2022-08

ENERGY UTILIZATION ASSESSMENT AND IMPROVEMENT IN ADDIS GAS AND PLASTICS FACTORY PLC

BIZUAYEHU, BIAMESH ZEWDU

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY (BIT)

SCHOOL OF RESEARCH AND GRADUATE STUDIES

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

POWER SYSTEMS ENGINEERING

MSC THESIS ON:

ENERGY UTILIZATION ASSESSMENT AND IMPROVEMENT IN ADDIS GAS AND PLASTICS FACTORY PLC

By:

BIZUAYEHU BIAMESH ZEWDU

AUGUST, 2022

Bahir Dar, Ethiopia

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY (BIT)

FACULTY OF ELECTRICAL AND COMPUTER ENGINEERING

Energy Utilization Assessment and Improvement in Addis Gas and Plastics Factory plc

By:

Bizuayehu Biamesh

A thesis Submitted in partial fulfillment of the

Requirement for the Degree of Masters of Science

In Power system Engineering

Principal Advisor

Yoseph Mekonnen(PhD)

August, 2022

Bahir Dar, Ethiopia

DECLARATION

This is to certify that the thesis entitled "Energy Utilization Assessment And Improvement In Addis Gas And Plastics Factory PLC", submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering (Electrical power Engineering) under Electrical Engineering, Bahir Dar Institute of technology, is record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged

Bizuayehu Biamesh		19-08-2022 G.C
Name of the candidate	signature	Date

BAHIR DAR UNIVERSITY

BAHIR DAR INSTITUTE OF TECHNOLOGY (BIT)

SCHOOL OF ELECTRICAL & COMPUTER ENGINEERING

FACULTY OF ELECTRICAL ENGINEERING

Approval of thesis for defense result

I hereby confirm that the changes required by the examiners have been carried out and incorporated in the final thesis.

Name of student Bizuayehu Biamesh Signature ______ Date 19/08/2022

As members of the board of examined, we examined this thesis entitled "Energy Utilization Assessment and Improvement in Addis Gas and Plastics Factory plc."

by Bizuayehu Biamesh . We hereby certify that the thesis is accepted for fulfilling the requirement for the award of the degree of masters of Science in

" Power System Engineering "

Board of Examiners

Name of Advisor Dr. Yoseph Mekonnen	Signature	Date 19/08/2022
Name of External Examiner Dr. Teshome Goa	Signature	Date 19/08/2022
Name of Internal Examiners Dr. Tassew Tadiwose	Signature August 2022	Date 22/08/2022
Name of Chairperson Mr. Abraham Hizkiel(Ass. Prof.)	Signature	Date 24/08/2022
Name of Chair Holder Mr. Yosef Berhan(Msc)	Signature	Date 22/09/2022
Name of Faculty Dean Mr. Tewodros Gera(Ass. Prof.)	Signature	Date 23/09/2022

Tewodros Gera Workineh
Electrical and Computer
Engineering Faculty Dean

Faculty Stamp

ACKNOWLEDGEMENT

First, I take this opportunity to give glory to the Almighty God, without whom the completion of this work would have been impossible.

Next, I would like to express my sincere gratitude to my advisor, Yoseph Mekonnen (PhD), for his guidance, constructive comments, suggestions and supports for the successful completion of this thesis. He has also played an indispensable role as the primary source of inspiration on every step of the activities or proceedings of my study.

Besides, I would like to acknowledge Addis Gas and plastic Factory for their all kind of support, especially the electrical department staffs, which helped me in collecting and measuring all the necessary data for my thesis work.

Lastly my family and wife (Betelehem Aregay) who have taught me many valuable lessons in life and have always gave their best advice. Their encouragement and pray have made me stronger to face all the problems in this thesis work.

ABBREVIATIONS

AC	Air condition
AGP	Addis Gas and plastic
ALR	Actual Lamp Required
CO_2	Carbon dioxide
DC	Direct Current
DEA	Detailed Energy Audit
ECM	Energy Conservation Measures
ECO	Energy-conserving opportunities
ED	Energy Difference
EEU	Ethiopian Electric Utility
Eff.	Efficiency
EMS	Energy Management System
ER	Energy Required
ES	Energy Saved
FL	Fluorescent Lamp
GC	Gregorian calendar
HEM	High Efficiency Motors
hp	Horse Power
IMSSA	International Motor Selection and Savings Analysis
MS	Money saving
NL	Number of Lamps
OH	Operating Hours
PEA	Preliminary Energy Audit
PFC	Power Factor correction
PLC	Programmable logic controller
PS	Power saving
RA	Room Area

RPM	Revolution per Minute
SPP	Simple Payback Period
TILu	Total Illuminations Produced
TLu	Total Lumens Out put
TP	Total Power
VSD	Variable Speed Drives

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ABSTRACT

Energy conservation and efficient usage are vital to the country's development. Energy demand is increasing globally due to the depletion of fossil fuel sources and other related issues. Significant results can be achieved by focusing on energy utilization assessment and consumption reduction efforts through improvement, better production management, and the introduction of new technologies; saving money on energy bills, improving energy efficiency, and maintaining a sustainable environment. The aim of this thesis is to assess the energy sources and utilization in the selected factory. And also, it is to study and identify energy utilization efficiencies of the different utilities in the factory. It has been found from energy audit results that there exists an average electricity energy intensity difference of 8.83kWh/Kg between the benchmarks and what exists at Addis Gas and Plastic Factory; the factory spends 7,536,165.28 birr per year on this account. Some under loaded motors have been replaced with proper-sized motors and energy-efficient motors. This brings energy savings of 9,757 kWh per year and money savings of 41,118.61 birr per year, with some payback years ranging from 1.96 to 6.28 years. Also, through improvements, the lighting systems resulted in money saving of 29,027.62 birr annually. In this thesis work, energy assessment, capacitor bank placement, and sizing for power factor correction at the selected factory have been assessed. Before the power factor correction, the power factor of AGP was 0.79, which is under penalty based on EEU bill tariff. The power factor of AGP is corrected to 0.9 and, based on power factor correction; the capacitor bank is designed for 176.8 F to the factory. Based on the losses, energy efficiency performance assessments on the major energy-intensive equipment like electric motors and drives, lighting, and the kiln have been done. Last, energy efficiency improvement opportunities for both electrical energy and fuel energy are recommended.

Key Words: Energy utilization assessment, Energy efficiency, Energy intensity, Energy losses, Power factor correction, Capacitor bank.

CHAPTER ONE

INTRODUCTION

1.1 Background

Energy efficiency is understood to mean the utilization of energy in the most cost effective manner to carry out a manufacturing process or provide a service, whereby wastage of energy is minimized and the overall consumption of primary energy resources is reduced. In other words, energy efficient practices or systems seek to use less energy while conducting any energy-dependent activity and at the same time minimize the corresponding (negative) environmental impacts of energy consumption. [1]. the industrial sector accounts around 40% of the commercial energy. It uses both the electrical and thermal energy in various equipments like motors, pumps, boilers, compressors, furnaces, diesel generating engines, refrigerators, etc. But there are many problems in the industry sectors to efficiently use their energy. They are not well informed on the concept of energy conservation. Due to this they lose lots of money on energy bills, causes problems on the environment, industries will not be competitive, etc [2].

Energy efficiency does not mean rationing or having to do without energy rather, energy efficiency means identifying wasteful energy use and taking actions to reduce or illuminate that waste: Production levels should not be affected, only the amount of energy and the expense incurred in generating that production. The objective is to reduce energy costs and consequently increase profitability [3].

In some industries energy costs may make a relatively small contribution to overall operating costs; but there could be a significant part of controllable costs. Reducing energy costs, without any reduction in productivity, results in a direct increase in profit. If the annual energy bill is proportional to the annual profit, then reducing energy costs by an achievable 10%, would contribute a 10% increase in profit. Increasing profit by 10% could also be achieved by increasing sales, but this has its own costs, financial and otherwise. Presumably these costs are prohibitive, or the effort would already have been made. Some reduction in energy costs, by contrast, could cost little or nothing [6].

Improving energy efficiency at the plant could be approached from several directions. Firstly, plants use energy for equipment such as motors, lightings, pumps compressors, boilers, etc. These important utilities require regular maintenances, good operation and replacement when necessary. Thus, a critical element of the plants energy management involves the efficient control of crosscutting equipments or utilities that powers the production process of the plant. A second important area is the proper and sufficient operation of the process. Process optimization and ensuring the most efficient technology is in place a key energy savings in plant's operations [2-5].

Despite the attention for energy efficiency today, the industry does not seem to adopt energy-efficient technology to the extent necessary. A reason which has been stressed is that not all benefits are included in the evaluation of energy-related investments, leading to an underestimation of their potential. Previous findings suggest that quantifying non-energy benefits can help showing the financial possibilities of energy-efficient technologies and increase the probability of adopting these investments. [7].

There are different energy consumers such as Gas and plastics industries, sugar industries, textile industries, cement industries etc. Gas and Plastics industries are the most energy intensive plants that use mostly electrical and fuel energies. The energy distribution and utilization assessment that has done on several industries mostly occur on the thermal energy efficiencies but the electrical energy has also major impact on the industries.

This documentation summarizes energy conservation opportunities identified during an energy audit conducted and power quality improvement at Addis Gas and plastic Factory. Data collected during the audit uses to estimate energy savings that can be achieved by implementation of the measures recommended. By using a systematic approach through which data concerning the energy utilization performance of the plant will be collected.

1.2 Energy Consumption and Costs

Electricity is purchased from Ethiopian electric utility (EEU). The cost for electricity is 6.23 birr per kWh, inclusive of all adjustments. In addition, there is also a demand charge of 305.12 birr (Average) and a service charge of 57.87 birr per month. A power factor penalty is included in the tariff for industrial users with power factor of less than 0.85. Both the Furness oil and diesel oil are purchased from abroad. The cost of Furness oil is in range between 11.23 – 14.65 Birr per liter. Table 1-3 shows the energy consumption by fuel type for the year 2018 G.C.

Table 1.1: Energy Consumption and Costs of the Year 2018 G.C

Energy	Year(G.C)	Unit	Consumption	Annual cost(Birr)
Electricity	2018	KWh	900,192	366,988.63
Furness oil	2018	Lit	793,440	14,837,328
Diesel oil	2018	Lit	1834	36,680
			Total	15,240,966

1.2.1 Energy Audit

An energy audit is an enquiry of all surfaces of organization's historical and current energy use with the objective of identifying and quantifying areas of energy wastage within the organization's activities. It establishes a starting position for any improvements in energy use. It is an important commercial tool to save energy and to improve financial state of an organization. Almost all the large scaled and many small scaled organizations i.e. industries as well as non-industrial sectors are guiding energy audit to save energy and to minimize the electricity cost. Energy audits support 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 [11]. The objectives of an energy audit can vary from one plant to another. However, an energy audit is usually directed to understand how energy is used within the plant and to find opportunities for enhancement and energy saving. Sometimes, energy audits are conducted to evaluate the efficiency of an energy efficiency project or program [11].

Types of Energy Audit

The type of industrial energy audit accompanied depends on the function, size, and type of the industry, the deepness to which the audit is needed, and the potential and magnitude of energy savings and cost reduction desired. Based on these criteria, an industrial energy audit can be classified into two types: a preliminary energy audit (walk-through audit) and a detailed energy audit (diagnostic audit) [12].

a) Preliminary Audit: In a preliminary energy audit, readily available data are mostly used for a simple analysis of energy use and performance of the plant. This type of audit does not involve a lot of measurement and data gathering. These audits take a comparatively short time and the results are overall, providing common chances for energy efficiency. The economic analysis is typically limited to calculation of the simple payback period, or the time required paying back the initial capital asset through realized energy savings [12].

b) Detailed Audit: For detailed (or diagnostic) energy audits, more in depth data and information are necessary. Measurements and a data inventory are usually accompanied and different energy systems (pump, fan, compressed air, steam, process heating, etc.) are evaluated in detail. Hence, the time required for this type of audit is longer than that of preliminary audits. The results of these audits are more all-inclusive and useful since they give a more precise picture of the energy performance of the plant and more explicit recommendation for enhancements [12].

1.3 Statement of the Problem

Industries use both electrical and thermal energy in various equipment like motors, pumps, boilers, compressors, furnaces, diesel generating engines, refrigerators, etc. But there are many problems in the industrial sectors' efficient use of energy. Due to this, they lose lots of money on energy bills, have problems with the environment, their industries will not be competitive, etc.

The main reason for Addis Gas and the plastic factory is that there is no power factor correction, which leads to high energy loss and energy billing. Lack of responsiveness and consciousness to energy efficiency management programs; incorrect design of electrical installations; lack of proper replacement; regular maintenance and control of industrial apparatus; and lack of spare parts and accessories are some of the common reasons for inefficient energy use. It has a high impact on the number of products and the time used to produce a single product. The factories will not be competitive with the world market. The factories will produce substandard products at incomparable costs. Hence, it is necessary to conduct an analysis of the energy assessment in the factory. It is necessary to analyze the lighting system. It is important to analyze electric motor and capacitor bank placement and sizing for power factor correction.

This thesis work will address problems encountered by gas and plastic factories with respect to energy, starting from the resources and through energy-user equipment like electric motors and drives, the kiln, boilers, pumps, air compressors, etc. The better solution suggests improving the efficiencies of these energy uses.

1.4 Objective

1.4.1 General objective

The general objectives of this study include the assessment of the energy utilization efficiency of Gas and Plastics industries with special attention on Addis Gas and Plastics factory with a great deal work emphasizing a proposing effective ways to decrease it.

1.4.2 Specific Objective

The specific objectives are:

- ✓ To analyze the major causes of energy losses at Addis Gas and Plastics Factory.
- ✓ To Study and analyze the Energy intensity of the factory.
- ✓ To Study and analyze the lighting systems.
- ✓ To Study and analyze the motors performance.
- ✓ To analysis the power factor correction and capacitor bank sizing of the factory.

1.5 Significance of the study

The energy utilization Assessment in a factory is a feasibility study. For it not only serves to identify energy use among the various services and to identify opportunities for energy conservation, but it is also a crucial first step in establishing an energy management program. The audit will produce the data on which such a program is based. The study reveals to the owner, manager, or management team of Addis Gas and plastic Factory or for any concerned body the alternatives available for reducing energy waste, the costs involved, and the benefits achievable from implementing those energy-conserving opportunities (ECOs).

1.6 Scope and Limitation

The scope of this thesis work includes assessment of factory electrical systems, major electrical drives (motors), and lighting systems. The study incorporates reading relevant literature, collecting (measuring) and analyzing data from the factory for energy consumption, monitoring, accounting and management in the factory the investment cost of the recommended. The analysis focus on identification of the major energy using processes and the amount of energy that is lost.

1.7 Methodology

The project was beginning by discussion with my advisor and site visiting. After finding write objectives, problem and other related issues, the finding is done doing some literature review. After that the project development is begin. The study will cover an in-depth study of factory electrical system, motors, power supply quality, lightings, steam distribution system and other major energy consuming equipment.

- **Data collection**

The necessary data for the thesis are collected from different sources. The necessary data are:-

- ✓ The energy consumptions of the factory for the last four years.
- ✓ The current energy requirement to produce a unit product (specific electrical and fuel consumptions).
- ✓ Specification, working conditions and maintenance procedures of the equipments in utility plants.
- ✓ The current production cost of the factory, energy bill, lighting data.
- ✓ Measurements like 3-phase voltage, 3-phase current, power factor, active power, reactive power, etc.

- **Data Analysis**

  All the above data are then analyzed quantitatively and qualitatively. Depending on the assessed data, opportunities to reduce energy loses are identified. From the analyzed data, conclusion and recommendation have been forwarded.

- **Software tools**

  Motor master + International software. It supports motor and motor systems improvement planning through identifying the most efficient action for a given repair or motor purchase decision. In addition, it is used to identify inefficient or oversized inventory motors and compute the energy and demand savings associated with selection and replacement energy-efficient model.

1.8 Outline of Thesis

This thesis is organized into the following chapters including this chapter:

Chapter-Two: Discusses the relevant literature review of the research including all the theory In addition, research studies relevant to this thesis.

Chapter-Three: It discusses all the factory manufacturing process, data collection, and measurements taken.

Chapter-Four: According to the collected data and the measurements taken in the factory, this chapter tries to summarize and identify the causes of major energy losses and their energy saving opportunities in plant factory. In addition, it tries to put all the summarized results, analysis and discussion of the thesis theoretically and Mathematical modeling based outputs.

Chapter- Five: In the last chapter, conclusions and recommendations for future research are presented. Finally, the references and appendices are presented at the end of the thesis.

CHAPTER TWO

LITERATURE REVIEW

2.1 INDUSTRIAL ENERGY EFFICIENCY BASICS

Energy is an essential input for almost all productive sectors in general and industry in particular. It is one of the most important inputs in the process of economic growth and industrial development. The rate of energy consumption varies across different industries depending on technological progress, extent of economic activities and several other factors. Industrial energy consumption at world level is expected to increase by 1.4 percent per annum. The industries are constantly in search of processes, technologies, and energy conservation opportunities which can help them reduce their consumption of energy [8].

Energy efficiency improvements for the factory refers to a decrease in the energy usage for a given energy service such as production, heating, lighting. This reduction in the energy consumption is not necessarily related to technical changes, since it can also result from a better organization and management or improved economic efficiency in the area. Energy efficiency is first a matter of individual behavior and rationale of energy consumers. Avoiding needless consumption of energy or choosing the most suitable equipment to reduce the cost of the energy add to decrease individual energy consumption without decreasing individual benefit and production. It is clear that it also pays to increase the overall energy efficiency of the national economy [10].

There are diverse opportunities to improve energy efficiency in a plant while keeping or enhancing productivity. Improving energy efficiency at a plant should be approached from numerous directions. First, the plant uses energy for different equipment's, which need consistent maintenance, good operation, and replacement, when necessary. Thus, a critical element of plant energy management includes the efficient control of crosscutting equipment that powers the production processes of a plant. A second and similarly essential area is the proper and efficient procedure of the processes. Process optimization and confirming that the most productive technologies are in place are keys to understand energy saving in a plant's operation [13].

2.2 Literature Review on Electrical Energy Auditing

The literature referred to in carrying out this thesis work includes guidelines, books, articles, publications, websites, and research papers mostly published in international journals have been reviewed and appropriate strategies and methodologies were adopted. The notes given under this chapter are taken from these sources.

Comprehensive knowledge of comprehensive energy audit, improving/optimizing energy use efficiency in the gas and plastics industries, management of power quality and parameters in industrial systems, improving power factor, and assessment of thermal energy loss in industry from various research works is required for the thesis work.

Hence Energy is an active and a largely growing area; many scholars have been and will do their research on the area using different approach so as to get a better performance. Here are some of Electrical Energy management approaches that have been developed in the literature.

A.E. Atabani, **R. Saidur**, and **S. Mekhilef** [22], this thesis describes a comprehensive literature review about industrial energy saving by management, technologies and policies. Latest literatures in terms of thesis (MS and PhD), journal articles, conference proceedings, web materials, reports, and books, handbooks on industrial energy management, policies and energy savings strategies have been compiled. Energy saving technologies, such as use of high efficiency motors (HEM), variable speed drives (VSD), economizers, leak prevention and reducing pressure drop. Based on these energy saving technologies results, it has been found that in the industrial sectors, a sizeable amount of electric energy, emissions and utility bill can be saved using these technologies. Payback periods for diverse energy savings measures have been recognized and found to be economically viable in most cases.

Rockwell Automation [25], according to this thesis, it would be difficult for companies today to be unaware of energy use in their facilities, i.e. Consumption of water, air, gas, electricity, and steam. Energy consumes an increasingly larger share of operating costs, and extracting, producing, or making anything from beverages and chemicals to machinery and raw materials-demands energy for myriad processes: prototyping, refining, processing, mixing, heat-treating, blending, stamping, painting, assembling, etc.

Electrical energy management is a topic that has reached specific concern in the twenty- first century due to its contribution to economic development and environmental advancement. It has as a logical outcome and the planning of varieties of initiatives that could be deployed to reduce energy consumption. Electrical energy management may be performed on the supply side or demand side. On the supply side, Electrical energy management on the demand side, energy management is used to reduce the cost of purchasing electrical energy and the associated penalties. The techniques used for Electrical energy management are aimed at achieving valley filling, peak clipping and strategic conservation of electrical systems. **Al-Shakarchi** & **Abu-Zeid**; and **Kissock** & **Eger** [27] presented the techniques used to decrease the need for additional capacity and the costs involved by increased fuel on the supply side.

The world over energy resources are getting scarcer and increasingly exorbitant with time. In India bridging the ever widening gap between energy demand and supply by increasing supply is an expensive option. The share of energy costs in total production costs can, therefore improve profit levels in all the industries. This reduction can be achieved by improving the efficiency of industrial operations and equipments. Energy audit plays an important role in identifying energy conservation opportunities in the industrial sector, while they do not provide the final answer to the problem; they do help to identify potential for energy conservation and induces the companies to concentrate their efforts in this area in a focused manner [28].

Malkiat Singh [29] presents his idea about industrial energy management. As there was a different industry, the demand for the energy is also variable (different), across the world with the growing technique and innovation in the field of energy has proved the path for achieving energy efficiency. It conveys us to look forward to more renewable resources present around us and with the managed approach of renewable energy source with the audit a more cost effective and efficient energy technology can be achieved .

R. S. Chanda [30] this paper identifies some areas of energy consumption, such as; cables, distribution systems, motors, lighting system, etc. According to the paper, replacing the standard energy efficient motors with premium high efficient motors (with 4-5% higher efficiency and cost 30% more than the standard ones) valuable energy can be saved with a small period of payback time.

2.2 Literature Review on Technical Loss Assessment

Bhansali, V.K [35] describes that the gap between supply and demand of energy is continuously increasing despite huge outlay for energy sector since independence. Further, the burning of fossil fuel is resulting in greenhouse gases which are detrimental to the environment. The gap between supply and demand of energy can be bridged with the help of energy conservation which may be considered as a new source of energy which is benign and environment friendly. The energy conservation is cost effective with a short payback period and modest investment. There is a good scope of energy conservation in various sectors, viz., industry, agriculture, transport and domestic. The energy audit can unearth huge profits to the industry. The industrial sector has failed to take full advantage of many financial incentives provided by the government to encourage energy conservation strategies. The planners have started appreciating the role and significance of energy conservation in future energy scenario of India. However, the achievements so far are far from satisfactory. It is imperative to develop energy conservation as a mass movement.

Mukesh k saini [36] in this paper the author state about the industrial development in India and provide recommendation for industry energy audit. He considered as electrical energy consumption by industries is about 60 percent of the total energy consumption. The industrial development in the country is progressing at a fast pace, due to the increase in the number of industries the gap between demand and supply of electricity is also increasing day by day and to solve this problem author suggest that doing the energy audit for all industries on regular bases as the best solution. The energy audit will determine energy wastage and losses and provide techniques and ways to minimize the losses. The energy consumption techniques suggested by the energy audit will not only minimize the losses but also reduce monthly electricity bill. In general, this paper suggests ways and means to conduct an energy audit in industry.

This paper focuses light on the advantages of the conventional energy sources and its lossless power generation every growing economy is mainly using the resources available on the earth and hot conserving the energy by innovation techniques. As electrical equipment, transmission also creates loss. A huge loss in the industries and at domestic level is existed because of the harmonics and distortion present which distorts the sinusoidal waveform.

The author [37] **Michael Lubliner** says about the past, present & future direction of energy audit of residential single family. In the paper the main aim is conducting audit for national institute of standards and technology. The purpose is to measure energy use and energy saving associate with short term energy and long term energy which is related to repairs, retrofit, remodeling for a single family house. Repair remodeling is one of the ways to save the energy. Utility billing analysis to improve the efficiency of energy in residential single family housing is another way. The need for the observation of utility billing data analysis is the current reality. The author was report the past, present & future direction of energy audit in single family houses for heating & ventilating air conditioning for industries. The residential or domestic energy audit research will improve the energy efficiency. The author's use the round robin auditing to improve energy auditing and retrofit practices. Finally, the author feedback from round robin to helps ensure that house owner get comparatively consistent, reliable, repeatable & useful recommendation from home performance contracting industry.

2.3 Literature Review on Power factor

Muhammad Rusli, et al [39] this paper presented the single tuned harmonic filter design as a total harmonic distortion compensator in a 20 KV distribution system. The level of harmonic distortion at individual level is increased due to non-linear loads. To avoid this unnecessary level of harmonics a passive filter with 3.465 KVA apparent powers was installed. As a result, the power factor was upgraded from 0.86 to 0.95

Mohammad Hamid Shwhdi [40] this paper investigates on harmonics in large steel factory with 49 buses, 38 two winding transformers, 3arc furnace, 2 ladle furnace and many inductive loads. Due to the existence of these loads the reading of power factor in different buses was 0.56-0.59. This would result in penalties to the factory. As a result, the paper presented with a solution that corrects the power factor value from 0.56 to 0.93 through designing passive filters.

Literatures gap summary

To minimize energy usage and potentially increased profits, through production efficiency gains, while procuring the lowest cost and most reliable supplies of power, the authors take of energy efficiency opportunities such as; more productive state of the art technology that improves a facility's competitive edge and improved environmental performance and compliance with environmental and pollution abatement regulations. Hence, applying a successful energy management process in different companies they improve production efficiency of the plant, maintaining a high energy load factor and correcting for low power factor. But, in this thesis correctness of the lighting installation was evaluated and corrected; using International Motor Selection and Savings Analysis (IMSSA) software by entering related data from nameplate information it calculates the annual cost saving and calculates the payback periods. Those were not considered in the previous researches. However, these factors have a great impact on the overall power consumption of the factory. In addition, the power factor correction for the factory was formulated to check were the factory under EEU penalty or not and design the suitable capacitor bank for the factory.

CHAPTER THREE

METHODOLOGY

3.1 Production Process of the Factory

Addis Gas and plastic factory is located in Addis Ababa city around 20 km far from the central Addis Ababa and is engaged in the production of mainly CO_2 and different plastic products. A brief process description follows.

At AGP, CO_2 gas is produced by combustion of diesel oil. The CO_2 generation plant of the company has a design capacity of producing 280kg/hr of CO_2 gas. CO_2 gas from oxidized diesel oil undergoes different chemical processes - scrubbing, stripping, and separation, before it is compressed into high-pressure steel cylinders for final delivery. The CO_2 gas produced has 98% purity.

The process of forming plastic resins into plastic products is the basis of the plastic industry. Plastic resins must be softened or sufficiently liquefied to get required shapes. Plastics are used extensively by many key industries – automobile, aerospace, construction, packaging, electrical, health etc. Useful properties of plastic include: lightness, non-rusty, manufacturability as different optical medium - transparent, translucent & opaque, and pigmented to a variety of colors.

Addis gas and Plastic factory was established in 1996 E.c. The plant consists of many buildings, which includes workshops, administrative office, CO_2 and plastic production rooms and a separate building houses an employee dining room [38].

3.1.1 Production Data

The factory is engaged in manufacturing and marketing of industrial gases (carbon dioxide and oxygen) and plastic creates for house hold and industrial uses. The Table 1-1 presents production statistics for the plant.

Engineers use production data to make decisions on forecasts and budgets, focusing on cost effectiveness. They also work with geologists on what wells they want to drill – plotting on future wells based on the performance of existing wells, which relies on accurate production data.

Table3.1: Production Data of the Factory

Item	Year(G.C)	Production	Unit
CO_2 production	2018	1,983,600	Kg
CO_2 production	2019	1,846,800	Kg
CO_2 production	2020	2,017,800	Kg

The production of CO_2 of AGP starting by the fuel is burned under carefully controlled conditions. After water/soda ash scrubbing, CO_2 from the flue gas is absorbed into a Mono-ethanolamine based solution which is subsequently heated by the combustion process to release the raw CO_2 gas. The CO_2 is then led to a vertical, two stage, dry running (oil free) compressor and on to the high pressure, potassium permanganate purifier. After thorough drying in an automatic twin tower molecular sieve drier, the CO_2 receives final purification in an activated carbon filter prior to feeding into an R404a refrigeration loop in the liquefier. The pure, liquefied CO_2 can then be fed to a bulk CO_2 storage tank. This continuous process is efficient, reliable and safe. The CO_2 meets international food-grade quality standards and is used daily by the world‘s top gas companies, soft drink and beer brands in over 100 countries. At AGP the control mechanism of CO_2 production is by programmable logic controller (PLC).

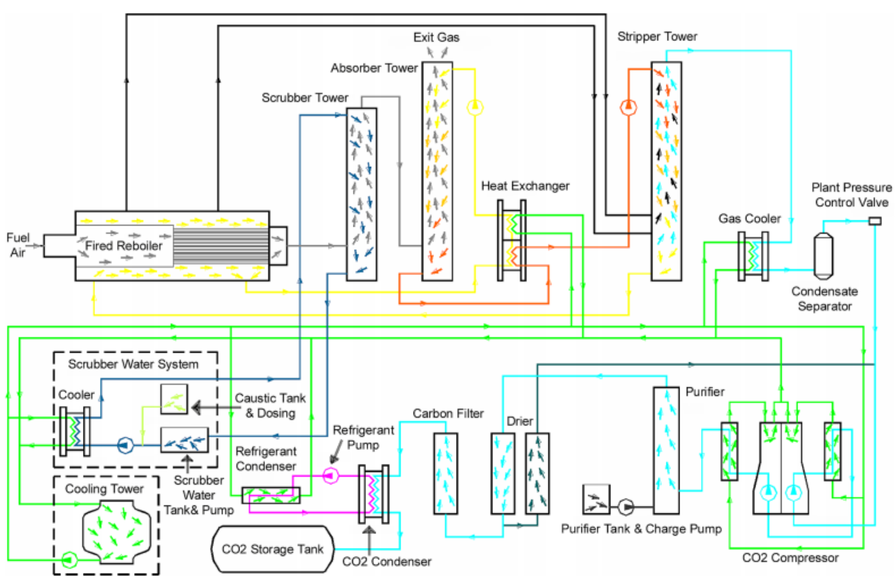


Figure 3.1: How CO_2 production processes look like

Although several different processes are currently under development for the separation of CO_2 from flue gases, absorption processes using aqueous solutions of chemical absorbents are the leading technology. The typical flow sheet of CO_2 recovery using chemical absorbents is shown in Figure 3.3.

After cooling the flue gas, it is brought into contact with the chemical absorbent in the absorber. A blower is required to pump the gas through the absorber. At temperatures typically between 40 and 60°C CO_2 is then bound by the chemical absorbent in the absorber. After passing through the absorber the flue gas undergoes a water wash section to balance water in the system and to remove any droplets or vapor carried over and then leaves the absorber. The "rich" absorbent solution, which contains the chemically bound CO_2, is then pumped to the top of a stripper, via a heat exchanger.

Figure 3.2: AGP purified Carbon-dioxide storage tanker.

The regeneration of the chemical absorbent is carried out in the stripper at elevated temperatures (100 – 140 °C) and pressures between 1 and 2 bar(a). Heat is supplied to the re-boiler to maintain the regeneration conditions. This leads to a thermal energy penalty as a result of heating up the solution, providing the required desorption heat for removing the chemically bound CO_2 and for steam production which acts as a stripping gas. Steam is recovered in the condenser and fed back to the stripper, whereas the CO_2 product gas leaves the condenser. The CO_2 -product is a relatively pure (> 99%) product, with water vapor being the main other component. Due to the selective nature of the chemical absorption process, the concentration of inert gases is low.

Figure 3.3 the interior part of AGP CO_2 production room.

The "lean" absorbent solution, containing far less CO_2 is then pumped back to the absorber via the lean-rich heat exchanger and a cooler to bring it down to the absorber temperature level. CO_2 removal is typically around 90%.

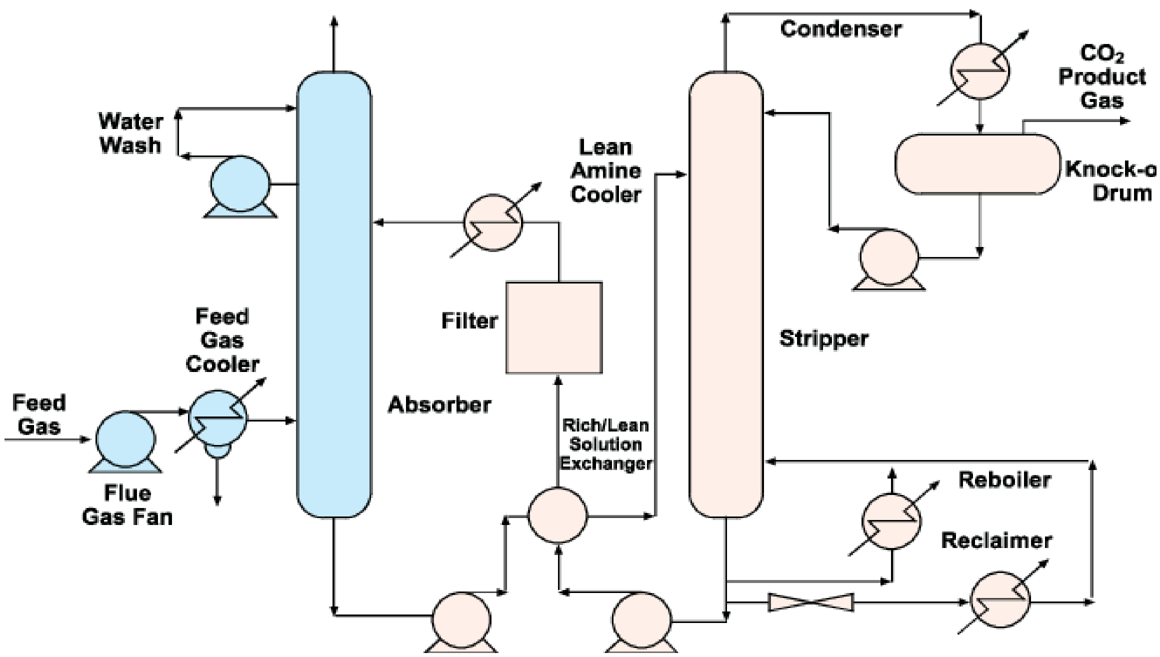


Figure 3.4: Process flow diagram for CO_2 recovery from flue gas with chemical absorbents

3.2 Major Energy Utilization Systems and Areas

Several major systems and processes in the factory consume energy. The following are the main energy sources used by the factory.

Electricity: AGP uses electricity as a main source of energy, which is supplied from EEU. In addition, this is a common energy source for running all AGP machines and lightning. It is used primarily for motive power, compressed air, and lighting. The main use of electricity is for the motors and drives associated with process equipment in the CO_2 and plastic productions.

Furnace oil: It is consumed by a steam boiler plant to produce steam for process use and one of raw material for CO2 production process.

Steam: Steam is one type of thermal energy and produced by combustion results of fuel and air at the required temperature. Combustion is carryout by mixing fuel and air at elevated temperatures.

Water: Water is the key source for producing steam, combining with steam it uses for AC of the factory and drinking and sanitation of the employees etc.

Compressed Air: - This is one form of energy, and used for converting the potential energy in air to mechanical energy of all valves and other parts.

3.3 The Industry Network Modeling

An Electronic System is a physical interconnection of components, or parts, that gathers various amounts of information together..A simple electronic system is made up of an input, a process, and an output. Both input and output variables to the system are signals. Examples of such systems include circulation pumps, compressors, manufacturing systems, refrigeration plant and motor control panels.

Electrical power enters to the AGP plant from a substation nearby with 15kV high voltage line. This 15kV high voltage-incoming line is connected to the factory's transformer with a capacity of 800kVA.The incoming 15kV is step-down to 380/220 volts for distribution. Plant power factor is not known or there is no power factor correction done. This means there is no capacitor bank. The total capacity of the factory is around 125kW.The utility-supplier provides a kWhmeter, located on the incoming power panel. There is no any additional electric supplier when utility electric is not available.

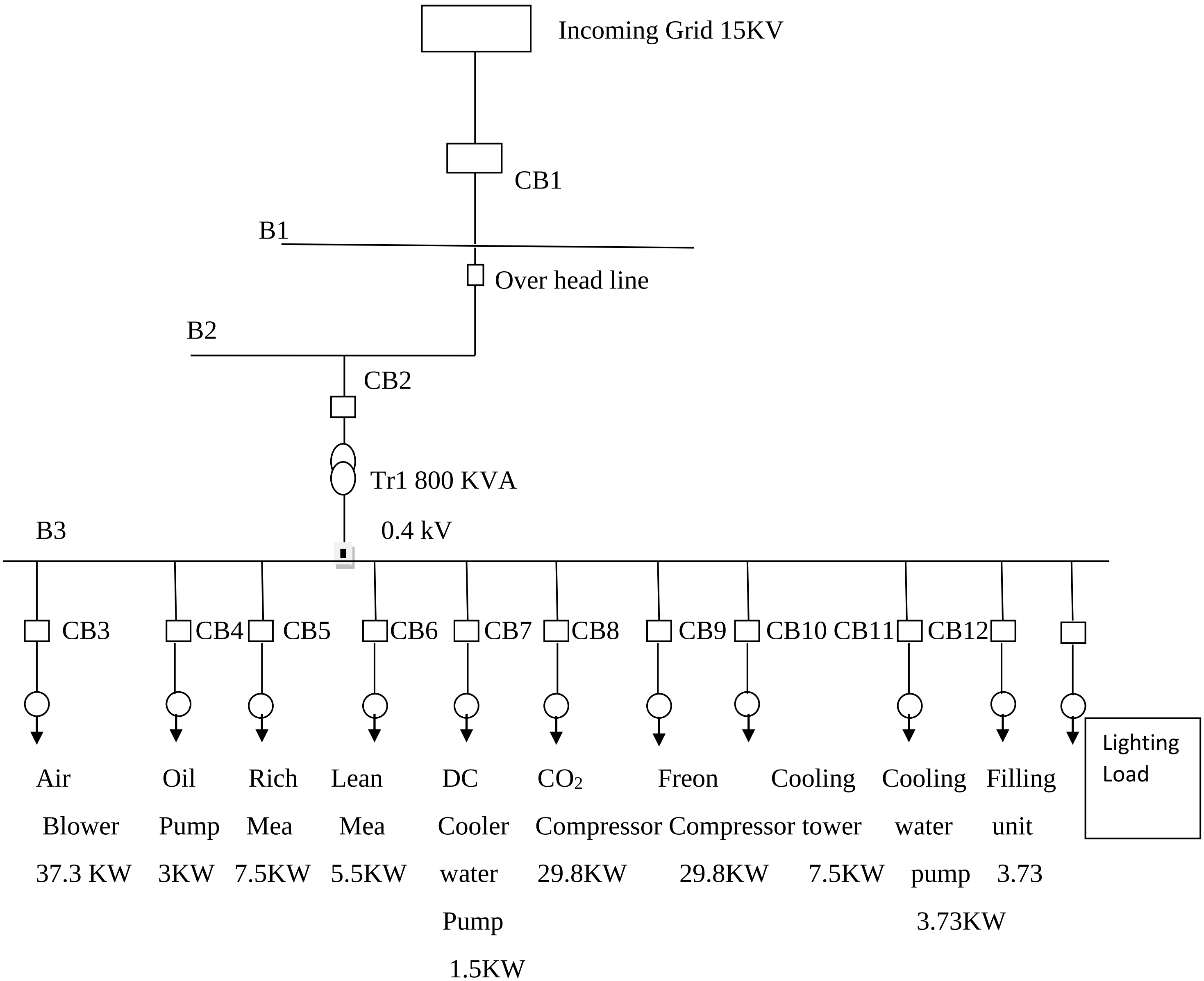


Figure 3.5: Simplified Single Line Diagram of the Power System in AGP

3.4 Lighting System

Lighting in the plant is delivered primarily by 8-foot fluorescent tubes mounted two per fixture. These tubes are of standard wattage. Many T -12 tubes FL provide lighting in the different departments of the factory. Some fluorescent tubes provide office area lighting. In the production room of CO_2 the lighting system is hay bay.A lighting survey of the plant indicated that most areas are under-light, compared with published recommended illumination levels for

Gas and plastic plants. This has apparently caused no problems in the performance of processing operations. The main cause for low light levels in some areas of AGP is primarily due to burn out without replacement. However, that ballasts serving these fixtures should be disconnected to increase energy savings.

For diverse types of lamps, there will be different levels of luminous intensity and illumination, which are essential in several working areas. Table 3-2 and Table 3-3 show the luminous intensity and lifetime of various lamps and illuminations necessary in various working station respectively. In addition, Table 3-2 and Table 3-3 are standard tables, which are needed to estimate whether the current installation system is appropriate, or not. Various terms and definitions are used to quantify light, light source, etc. These are luminous flux, luminous intensity, illumination, luminance, etc. and their corresponding mathematical expressions are given.

Table 3.2: Luminous Intensity and Lifetime of Various Lamps [14]

No	**Lamp type**	**Output power (Watt)**	**Luminous Intensity (Efficiency) (Lumen/Watt)**	**Service life (hrs)**
1	Incandescent lamp	3-1000	10-15	1,000-2,000
2	Halogen lamp	5-500	15-25	2,000-4,000
3	Fluorescent tube	4-60	50-100	7,500 -24,00
4	Compact Fluorescent (CFL)	5-40	50-80	10,000-20,000
5	Metal Halide	30-2000	50-115	6,000-20,000
6	HP Mercury vapor	40-1000	25-55	16,000-24,000
7	High Pressure Sodium	35-1000	40-140	16,000-24,000
8	Low Pressure Sodium	35-180	100-185	14,000-18,000
9	Light Emitting Diode (LED)	1-400	>100 (continuous increase)	20,000-50,000

Table 3.3: Illuminations Required in Various Working Stations [15]

No	Working Area	Average Luminance required (Lux)
1	Office	500
2	Work Shop	200-750
3	Corridors, Stairs	100
4	Fine Painting(industry)	750
5	Precision assembly(industry)	1000
6	Boilers and Pump house	20-100
7	Final inspection	700-1000
8	Canteens	150
9	Grey close inspection	700-1000

3.4.1 Mathematical Formulas for Lighting Analysis

Lighting Analysis a process in which to determine the most effective lighting method based on engineering and design specifications. Light can be measured subjectively, based on the brightness seen by the human eye. Units include candles, lumens, foot-candles and lux. Important Formulas for Lighting Assessment [17].

$$TP = LR \times NL \tag{3.1}$$

Where;

TP = Total power ratings (Watts) of the lamps installed in the department.

LR = Lamp Rating (Watt).

NL = Number of lamps installed.

$$TL_u = NL \times L_o \tag{3.2}$$

Where;

TL_u = Total lumens output of lamps installed in the department (Lumen).

L_o = is the luminous output of each fluorescent lamp, which is 85 Lumens/Watt, obtained Table 3.1 for fluorescent lamps.

$$\mathbf{T}\boldsymbol{ILu} = \boldsymbol{TL_u} / \boldsymbol{R}\mathbf{A} \quad (3.3)$$

Where;

TILu = the illumination produced by the installed lamps expressed in Lux (1Lux = 1Lumens/m2). RA = Room area of each department (m2)

$$\boldsymbol{ALR} = (\boldsymbol{ILuR} / \boldsymbol{ILu}) \times \boldsymbol{N}\mathbf{L} \quad (3.4)$$

Where;

ALR = The actual lamps required for proper illumination, which uses to analyze energy wastes due to improper illumination.

IL_uR = is the illumination required in each area. (E.g., for office, IL_uR is 500 Lux from Table 2-2 and this figure is compared with the actual Lux produced in each office.)

The actual fluorescent lamp required (ALR) are calculated for each department and compared with number of lamps (NL) currently installed.

$$\boldsymbol{EU} = \boldsymbol{NL} \times \boldsymbol{LR} \text{ x } \mathbf{OH} \quad (3.5)$$

Where;

EU = Energy utilization for the lighting systems (kWh)

$$\boldsymbol{ER} = \boldsymbol{ALR} \times \boldsymbol{LR} \text{ x } \mathbf{OH} \quad (3.6)$$

Where;

ER = Energy required after a proper illumination (kWh)

$$\boldsymbol{ED} = \boldsymbol{EU} - \boldsymbol{E}\mathbf{R}$$

(3.7)

Where;

ED = Energy difference (kWh). It compares the

EU, of the currently installed lamps, with the ER, after proper illumination.

3.5 Electric Motor

The electric motor is a machine capable of converting electrical energy into mechanical energy. The induction motor is the most widely used type of motor because it combines all the advantages offered by the electrical energy such as low cost, easy of supply and distribution, clean handling and simple controls - together with those of simple construction and its great versatility to be adapted to wide ranges of loads and improved efficiencies. The most common types of electric motors are:

a) Direct current motors: These motors are quite expensive requiring a direct current source or a converting device to convert normal alternating current into direct current. They are capable of operating with adjustable speeds over a wide range and are perfectly suited for accurate and flexible speed control. Therefore, their use is restricted to special applications where these requirements compensate the much higher installation and maintenance costs.

b) Alternating current motors: These are the most frequently used motors because electrical power is normally supplied as alternating current. The most common types are:

Synchronous motors: synchronous motors are three-phase AC motors which run at fixed speed, without slip, and are generally applied for large outputs (due to their relatively high costs in smaller frame sizes).

Induction motor: these motors generally run at a constant speed which changes slightly when mechanical loads are applied to the motor shaft. Due to its simplicity, robustness and low cost, this type of motor is the most widely used and, in practical terms, is quite suitable for almost all types of machines. Currently it is possible to control the speed of induction motors by frequency inverters.

When considering energy-efficiency improvements to a facility's motor systems, a systems tactic must be used in order to achieve optimal savings and performance. In the following, essential mathematical formulas, bearing in mind with respect to energy use and energy saving opportunities, for a motor system are presented.

There are several occasions in industries that motor systems are over sized due to consideration of successive safety factors in the design of the systems. Motors that are oversized present high losses, lower efficiency and also low power factor. In such a situation oversized motors have to be changed by the correct sized motors. Distribution cables are used to supply currents to motors and these cables produce I*I*R losses. Correct sizing of the cables will allow cost effective minimization of those losses and it will also reduce voltage drops in the distribution cables.

3.5.1 Motor Efficiency

The efficiency of a motor can be well defined as the ratio of mechanical power output to its electrical power input. It is expressed as:

$$\eta = \frac{0.746 \times \mathrm{hp} \times \mathrm{Load}}{\mathrm{pi}} \tag{3.8}$$

Where, η = Efficiency as operated in %

h_p= Name plate rated horsepower

$Load$ = Output power as a % of rated power

P_i = Three phase power in kW

An electric motor's function is to convert electrical energy to mechanical energy to accomplish useful work. In the procedure of converting electrical energy to mechanical energy to serve a certain load, motor losses their energy as shown in the Figure 2-1. Losses can differ from approximately 2% to 20% [15].

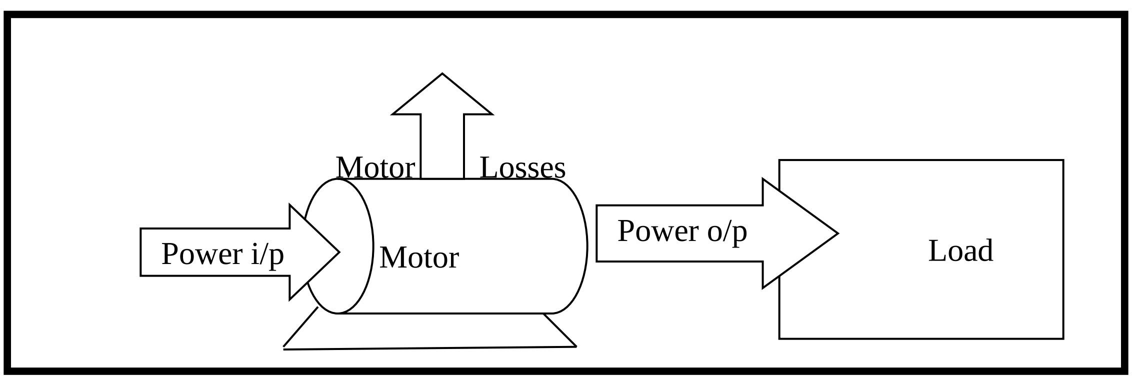


Figure 3.6: Illustration of Motor Energy Losses [16]

The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: fixed losses - independent of motor load, and variable losses - dependent on load. Fixed losses involve of magnetic core losses, friction and winding losses. Magnetic core losses, sometimes called iron losses, consist of eddy current and hysteresis losses in the stator. They differ with the core material, geometry and with input voltage. Friction and winding losses are caused by friction in the bearings of the motor and aerodynamic losses related with the ventilation fan and other rotating parts. Variable losses comprise of resistance losses in the stator and in the rotor and miscellaneous stray losses.

The primary factors affecting motor efficiency are:

- ✓ The size of the motor: Larger motor rate capacity tends to be more efficient.
- ✓ Speed: High-speed motors tend to be more efficient.
- ✓ Kind of enclosure: Open enclosures tend to be more efficient.
- ✓ Design classification: Lower slip motors tend to be more efficient.
- ✓ Size of the air gap stuck between the rotor and the stator: Large air gaps tend to exploit efficiency at the expense of power factor, while small air gaps slightly compromise efficiency while significantly improving power factor.
- ✓ Rewinding: It may diminish its efficiency.
- ✓ Motor load: In general motors' operating below 75% of full load relatively reduces their efficiency and with operating below 50% very inefficient.
- ✓ Age: New motors are more efficient.
- ✓ Temperature totally enclosed fan-cooled (TEFC) motors are more efficient than screen protected drip-proof (SPDP) motors.

3.5.2 Motor Loading

Loading or load factor is defined as the ratio of the average load over a given period to the maximum demand, peak load, occurring in that period. In other words, the load factor is the ratio of energy consumed in a given period of hours to the peak load, which has happened during that particular period or is the amount of work the motor does compared with its maximum rated power output. Load factor means how professionally we use energy. It is the measure of the use of electrical energy during a given period to the maximum energy, which would have been consumed in that period. For example, a motor rated at 80kW driving a 60kW load is said to be 75% loaded. Modern motors work most efficiently above 50% loading with a peak between 75% and 90% load. Note that the rating plate on a motor announces its output power at the shaft, so that the real electrical input energy drawn will be the output power at the shaft and the power lost due to the motor inefficiency [17].

Since the efficiency of a motor is hard to assess under normal operating conditions, the motor load can be measured as an indicator of the motor's efficiency. As loading increases, the power factor and the motor efficiency increase to an optimum value at around full load. Most electric motors are designed to run at 50% to 100% of rated load. Maximum efficiency is usually near 75% of rated load [18]. Thus, an 80 hp motor has an acceptable load range of 40 to 80 hp, peak efficiency is at 60 hp. A motor's efficiency tends to reduction dramatically below about 50% load. However, as Figure 2-2 shows, the range of good efficiency differs with individual motors and tends to extend over a wider range for larger motors.

A motor is considered under loaded when it is in the range where efficiency drops meaningfully with reducing load. Overloaded motors can overheat and lose efficiency. Many motors are designed with a service factor that allows irregular overloading. Service factor is a multiplier that indicates how much a motor can be overloaded under ideal ambient conditions. For example, a 20 hp motor with a 1.15 service factor can handle a 21.5 hp load for short periods without suffering important damage. Although many motors have service factors of 1.15, running the motor continuously above rated load reduces efficiency and motor life. The US DOE fact sheet provides tables with typical motor efficiency values [18].

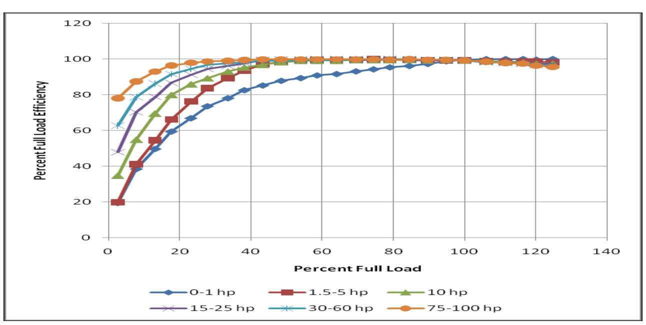


Figure 3.7: Motor Part Load Efficiency as a Function of % Full Load

[Taken from a fact sheet, US Department of Energy] [18]

Motor Load Estimation Techniques

Operating efficiency and motor load values must be assumed or based on field measurements and motor nameplate information. The motor load is typically derived from a motor's part load input kW measurements as compared to its full-load value (when kW or voltage, amperage, and power factor readings are available), from a voltage compensated amperage ratio, or from an operating speed to full-load slip relationship.

Equations used to estimate motor load are summarized below. The kilowatt technique should be used whenever input kilowatt measurements are available. Use the slip technique only when strobe tachometer readings are at hand and kilowatt values are not available. The full load or synchronous speed for the existing motor may be extracted from the nameplate, whereas speed characteristics for new motors are obtained from manufacturers' catalogs [9].

Motor load estimation techniques are:

- **Input Power Measurements Method:**

When direct-read power measurements are available, use them to estimate motor part-load. With measured parameters taken from hand-held instruments, Equation 2.9 can be used to calculate the three-phase input power to the loaded motor. Then the motor's part-load can be computed by comparing the measured input power under load to the power essential when the motor operates at rated capacity. The relationship is shown in Equation 2.11 [18].

Measuring the motor's actual power delivers a convenient and accurate way to decide the load. In this case, the motor's measured kW (or V, PF and I) is required.

Measurements Required:

$P_{input\ measured} = P_{im}$ = Measured motor load, kW (from the instrument)

OR

I = Measured RMS motor current, average of 3-phases

V = Measured average RMS line-to-line voltage

PF = Measured power factor

Inputs Required:

hp = Motor's rated power output, hp (or kW)

ηfl= Motor's full load rated efficiency

Formula:

With measured parameters taken, use Equation 2.9 to calculate the three-phase input power to the loaded motor.

$$P_{im}=\frac{\sqrt{3} \times V \times I \times PF}{1000}[kW] \quad (3.9)$$

$$P_{ir}=\frac{hp \times 0.746}{\eta fl}[kW] \quad (3.10)$$

Where,

Pir= Motor's power input at rated full load [kW]

Therefore,

$$Load=\frac{Pim}{Pir} \times 100\% \quad (3.11)$$

Where,

Load = Output power as a % of rated power

With Equation 2.10, the exact efficiency (ηfl) is almost never known, but there are several ways to reach at a rational estimate. One way is to refer to motor manufacturer's literature or motor nameplate data.

- **Kilowatt ratio technique**

$$\text{Motor load} = \frac{KW_{input}}{(hp*0.746)/\eta_{fl}} = \frac{\sqrt{3}*volts_{avg}*amps_{avg}*pf}{1000*hp*0.746/\eta_{fl}} * 100\% \quad (3.12)$$

Another technique used to calculate motor loads is amperage ratio technique as suggests that loads be estimated by comparing a motor's true root-mean-square (rms) amperage draw against its full-load or nameplate value. Thus, the load on a motor is defined as:

- **Amperage ratio technique:**

This method assumes that the percentage of load is closely proportional to the percentage of the ratio of measured current to full load current. The amperage draw of a motor varies almost linearly with respect to load, down to approximately 50 - 60% load. Below this load range, magnetizing current desires and other ineffectiveness cause increasing non-linearity. Therefore, if the nameplate full-load current is known and the actual current is measured, one can estimate the motor load. As with rated speed in the slip calculations, the rated full load current is based on operation at the rated voltage. If the actual operating voltage is different from the rated voltage, the full-load current must be corrected [18].

$$\text{Motor load} = \frac{amps_{\ measured}}{amps_{\ nameplate}} * \left(\frac{volts_{\ measurd}}{volts_{\ nameplate}}\right) \quad (3.13)$$

Where;

kW (input) – input power in Kilowatt
Volts (avg) – average three phase voltage
Volts (nameplate) – nameplate three phase voltage
Amps (avg) – average three phase current
Amps (nameplate) – nameplate three phase current
Pf – power factor
Hp – horse power (rated power)
η(fl) – full load efficiency
rpm (sych) – synchronous speed in revolution per minute
Rpm (measured) - measured speed in revolution per minute
Rpm (nameplate) nameplate speed in revolution per minute

Formula:

The equation that relates motor load to measured current values is shown in Equation 2.14.

$$\text{Load} = \frac{I}{I_r} \times \frac{V}{V_r} \times 100\% \quad (3.14)$$

Where,

Load = Output power as a % of rated power

- **Slip Method:**

Slip is the variance between synchronous and shaft speed. A motor's speed and slip is comparative to its load. The amount of slip present is proportional to the load imposed upon the motor by the driven apparatus [18].

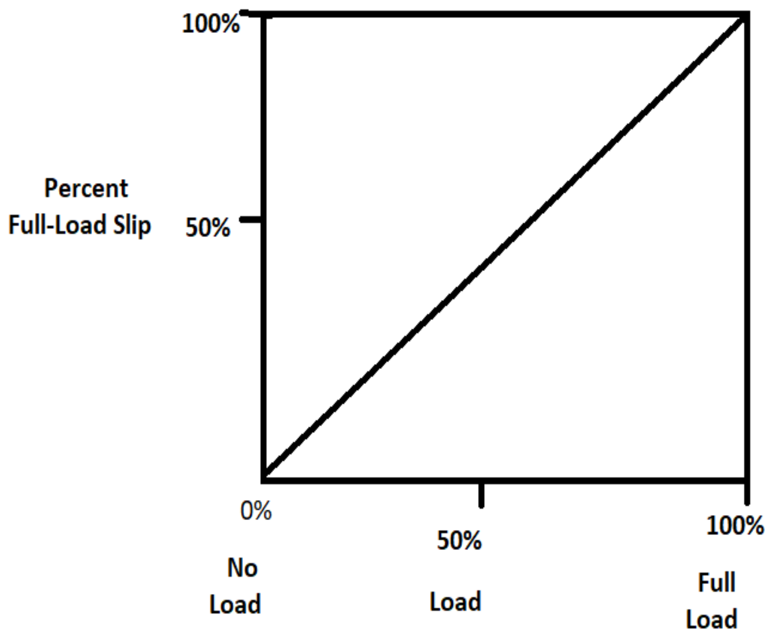


Figure 3.8: Percent Motor Slip as Function of Motor Load

[Taken from a fact sheet, US Department of Energy] [18]

The synchronous speed of an induction motor is usually accessible from motor nameplate rating or can be calculated. It depends on the frequency of power supply and on the number of poles for which the motor is wound.

Measurements required:

S = Measured motor speed, RPM

Inputs required:

S_S = Motor's synchronous speed (RPM)

S_r = Motor's nameplate full load speed (RPM)

P = Number of poles

f = Frequency in Hz

Formula:

The motor load can be expected with slip measurements as shown in Equation 2.15.

$$\text{Load}= \frac{Slip}{S_s - S_r} \times 100\% \quad (3.15)$$

Where,

Load = Output power as a % of rated power

$$\text{Slip}=Ss–S \quad (3.16)$$

$$\text{S}_{\text{s}}= \frac{120 \times f}{P} \quad (3.17)$$

Energy Efficiency Opportunities in Electric Motors

When planning to increase the efficiency of the motor system in an industry, a system method including pumps, compressors, and funs must be used in order to achieve optimum savings and performance. Consideration with respect to energy use and energy saving chances for a motor system are discussed as follow.

a) Replacing Under Load Motors with Proper Sized Motors

Possibly the utmost common practice contributing to less motor efficiency is that of under loading. Under loading effects in lower efficiency, power factor and higher than required first cost for the motor and associated control equipment.

Under loading rises motor losses and reduces motor efficiency and the power factor. Under loading is the most common reason of inefficiencies for numerous causes:

- ✓ Apparatus producers tend to use a big safety factor when choosing the motor.

- ✓ Equipment is often under-utilized. For example, machine tool apparatus producers offer for a motor rated for the full capacity load of the equipment. In reality, the user may rarely want this full capacity, causing in under-loaded operation most of the time.
- ✓ Large motors are designated to allow the output to be retained at the preferred level even when input voltages are unusually low.
- ✓ Large motor is chosen for applications demanding a high starting torque but where a smaller motor that is designed for; high torque would have been more appropriate.

Motor size should be carefully chosen based on a cautious evaluation of the load. However, when substituting an oversized motor with a smaller motor, it is also significant to consider the potential efficiency achievement. Larger motors namely have essentially higher rated efficiencies than smaller motors. Therefore, the replacement of motors operating at 60 – 70% of capacity or higher is generally not recommended. If the plant's motor functions under 50% of full rated load, it considers to replace large, partially loaded motors with lesser, full loaded motors either from company index or new energy efficient motor.

On the other hand, there are no firm rules governing motor selection and the savings potential desires to be estimated on a case-by-case foundation [19].

b) Replace Standard Motors with Energy Efficient Motors

High efficiency motors have been designed specially to raise operating efficiency compared to standard motors. Design enhancements emphasis on decreasing intrinsic motor losses and contain the use of lower-loss silicon steel, a longer core, thicker wires, thinner laminations, smaller air gap between stator and rotor, copper instead of aluminum bars in the rotor, superior bearings and a smaller fan, etc. Energy efficient motors cover a wide range of ratings and the full load. Efficiencies are 3% to 7% higher compared with standard motors as shown in Figure 2-3, for a typical three-phase induction motor.

Due to the changes in improving performance, the costs of energy efficient motors are greater than standard motors. The greater cost will often be paid back quickly through reduced operational costs, particularly in new applications or end-of-life motor replacements. However, replacing existing motors that have not reached the end of their useful life with energy efficient motors may not always be financially feasible, and therefore it is recommended to only replace these with energy efficiency motors when they fail [16].

Though high efficiency motors typically cost 30% more than standard motors, the reduced electricity usage can offset the higher capital costs in a short period. An industrial motor can use electricity worth about four times its capital cost yearly. Shifting to high efficiency models produces larger efficiency enhancements and percentage cost savings in the small motor sizes, but greater absolute cost savings in the large. Larger motors are often rewound, not substituted, when they failure. Rewinding is at first less expensive than purchasing a new motor, but eventually costs more because of degraded efficiency. The efficiency of a rewound motor is typically about 2% points below that of a new standard motor [20].

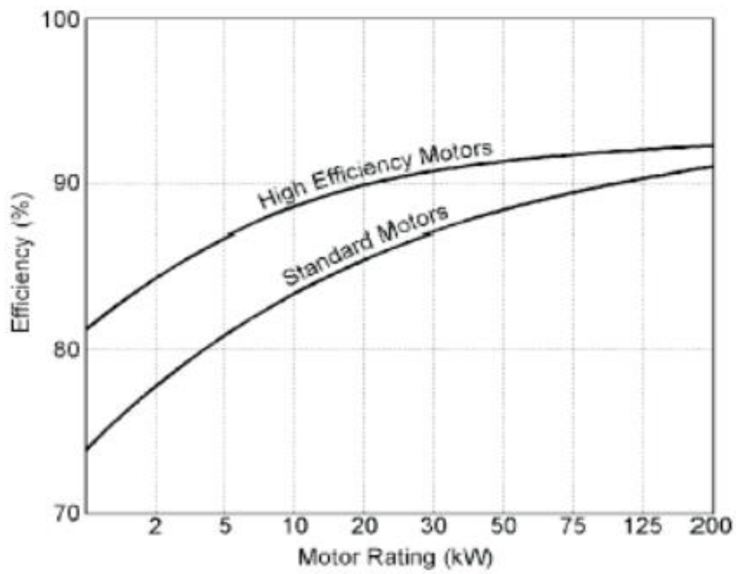


Figure 3.9: Typical Efficiencies of Standard and Energy Efficient Motors

(Taken from Bureau of Energy Efficiency Publications)

Motor Master + international (IMSSA) Software

Motor Master + international software can support in appropriate motor selection and helps for motor systems enhancement scheduling, through recognizing the cost effectiveness, operating cost due to the continual operation of an existing standard efficiency motor to make decision on buying new premium efficiency, rewinding or replacing of the existing motor. This software aids on motor selection and analysis of the saving potential as the outcome of comparison of the existing motor with efficient motor.

U.S department of energy’s best practices program provides the software for the purpose of [21]:

- ✓ Estimating the performance of the existing motor with the appropriate energy efficient motors.
- ✓ In judgments concerning replacement of oversized and under loaded motors.
- ✓ Demand attention to a life-cycle cost approach to motor replacement judgments.
- ✓ Support motor users in choosing the appropriate motor for an application.
- ✓ Increase consciousness of electric motor system efficiencies.

Motor Master + international software uses field data measurements of a motor as input parameters for the existing motor in a factory. In addition, field data measurements and the purchase price for the energy efficient motors column taken from the Motor Master + international software catalogue. Table 3.3 shows, the input and output field data measurements for analysis saving potential of electric motor using Motor Master + international software.

Table 3.4: Input and Output Field Data Measurements of Motor Master Software

Existing Motor Input Data	Energy Efficient Motor Input Data (Software catalogue)	Output parameters
Power Rating (kW)	Power Rating (kW)	Energy Saving (kWh)
Loading (%)	Loading (%)	Demand Saving (kW)
Efficiency (%)	Efficiency (%)	Simple pay-back period (yrs.)
Name Plate Speed (RPM)	Name Plate Speed (RPM)	NA
Voltage Rating (V)	Voltage Rating (V)	NA
NA	Purchase Price (US $/ birr)	NA

c) Improving Motor Maintenance

The purposes of motor maintenance are to increase motor life span and to forecast a motor failure. Motor maintenance procedures can be categorized as either preventive or predictive. The aim of preventative measures is to prevent unexpected downtime of motors, include electrical consideration, voltage unbalance minimization, load consideration, and motor ventilation, alignment, and lubrication. The aim of predictive motor maintenance is to detect ongoing motor temperature, vibration, and other operational facts to recognize when it becomes essential to repair or substitute a motor before failure occurs. The savings related with an on-going motor maintenance program are important, and could range from 2% to 30% of total motor system energy use [23].

D) Rewinding

It is common practice in industry/factory to rewind burnt motors. The number of rewound motors in some industries exceeds 40% of the total number of motors. Careful rewinding can sometimes maintain motor efficiency at previous levels, but in most cases results in efficiency losses. Rewinding can be affected by a number of factors that contribute to deteriorated motor efficiency. Such as: - winding and slot design, winding material, insulation performance, and operating temperature. For example, when heat is applied to strip old windings the insulation between laminations can be damaged, thereby increasing eddy current losses. A change in the air gap may affect power factor and output torque. [23]

3.6 Power factor correction

Inductive loads like transformers, electric motors, and HID lighting may cause a low power factor. A low power factor may result in increased power consumption, and hence increased electricity costs. The power factor can be corrected by minimizing idling of electric motors (a motor that is turned off consumes no energy), replacing motors with premium-efficient motors.

By definition power factor is a ratio of true power (useful power) expressed in kilo watts and apparent power expressed in kilo volt amperes. Because true power and apparent power form the adjacent and hypotenuse sides of a right triangle, respectively, the power factor ratio is also equal to the cosine of that phase angle and is a unit less parameter.

$$\text{Power factor} = \left(\frac{\text{truepower}}{\text{apparentpower}}\right) \qquad (3.18)$$

A large proportion of the electric machinery used in industry has an inherently low pf, which means that the supply authorities have to generate much more current than is theoretically required. In addition, the transformers and cables have to carry this high current. When the overall pf of a generating station's load is low, the system is inefficient and the cost of electricity corresponding high. To overcome this, and at the same time ensure that the generators and cables are not loaded with the wattles current, the supply authorities often impulse penalties for low pf .

Some of the machinery or equipment with low pf is listed below:

a. Induction motors of all types
b. Power thyristor installations
c. Welding machines
d. Electric arc and induction furnaces
e. Choke coils and induction furnaces
f. Neon signs and fluorescent lighting

The method employed to improve the pf involves introducing reactive (kVAr) into the system in phase opposition to the wattles or reactive current.

Standard practice is to connect power capacitors in the power system at appropriate places to compensate the inductive nature of the load.

3.6.1 Power factor Improvement

Improve power factor by adding power factor correction capacitors to the plant distribution system. When apparent power (kVA) is greater than working power (kW), the utility must supply the excess reactive current plus the working current. Power capacitors act as reactive current generators.

The apparent power (KVA) in a.c circuit can be resolved into two components, the in-phase component which supplies the useful power (KW), and the wattles component (kVAr) which does no useful work. The pharos sum of the two is the KVA drawn from the supply.

The cosine of the phase angle between the KVA and the KW represents the power factor of the load. This is shown by the pharos diagram in Figure. 2.5(a).

To improve the power factor, equipment drawing kVAr of approximately the same magnitude as the load kVAr, but in phase opposition (leading), is connected in parallel with the load. The resultant KVA is now smaller and the new power factor (cos Φ2) is increased d (Figures. 2.5(a) and (b)). Cos Φ2 are controlled by the magnitude of the kVAr added. Thus any desired power factor can be obtained by varying the leading kVAr.

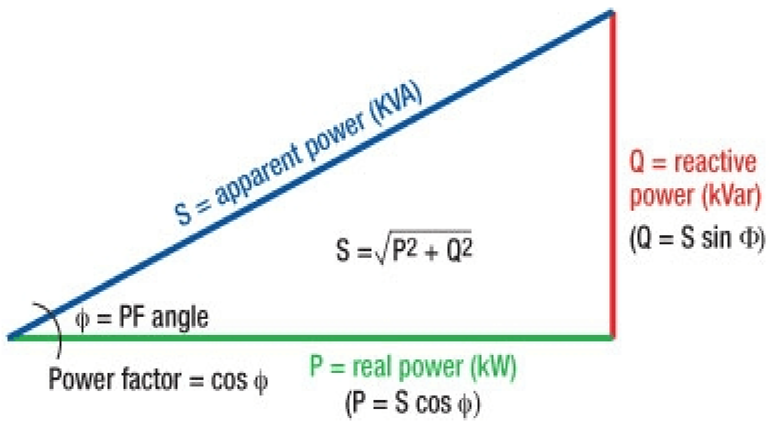


Figure 3.10(a) Pharos Diagram of a plant operation at lagging power factor

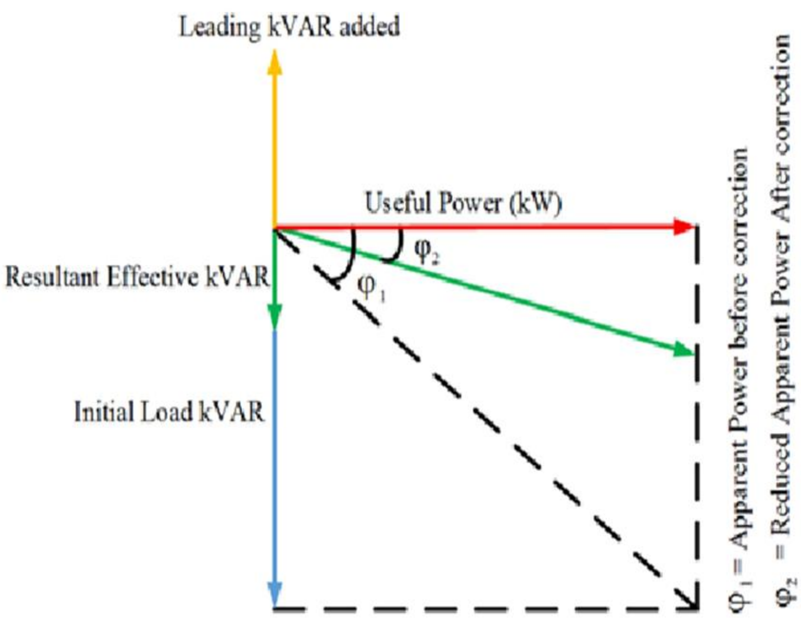


Figure 3.11(b) Power factor correction by adding leading kVAR

$$\mathbf{S} = \frac{\mathbf{P}}{\mathbf{pf}} \tag{3.19}$$

Where;

S=Apparent power

P=Input power

Pf=Power factor

$$\mathbf{Q} = \sqrt{\boldsymbol{s^2} - \mathbf{p^2}} \tag{3.20}$$

Where;

Q= Reactive Power

$$\mathbf{I_L} = \frac{\mathbf{St}}{\mathbf{Vl\ x}\sqrt{\mathbf{3}}} \tag{3.21}$$

Where;

I_L= Line Current

V_L= Line Voltage

$$\mathbf{Tan\ \Theta t} = \frac{\mathbf{Q}}{\mathbf{P}} \tag{3.22}$$

Where;

Tan Ɵt= Angle

$$\mathbf{I_P} = \frac{\mathbf{I(line)}}{\sqrt{\mathbf{3}}} \tag{3.23}$$

Where;

$I_{P=}$ Phase current

- **Advantages of Power Factor Improvement**

The benefits that can be achieved by applying the correct power factor correction are:

A. Reduction of power consumption due to improved energy efficiency. Reduced power consumption means less greenhouse gas emissions and fossil fuel depletion by power stations.
B. Reduction of electricity bills
C. Extra kVA available from the existing supply
D. Reduction of I^2R losses in transformers and distribution equipment
E. Reduction of voltage drops in long cables.
F. Reduced electrical burden on cables and electrical components.

3.6.2 Capacitor Bank

There are two categories of connecting capacitor bank. They are shunt and series connecting. Among these two categories, shunt capacitors are more commonly used in power system of all the voltage levels.

Capacitors connected in parallel (shunted) with the motor are often used to improve the power factor. The capacitor will not improve the power factor of the motor itself but of the starter terminals where power is generated or distributed. The benefits of power factor correction include reduced KVA demand (and hence reduced utility demand charges), reduced I*I*R losses in cables upstream of the capacitor (and hence reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system [9]. A typical arrangement of shunt capacitor connected in parallel with a load is shown in Figure 2.6.

So if we connect a capacitor in parallel it will be drawn leading current according to its rated value. Job of capacitor is to reduce ripple. So it is connected in parallel. It charges to peak of ripple and discharge through the load to smoothen out voltage variation in the output.

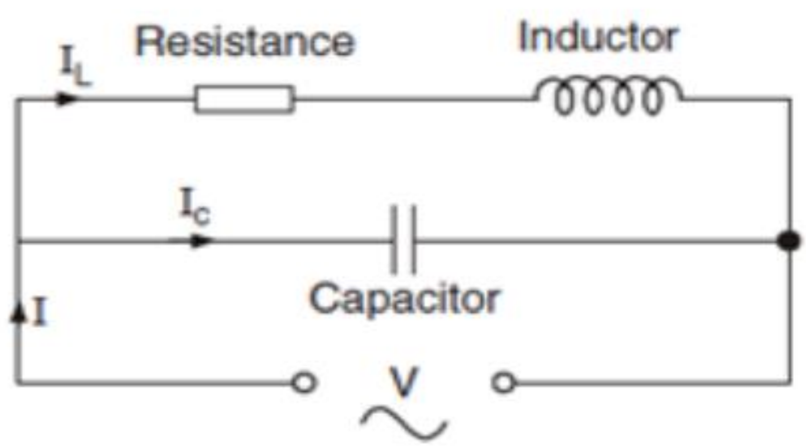


Figure 3.12: Capacitor connected in parallel with load

$$Z_P = \frac{V}{I} \text{ (Ohm's law)} \quad (3.24)$$

$$Cp = \frac{1}{2\pi f X_C} \text{ ; } Z = X_C \quad (3.25)$$

There are some specific advantages of using shunt capacitors such as:

i. It reduces line current of the system.

ii. It improves voltage level of the load.
iii. It also reduces system losses.
iv. It improve power factor of the source current.
v. It reduces load of the alternator.
vi. It reduces capital investment per megawatt of the load.

All the above mentioned benefits come from the fact that the effect of capacitor reduces reactive current flowing through the whole system. Shunt capacitor draws almost fixed amount of leading current which is superimposed on the load current and consequently reduces reactive components of the load and hence improve the power factor of the system. Series capacitor on the other hand has no control over flow of current. As these are connected in series with load, the load current always passed through series capacitor bank. The capacitive reactance of series capacitor neutralizes the inductive reactance of the line hence, reduces, effective reactance of the line.

3.7 Data Collections

In this thesis work, on energy utilization assessment and efficiency improvement at the factory, the data collection has been done through different methods such as personal interviews, direct observation of the factory, by taking measurements, telephone communication, and the available documents of the factory.

The following tables provides the factory four years of CO_2 production and energy consumption data and also shows the specific energy consumption, costs of energy per year, energy costs of AGP. And there are electric motors data and lighting data obtained from the selected factory.

3.7.1 Factory Production and Energy Consumption Data

Energy consumption refers to ALL the energy used to perform an action, manufacture something or simply inhabit a building. Table 3.5 provides the factory's four years of CO_2 production, energy consumption data, the specific energy consumption and energy intensity.

Table 3.5: Review of CO_2 production and energy consumption at AGP

No	Item	Unit	Years (E.C)			
			2009	2010	2011	2012
1	CO_2 Production	Kg	1,983,105	1,889,800	2,142,800	2,351,277

2	Electric Consumption	KWH	29,566,575	26,143,767	25,252,260	24,253,749
3	Fuel Consumption	Lit	160,451	150,320.5	145,631	138,450
4	Specific Electric Consumption	KWH/kg	14.01	13.83	11.78	10.32
5	Specific Fuel Consumption	Lit/Kg	0.08	0.07	0.06	0.05
6	Energy intensity (Ele)	KJ/Kg	3,254.48	3,191.74	2,727.2	2,351.9
7	Energy intensity (fuel)	KJ/Lit	54,000	49,800.31	42,424.02	37,135.02

3.7.2 Factory Energy Cost Data

Energy costs, of four years, for electric energy and furnace oil are shown in Table 3.7 as follow.

Table 3.6: Energy Costs at AGP for both electrical and fuel

Item	Unit	Years(E.C)			
		2009	2010	2011	2012
Furnace oil	Birr	14,837,328	14,483,700	15,595,200	18,987,654
Electrical Energy bill	Birr	366,988.63	962,426.90	1,847,590.37	2,508,077
Total	Birr	15,204,316.63	15,446,126.9	17,442,790.37	21,495,731

3.7.3 Factory Lighting Data

Various terms and meanings are used to quantify light, light source. In addition, their corresponding mathematical expressions are given in the above. According to the important formulas on Lighting Analysis, all the necessary lighting data are summarized in Table 3.7. In addition, Table 3.8 shows the number of non-functional ballasts that still consumes an electrical energy.

Table 3.7: Lighting Data of the factory

No	Department	NL	TP (Watt)	TL (Lumen)	RA (m^2)	TIL (Lux)	ALR	OH	EU (KWh)	ER (KWh)	ED (wh/day)
1	Guard	4	72	6120	20	306	2	12	0.86	0.432	0.428
2	Laboratory	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
3	Mechanical and electrical work shop	12	432	36720	20	1836	9	24	10.36	7.776	2.584
4	Finance service	40	720	61200	60	1020	32	8	5.76	4.608	1.152
5	Conference room	24	432	36720	50	734.4	18	8	3.45	2.592	0.858
6	Sales	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
7	Show room	24	432	36720	32	1147.5	18	8	3.45	2.592	0.858
8	Electrical and technical mgt	32	576	48960	36	1360	30	10	5.76	5.400	0.34
9	Corridor and stairs	54	972	82620	64	1290.9	45	12	11.66	9.720	1.94
10	Personal and general service	20	360	30600	30	1020	15	8	2.88	2.160	0.72
11	HR service	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
12	Material mgt	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
13	Purchasing and store	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
14	General manager	24	432	36720	32	1147.5	18	8	3.45	2.592	0.858
15	Graphic design	16	288	24480	25	979.5	12	8	2.30	1.728	0.572
16	CO_2 production room	200	7200	612,000	200	3060	150	24	172.8	129.600	43.2
17	Cooling water area	4	72	6120	8	765	3	12	0.86	0.648	0.212

18	Electrical and mechanical super visor	4	72	6120	8	765	3	10	0.72	0.540	0.18
19	Latrines	40	720	61200	50	1224	30	12	8.64	6.480	2.16
20	Manufacturing and operation	16	288	24480	25	979.2	12	8	2.30	1.728	0.572
21	Casher	4	72	6120	8	765	3	8	0.57	0.432	0.138
	Total	598	14580				460		243.06	187.668	59.632

Table 3.8: Non-functional Ballasts to Remove

NO.	Area or Location	Number of Ballast	Annual hours of Use
1	Mechanical and electrical work shop	3	4800
2	CO_2 production room	30	4800
3	Finance service	11	2000
4	Corridor and stairs	15	2000
5	Electrical and technical mgt	8	2000
6	Office	35	2000

3.7.4 Factory Motor Data

A motor absorbs energy in the form of current and voltage, so a motor's datasheet will provide various electronic specifications. It delivers energy in the form of rotational movements. The movements imply speed and torque.

Table 3.9 shows the nameplate data, measured data and calculated parameters of the motor in the factory in each departments of the factory. To determine motor loading, input power measurements method is used in this thesis. Because kW readings take into account the change in power factor and amperage that occur as the motor loading changes, as it is described in Equation 3.9 through Equation 3.11.

Table 3.9: Summary of Measured Electric Motor Data of AGP

NO	Machine Description	**Motor Name Plate data**			**Motor Measured Data**			**Motor calculated Data**		
		Rated power (KW)	Rated Efficiency (%)	Speed (RPM)	Voltage (V)	Current (A)	PF	Actual power o/p (KW)	Actual power i/p (KW)	Loading (%)
1	Air blower	37.3	93.7	3000	397	43.70	0.78	25.89	27.64	72.73
2	Oil pump	3	75	1440	385.5	3.5	0.73	1.43	1.91	47.7
3	Rich mea pump	7.5	78	1500	390	7.6	0.68	3.19	4.10	42.6
4	Lean mea pump	5.5	89.5	3000	385	6.20	0.69	3.30	3.64	59.67
5	Dc cooler pump	1.5	88.5	3480	375	1.75	0.75	0.82	0.92	54.43
6	CO_2 compressor	29.8	94.5	1500	370	51.30	0.81	28.27	29.92	94.98
7	FREON compressor	29.8	90.3	1500	368	51.50	0.80	24.59	27.24	82.54
8	Cooling tower fan	7.5	75	1460	390	7	0.72	3.15	4.21	41.3
9	Cooling water pump	3.73	87	2900	396	4.52	0.71	2.31	2.66	63.33
10	Cylinder filling unit	3.73	89.5	1500	382	4.52	0.79	2.38	2.66	64.87
11	Chemical metering pump	2	75	3000	383.8	2	0.70	0.79	1.06	39.8
12	Mixing motor soda ash tank	5.5	75.5	1475	391.7	5.5	0.76	2.43	3.24	44.2
13	$KMno_4$ transfer pump	5.5	80.3	1500	375.6	5.6	0.77	2.44	3.06	44.5
14	mixing motor $KMno_4$	0.35	78.1	1450	388.1	0.4	0.74	0.2	0.22	51.8

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

4.1 Analysis of the Energy Assessment in the Factory

According to the walk-through audit conducted in the factory as well as information from the collected data, the major energy consuming areas in the factory, which have high energy saving opportunities, are identified. These areas are lightings, electric motors, and power quality related problems. The following sections show the main Result, analysis, and discussion of the energy assessment within the factory.

4.1.1 Computation of Energy Intensity of the Plant

Energy intensity is defined as the amount of energy used to produce a given level of output or activity. Using less energy to produce a product or provide a service results in reduced energy intensity.

Energy Intensity is measured by the quantity of energy required per unit output and it is a measure of the energy efficiency of the plant. The following graph shows the plot of the energy intensity of the Addis gas and plastic factory from year 2009 to 2012E.C and the energy intensity of the selected plants taken as a benchmark. Then, comparison of specific energy between AGP factory and the plant used as a benchmark has been done.

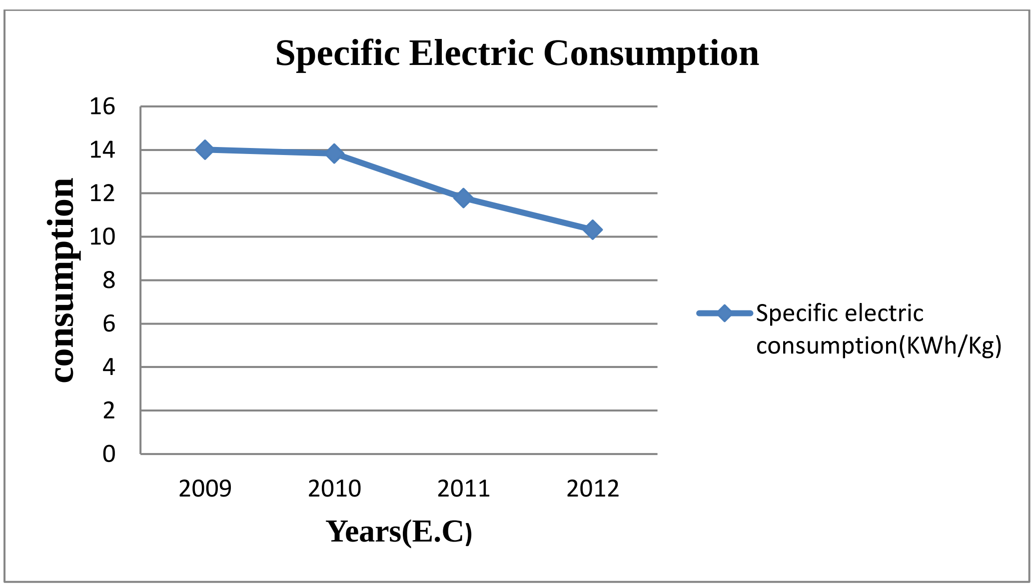


Figure 4.1: The Specific Electrical consumption of AGP

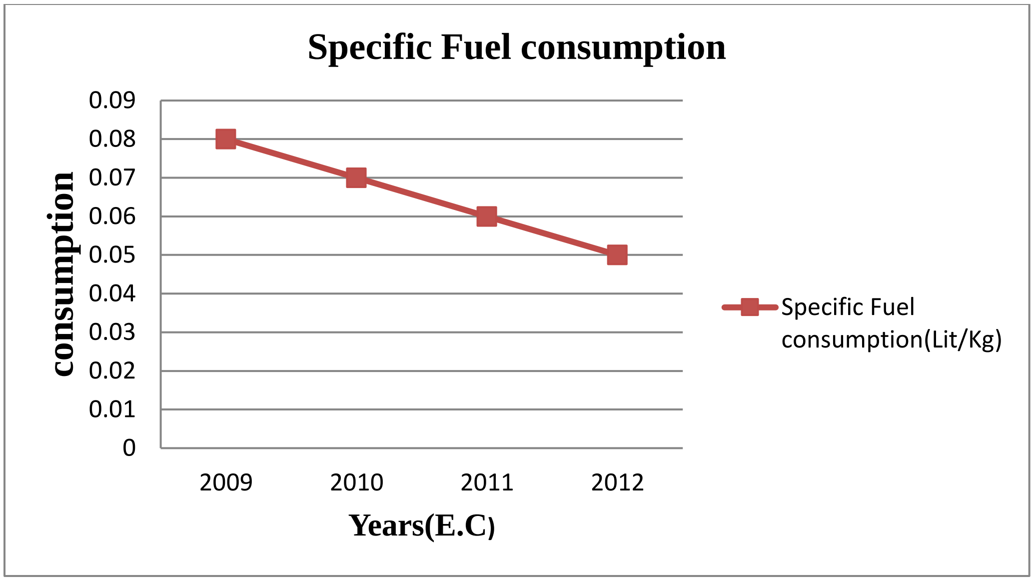


Figure 4.2: The Specific Fuel consumption of AGP

The Annual Electric energy intensity of Addis gas and plastic factory PLC from 2009 to 2012E.C ranges from 10.32kW/kg to 14.01 kWh/kg for CO_2 production with an average energy intensity of 12.49kWh/kg.

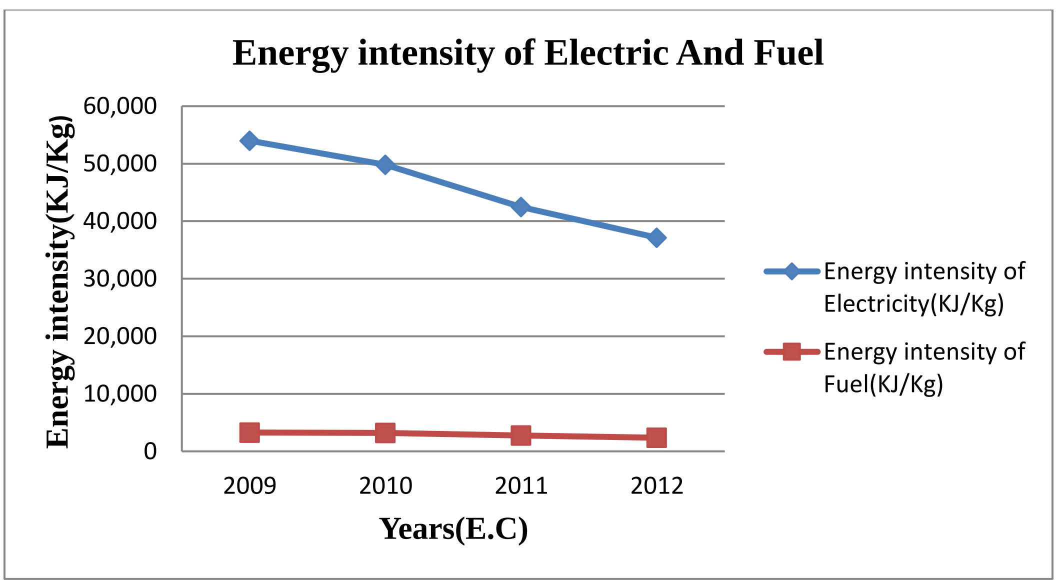


Figure 4.3: The Energy Intensity of AGP

The total electric energy intensity of selected plant as a benchmark showed in Figure 4.3 and Figure 4.4 has an average energy intensity of 4.275kWh/kg [34]. Therefore, the difference in specific energy consumption of Addis gas and plastic factory PLC and the selected plant as benchmark is 8.22kWh/kg.

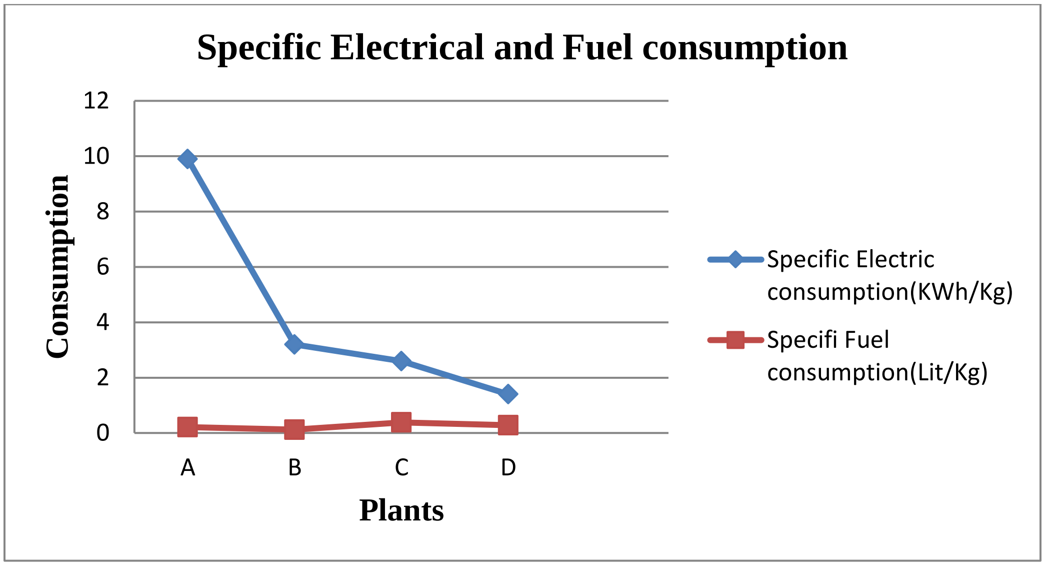


Figure 4.4: The Specific Energy of Selected Plant

The fuel energy intensity from year 2009 to 2012E.C ranges between 2,351.9kJ/kg to 3,254.48 kJ/kg of CO_2 production with average intensity of 2,881.33kJ/kg. The Total fuel energy intensity of plants taken as benchmarks shown in Figure 4.4 gives an average energy intensity of 9,750kJ/kg [34].

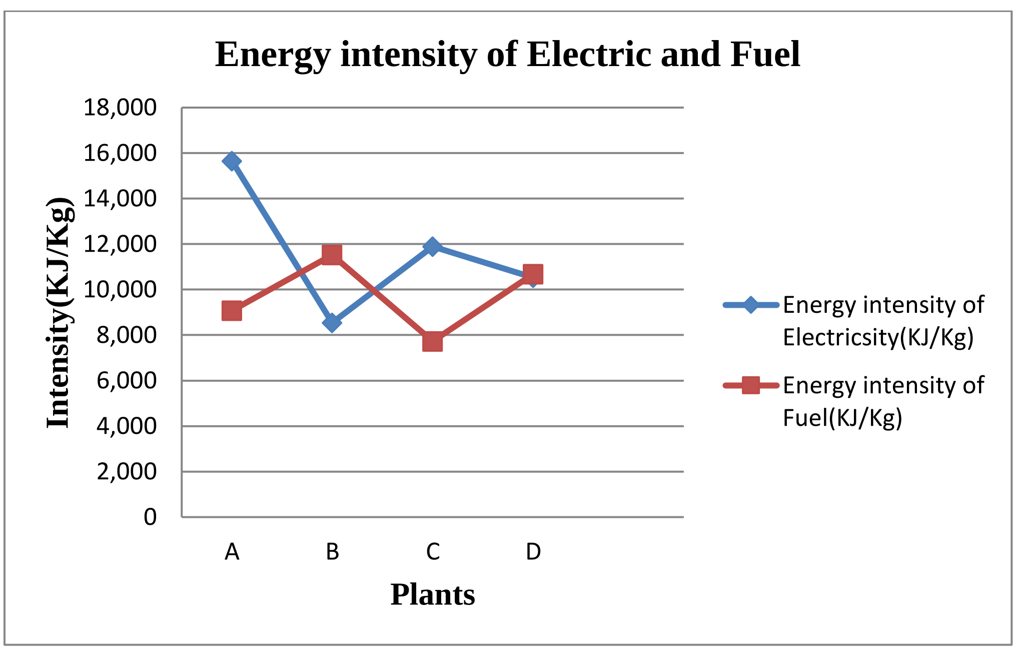


Figure 4.5: The Energy Intensity of Selected Plant

- **Energy Saving Opportunity from Electric Energy Intensity**

From the analysis, there is a difference between the electric energy intensity of AGP PLC and selected plant as a benchmark. Hence, the calculation for the inefficiency of electric energy intensity of Addis gas and plastic factory is calculated below.

- ✓ Annual Average production of CO_2 2,088,773.5 kg per year.
- ✓ Cost of Electricity = 0.4086 birr per/kWh.
- ✓ Cost of Fuel oil = 17.63 birr/per lit.
- ✓ Specific Heat of Fuel Oil = 40,128kJ/lit.
- ✓ Difference in Electricity Energy Intensity = 8.22kWh/Kg

Annual cost due to inefficient use of electric energy intensity

$$= \text{Electric consumption in kWh} \times \text{Cost of electricity}$$

$$= \text{Energy int. (kWh / kg)} \times \text{Production (kg)} \times \text{Cost of electricity}$$

$$= 8.83 \text{KWh/Kg} * 2,088,773.5 \text{ kg/yr} * 0.4086 \text{ birr/KWh}$$

$$= 7.02 \text{ Mbirr/yr}$$

4.1.2 Analysis of the Energy Assessment in the Existing Lighting System

- **Energy Saving Opportunity in the Illumination Optimization of the Light**

By referring, the lighting data on Table 3-7 in the previous chapter totally there are 598 florescent lamps, 212 of which are 36-Watt and 386 are 18-Watt ratings, and are currently installed in the factory. The total installed capacity of the lighting system is 14.58 kW and daily energy consumption is 349.93 kWh. According to the lighting data on Table 3-7, the actual florescent lamps required in the factory are calculated and are 460 lamps. Therefore, there are around 138 unnecessary lamps installed. Because of this, there is electrical energy loss. There are a significant energy differences (ED) between the energy utilization (EU), due to currently install florescent lamps, and the actual energy required (ER). This shows that there are energy losses due to miss use of lighting systems in the factory.

According to the Lighting analysis and using the appropriate illumination, only 460 lamps would be required whereas the currently installed number of fluorescent lamps in the AGP is 598. This result in total reduction of 138 lamps, which is equivalent to the following savings:-

Power Saving (PS):

PS = [(Number of FL with 18W Rating) + (Number of FL with 36W Rating)]

= [(53 × 36W) + (85 × 18W)]

= (1908W + 1530W)

= 3.43 kW

Energy saving (ES):

ES = (Power Saved × Hours of operation/day × Number of days of operation/year)

= (3.43kW ×16hrs/day × 310days/yr.)

= **17,012.8 KWh/yr.**

Money saving (MS):

MS = (Annual Energy Saving × Energy Cost Rate/kWh)

= (17,012.8× birr 1.019)

= **17,336.04 Birr/yr**

Simple Payback Period (SPP):

Cost of implementation = Small Money

SPP = Investment / Money Saving

= Small Money / Money Saving

= **0 yr.** (Immediate)

Therefore, by optimization of the existing lighting system the AGP can save energy of 17,012.8kWh annually.

- **Energy Saving Opportunity in Replacing T-12 FL Tubes by T-8 FL Tubes**

Almost all the type of fluorescent lamps that have been found in AGP is T-12 tube florescent lamps. The initial output and energy consumption of these lights is high. These also have extremely poor efficiency, lamp life, lumen depreciation, and color rendering index. T-8 tubes generally last 60% longer than T-12 tubes, which lead to savings in maintenance costs. Typical Energy savings from the replacement of a T-12 lamp by a T-8 lamp are around 30% [32]. Referring to Table 3-7, there are 598 T-12 tube lamps currently installed in the factory. After The correct installation, however, only 460 lighting points would be required. Replacing these 460 T 12 lamp tubes with T-8 lamp tubes, the factory can have the following savings.

Power Saving (PS):

PS = (0.3 × Actual Lamp Required × Lamp Rating)/1000

= (0.3 × 159 × 36W)/1000 + (0.3 × 301× 18W)/1000

= **3.35kW**

ER = 59.63 kWh/day (from Table 3-3)

Energy Saving (ES):

ES = (0.3 × Energy Required/day × Number of days of operation/year)

= (0.3 × 59.63 kWh/day × 310 days/yr.)

= **5545.59kWh/yr.**

Money Saving (MS):

MS = ES× Energy Cost Rate/kWh

= 5545.59 kWh/yr. × 1.019 Birr/kWh

= **5650.95 Birr/yr.**

Simple Payback Period (SPP):

Cost of implementation = 10,684.21

SPP = Investment / Money Saving

= 10,684.21/5650.95

= 1.9yrs.

- **Energy Saving Opportunity in Removing Ballasts from Un-used Fluorescent Fixtures**

In many sections of the factory, it was observed a burn out FL. This can cause a reduction in plant illumination levels. Therefore, these ballasts should be removed from the fixtures as the ballasts consume energy even when the tubes are not alive. Table 3-9, in the previous chapter, provides a number of ballasts to be removed. According to this, we can get the following savings.

Power consumption per ballast = 20 Watt

Energy savings (ES):

ES = [(Number of ballast × Watt/ballast × hours of operation/year)] / 1000 kWh

= [(33 × 20W × 4800 hrs /yr.) + (69 × 20 W × 2000 hrs/yr.)] / 1000

= 5928 kWh/yr.

Money savings (MS):

MS = ES× Energy Cost Rate/kWh

= 5928 kWh/yr. × 1.019 Birr/kWh

= 6040.63 Birr/yr.

Simple Payback Period (SPP):

Cost of implementation = Small Money

SPP = Investment / Money Saving

= Small Money / Money Saving

= 0 yr. (Immediate)

- **Energy Saving Opportunity in the Lighting Controls**

In the factory, there are only manual light control mechanisms. It is observed that there is a time by which some lights are not turned off during non-working time. Due to this, some light energy is wasted. Lights can be shut off during non-working hours by automatic controls, such as occupancy sensors, which turn off lights when a space becomes unoccupied. Occupancy sensors can save up to 10-20% of facility lighting energy use. Manual controls can be used in addition to automatic controls to save additional energy in the factory.

- **Use of Natural Day Lighting**

Day lighting is the effective use of natural light in order to minimize the need for artificial light in buildings. Increasing daylight levels within rooms can reduce electrical lighting loads. Effective day lighting system may provide evenly dispersed light without creating heat gains. Day lighting differs from other energy conserving measures because its features are integral to the architecture of a building, and so it is applied primarily to new buildings and incorporated at the design stage. However, existing buildings can be cost-effectively refitted with day lighting systems. Various day lighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building. Day lighting can be combined with lighting controls to maximize its benefits. Because of its variability, day lighting is usually combined with artificial lighting to provide the necessary illumination on cloudy days or after dark. Day lighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) roof lights, clerestories, light shelves, and light ducts. Clerestories, light shelves, and light ducts utilize angles of the sun and redirect light with walls or reflectors. Not all parts of a facility may be suitable for the application of day lighting. Day lighting is most appropriate for those areas that are used in daytime hours by people. In office spaces, day lighting may save between 30 and 70%. The savings will vary widely depending the facility and buildings. Some problems associated with day lighting in 46 industrial buildings have been identified due to the structure of the building. Various companies offer day lighting technologies. Day lighting systems will have a payback period of around 4 years, although shorter paybacks have been achieved [33].

- **Lighting Maintenance**

Maintenance is basic to lighting efficiency. The light levels decrease through time because of aging lamps and dirt on fixtures, lamps and room surfaces. These factors can reduce total illumination by 50 percent or more, while lights continue drawing full power. The following basic and simple maintenance suggestions can help prevent this. -Replace lenses if they appear yellow. -Make fixtures, lamps and lenses clean every 6 to 24 months by wiping off the dust. -Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect. [33]

4.1.3 Analysis of the Energy Assessment in the Electric Motor

- **Analyzing Electric Motors of the factory with Motor Master + International Software**

Many motors of different power ratings are currently in operation in the factory. Most of these motors are old, rewound and not regularly maintained. At present, the motor technology is improved. Energy efficient motors are being designed to transfer the input energy to the shaft very efficiently. Efficient motors also tend to have a better relative performance at part load, which is of increased benefit for applications with variable load requirements. In this regard, there is a high opportunity to save energy in the factory. The under loaded motors can be selected and analyze from Table 3.9 in previous chapter using Motor Master + international software. Figure 4-3 through Figure 4-5 shows how Motor Master + international software selects the required motor to specific application and evaluates the energy saving potential and effectiveness of the efficient motors of the factory. Figures 4-3 through 4-5 show sample outputs of the Motor Master +international (IMSSA) software. The energy saving and simple payback period columns explain the kWh energy savings per year and the number of years required to recover the investment in energy efficient motors, respectively. The investment cost, which is paid in short payback period, needed to buy that energy efficient motors was effective. From the energy analysis summarized in Figure 4-5, i.e. to buy an energy efficient motor, the factory should pay 30,272.4 birr to purchase the motor, 3,419.66 birr for the installation. However, these costs will be back after 3.85 years with an energy savings of 2,546 kWh per year and 7,848.4 birr/yr. of cost saving with reduction of 1.0 ton/yr. CO_2. This is due to replacement of under load motors with proper sized motors and standard electric motors with energy efficient electric motors.

The **Motor Selector** report indicates the motor manufacturer, model, catalog number, nameplate kilowatt rating, degree of protection, full-load efficiency (taken in accordance with the IEC testing protocol), voltage rating, definite purpose, full-load speed, and power factor; full-load amps, frame designation, locked rotor torque, and list price.

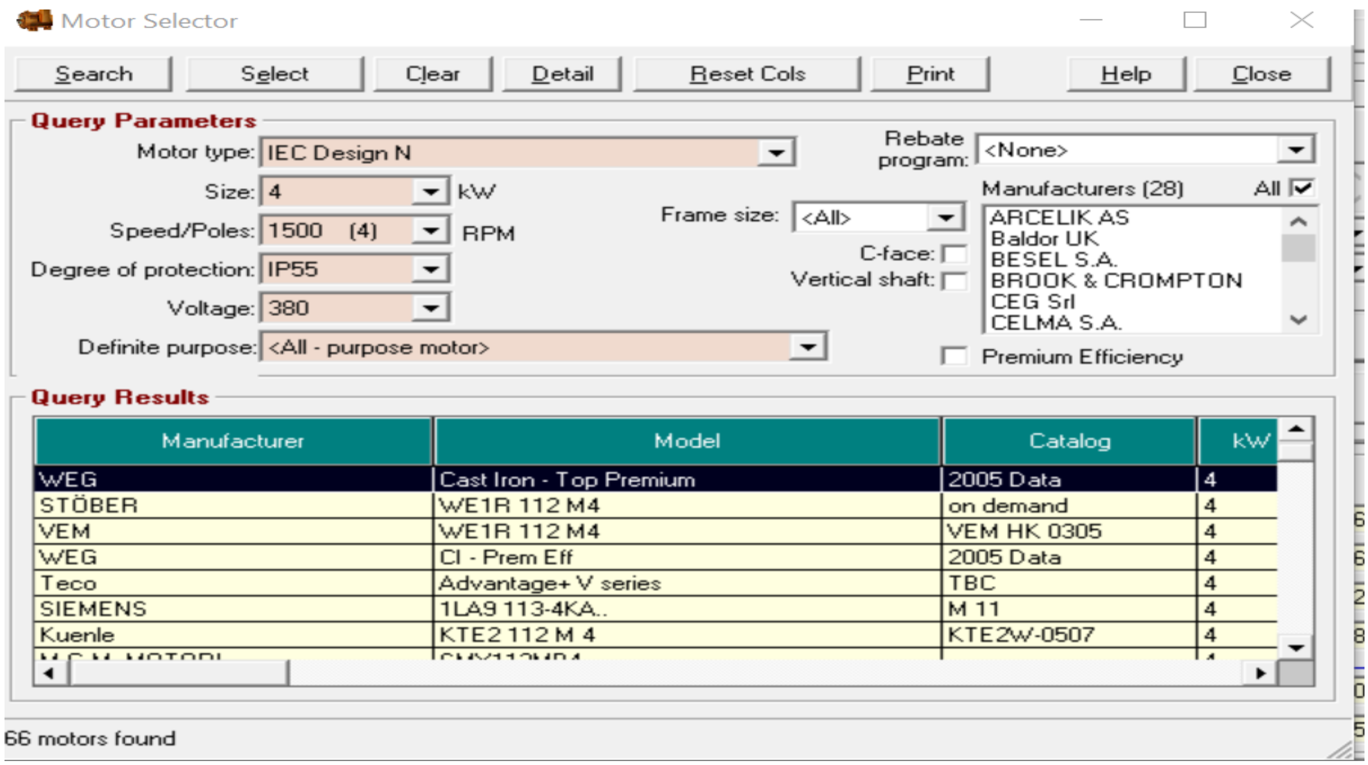


Figure 4.6: Energy Efficient Motor Selection from Motor Master Catalogue

The report also indicates the date that the manufacturer last submitted motor price and performance information.

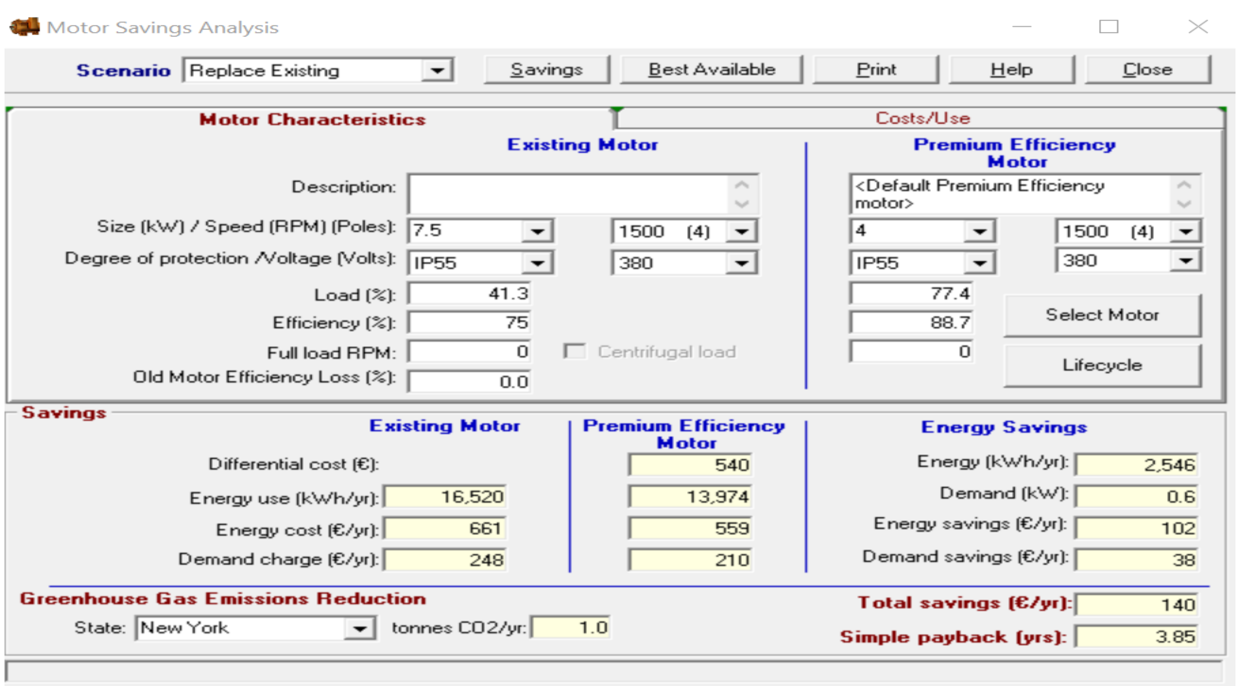


Figure 4.7: Energy Saving Potential of Energy Efficient Motor versus Existing Motor

The **Motor Savings Analysis** screen is designed with two data entry tabs: the **Motor Characteristics** tab and the **Costs/use** tab. The **Motor Characteristics** tab allows the user to specify a motor by entering motor descriptors, operating parameters, and performance values. Values for the existing or lower-efficiency motor are selected from the combo box choices and entered in the left column.

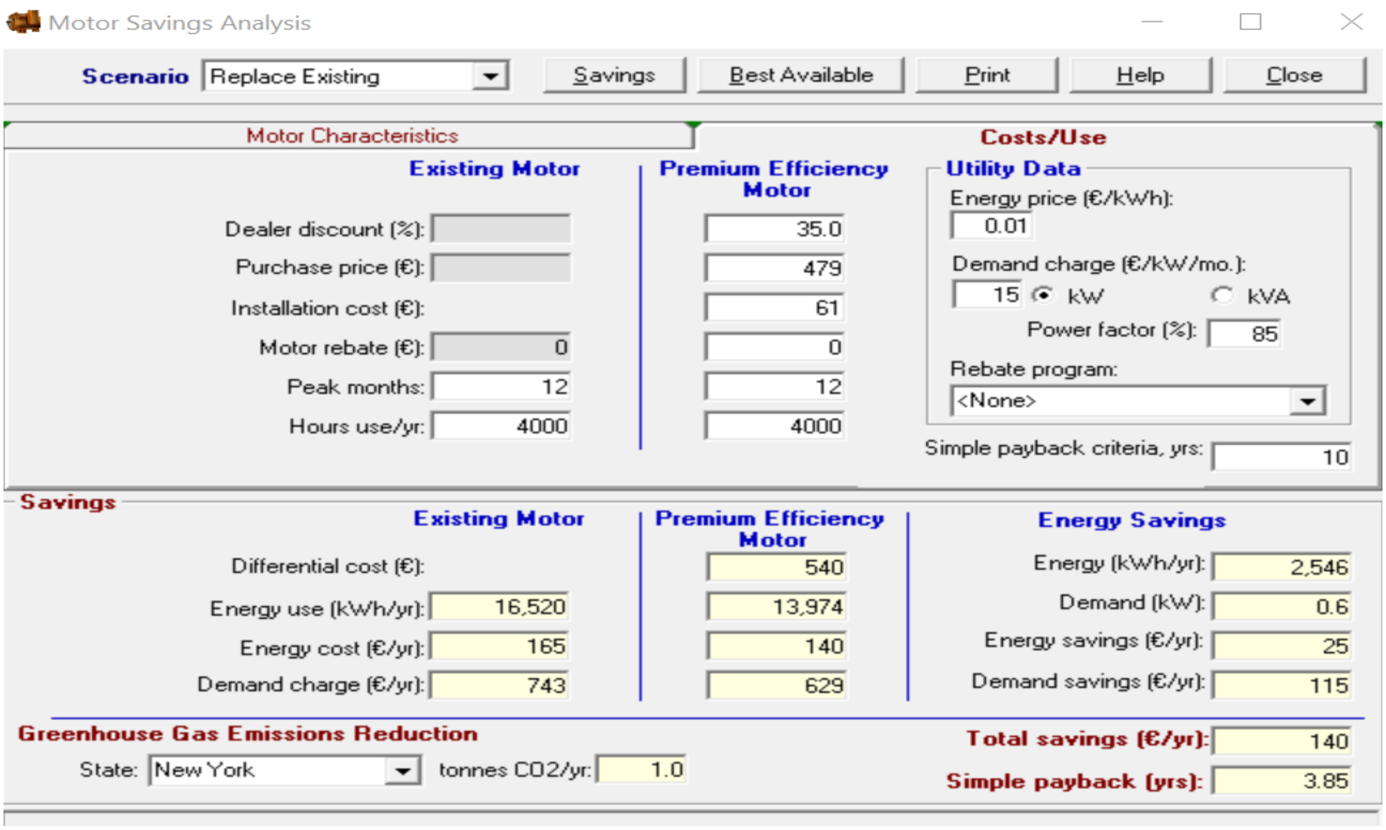


Figure 4.8: Saving Energy Potential and Utility Cost Effectiveness

- **Energy Saving Opportunity in the Existing Under-Loaded Electric Motors**

The summarized potential of energy and cost saving of proper sized motors and energy efficient motors as compare with the existing (standard) inefficient electric motors of the factory are shown in Table 4-1. As discussed in chapter-3, motors operating below 75% of full load relatively reduces their efficiency and motors operating below 50% totally inefficient, electric motors operates under load should be replaced. Replacement of large, partially loaded motors with smaller, full loaded motors from either company stock or new energy efficient motor is significant. As the result, replacement of standard motors with energy efficient motors i.e.

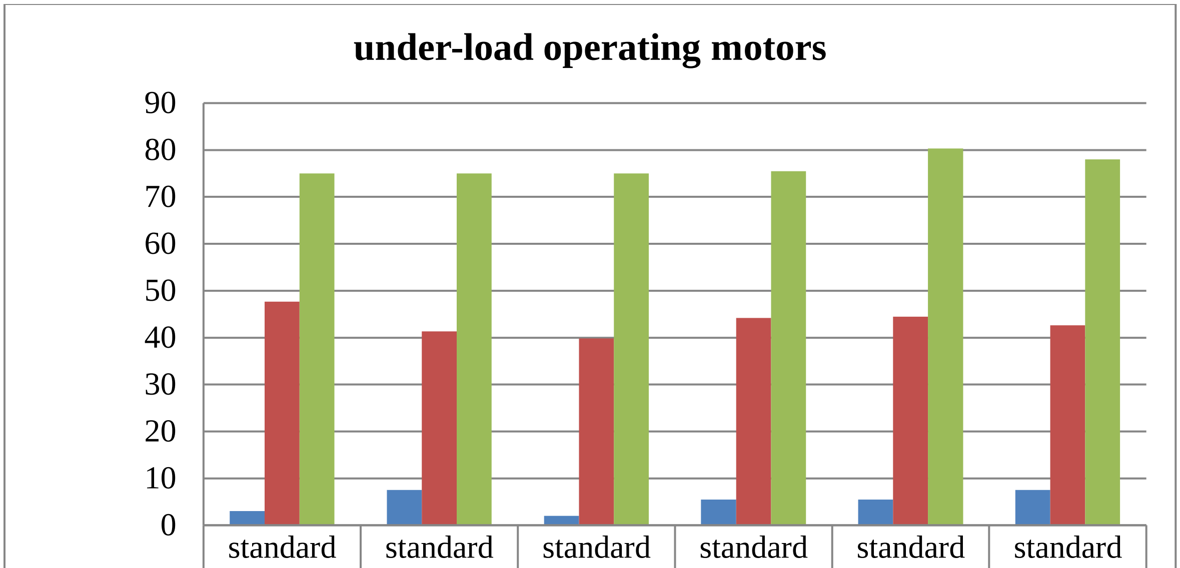
replacement of under load motors with proper sized motor can save 9.757MWh of energy and 41091.98 birr of money per year and with pay back periods of ranging from 1.95 to 6.28 years.

Table 4.1: Summary of Electric Motors

with Replacement of Under-load Operating Motors with Proper Sized Motors

No	Existing Motor				Replaced Efficient Motor				Invest. Cost (Birr/yr)	Energy Saving (kWh/yr)	Money Saving (Birr/yr)	SPP (yrs.)	CO2 Reduction (ton/yr)
	Motor Type	kW	Load (%)	η (%)	kW	Load (%)	η (%)	Motor Type					
1	Standard	3	47.7	75	1.5	95.4	85.3	Premium Efficiency Motor	18387.68	1,056	3699.96	4.99	0.4
2	Standard	7.5	41.3	75	4	77.4	88.7	Premium Efficiency Motor	30272.4	2,546	7848.4	3.85	1.0
3	Standard	2	39.8	75	1.1	79.6	84.1	Premium Efficiency Motor	10202.92	414	10202.92	6.28	0.2
4	Standard	5.5	44.2	75.5	3.7	65.7	88.5	Standard Efficiency Motor	15640.74	2,046	6783.26	2.31	0.8
5	Standard	5.5	44.5	80.3	3.7	66.1	88.5	Standard Efficiency Motor	15640.74	1,277	4540.86	3.45	0.5
6	Standard	7.5	42.6	78	3.7	86.4	88.7	Premium Efficiency Motor	30272.4	2,418	8016.58	1.95	0.9
Total									**120,416.88**	**9,757**	**41,118.61**		**3.8**

The Existing Electric motors used in AGP under-load operating motors are summarized in the below figure 4-6. From the total motors in AGP those are motors operating 75% full load and 50% and below efficiency.

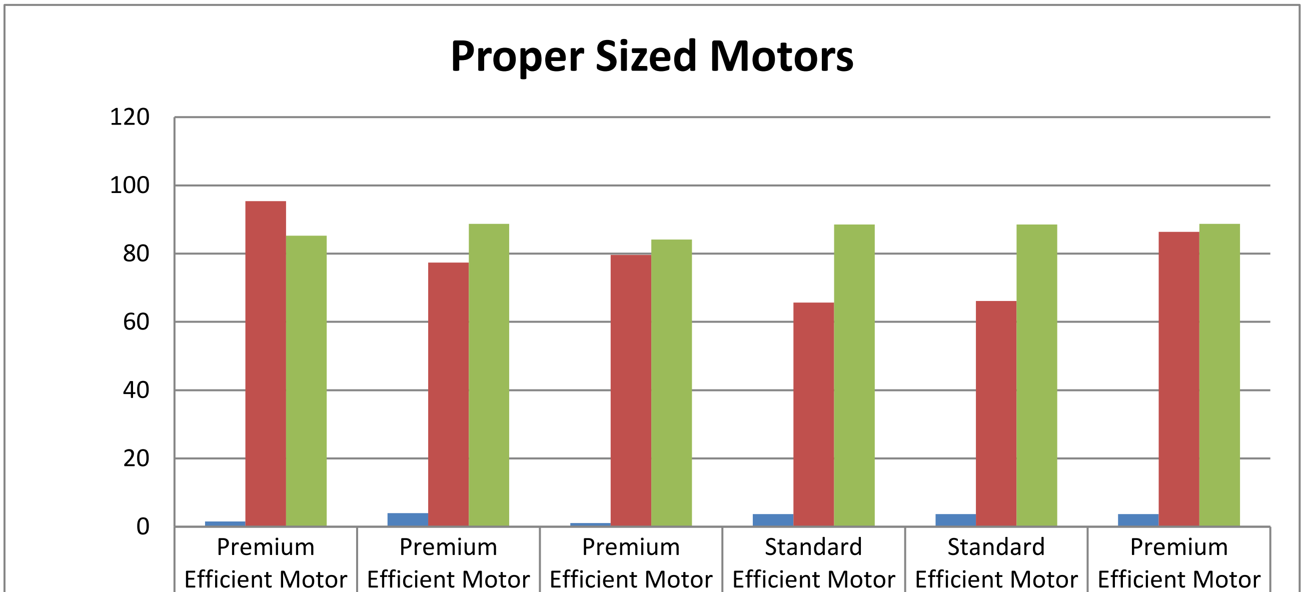


	standard	standard	standard	standard	standard	standard
KW	3	7.5	2	5.5	5.5	7.5
Load(%)	47.7	41.3	39.8	44.2	44.5	42.6
η(%)	75	75	75	75.5	80.3	78

Figure 4.9: The Existing electrical under-load operating motors

By using Motor Master +international (IMSSA) software the existing electrical under load operating motors are can be proposed to replace by proper sized motors summarized in the figure 4-7. When the motors replaced by efficient motors the AGP can get a lot of benefits like reduce investment cost, there will be energy saving and also money is saving. software can support in appropriate motor selection and helps for motor systems enhancement scheduling, through recognizing the cost effectiveness, operating cost due to the continual operation of an existing standard efficiency motor to make decision on buying new premium efficiency, rewinding or replacing of the existing motor.

This fact sheet will assist in decisions regarding replacement of oversized and under loaded motors. It includes a discussion of how the Motor-Master software can be used to conduct motor replacement analyses. Motors rarely operate at their full-load point. Field tests of 60 motors at four industrial plants indicate that, on average, they operate at 60% of their rated load. Motors that drive supply or return air fans in heating, ventilation and air-conditioning (HVAC) systems generally operate at 70% to 75% of rated load. A persistent myth is that oversized motors, especially motors operating below 50% of rated load, are not efficient and should be immediately replaced with appropriately sized energy-efficient units. In actuality, several pieces of information are required to complete an accurate assessment of energy savings. They are the load on the motor, the operating efficiency of the motor at that load point, the full-load speed (in revolutions per minute [rpm]) of the motor to be replaced, and the full-load speed of the downsized replacement motor.



	Premium Efficient Motor	Premium Efficient Motor	Premium Efficient Motor	Standard Efficient Motor	Standard Efficient Motor	Premium Efficient Motor
KW	1.5	4	1.1	3.7	3.7	3.7
Load(%)	95.4	77.4	79.6	65.7	66.1	86.4
η(%)	85.3	88.7	84.1	88.5	88.5	88.7

Figure 4.10: Replaced electrical motors with proper sized

- **Other Energy Saving Opportunity in the Existing Electric Motors**

In AGP, the maintenance condition of the motors is poor. This is because there is no a regular schedule for measuring the line voltages and currents to check the line imbalance and loading conditions of the motors. They do not inspect motors regularly for wear in bearings and housings, to reduce frictional losses, and for dust in motor ventilating ducts, to ensure proper heat dissipation. Although more motors do have their own ventilating fun for cooling, there are some motors, which do not have fan for ventilation. Also appropriately, lubrication is not done according to the manufacturer's recommendations. Thus, a proper ongoing motor maintenance program should be applied to minimize unnecessary energy and efficiency loss. Motor rewinding is also another common practice in AGP. However, there are some problems in the process, removing the old winding, selecting wires of appropriate size, slot size design and rewinding the motors more than one times. All these have an impact on the efficiency of the rewound motor. However, if proper measures are taken, the motor efficiency can be maintained after rewinding.

4.2 Improvement of the power factor and capacitor Bank Design

By using the data collected from AGP in table 3.9 about motor data can be improve the power factor of the factory. The reactive power in the lighting system and socket outlet are negligible. In the table 3.9 the measured, Name plated and, calculated value of different motors in the factories are stated.

From the table 3.9 data calculating the apparent power (S), and Reactive power (Q) of each motors. Then finding the total value of Apparent power(S), and Reactive power (Q).

The final steps after finding the apparent power and reactive power correcting the pf to 0.9 and sizing the capacitor power bank of the system for the proposed power factor. Now starting to calculate each motors Apparent and Reactive power:-

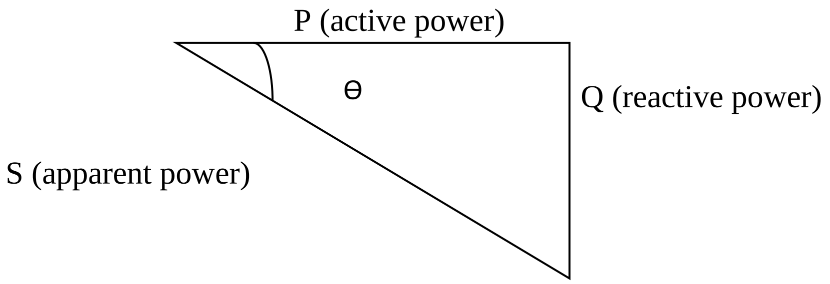


Figure 4.11: The power triangle representation

By using the equation 3.19 and 3.20 we can calculate each motors apparent power(S) and Reactive power (Q). Mentioned in the earlier the calculated value of active power (P) and power factor (pf) are given in table 3.10 for each motor. After calculation the value of each motors apparent power and reactive power are shown in table 4.2.

Table 4.2: The calculated value of apparent power and reactive power of each motor

No	Active power(KW)	Power factor(pf)	Apparent power (KVA) $S = \frac{P}{pf}$	Reactive power(KVAR) $Q = \sqrt{s^2 - p^2}$
1	27.64	0.78	35.44	22.18

2	1.91	0.73	2.61	1.77
3	4.10	0.68	6.03	4.42
4	3.64	0.69	5.20	3.81
5	0.92	0.80	1.22	0.80
6	29.92	0.81	36.94	21.66
7	27.24	0.80	30.30	13.27
8	4.21	0.72	5.84	4.05
9	2.66	0.71	3.74	2.63
10	2.66	0.79	3.37	2.67
11	1.06	0.70	1.51	1.08
12	3.24	0.76	4.26	2.77
13	3.06	0.77	3.97	2.53
14	0.22	0.74	0.29	0.18
Total	109.82		137.08	82.05

All motors are connected with line voltage (VL) 380v/50Hz. The total value of P_T, Q_T and S_T are calculated like in the below.

The total Active power $P_T = P1+P2+P3+P4+\ldots+P14$

$$= 109.82 \text{ KW}$$

The total Reactive power $Q_T = Q1+Q2+Q3+\ldots+Q14$

$$= 82.05 \text{ KVAR}$$

The Apparent power $S_T = \sqrt{P^2 + Q^2}$

$$= 137.08 \text{ KVA}$$

The line current (I_L) in the system and the total power factor of the system before any compensation or power factor correction calculated in the below. Using equation 3.21 and 3.22

$I_L = \frac{St}{Vl \times \sqrt{3}}$

$= \frac{137.08KVA}{(380V \times \sqrt{3})} = 208.27$ A

Tan $\Theta_t = \frac{Q}{P}$

Tan $\Theta t = 0.75$

Tan-1 $0.75 = \Theta_t$

$\Theta_t = 36.89^o$

The power factor Cos Θ_t = Cos (36.89^o) = **0.79**

EEU billing tariff for Industrial sectors is presented as follows: -

- ✓ 380V input line low voltage customer pay 0.5778 cents/KWH
- ✓ 15 KV input line high voltage industries pay 0.4086 cents/KWH
- ✓ 132KV input line high voltage industries pay 0.3805cents/KWH
- ✓ The power factor penalty for high voltage industries is 68.369 birr/0.01pf, if the power factor is less than 0.9.

Based on the EEU billing tariff the power factor of AGP under penalty, therefore the power factor need to be improve and the capacitor bank sizing need to be calculated to compensate the whole system.

The next step is correcting the AGP power factor to the standard value of EEU which is 0.9 and sizing the capacitor bank. After sizing the capacitor connected with the system using shunt capacitor connection.

From the calculation part the apparent power , reactive power , active power and the line current before the power factor correction are:-

Sold=137.08 KVA

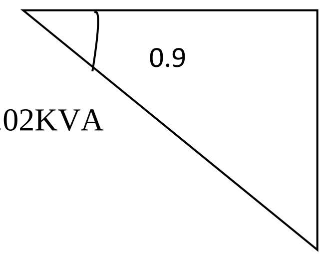
Q old=82.05 KVAR and I_L= 208.27 A

P old=109.82 KW

The goal of power factor correction always is to reduce the incoming line current. It is not can change each motor current value.

Now add capacitor bank in to the system and connecting by shunt capacitor with delta connection.

The new power triangle 109.82KW



$S\ new = \frac{P}{pf} = 122.02KVA$ 53.18KVAR=Q new=$\sqrt{S^2 - P^2}$

Figure 4.12: The power triangle representation after pf correction

The active power (wattage) is not change P old= P new =109.82KW and the new power factor or the proposed one is 0.9.

The line current for the proposed power factor after the calculation of the apparent power is given by

$I_L = \frac{S\ new}{Vl\ x\ \sqrt{3}} = 185.39\ A$

Now sizing the capacitor bank before that the difference value of the old and the new reactive power is needed.

Q old – Q new=82.05 KVAR – 53.18 KVAR= 28.87 KVAR

Keeping this KVAR=KVA or S=Q (purely capacitive)

Now determine the line current for the new value of apparent power (reactive power) from the difference value of the old and new reactive power.

$I_L = \frac{28.87\ KVA}{380\ x\sqrt{3}} = 43.86\ A$

The capacitor bank is connected in delta have a phase current

$I_P = \frac{I(line)}{\sqrt{3}} = 25.32\ A$

$V_P = 380V = V_L$

The next step is determine the Impedance value using the phase value of current and voltage by equation 2.24

$Z_P = \frac{V}{I}$ (Ohm's law) $= \frac{380}{25.32} = 15\Omega$

For the capacitive circuit the value of impedance and reactance are equal which means Z=X c. calculate the capacitor value using equation 2.25.

$Cp= \frac{1}{2\pi fXc}$ where f is frequency which is 50Hz

Cp= **176.8 μF**

Before the power factor correction the power factor of AGP is 0.79 which is under penalty based on EEU bill tariff. The power factor of AGP corrected to 0.9 and based on power factor correction the capacitor bank needs to be designed for 176.8μF to the factory. Knowing the power factor of the factory is huge benefit which is helps to identify the power factor of the factory under penalty or not and if it is can make the capacitor bank sizing for it.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE WORK

5.1 CONCLUSIONS

Addis Gas and Plastic Factory give good attention on how they are profitable by producing many products. However, they give low attention on follow-up of their energy utilization and energy efficiency. This implies a lot of unnecessary expenditure on energy due to inefficient use of their energy. This study may help them for analyzing the progress of their energy utilization and energy efficiency, especially on their lighting system, air compressor, and boiler. Also, on their majority electric motors by using Motor Master + International software check there performance. The software helps them on how they can get the energy efficiency opportunities to improve the system. This study shows that energy efficiency improvement opportunities in some areas. These areas include optimizing the illumination of the existing lighting system by which the factory can save 17,012.8 kWh/yr or money of 17,336.04 birr annually. Also by replacement of existing lamps with energy efficient lamps which saves up to 30% of the energy required by the existing lamps. Because of this, the factory can save 5,545.59kWh/yr. or money of 5,650.95 Birr annually.

Addis Gas and Plastic factory uses a vast number of relatively small electric motors. These are used to drive many different machines. The motors consume more than 75% of electrical energy in the factory. By improving the efficiencies of these motors or by replacing with energy efficient motors 5% to 15% of electrical energy can be saved with short payback period. Even if rewinding different types of motor have low initial cost, its running cost with short period of time can buy the new motor or energy efficient motor. So care should be taken while rewinding the motor. And replacing under loaded motor can have significant saving.

On the other hand, there are no rigid rules governing motor selection and the savings potential need to be evaluated on a case-by-case basis. As the result of the analysis, this factory uses electric motor operated inefficient due to under load operation and low efficiency of rating thus needs to improve their energy efficiency.

Using motor master+ international software, it has been seen that replacement of energy efficient motors with the standard motors, selecting of proper sized motors, can save 9,757 KWh of energy and 41,118.61 Birr of money per year with pay back periods of ranging from 1.95 to 6.28 years.

Also this study assess the power factor of the factory which is helps to know the AGP power factor is under penalty based on EEU bill tariff. Before the power factor correction the power factor of AGP is 0.79. The power factor of AGP corrected to 0.9 and based on power factor correction the capacitor bank needs to be designed for 176.8μF to the factory.

Some of the energy savings opportunities in this work are quick and low cost measures that can be implemented in the existing systems. The high cost or capital intensive measures may need further detailed audit and analysis. However, the results of the study should be used as a guide line for future expansions and purchases of new machineries.

5.2 RECOMMENDATIONS

If this factory uses Motor Master + International software properly, to select the energy efficient electric motor, they can have best understanding on the electric motor of their energy efficiency, energy saving potentials and on having proper documentation about electric motor operating specifications before the motor disturb the system like fail or name plate paint out.

The factory managers & their staff give low care on how their energy uses resourcefully, which is a means of most successful and cost-effective way of bringing optimum energy consumption. Thus, improving the efficiency of new technologies alone cannot achieve optimal savings, but when combined with a strong energy management program such as good operational and maintenance practices, day to day follow-up on their energy utilization and efficiency as well as understanding on systems perspective can lead to significant savings. The results of this thesis have shown that there is unnecessarily energy lost in AGP due to the existence of low energy efficient motors, Accessories, lightings etc. thus replacement with energy efficient equipment and proper lighting installation is necessary. The government also gives low attention to check whether the amount of energy presently being generated is efficiently used and give awareness of energy conservation especially for the industry sectors of the country. Thus, the government should involve with a technical and financial expenditure of improving energy efficiency of industries. Especially on:

- ✓ Creating awareness on general management of the industry on use of their energy efficiently without investment
- ✓ Implement the cost effective measures (especially for lighting system) with investing such as to optimization system.

5.3 SUGGESTIONS FOR FUTURE WORK

- ✓ Some of the energy savings opportunities in this thesis are quick and low cost measures, which can be implemented in the existing systems immediately. The high cost measures such as installing economizers around the boiler flue gas outputs may need further detailed audit and analysis.
- ✓ The factory is in the process of expansion to increase its production. Therefore, complete technical energy loss assessment of the expanded factory may be carried out.

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APPENDICES

Appendix A

Formulas used to calculate the Annual Saving Cost of Replaced Lamp

Energy (KWh) = Quantity of Lamp*Power (KW) *Operating Time (h)

Annual Cost =Quantity of Lamp*Energy (KWh) X (Cost of Energy)

Annual Savings Cost=Cost of Currently Installed Lamps in the Year-Cost of Replaced

Lamps in the Year

Simple Payback Period = Initial Cost /Annual Savings Cos

Appendix B

Support Programs for Industrial Energy Efficiency Improvement

This appendix provides a list of energy efficiency support available to industry. A brief description of the program or tool is given, as well as information on its target audience.

Motor Master+

Description: Energy-efficient motor selection and management tool, including a catalogue of over 20,000 AC motors. It contains motor inventory management tools, maintenance log tracking, efficiency analysis, savings evaluation, energy accounting, and environmental reporting capabilities.

Target Group: Any industry

ASDMaster: Adjustable Speed Drive Evaluation Methodology and Application

Description: Software program helps to determine the economic feasibility of an adjustable speed drive application, predict how much electrical energy may be saved by using an ASD, and search a database of standard drives.

Target Group: Any industry

Approach to Motor Management

Description: A step-by-step motor management guide and spreadsheet tool that can help motor service vendors, utilities, and energy-efficiency enters, organizations, and others convey the financial benefits of sound motor management

Target Group: Any industry

AirMaster+: Compressed Air System Assessment and Analysis Software

Description: Modelling tool that maximizes the efficiency and performance of compressed air systems through improved operations and maintenance practices

Target Group: Any industry operating a compressed air system

Fan System Assessment Tool (FSAT):

Description: The Fan System Assessment Tool (FSAT) helps to quantify the potential benefits of optimizing a fan system. FSAT calculates the amount of energy used by a fan system, determines system efficiency, and quantifies the savings potential of an upgraded system.

Target Group: Any user of fans

Power Application tool (CHP):

Description: The Combined Heat and Power Application Tool (CHP) helps industrial users evaluate the feasibility of CHP for heating systems such as fuel-fired furnaces, boilers, ovens, heaters, and heat exchangers.

Target Group: Any industrial heat and electricity user

Tool 2004 (PSAT):

Description: The tool helps industrial users assess the efficiency of pumping system operations. PSAT uses achievable pump performance data from Hydraulic Institute standards and motor performance data from the MotorMaster+ database to calculate potential energy and associated cost savings.

Target Group: Any industrial pump user

Appendix C

Common Capacitor Specifications

COMMON CAPACITOR SPECIFICATIONS

Terminal-to-Terminal Voltage	kVAR	No. of Phases	BIL, kV
216	5, 7.5, 13.3, 20, and 25	1 and 3	30
240	2.5, 5, 7.5, 10, 15, 20, 25, and 50	1 and 3	30
480	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30
600	5, 10, 15, 20, 25, 35, 50, 60, and 100	1 and 3	30
2,400	50, 100, 150, and 200	1	75
2,770	50, 100, 150, and 200	1	75
4,160	50, 100, 150, and 200	1	75
4,800	50, 100, 150, and 200	1	75
6,640	50, 100, 150, 200, 300, and 400	1	95
7,200	50, 100, 150, 200, 300, and 400	1	95
7,620	50, 100, 150, 200, 300, and 400	1	95
7,960	50, 100, 150, 200, 300, and 400	1	95
8,320	50, 100, 150, 200, 300, and 400	1	95
9,540	50, 100, 150, 200, 300, and 400	1	95
9,960	50, 100, 150, 200, 300, and 400	1	95
11,400	50, 100, 150, 200, 300, and 400	1	95
12,470	50, 100, 150, 200, 300, and 400	1	95
13,280	50, 100, 150, 200, 300, and 400	1	95 and 125
13,800	50, 100, 150, 200, 300, and 400	1	95 and 125
14,400	50, 100, 150, 200, 300, and 400	1	95 and 125
15,125	50, 100, 150, 200, 300, and 400	1	125
19,920	100, 150, 200, 300, and 400	1	125
20,800	100, 150, 200, 300, and 400	1	150 and 200
21,600	100, 150, 200, 300, and 400	1	150 and 200
22,800	100, 150, 200, 300, and 400	1	150 and 200
23,800	100, 150, 200, 300, and 400	1	150 and 200
23,940	100, 150, 200, 300, and 400	1	150 and 200
4,160 GrdY/2400	300 and 400	3	75
4,800 GrdY/2770	300 and 400	3	75
7,200 GrdY/4160	300 and 400	3	75
8,320 GrdY/4800	300 and 400	3	75
12,470 GrdY/7200	300 and 400	3	95
13,200 GrdY/7620	300 and 400	3	95
13,800 GrdY/7960	300 and 400	3	95
14,400 GrdY/8320	300 and 400	3	95

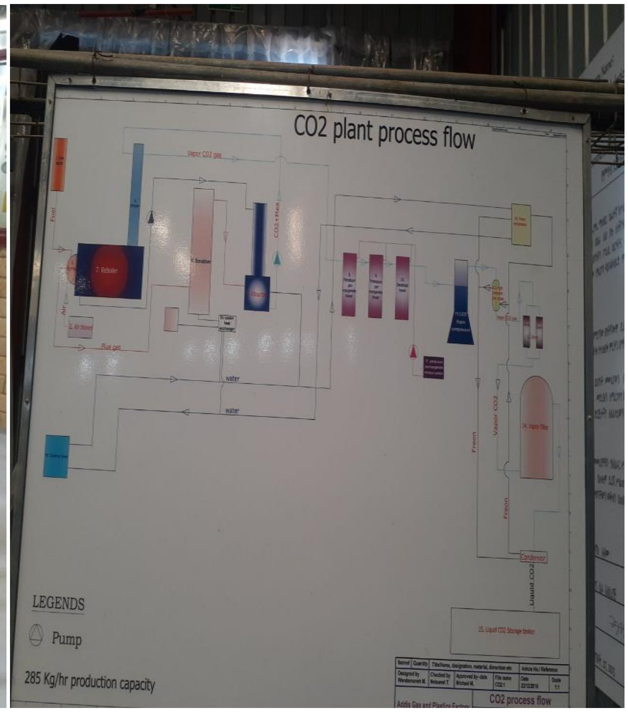
Appendix D

Production, Energy use, and Energy intensity for Chlorine production [34].

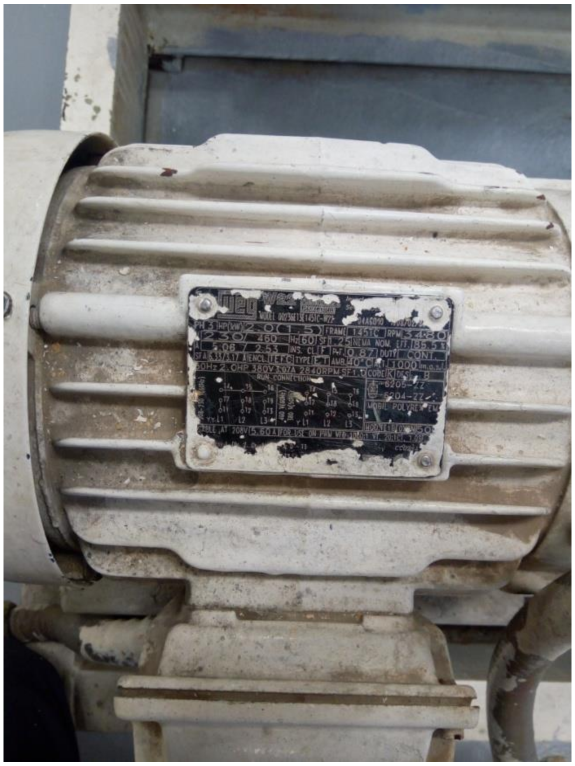
Plant	Annual production (tone)	Annual Elec. Consumption(KWH)	Annual fuel consumption(GJ)	Spec. Elec Con.(KWH/Kg)	Spec. Fuel con.(lit/Kg)	Elec. Energy int.(GJ/tone)	Fuel energy intensity(GJ/tone)
A	1075	10,670,330	33,550	9.9	0.211	15,654	9,070
B	2041	6,567,030	57,694	3.2	0.122	8,543	11,520
C	7226	18,765,008	19,808	2.6	0.381	11,891	7,730
D	8284	11,567,908	21,543	1.4	0.287	10,531	10,680

Appendix E

Some Pictures Taken during the Measurements and data collection in the AGP.



CO2 plant process flow
LEGENDS
Pump
285 Kg/hr production capacity
CO2 process flow


SODA ASH TANKER




CO2 COMPRESSOR