Required for the PF Improvement of Power Lines of WSI

S.No	Power Lines Name	Installed Load (kW)	Operating Load(kW)	Capacitor for PF correction (kVAR)
1	Line 60(1) HF	167.5	18.14	25
2	Line 60(1) saw	77.5	9.45	13
3	Crane and office	106.7	10.72	15
4	Cut to size(1)	70.85	8.72	12
5	Cut to size(3)	121.1	14.3	20
6	Line 38(1) HF	150	16.25	22
7	Line 38(1) saw	85.7	10.48	15
8	Line 76(2) HF	167.5	18.14	25
9	Line 76(2) saw	77.5	9.45	13
10	Slitting (1)	257.86	27.86	38
11	Line 38(3) HF	75.46	9.19	13
12	Line 38(3)saw	50.31	6.28	9
13	Line 60(3)	245	26.48	36
14	Line 38(2)	258.6	27.94	38
15	Cut to size(4)	206	22.28	30
16	Line 200(1) HF	600	64.51	87
17	Line 200(1) DC motor	150	16.25	22
18	Silting(5)	324	34.96	47
19	Line 200(1) storage motor	90	11.03	15
20	Line 200(1) saw motor	535.4	57.6	78
21	Line60(1)	245	26.48	36
22	Line60(2)	245	26.48	36
23	Silting(3)	214.9	23.24	32
24	Cut to size(2)	54.59	6.85	10
25	Silting(4)	444.1	47.83	65

## **6.7. Optimal placement of Power Factor Corrector**

As discussed above, the sources of reactive power are inductive loads like motors and transformers that reduce the power factor of a system. On the other hand, capacitors are consumers of reactive power that is it is generators of reactive current required by the loads by doing that reduces the total current that would have been flowing through the cables and up streams of the power distribution network of the factory. Hence, capacitors can increase power factor of system and improve significantly the energy loss of the power distribution system.

To achieve the above mentioned advantages knowing where to install PFC in the system matters a lot. Accordingly, in WSI placing the PFC at the power lines which are feeding power to a group of motors is considered that is group or central compensation is applied and preferred over individual compensation or installing PFC to each and every motors of the factory. This preference is made based on the variable trend of daily or monthly power consumption pattern of the factory. As a result, the cable and transformer losses of the factory can be mitigated. Thus, installing the PFC near to the group loads of the motors is considered for the factory under consideration of this thesis work.

### **6.7.1. Average and Peak Load of WSI**

As per the operating load of the factory, the apparent power is 1146KVA. Moreover, the data obtained from Sebeta substation revealed that the average and peak power of the factory which was taken for a week time in every thirty minutes of the feeder which is feeding power to the factory only was found to be 753KVA and 1688KVA.

However, the installed capacity of the factory is 3x1250KVA and 3x1600KVA which is of 8550KVA total capacity. Thus, as per load profile of the factory this capacity is underutilized and is only becoming the source of no load losses. Therefore, as per the load profile of the factory and the substation data transformers of 2x1250KVA capacity is enough for the power requirement of the factory.

## **6.8. ETAP power flow analysis outputs after PFC is incorporated in the system**

As per the discussions and design made above, to mitigate the losses found in the cables and transformers, properly sizing the capacity of transformers require to the actual requirement of factory and improve the power factor of the factory designs has been made those are:

- Optimal placement of PFC as per the calculated values of the required capacitor KVAR for each of the 25 lines of group of loads.
- Decided the number of transformers required for the factory as per actual power or the capacity requirement of the factory.
- Reconfiguring the power distribution lines.

Then, the load flow analysis has been carried out using ETAP 16.0.0 software on the designed power distribution networks and the losses found on cables and the transformers are summarized in the following table Table 6-4.

Table 6-4 Distribution Transformers and Power Cables Energy Losses of the designed network

Description	Type of Loss		Total Losses (MWh/yr)
	No Load Losses (MWh/yr)	Load Losses (MWh/yr)	
Distribution Transformers	39.74	4.56	44.31
Power Cables		4.66	4.66
Grand Total Losses(Transformer and Cables)			48.96

As per Table 6-4, the annual energy losses of the designed power distribution network of the factory having 2x1250KVA transformers and 25 power lines with their respective loads is 44.31MWh and 4.66MWh respectively which is equivalent to 48.96MWh total annual energy losses both in the transformers and cables.

When this still existing energy loss is converted into monetary terms using the revised tariffs of EEU, the annual financial losses due to the transformer and cable energy losses is 1,708.63Euro which is 74,957.76ETB.

### **6.8.1. Technical and Economic Evaluation Of The Designed Network**

As per the load flow analysis conducted for the existing and designed power distribution networks of the factory, the energy losses were found to be 158.49MWh/yr and 48.96MWh/yr respectively. Thus, it can be seen from the values that by correcting the power factor of the system and reconfiguring the network the energy loss has decreased by 69.1%.

When it comes to the annual cost saving, 3,822.44Euro which is 167,690.43ETB can be saved from the avoided loss. On monthly basis, the savings from the energy usage is 13,974.20ETB, from demand charge is 7,021.15ETB and from the power factor penalty is 236,250.00ETB. Thus, the total saving is 257,245.35ETB. But, the cost of PFC per KVAR for low voltage PFCs is 35USD[36] and for the total KVAR required for the correction of the operating power factor of the factory is 752KVAR thus, the total cost including installation cost becomes 1,261,543.92ETB thus the payoff becomes 4.9 months where the installation is assumed to be the thirty percent of the equipment cost.

Besides, to above mentioned cost saving advantages gained when the power factor is corrected to the desired value and the reduction in losses will also decrease transformer capacity requirement to proper KVA size of transformers that suits right to the actual power consumption pattern of the factory. Therefore, capacities of 1x1250KVA and 3x1600KVA capacity of transformers have been identified as extra capacities and can be saved for other uses like in expansion works of the factory considered to be under taken.

## **CHAPTER SEVEN**

### **CONCLUSION AND RECOMMENDATIONS**

#### **7.1. CONCLUSION**

The main goal of energy audit is to achieve energy savings and the point of view is energy consumption and saving possibilities. However, the technical, financial and environment conditions shall be considered for better decision making strategy by adjusting and optimizing energy using systems to reduce energy requirements per unit of product while holding constant or reducing total costs of producing the output from these systems. Hence, on this thesis work the energy performance of WSI has been assessed and the possible energy conservation measures were identified.

For analysis of the energy usage of the factory, specific energy consumption, to evaluate the overall energy performance of the factory 23 months (April 2018-February 2020) data of electrical energy from the EEU grid, energy from diesel fuel ,production data of the factory and benchmark data were collected. Besides, measurements on 100 motors and substation data of the feeder which is feeding to the factory has been collected and used for the analysis made in thesis work.

As per the analysis of the energy bill and production data of the factory, the monthly average power factor value was 0.48 while the minimum requirement of EEU is 0.9. Likewise, the monthly average load factor of the factory is 31.80% which is low load factor. Additionally, from the monthly average electrical energy cost of WSI 60,896.93ETB was the monthly average real energy cost, 45,481.52 ETB was the power factor penalty cost and 36,083.15ETB was the maximum demand penalty cost thus the factory was paying 81,564.67ETB monthly on average for penalty of inefficient energy usage which is 57% of the monthly average electrical energy cost which is on the average paying 978,776.04ETB for penalty on annual base.

As per the loading analysis of the motors, of the hundred motors twenty five of them has been found under loaded and were operating inefficiently. Thus, needs to improve their energy efficiency. Then, using motor master+ international software, it has been seen that replacing the under loaded ones with proper sizing of motors can save 408.15MWh annually and the energy cost savings gained is 16,075.00Euro which is 705,210.25ETB annually with payback periods ranging from 0.92years to 2.74years thus replacing the 25 existing energy inefficient motors is technically and economically feasible energy conservation opportunity for WSI.

Finally, the existing and designed power distribution system of WSI has been analyzed using ETAP 16.0.0 software package. Accordingly, the annual energy and financial losses of the factory for the existing were found 158.49MWh and 242,648ETB, for the designed were found to be 48.96MWh and 74,957.76ETB respectively.

Thus, in the designed power distribution system by correcting the power factor of the system and reconfiguring the network the energy loss has decreased by 69.1%. In addition to this, the annual cost saving of 3,822.44Euro which is 167,690.43ETB is gained from the avoided loss. On monthly basis, the savings from the energy usage is 13,974.20ETB, from demand charge is 7,021.15ETB and from the power factor penalty is 236,250.00ETB. Thus, the total saving is 257,245.35ETB and the total cost including the installation cost of PFC is 1,261,543.92ETB thus the payoff becomes 4.9 months.

Additionally, PFC installation in the system has down sized the installed transformer capacity to the system's actual capacity requirement. Therefore, out of 8550KVA existing installed capacity 6050KVA has been saved and identified as extra capacity.

## **7.2. RECOMMENDATIONS**

In this thesis work, from the conducted detail energy audit of the factory major energy conserving measures has been recommended so that the factory can optimize its energy usage thereby reduce its energy cost.

Accordingly, replacing the under loaded motors with proper sizes of better efficiency, installing PFC in all the power distribution lines is highly recommended. Nevertheless, while installing the PFC the total harmonic distortion content of the power system of the factory shall be analyzed first. For better maintenance and procurement plans of the factory conducting periodic motor inspection as per the check list attached in Appendix H is also recommended.

And as per the interview made with the factory's managers and staffs, the energy management of the factory has been given low attention; but it is known that energy is a top rank cost factor in industries. Thus, to bring successful, cost-effective and optimum energy usage in the factory resizing the motors and power factor correction alone are not enough but the factory should establish energy management team who can develop operational and maintenance manuals for better motor management plans so that the energy usage could be monitored seriously and energy management awareness can be created across all managers and staffs of the factory.

Last but not least, the government in general and EEU, in particular, should not only penalize factories of inefficient energy users which are having poor power factor, poor load factors, and having any other inefficiency reasons but also should have other better-enforcing laws that urge those industries to correct their inefficient energy usages.

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**Appendix A: Monthly Energy Consumption from EEU Grid Data**

<b>Month (Billing Period)</b>	<b>KWh</b>	<b>KVARh</b>	<b>Maximum Demand (KW)</b>	<b>Power Factor</b>	<b>Cost per KWh</b>	<b>Monthly Energy Cost</b>	<b>PF Charge</b>	<b>Maximum Demand Cost</b>	<b>Total Electrical Energy Cost</b>
April 2018	144,000.00	234,000.00	1350	0.52	0.4086	58,838.40	31,277.31	-	90,115.71
May 2018	90,000.00	216,000.00	1350	0.38	0.4086	36,774.00	42,883.04	-	79,657.04
June 2018	252,000.00	333,000.00	1350	0.6	0.4086	102,967.20	24,675.32	-	127,642.52
July 2018	63,000.00	117,000.00	1350	0.47	0.4086	25,741.80	35,437.41	-	61,179.21
August 2018	126,000.00	216,000.00	1350	0.5	0.4086	51,483.60	32,960.27	-	84,443.87
September 2018	108,000.00	189,000.00	1350	0.5	0.4086	44,128.80	33,603.62	-	77,732.42
October 2018	81,000.00	153,000.00	1350	0.47	0.4086	33,096.60	35,954.29	-	69,050.89
November 2018	117,000.00	207,000.00	1350	0.49	0.4086	47,806.20	33,943.24	-	81,749.44
December 2018	117,000.00	207,000.00	1350	0.49	0.4086	47,806.20	33,943.24	-	81,749.44
January 2019	72,000.00	99,000.00	1350	0.59	0.6047	43,538.40	26,399.46	49,794.75	119,732.61
February 2019	90,000.00	189,000.00	1350	0.43	0.6047	53,423.00	54,442.92	49,794.75	157,660.67
March 2019	81,000.00	135,000.00	1350	0.51	0.6047	48,980.70	37,310.49	49,794.75	136,085.94
April 2019	162,000.00	279,000.00	1350	0.5	0.6047	97,961.40	39,454.61	49,794.75	187,210.76

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<b>Month (Billing Period)</b>	<b>KWh</b>	<b>KVARh</b>	<b>Maximum Demand (KW)</b>	<b>Power Factor</b>	<b>Cost per KWh</b>	<b>Monthly Energy Cost</b>	<b>PF Charge</b>	<b>Maximum Demand Cost</b>	<b>Total Electrical Energy Cost</b>
May 2019	99,000.00	180,000.00	1350	0.48	0.6047	59,865.30	82,077.48	94,610.03	236,552.81
June 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	12,557.15	13,278.60	91,143.35
July 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
August 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
September 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
October 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
November 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
December 2019	108,000.00	207,000.00	1350	0.46	0.6047	65,307.60	47,089.31	49,794.75	162,191.66
January 2020	108,000.00	207,000.00	1350	0.46	0.6047	82,956.60	86,330.41	91,290.38	260,577.39
February 2020	135,000.00	252,000.00	1800	0.47	0.8008	108,108.0 0	120,288.9 3	132,786.00	361,182.93

## Appendix B: Monthly Energy Consumption from Diesel Fuel and Production Data

Month(Billing Period)	Fuel used per Month(l)	Energy from the fuel per Month(MJ)	Monthly Production of Steel (tons)
April 2018	200	7605	1415.7
May 2018	200	7605	1505.6
June 2018	400	15210	839
July 2018	2900	110272.5	978.02
August 2018	600	22815	654.94
September 2018	500	19012.5	809.57
October 2018	400	15210	856.88
November 2018	400	15210	699.84
December 2018	13300	505732.5	956.96
January 2019	500	19012.5	987.97
February 2019	400	15210	861.06
March 2019	200	7605	816.52
April 2019	400	15210	542.3
May 2019	600	22815	425.6
June 2019	200	7605	473.6
July 2019	200	7605	2511.91
August 2019	800	30420	2161.71
September 2019	2800	106470	1298.63
October 2019	13300	505732.5	1311.65
November 2019	200	7605	729.63
December 2019	200	7605	1177.07
January 2020	600	22815	1218.5
February 2020	0	0	1192.09

### Appendix C: WSI Electrical Motors Nameplate, Measured and Calculated Data

S.No	Motor Description	Quantity	Name plate data							Measured Data		Calculated	
			Rated power (KW)	Rated PF	Rated Efficiency	Rated V (V)	Rated I(A)	Rated Speed (Rpm)	No of Poles	Input Power (KW)	Shaft Speed (Rpm)	loading (%)	Synchronous speed(rpm)
1	DC machine	1	75	-	84.9	440	6.48	1485	4	15.44	1497	20.6	
2	Belt Motor	1	15	0.8	81.3	380	28.8	1460	4	4.14	1490	27.6	1500
3	Cutting Motor	1	11	0.89	89.6	380	21	2930	2	7.37	2958	67	3000
4	Air Pump	1	11	0.83	89.8	380	22.6	1460	4	8.57	1472	77.9	1500
5	Saw Motor	1	5.5	0.85	87	380	11.1	2900	2	3.54	2944	64.4	3000
6	Cart Motor	1	7.5	-	86	440	20.6	1470	4	5.32	1482	70.9	1500
7	Material Motor	1	55	-	85	440	142	1474	4	34.29	1486	62.3	1500
8	Hydraulic Motor	1	7.5	0.76	88.7	400	16	1455	4	6.34	1466	84.5	1500
9	Material Feeding Motor	2	37	0.82	92.2	400	71	985	6	27.29	990	73.8	1000
10	Cutting Motor	1	22	0.85	86	380	42.2	2880	2	14.58	2932	66.3	3000
11	DC Motor for cutting Home	1	15	-	83	440	39.3	1470	4	13.37	1478	89.1	
12	DC Master	1	132	-	91.4	440	326	1485	4	36.65	1496	27.8	
13	Coil store Motor	1	15	0.84	85	380	30.3	1460	4	12.18	1472	81.2	1500
14	Distilled water pump motor	1	11	0.86	87	380	22.6	2900	2	9.23	2927	83.9	3000
15	Coolant water pump motor	1	7.5	0.85	84	380	15	2900	2	6.7	2925	89.3	3000

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S.No	Motor Description	Quantity	Name plate data							Measured Data		Calculated	
			Rated power (KW)	Rated PF	Rated Efficiency	Rated V (V)	Rated I(A)	Rated Speed (Rpm)	No of Poles	Input Power (KW)	Shaft Speed (Rpm)	loading (%)	Synchronous speed(rpm)
16	Cutting Motor	1	22	0.85	80.2	380	42.2	2880	2	5.69	2973	25.9	3000
17	DC Motor for cutting Home	1	15	-	86	440	39.3	1450	4	9.94	1472	66.3	
18	DC Master	1	132	-	85	440	326	1475	4	100.94	1484	76.5	
19	Coil store Motor	1	11	0.86	88.4	380	23	1480	4	9.21	1485	83.7	1500
20	Coolant water motor	1	7.5	0.87	89	380	20.6	2900	2	6.4	2924	85.3	3000
21	Cutting Motor	1	18.5	0.89	77.7	380	34.7	2930	2	5.65	2981	30.5	3000
22	DC Motor for cutting Home	1	22	-	86	440	58.8	1470	4	16.63	1481	75.6	
23	DC Master	1	132	-	85	440	332	965	6	86.96	980	65.9	
24	Coil storage Motor	1	11	0.8	79	380	23	1480	4	2.71	1496	24.6	1500
25	Servo motor	1	11	0.86	81.1	380	22.6	1460	4	3.3	1489	30	1500
26	DC Master	1	75	-	89	440	188	1480	4	47.19	1489	62.9	
27	Cutting Motor	1	11	0.84	89.8	380	22.3	1460	4	8.33	1473	75.7	1500
28	Uncoiler roller motor	1	5.5	0.87	90	380	10.6	2900	2	4.4	2928	80	3000
29	Cutting Motor	1	18.5	0.89	90	380	34.7	2930	2	10.89	2963	58.9	3000
30	DC motor for cutting home	1	22	-	88	440	58.8	1478	4	16.5	1485	75	
31	DC Master	1	132	-	89	440	332	987	6	105.3	991	79.8	
32	Coil storage	1	11	0.8	88.4	380	23	1480	4	9.71	1484	88.3	1500

*Energy Audit of Walia Steel Industry*

S.No	Motor Description	Quantity	Name plate data							Measured Data		Calculated	
			Rated power (KW)	Rated PF	Rated Efficiency	Rated V (V)	Rated I(A)	Rated Speed (Rpm)	No of Poles	Input Power (KW)	Shaft Speed (Rpm)	loading (%)	Synchronous speed(rpm)
	motor												
33	Uncoiler motor	2	7.5	0.85	85	380	15	1440	4	6.53	1456	87.1	1500
34	DC motor	1	55	-	84	440	137	1465	4	42.56	1477	77.4	
35	Saw motor	1	11	0.86	72.9	380	21.5	2930	2	2.94	2983	26.7	3000
36	Cart motor	1	15	-	80.7	440	39.3	1490	4	3.79	1498	25.3	1500
37	Material feeding motor	1	15	0.83	81.9	380	30.3	1460	4	4.52	1490	30.1	1500
38	DC motor	1	37	-	85.8	440	95	1475	4	9.43	1495	25.5	
39	Hydraulic motor	1	11	0.84	88	380	22.3	1460	4	7.88	1475	71.6	1500
40	DC motor	1	110	-	86	440	275	1470	4	71.63	1483	65.1	
41	DC motor	1	132	-	87	440	326	1480	4	104.69	1486	79.3	
42	Coil transport	1	55	-	89	440	148	1480	4	39.55	1487	71.9	1500
43	Air pump	1	11	0.84	88	380	22.3	1460	4	9.63	1469	87.5	1500
44	Leveling motor	1	110	-	86	440	123	1470	4	88.26	1479	80.2	1500
45	Cutting motor	1	30	0.86	88.1	380	57.6	1465	4	7.66	1492	25.5	1500
46	Saw motor	1	18.5	0.89	76.1	380	34.7	2930	2	4.73	2984	25.6	3000
47	DC motor for cutting home	1	22	-	87.1	440	58.8	1400	4	6.01	1477	27.3	
48	DC master	1	132	-	90.9	440	132	950	6	45	985	34.1	
49	Coil storage motor	1	11	0.86	81.4	380	23	1460	4	3.39	1489	30.8	1500
50	Air storing motor	1	7.5	0.8	87	380	15.4	1440	4	5.17	1464	68.9	1500

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S.No	Motor Description	Quantity	Name plate data							Measured Data		Calculated	
			Rated power (KW)	Rated PF	Rated Efficiency	Rated V (V)	Rated I(A)	Rated Speed (Rpm)	No of Poles	Input Power (KW)	Shaft Speed (Rpm)	loading (%)	Synchronous speed(rpm)
51	Coolant pump motor	1	7.5	0.85	89	380	15.4	2900	2	4.72	2944	62.9	3000
52	DC motor	1	55	-	83.5	440	140	1474	4	11.61	1495	21.1	
53	Hydraulic pump motor	1	11	0.85	88	380	22.3	1460	4	8.13	1474	73.9	1500
54	Up and down motor	1	5.5	0.83	90	380	11.7	1440	4	4.28	1458	77.8	1500
55	Cutter motor	1	132	-	89.4	440	334	2950	2	36.41	2988	27.6	3000
56	Strips recoiler motor	1	200	-	86	440	488	992	6	123.26	996	61.6	1000
57	Hydraulic motor	1	7.5	0.86	90	380	15.4	1440	4	5.25	1462	70	1500
58	Hydraulic motor	1	15	0.85	81.4	380	30.1	1460	4	4.19	1490	27.9	1500
59	Roller motor	1	22	0.83	85.3	380	44.6	970	6	6.81	992	31	1000
60	Material storage motor	1	90	0.85	89.6	380	167	985	6	26.59	996	29.5	1000
61	Roller motor	1	55	0.84	86	380	103	750	8	43.49	750	79.1	750
62	Forming die motor	2	90	-	87	440	234	985	6	74.48	989	82.8	1000
63	Shaping die motor	1	160	-	85	440	401	750	8	118.59	750	74.1	750
64	Hydraulic motor	1	22	0.86	90.5	380	43.2	1470	4	18.23	1478	82.9	1500
65	Coolant return motor	1	15	0.85	89	380	28.8	2900	2	13.31	2921	88.7	3000
66	Saw motor	1	160	0.89	94.9	380	286	1480	4	109.59	1487	68.5	1500

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S.No	Motor Description	Quantity	Name plate data							Measured Data		Calculated	
			Rated power (KW)	Rated PF	Rated Efficiency	Rated V (V)	Rated I(A)	Rated Speed (Rpm)	No of Poles	Input Power (KW)	Shaft Speed (Rpm)	loading (%)	Synchronous speed(rpm)
67	Distilled water pump motor	1	11	0.89	89.4	380	21.3	2930	2	9.23	2948	83.9	3000
68	Carriage motor	1	45	-	86	440	180	980	6	29.3	989	65.1	1000
69	Conveyor motor	4	5.5	0.77	84.9	400	12.2	960	6	4.79	970	87.1	1000
70	Hydraulic motor	1	15	0.81	90.6	400	29.4	1470	4	10.6	1481	70.7	1500
71	Roller motor	1	37	0.86	92.7	400	67	1475	4	29.54	1482	79.8	1500
72	Material storage motor	11	5.5	0.82	87.7	400	11.05	1455	4	4.7	1466	85.5	1500
73	Forming die motor	2	132	0.84	94.6	400	240	990	6	86.51	994	65.5	1000
74	Shaping die motor	1	90	0.84	87.7	400	165	990	6	20.11	998	22.3	1000
75	Hydraulic motor	1	22	0.8	84.1	400	43	1475	4	4.33	1496	19.7	1500
76	Coolant return motor	1	15	0.85	89.5	380	28.8	2900	2	11.4	2932	76	3000
77	Jaw uncoiler motor	2	30	0.85	88.8	400	55	1470	4	9.43	1491	31.4	1500
78	Cutter motor	1	110	0.82	92.3	400	210	740	8	79.85	743	72.6	750
79	Hydraulic motor	1	22	0.81	91.6	400	43	1475	4	17.53	1482	79.7	1500
80	Material strightness motor	1	11	0.83	89.8	400	21.3	1465	4	9.92	1472	90.2	1500
81	Uncoiler motor	1	110	0.84	94.3	400	200	980	6	76.99	987	70	1000
82	Chips uncoiler motor	1	11	0.83	89.8	400	21.3	1465	4	9.31	1473	84.6	1500

## Appendix D: WSI load reading from the Energy meter of Sebета Substation

Time	15KV feeder load in Ampere(August 10-August 16/2020)						
	Sebета 05(F5)						
7:00		15	25	12	15	30	15
7:30		15	13	12	20	22	20
8:00	30	25	17	35	25	33	27
8:30	38	35	15	42	18	38	20
9:00	55	15	19	40	50	22	15
9:30	39	54	20	35	50		15
10:00	45	47	22	58	43	42	12
10:30	30	48	11	45	47	40	15
11:00	35	52	9	55	24	48	10
11:30	25	60	9	60	24	40	10
12:00	30	36	9	20	30	30	5
12:30	28	17	9	20	28	29	15
13:00	25	23	9	50	21	27	15
13:30	20	40	9	65	25	36	15
14:00	25	59	9	55	46	36	5
14:30	25	51	9	47	47	39	15
15:00	20	52	10	55	46	44	15
15:30	35		22	50	30	42	15
16:00	36	40	15	55	55	35	15
16:30	25	40	14	58	22	37	
17:00	40	54	15	47	22	30	15
17:30	45	48	23	57	22	42	15
18:00	40	48	9	45	22	26	10
18:30	35	56	10	38	31	19	10
19:00	10	56	15	35	23	20	15
19:30	15	38	8	40	25	18	15
20:00	20	45	15	38	28	37	15
20:30	15	20		34	38	30	12
21:00	15	34		30	39	32	10
21:30	20	43		46	38	30	10
22:00	25	35		40	22	26	10
22:30	25	35		50	37	22	10
23:00	30			55	30	20	10
23:30	30			49	21	19	10

### Appendix E: IMSSA Analysis output of Replacing Existing Under loaded Motors

Existing Motor Rated power (KW)	Measured input power (KW)	Replacing Motor Rated Power (KW)	Existing Motor			Replacing Motor			Energy Savings			Total Savings (€/yr.)	Simple Payback (yrs.)	
			Energy use (KWh/yr.)	Energy Cost (€/yr.)	Demand Charge (€/yr.)	Differential Cost (€)	Energy use (KWh/yr.)	Energy Cost (€/yr.)	Demand Charge (€/yr.)	Energy Savings (KWh/yr.)	Energy Savings (€/yr.)			Demand Savings (€/yr.)
75	15.44	18.5	81167	2841	356	1634	52029	1821	228	29138	1020	128	1148	1.42
15	4.14	5.5	22161	776	97	675	14385	503	63	7776	273	34	307	2.2
132	36.65	37	163140	5710	715	2429	121771	4262	534	41369	1448	181	1629	1.49
22	5.69	7.5	30364	1063	133	823	19676	689	86	10688	374	47	421	1.95
18.5	5.65	7.5	31874	1116	140	823	19484	682	85	12390	434	55	489	1.68
11	2.71	3	14836	519	65	440	9663	338	42	5173	181	23	204	2.16
11	3.3	3.7	17429	610	76	279	11619	407	51	5810	203	25	228	1.22
11	2.94	3	18041	631	79	331	10498	367	46	7543	264	33	297	1.11
15	3.79	4	20240	708	89	540	13352	467	59	6888	241	30	271	1.99
15	4.52	5.5	23199	812	102	675	15687	549	69	7512	263	33	296	2.28
37	9.43	11	45444	1591	199	913	32171	1126	141	13273	465	58	523	1.75
30	7.66	11	36686	1284	161	913	26119	914	114	10567	370	47	417	2.19
18.5	4.73	5.5	27568	965	121	402	16529	579	72	11039	386	49	435	0.92
22	6.01	7.5	28579	1000	125	849	20672	724	91	7907	276	34	310	2.74
132	45	55	191624	6707	840	3827	150318	5261	659	41306	1446	181	1627	2.35
11	3.39	3.7	17570	615	77	279	11936	418	52	5634	197	25	222	1.26
55	11.61	15	64092	2243	281	1300	39265	1374	172	24827	869	109	978	1.33
132	36.41	37	167904	5877	736	2896	121240	4243	531	46664	1634	205	1839	1.57
15	4.19	5.5	22108	774	97	675	14541	509	64	7567	265	33	298	2.27
22	6.81	7.5	33946	1188	149	625	24300	851	107	9646	337	42	379	1.65
90	26.59	30	122482	4287	537	2208	89999	3150	395	32483	1137	142	1279	1.73
90	20.11	22	97584	3415	428	1835	68715	2405	301	28869	1010	127	1137	1.61
22	4.33	5.5	23865	835	105	675	15058	527	66	8807	308	39	347	1.95
30	9.43	11	44756	1566	196	913	32119	1124	141	12637	442	55	497	1.84
30	9.43	11	44756	1566	196	913	32119	1124	141	12637	442	55	497	1.84

**Appendix F: ETAP Analysis output On the Existing power Distribution Network**

<b>ID</b>	<b>Type</b>	<b>MW Flow</b>	<b>Mvar Flow</b>	<b>Amp Flow</b>	<b>% Loading</b>	<b>kW Losses</b>	<b>kvar Losses</b>
Cable1	Cable	0.0182	0.0332	55.01	18.1	0.0429	0.0333
Cable3	Cable	0.0095	0.0173	28.64	14	0.0179	0.0091
Cable5	Cable	0.0108	0.0195	32.44	25.3	0.0736	0.0225
Cable7	Cable	0.0087	0.0159	26.44	12.9	0.0286	0.0145
Cable9	Cable	0.0144	0.0262	43.41	21.2	0.0771	0.0391
Cable11	Cable	0.0163	0.0297	49.29	24.1	0.0398	0.0202
Cable13	Cable	0.0105	0.0192	31.79	24.8	0.0283	0.0086
Cable29	Cable	0.0182	0.0332	54.94	13.4	0.0336	0.041
Cable31	Cable	0.0095	0.0173	28.6	14	0.0201	0.0102
Cable32	Cable	0.0279	0.051	84.38	41.3	0.0777	0.0394
Cable34	Cable	0.0092	0.0168	27.81	10.8	0.0118	0.0075
Cable36	Cable	0.0063	0.0115	19	9.3	0.0069	0.0035
Cable47	Cable	0.0269	0.0487	81.06	26.6	0.466	0.361
Cable48	Cable	0.0286	0.0515	85.67	33.2	0.64	0.405
Cable49	Cable	0.0227	0.0409	68.07	33.3	0.379	0.192
Cable50	Cable	0.065	0.118	196.7	55	0.534	0.528
Cable51	Cable	0.0163	0.0297	49.37	13.8	0.0336	0.0332
Cable53	Cable	0.0351	0.0641	106.7	29.8	0.188	0.186
Cable55	Cable	0.011	0.0202	33.55	9.4	0.0124	0.0123
Cable57	Cable	0.0579	0.105	175.5	85.8	0.252	0.128
Cable59	Cable	0.0268	0.0487	81.16	19.7	0.293	0.358
Cable61	Cable	0.0268	0.0487	81.16	19.7	0.293	0.358
Cable62	Cable	0.0237	0.0428	71.33	27.6	0.444	0.281
Cable64	Cable	0.0069	0.0125	20.9	10.2	0.0477	0.0242
Cable66	Cable	0.049	0.0883	147.4	48.5	1.16	0.895
T1	Transf. 2W	0.0885	0.162	7.12	12.2	0.201	1.43
T5	Transf. 2W	0.0712	0.131	5.726	9.8	0.13	0.925
T10	Transf. 2W	0.0784	0.143	6.261	13.7	0.199	1.41
T11	Transf. 2W	0.0816	0.15	6.562	14.4	0.219	1.55
T13	Transf. 2W	0.104	0.192	8.419	18.4	0.36	2.56
T15	Transf. 2W	0.134	0.244	10.72	18.3	0.456	3.24

## Appendix G: ETAP 16.0.0 Analysis output On the Designed power Distribution Network

ID	Type	MW Flow	Mvar Flow	Amp Flow	% Loading	kW Losses	kvar Losses
Cable1	Cable	0.0181	0.0087	29.32	9.6	0.0122	0.0094
Cable3	Cable	0.0095	0.0045	15.28	7.5	0.0051	0.0026
Cable5	Cable	0.0107	0.0049	17.12	13.3	0.0205	0.0063
Cable7	Cable	0.0087	0.0042	14.1	6.9	0.0081	0.0041
Cable9	Cable	0.0143	0.0066	22.97	11.2	0.0216	0.011
Cable11	Cable	0.0163	0.0082	26.52	13	0.0115	0.0058
Cable13	Cable	0.0105	0.0045	16.62	12.9	0.0077	0.0024
Cable29	Cable	0.0181	0.0087	29.31	7.1	0.0096	0.0117
Cable31	Cable	0.0095	0.0045	15.28	7.5	0.0057	0.0029
Cable32	Cable	0.0279	0.0137	45.29	22.1	0.0224	0.0114
Cable34	Cable	0.0092	0.0041	14.64	5.7	0.0033	0.0021
Cable36	Cable	0.0063	0.0027	9.939	4.9	0.0019	0.001
Cable47	Cable	0.0266	0.0136	43.54	14.3	0.134	0.104
Cable48	Cable	0.0281	0.0144	46.05	17.8	0.185	0.117
Cable49	Cable	0.0224	0.0116	36.78	18	0.111	0.0562
Cable50	Cable	0.0647	0.0332	105.9	29.6	0.155	0.153
Cable51	Cable	0.0163	0.0082	26.52	7.4	0.0097	0.0096
Cable53	Cable	0.035	0.018	57.38	16	0.0545	0.0539
Cable55	Cable	0.011	0.0055	17.93	5	0.0035	0.0035
Cable57	Cable	0.0577	0.029	94.08	46	0.0725	0.0368
Cable59	Cable	0.0266	0.0135	43.4	10.6	0.0838	0.102
Cable61	Cable	0.0266	0.0135	43.4	10.6	0.0838	0.102
Cable62	Cable	0.0234	0.0115	37.97	14.7	0.126	0.0796
Cable64	Cable	0.0069	0.0028	10.78	5.3	0.0127	0.0064
Cable66	Cable	0.0482	0.0249	79.01	26	0.332	0.257
T1	Transf. 2W	0.277	0.143	11.99	26.2	0.731	5.19
T5	Transf. 2W	0.277	0.143	11.99	26.2	0.731	5.19
T10	Transf. 2W	0	0	0	0	0	0
T11	Transf. 2W	0	0	0	0	0	0
T13	Transf. 2W	0	0	0	0	0	0
T15	Transf. 2W	0	0	0	0	0	0

## Appendix H: Periodic Motor Inspection Checklist for WSI

### Motor History Card

Basic Information of the motor			
Date			
Factory No and Production Line			
Motor Description			
Motor Rating			
Descriptions	Diagnosis Results and Recommendations		
Motor Status	New <input type="checkbox"/>	Rewound <input type="checkbox"/>	Aged <input type="checkbox"/>
Check wears on bearings and housings and dusts in motor and ventilating ducts			
Check Voltage and Current unbalance on the motors			
Check Status of motor foundation			
Check for vibration of the motor			
Check if fan is working or not			
Check status of motor surface temperature			
Check lubricating condition			
Check status of motor loading condition			
Check status of motor shaft alignment			
Check the wiring and size of the electrical wires at motor terminal connection.			

**Appendix I: Interview Questionnaire on Energy Management for WSI Staffs**

1. Do you know that Energy is manageable means using less energy per unit of a product while maintaining the same level of service? If yes, what is the need to manage it \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
2. Have you ever done technical supervision on energy consuming equipment in your factory for technical energy management concern \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
3. How often in a year do you let your operation staffs aware them to wisely use energy like off lighting while offices, areas are unattended and unplug motors which are not functioning that time or do you have any other way of communicating to raise their awareness of energy management ? \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
4. Do you have any motor management plans in your company? Like
  - I. Creation of a motor survey and tracking program.
  - II. Development of guidelines for proactive repair/replace decisions.
  - III. Preparation for motor failure by creating a spares inventory.
  - IV. Development of a purchasing specification.
  - V. Development of a repair specification.
  - VI. Development and implementation of a predictive and preventive maintenance program.\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_
5. Have you ever conducted any energy performance status checking of your factory? If yes what was your finding and recommendation? And have you communicated the results to all management and operation staffs? \_\_\_\_\_  
\_\_\_\_\_

6. Do you have a department/sub department with adequate staffs both in number, qualification and skill who are responsible for energy management issue of the factory?

7. Do you feel that your factory's top management members are concerned for energy management issue of the factory? If yes Explain\_\_\_\_\_

If no, what do you think is the reason behind it

## Appendix J: EEU Revised Energy Tariff

### Tariff Adjustement

<b>Energy Tariff Implementation for Residential Consumer Class</b>						
Customer Block	Consumption	Base Tariff	Energy Tariff ( Birr/KWh)			
		Old Tariff	Dec' 2018	Dec' 2019	Dec' 2020	Dec' 2021
1 st Block	up to 50 KWh	0.2730	0.2730	0.2730	0.2730	0.2730
2 st Block	up to 100 KWh	0.3564	0.4591	0.5617	0.6644	0.7670
3 st Block	up to 200 KWh	0.4993	0.7807	1.0622	1.3436	1.6250
4 st Block	up to 300 KWh	0.5500	0.9125	1.2750	1.6375	2.0000
5 st Block	up to 400 KWh	0.5666	0.9750	1.3833	1.7917	2.2000
6 st Block	up to 500 KWh	0.5880	1.0423	1.4965	1.9508	2.4050
7 st Block	KWh > 500 KWh	0.6943	1.1410	1.5877	2.0343	2.4810
<p align="center"><b>Service charge post paid 0 up to 50 KWH etb 10.00 &amp; Beyond 50 KWH etb 42 .00</b>  <b>Prepaid 0 up to 50 KWH etb 3.50 &amp; Beyond 50 KWH etb 14.70</b></p>						

<b>Energy Tariff Implementation for General, Industrial and Bulk Supply</b>					
Customer Class	Base Tariff (Birr/KWh)	Energy Tariff ( Birr/KWh)			
		Dec' 2018	Dec' 2019	Dec' 2020	Dec' 2021
<b>General</b>	0.6723	1.0352	1.3982	1.7611	2.1240
<b>LV Industrial</b>	0.5778	0.8161	1.0544	1.2927	1.5310
Demand Charge	0.0000	50.000	100.00	150.00	200.00
<b>MV Industrial</b>	0.4086	0.6047	0.8008	0.9969	1.1930
Demand Charge		36.885	73.77	110.655	147.5400
<b>HV Industrial</b>	0.3805	0.5174	0.6543	0.7911	0.9280
Demand Charge	0.0000	21.9100	43.8200	65.7300	87.6400
<b>Bulk Supply</b>	0.0000	0.2218	0.4435	0.6653	0.8870
Demand Charge	0.0000	39.2908	78.5815	117.8723	157.1630
<p align="center"><b>Service charge post paid General ALL kwh Etb 54.00 &amp; Prepaid 0 up to 50 KWH ETB 18.90</b></p>					
<p align="center"><b>Street light charge is taken as as similar as general(commercial)</b></p>					