UNIVERSITY OF NAIROBI

SCHOOL OF ENGINEERING

DEPARTMENT OF MECHANICAL AND MANUFACTURING ENGINEERING

Project Report

EVALUATION OF ENERGY CONSERVATION OPPORTUNITIES IN MANUFACTURING INDUSTRY: A CASE STUDY OF SCHNEIDER ELECTRIC MANUFACTURING PLANT IN NAIROBI.

By

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Registration number F56/34186/2019

July 2021

DECLARATION

I hereby declare that this project report has not been previously submitted for award of a degree to this or other university. To the best of my knowledge and belief the contents of this report have not been published elsewhere except where appropriate references have been made.

Maureen Adhiambo

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ACKNOWLEDGEMENTS

My Sincere appreciation goes to my family who have supported me immensely throughout the study period, both by keeping me harmonious and helping me put pieces together.

I would like to express heartfelt gratitude to my Supervisors Dr. Peter Musau and Prof. Cyrus Wekesa for their unwavering support, useful comments, remarks and engagement throughout the study period and Project report writing.

Special thanks go to the Industrial Operations Director at Schneider electric Mr. Philippe Masson for his support on the topic and allowing me to conduct the study at the manufacturing plant. Also, I thank my colleagues at Schneider electric for their insightful contribution and constant challenge to keep me going.

Furthermore, I appreciate my classmates at University of Nairobi who inspirited my efforts to overcome the challenges that come with adult schooling and for their invaluable comments and input into my work. I will forever cherish you. My gratitude also goes to the staff of University of Nairobi for administrative support and for the push to complete my studies within the stipulated period.

Finally, I am eternally grateful to God for his provision, good health, and peace of mind throughout the study period. To God be the Glory.

Declaration of Originality

This Report is my original work and has not been presented for a degree award in any other Institution for degree award or other qualification.

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Title of work: Energy Conservation Opportunities in Manufacturing Plant. A case study of Schneider Electric Manufacturing Plant in Nairobi

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ABSTRACT

One of the main pillars of the modern industry is the uninterrupted supply of energy at an affordable cost. In Kenya, the installed generation capacity is made up of 29.4% hydro, 29.8% geothermal, 26.1% thermal, 11.9% wind, 0.9 biomass and 1.8% solar [According to Power Africa study done in August 2019]. Electricity bills have a fuel cost, which is mainly a component of fossil fuels, which are progressively becoming more expensive. This increases the cost of energy and subsequently the cost of production of goods. It has therefore been established that energy efficiency is important not only for environment conservation but also for sustainable production in the manufacturing industries. This project evaluated the Energy saving potential of Energy Conservation Opportunities (ECOs) existing in Schneider Electric Manufacturing Plant in Nairobi. This was done through a Level III Energy Audit. The results of the energy audit were then analyzed to help identify the ECOs within the Plant, with the main area of focus being the Manufacturing Plant's paint line which consumes nearly half of the facility's total energy requirement. Consequently, techno-economic evaluation of the identified ECOs was carried out. The evaluated ECOs revealed that there is unexploited potential for energy savings in the manufacturing plant, taking into consideration that some initiatives had been undertaken prior to the energy audit. Migration of tariff from CI1 to CI2 has a Payback period of two and half years while supplementing the energy needs by onsite generation by solar PV Plant shows a positive Net Present Value. This project has also established that the efficiency of industrial motors plays a big role in energy conservation. Replacement of some of the existing motors with energy efficient motors results in a considerable saving in energy costs with a pay payback period of 3 months. The project provides an assurance to Manufacturing industries in Africa, specifically Kenya, that the energy costs associated with production can be lowered through Energy Conservation Measures, which will in turn lower the cost of production of goods and gain competitive advantage in the market.

Keywords: *Energy Management; sustainability; Energy Audit; Energy efficiency; Energy Conservation Opportunities; Energy Conservation Opportunities.*

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ECOs	Energy Conservation Opportunities
EIA	Energy Information Administration
KETRACO	Kenya Electricity Transmission Company
GDC	Geothermal Development Company
REA	Rural Electrification Authority
REREC	Rural Electrification and Renewable Energy Corporation
ERC	Energy Regulatory Commission
ERPA	Energy and Petroleum Regulatory Authority
LMCP	Last Mile Connectivity Project
K-OSAP	Kenya Off-Grid Solar Access Project
FIT	Feed-In Tariff
ET	Energy Tribunal
IPPs	Independent Power Producers
KENGEN	Kenya Electricity Generating Company
KPLC	Kenya Power and Lighting Company
FEC	Fuel Energy Cost
FERFA	Foreign Exchange Rate Fluctuation Adjustment
WRMA	Water Resource Management Authority
EEMs	Energy Efficiency Measures
ECMs	Energy Conservation Measures
LCC	Life Cycle Cost
SLD	Single Line Diagram
NEMA	National Electrical Manufacturers Association
PV	Photovoltaic
LED	Light Emitting Diode
CFL	Compact Fluorescent Lighting
FTL	Fluorescent Tube Lamps

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy is extensively used in the industrial sector in different forms and to drive various processes. The applications of energy in the industrial sector includes motor and machinery operation, heating and cooling, ventilation, running of computers and office equipment, and lights.

In the last decade, energy management and sustainability has gained popularity due to; increase in fuel prices, depletion of fossil fuels, global warming, economic crisis, and strict international environmental and energy policies. These factors have forced companies to reduce their energy consumption by cutting down on wastages and adopting efficient use of energy practices [1]. As such, Manufacturing industry have also not been left behind, given that it accounts for 90% of industry energy consumptions, which translates to 51% global energy use [2]. Various energy conservation measures have been adopted by industries to cut on their consumption such as the use of energy efficient motors, soft starters for motor starting, variable speed drives, use of LED Lighting, onsite generation to reduce losses, implementation of energy management programs etc. These initiatives have greatly improved the energy situation in the industrial sector. Research has however shown that there exists approximately more than half of energy saving potential that remains unexploited in the industrial sector.

This project seeks to evaluate the potential of Energy Conservation Measures that are unexplored in the manufacturing plant under study.

1.2 Problem Statement

Schneider Electric manufacturing plant uses Electricity and diesel for its energy requirements. The main source of power is electricity from the grid and the diesel generator is only used as backup during outages.

The electricity demand of the manufacturing plant is 40MWh per month, which translates to 480MWh per year. An increase in the energy consumption of the plant increases the cost of production hence increase in the price of the equipment produced. For the business to remain competitive, there is need to maintain the production costs such as electricity at the minimum. This can only be achieved by ensuring energy efficient processes of production to minimize the amount of energy consumed.

The manufacturing plant is almost 30yrs old (formerly known as Power Technics) and as such, most of the technologies and equipment in place are old and some have become obsolete. Since its acquisition in 2015, Schneider electric has embarked on modernization and implementation of energy efficient practices such as the implementation of LED lighting which has seen the company achieve some energy savings. However, there's much more that needs to be done, including the electric motor line energy consumption evaluation, which could be accounting for more than half of the manufacturing plant's energy usage. For this reason, an Energy audit for the plant was carried out to help identify more energy Conservation Opportunities that would lower further the energy consumption.

1.3 Justification

Globally, companies are under a lot of pressure to remain competitive in an extremely dynamic market. The African market specifically has seen arise in cheap imports from China, because of low production costs. There has also been a worldwide focus on energy conservation, sustainability, and environmental conservation. Manufacturing industries, alike, have not been left behind. Since the biggest loads on industries are made up of motors, there exists a huge potential of energy savings if energy efficient ones are used instead of standard efficiency ones. This data can only be verified and put into good use if an energy audit is carried out, the various ECOs identified and financially evaluated.

1.4 Research Objectives

1.4.1 Main Objective

To establish Energy Conservation Opportunities in Schneider electric manufacturing plant in Nairobi, without compromising the output.

1.4.2 Specific Objectives

The specific Objectives of the project are:

i) Analyze the energy situation of the manufacturing plant through a Level III Energy Audit, with focus on motor loads section.
ii) Perform techno-economic evaluation of the Energy Conservation Opportunities (ECOs) identified.
iii) Make recommendations of the most viable Energy Conservation Opportunities for adoption by Schneider Electric manufacturing plant.

1.5 Research Questions

i) What is the current Energy consumption of the different sections of the plant?
ii) What are the potential Energy Conservation Opportunities within the plant and their cost implications?
iii) What's the current method of motors starting and how much energy saving can be realized by the use of energy efficient motors?

1.6 Scope

The scope of project entailed the study of energy trends of Schneider electric manufacturing plant, through an energy audit. The Energy audit focused only on Electricity consumption in the manufacturing processes.

The parameters under study were obtained using a Power Logger and the results analyzed to help identify areas of wastage, which in turn helped to identify Energy Conservation Opportunities (ECOs). Economic evaluation of the identified ECOs was also carried to and recommendation of three most viable ECOs for implementation.

1.7 Beneficiaries

The main beneficiary of the project is Schneider electric manufacturing plant. The results of my project pinpointed areas of energy wastage that will help the organization to make decision on which ECOs to adopt based on their economic feasibility. This will also help to define manufacturing best practices to achieve Energy efficient processes. In the long run, the organization will spend less on Energy cost, make savings on the costs of production, and eventually benefit consumers through competitive product pricing.

1.8 Report Organization

Generally, this project report has five chapters: Introduction, Literature Review, Methodology, Results and Analysis and Conclusion and Recommendations. The Introduction covers the project's background information, problem statement, justification, objectives, research questions, scope, and beneficiaries. The Literature review section details research that has been conducted on the same topic and the gaps that this project aims to address. The Methodology explains the methods and tools that were used to collect data relating to the project. Chapter Four gives a description of the results obtained and tools used in analysis, including financial formulas.

The last Chapter describes the findings and recommendations of Energy Conservation Opportunities to be adopted by the Manufacturing plant and a conclusion.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter documents research that has been conducted before around the topic. It explains the need of energy efficiency and conservation measures, the electricity reforms and electricity prices in Kenya, Energy audit concept, its needs, and the different levels of energy audit. This chapter also covers the Energy saving considerations in a manufacturing industry, as this will form a basis of the identified and recommended ECOs.

2.2 Need for Energy Efficiency

The cost of energy is escalating and will continue doing so in future. As such, there's it's important to conserve energy through Energy efficiency programs. Energy Efficiency is a method of reducing Energy input into a process to attain the same level of output, without compromising the quality. On the other hand, Energy conservation is using less energy for a constant service. For example, switching off lights when not in use is Energy conservation while replacing incandescent light with a compact fluorescent light is energy efficiency. The main benefits for Energy Efficiency programs include reduced greenhouse gas emissions, lowering of production as well as household costs and reduced demand on energy generation facilities [1].

It has been projected that the worldwide energy consumption will increase by approximately 50% by 2050. This is according to a research conducted by the US Energy Information Administration (EIA) in 2018. Nearly half of this energy is accounted for by the industrial sector, and it is expected to increase by approximately 30% by 2050, totaling to about 315 quadrillion British thermal units (Btu) [2].

Worldwide energy generation is heavily reliant of fossil fuels, whose depletion is on a steady increase. As a result, the worldwide energy produced is at a risk of not meeting the future demand. Also, a greater percentage of the world's energy sources is only found in few geographical locations. As a result, events taking place in the economic and political environment in these regions play a predominant role in the global energy system.

Since the 1930s the Middle East and Russia have been the world's leading producers of oil and gas respectively. The recent political developments in these regions have raised worldwide concerns about the future of energy and its sustainability. Additionally, nuclear energy which was expected from the 1970s to form a greater percentage of alternative sources of energy remains highly unexploited due to high capital costs and strict safety requirements as far as disposal is concerned [2].

Due to the unpredictability in the energy availability trends, there's been a lot of initiatives in the recent past on energy efficiency programs to save on consumption, concentrate more on developing renewable Energy sources and reduce carbon emission levels for a more sustainable growth. Energy Efficiency programs are mainly aimed at reducing energy costs and environmental degradation. The energy efficiency measures can result to other benefits apart from energy savings such as improved production efficiency, and these can be taken into consideration when evaluating the success of these programs, especially where energy savings are low. Policy makers should therefore take into consideration and determine the tradeoff between the achieved energy savings and socioeconomic welfare gains arising from an energy efficiency measures and in designing energy efficiency policies.

The main advantage of energy conservation measures, unlike others, is that the results are realized within a very short duration, hence it is one of the best options towards attaining reduced energy demand and greenhouse gas emissions.

2.3 Electricity Reforms in Kenya

Before 1997, the electricity sector in Kenya was a highly monopolized sector where generation, transmission, and distribution services were fully owned and controlled by the state. From 1997 to date, major changes have taken place due to strong legal and regulatory reforms which led to the introduction a Liberalized energy market. The Sessional Paper No. 4 of 2004 and the Energy Act No.12 of 2006 unbundled the power sector further leading to creation of energy parastatals such as the Geothermal Development Company (GDC) to be in charge of geothermal energy development, the Kenya Electricity Transmission Company (KETRACO) to increase penetration of the transmission network to load centers, the Rural Electrification Authority (REA) to spur growth of connections to rural areas and the Energy Regulatory Commission (ERC),currently known as the Energy and Petroleum Authority(ERPA) to strengthen technical and economic regulation of the sector . The new policy and energy law of 2016 was established to increase energy access and significantly reduce power shortages that were being experienced then [3].

Although not so much was achieved in the first 5 years after operationalization of the Energy Act of 2006, significant gains have been achieved after the year 2013 when the government introduced a fast-tracked programme to increase power generation and connections to rural areas, public institutions, and poor urban settlements. Example of such initiative is the last mile project that has seen connectivity of Kenyans to electricity rise to about 60%. In 2015, the Last Mile Connectivity Project (LMCP) was launched to improve electricity connectivity in rural and peri-urban areas by providing access and enabling electricity consumers to get electricity at affordable cost. Apart from aiding in economic growth in the rural areas and improving the quality of lives of many Kenyans, LMCP has also contributed to the growth of Electricity users and sales, which has in turn led to viability of the electricity business. The Kenya Off-Grid Solar Access Project (K-OSAP) is another ongoing initiative by the Government of Kenya to increase access to electricity in the country. It is projected to help connect, 1,097 community facilities, 380 boreholes and 277,000 households via solar mini grids [3].

The energy bill of 2017, which was passed by parliament and enacted into law in 2019, proposed further advancement in reforms in Kenya's Energy sector [3]. The bill aimed to:

i) Regulate the establishment, functions and powers of the energy sector entities.
ii) Consolidate the laws relating to energy.
iii) Creation of awareness and Promotion of renewable energy, including exploration, recovery, and commercial utilization of geothermal energy.
iv) Define the National and County Government functions in relation to energy.
v) Regulation of production, supply and sustainable use of electricity and other energy forms of energy in a sustainable manner.
vi) Regulation of petroleum and coal activities.

The regular review of the Feed in Tariff (FIT) has also attracted Investors in renewable energy sector in Kenya. **A Feed-in-Tariff (FIT)** is a mechanism that is used to promote generation of electricity from renewable energy sources. It allows power producers to sell Electricity generated from Renewable energy sources to the national distributor at a fixed rate within a specified period.

The Renewable energy sector has a massive potential, and can meet the current and forecasted energy Kenya is demand if the resources are used sustainably ,and the transmission and distribution networks are expanded, Feed-in-Tariff made more attractive and decentralized generation encouraged [4].

Over the last 3 decades, the market concentration has decreased because of strong Government policies which are aimed at protecting the investor, the consumers and promoting the entry of Independent power investors. The major gains that have been achieved as a result of these policies are; Increased connectivity, Increase of generation of electricity from renewable energy sources and reduction of the use of fossil fuel-based resources such as diesel and Heavy Fuel oils which cause pollution and hence environmental Degradation. The gains that have been achieved by in the electricity sector in Kenya has been made possible by the various stakeholders in the industry that interrelate as shown in Figure 2.1.

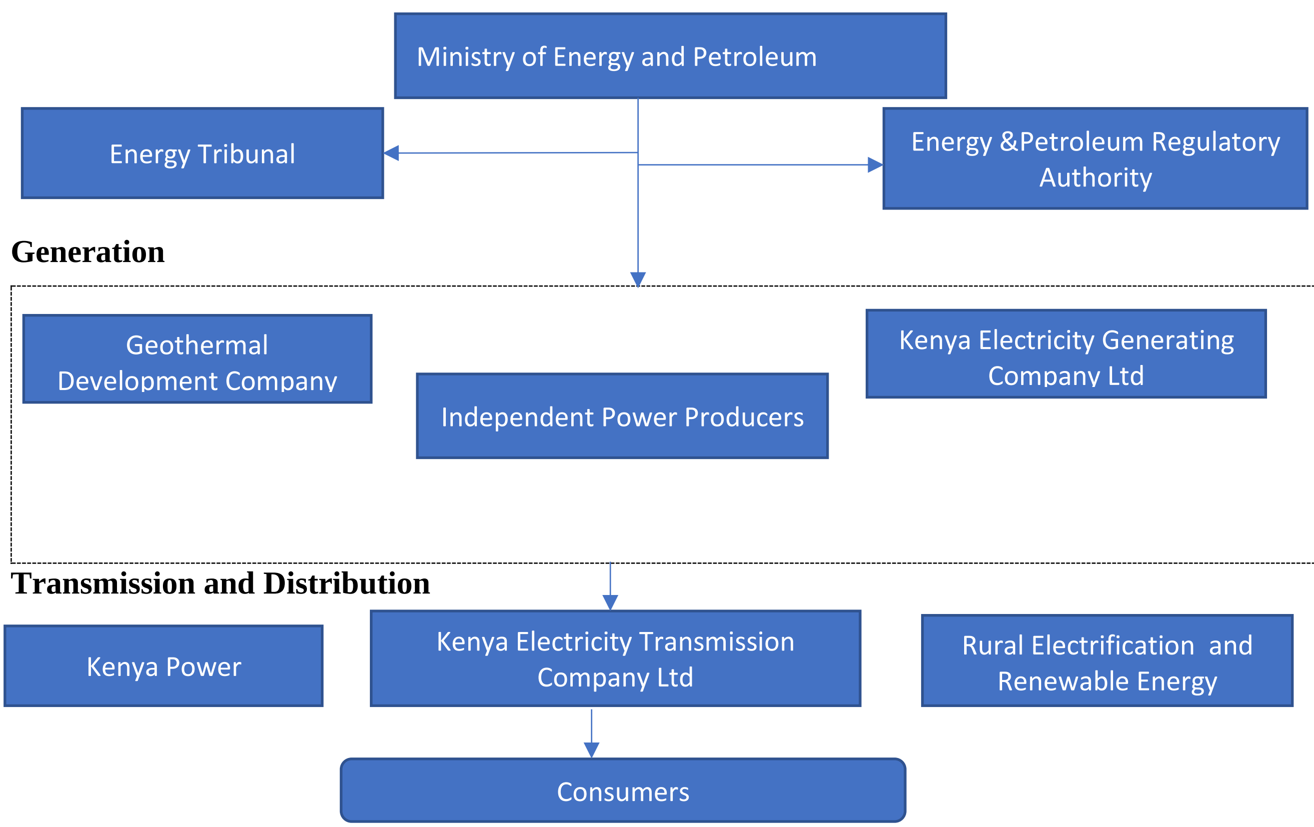

Figure 2.1: Overview of Kenya's Electricity Sector Stakeholders [5]

2.4 Electricity Prices in Kenya

ERC, currently known as the Energy Regulation and Petroleum Authority (ERPA), was established under the Energy Act, 2006. Its mandate is to:

- Set and review energy Tariffs, Enforcement of established standards in the energy sector, Licensing, review, and approval/denial of Power purchase
- Settlement of disputes that may arise within the energy sector
- Regulation of Petroleum and coal.

Table 2.1 shows the current electricity tariff rates in Kenya as set by the Regulatory body.

Table 2.1: Summary of Electricity Retail Tariffs 2018/2019 [6]

Code	**Customer Type**	**Units of Energy consumed(kWh)/month**	**Charge Method**	**Unit**	**Charge Rates**
DC-L	Domestic - Lifeline	0-10	Energy	Kshs/ kWh	12.00
DC-O	Domestic -	>11	Energy	Kshs/kWh	15.80
SC	Small Commercial	0 – 15,000	Energy	Kshs/ kWh	15.60
CI1	Comm./Industrial	>15,000	Energy	Kshs/ kWh	12.00
			Demand	Kshs/ kVA	800
CI2	Comm./Industrial	No Limit	Energy	Kshs/ kWh	10.90
			Demand	Kshs/ kVA	520
CI3	Comm./Industrial	No Limit	Energy	Kshs/ kWh	10.50
			Demand	Kshs/ kVA	270
CI4	Comm./Industrial	No Limit	Energy	Kshs/ kWh	10.30
			Demand	Kshs/ kVA	220
CI5	Comm./Industrial	No Limit	Energy	Kshs/ kWh	10.10
			Demand	Kshs/kVA	220
SL	Street Lighting	No Limit	Energy	Kshs/kWh	7.50

The general costs reflecting on all tariffs include [6]:

i) **ERC Levy**: This is currently 3 cents/kwh.

ii) **REP Levy:** This cost accounts for 5% of the total units of power consumed by a customer. It is allocated to REREC to facilitate Rural Electrification.

iii) **Fuel Energy Cost (FEC):** This reflects the cost of fuel used to generate electricity from thermal sources. It is a variable cost and is published monthly in the Kenya Gazette. This money is collected by Kenya Power who in turn passes it to electricity generating companies to pay fuel suppliers.

iv) **Water Resources Management Authority** (WARMA) Levy. This is 5 cents/kWh charged on the cost of all units of energy generated from hydropower plants above 1MW. This rate is variable per kWh and the amount collected is channeled to WRMA for maintenance of such resources.

v) **Inflation Adjustment:** This rate varies with the consumer price index for every kWh of units consumed.

vi) **Foreign Exchange Rate Fluctuation Adjustment (FERFA):** This cost is associated with fluctuation of foreign currencies in relation to the Kenya Shilling for costs associated with power purchasing agreement between utility company and the Power Producers.

Note: FEC, FERFA, Inflation and WARMA vary monthly and the cost components published on the Kenya Gazette.

From the above information on electricity prices in Kenya, it is evident the electricity bill is heavily dependent on the units of kwh consumed. The higher the number of units consumed, the higher the bill paid. Companies can reduce this consumption through adoption of energy conservation and efficiency measures.

2.5 Energy Audit

Energy forms the biggest portion of costs that can be controlled in many organizations, especially industries. As such, there exists a big potential for such organizations to reduce their energy consumption and therefore the associated costs. This can be done through the implementation of energy efficiency programs, which are as a result of Energy audit/surveys.

An energy audit is the assessment and analysis of energy use pattern in a process/building to optimize the energy consumed, while maintaining the same level of output. The main aim of an energy audit is to establish where, when, why and how energy is used in a building/process and to identify opportunities to minimize wastage [7]. This is done by identifying areas of energy losses and providing conservation measures that will minimize the associated losses. The results of the energy audit form the basis upon which most energy management programs are formulated. The Energy audit should reveal the areas of energy wastage within a facility, potential Energy Conservation Opportunities (ECOs), the costs involved and the savings/benefits that will be achieved by implementation of the ECOs. This will form a cost-benefit analysis of the findings to give a clear picture to help the facility management in decision making in as far as energy is concerned.

Energy Conservation Measures will not only reduce the energy losses incurred in systems or processes but also reduce electricity bill.

There are 3 different Levels of Energy audits [7]:

i) **Level I: Site Assessment/Preliminary Audits**

This level of audit involves the identification of low/no cost energy saving opportunities. It also entails a general overview of potential capital installation improvements. The main activities here include minimal interviews with operation personnel, an inspection of electricity bills and the facility under study to identify the obvious sections of energy wastage.

ii) **Level II: Energy Survey and Engineering Analysis Audits**

This level of audit involves activities in Level I and goes further to identify Energy Efficiency Measures (EEMs) and potential capital-intensive Energy Conservation Opportunities (ECOs). It involves an in-depth survey of energy usage in the facility and analysis of the associated costs.

The result of this level of audit is a summary of corrective measures needed to save energy, their costs and calculation of the payback period for these investments.

However, this level of audit does not provide a detailed analysis of the facility's energy consumption, but the data can be used to give the facility management team ideas on what energy Conservation measures to prioritize and the savings expected.

iii) Level III: Detailed Analysis of Capital-Intensive Modification Audits

This is also referred to as an "investment grade" audit. It involves detailed identification and recommendation of ECOs, in relation to economic analysis of the same. In addition to Level I and Level II energy audit activities, this level of audits includes detailed data collection, Monitoring and Engineering analysis of systems to make them more efficient.

The choice of the level of Industrial audit to conduct is dependent on the following factors:

i) The type and function of the Industry.
ii) The depth of Energy inspection required to obtain the targeted data.
iii) The desired amount of savings to be achieved.

For this project, a level III Energy Audit was conducted. This is because apart from analysis of energy usage and costs I needed to conduct an economic analysis of three major capital investments ECOs identified to give a justification to the management on what measure need to be adopted.

Generally, depending on the targeted sector, energy audit can also be classified as below:

2.5.1 Household Energy Audits

This is aimed at identifying areas of energy wastage in your home, which is mainly contributed by human behavior and the use of less efficient alighting systems and home appliances. Examples of areas of energy wastage in a home includes leaving the lights on when there's no occupancy, use of fluorescent bulbs instead of energy efficient LEDs etc.

2.5.2 Commercial Buildings Energy Audits

This entails the audit of commercial buildings usage of energy. This will involve individual office/commercial space and common amenities such as the walkways, washrooms etc. In this case, energy bills of various tenants will be collected and compared, based on their different needs and establish ways of improving the same.

2.5.3 Utility Energy Audits.

This mainly focusses on Energy generation and distribution sectors. Most generation facilities are always oversized to cater for transmission losses and distribution systems inefficiencies. For example, if these losses are kept at minimum, there will be no need to oversize the generation facilities and hence be able meet the ever increasing electricity demand without incurring huge capital expenditures to establish new generation stations or increase the capacity of existing ones.

2.5.4 Manufacturing Industry Energy Audits.

Energy auditing concept came into being because of the oil energy crisis in the early 1970s [8]. Back then, there were many inefficiencies in energy use and therefore, it was easy for an energy auditor to identifying ECOs [9]. As the years go by, companies have increasingly become conscious of their energy consumption, hence the need of energy efficiency in industrial processes. Energy efficiency has continued to play a major role in promoting sustainable industrial development, especially in the industrialized countries [10].

In Kenya and most developing countries, the story is currently different as the huge benefits that can be achieved from Energy Efficiency measures by industries are largely underutilized mainly due to lack of awareness and poor government policies. As a result, industries have not managed to significantly lower their energy costs, which is a major contributor to production cost. The consequence of this is lack of competitiveness of their industrial products in the global market. As a matter of urgency, industries in developing countries should explore low cost, low risk but high impact energy conservation measures that will reduce the base-line costs of energy. In so doing, measures will be put in place and lead time defined to achieve high level efficiency in production processes that will be supported by an already established energy efficient culture.

Energy, in different forms, is one of the most important input to most of the industrial processes. Energy, in its different forms, is required as a continuous input to all industrial processes. The total energy consumed by the industrial sector in developed countries is approximately 30-40% of the world's total energy demand [11].

Manufacturing industry Energy audit is a measure of energy efficiency in a manufacturing process. This is derived from the measure of energy performance of the machines and plants associated directly or indirectly with the manufacturing processes [12]. Energy audit of manufacturing plants should be a continuous process that is essential to reduce energy consumption in manufacturing processes and attain sustainable energy efficiency.

Industrial energy costs, just like other sectors are directly related to amount of energy consumed. However, tariffs, market flows and energy options available also play a major role in energy demand profile of companies, which in turn affect the Specific Cost of Energy.

From economics, it's important to define a physical economic Index and evaluate energy efficiency through its evolution with time. The Index [12] is expressed by:

$$\frac{\text{Cost of Energy}}{\text{Production Volume}} = \frac{\text{Cost of Energy}}{\text{Energy Consumption}} \times \frac{\text{Energy Consumption}}{\text{Production Volume}} \quad (2.1)$$

or

$$\frac{1}{\text{Energy Productivity}} = \text{Specific cost of energy} \times \text{specific energy consumption}$$

Where.

i) The cost of Energy is expressed in currency i.e. Euros.

ii) Production Volume (Units)

iii) Energy Consumption (kwh)

From equation 2.1, it is evident that the cost of energy can be reduced by the reduction of specific cost of energy, specific energy consumption or both, depending on the available opportunities and companies' policies that are in place.

2.6 Energy Saving Consideration in a Manufacturing Industry.

From the Physical Economic Index, an energy auditor can develop a conceptual framework to identify and classify energy conservation measures in manufacturing plants. Thus, the two main variants in the physical economic index, i.e. specific energy consumption and specific cost of energy can be influenced by measures performed with regards to the following factors [12]:

i) Contractual Purchasing Conditions

ii) Onsite Energy Generation

iii) Choice of Supplier and Tariff

iv) Distribution and Transformation of Energy

2.6.1 Contractual Purchasing Conditions

This includes all actions towards attaining compliance claims and provisions of the chosen energy purchasing contracts to avoid fines and surcharges. In most large industrial firms, the capability to comply to contractual purchasing conditions heavily depends on the commitment of the organization, culture and attitude to energy saving programs put in place. It is therefore important to increase people's awareness and knowledge of energy management and how their choices affect global costs through introduction of energy management programs and training.

2.6.2 Onsite Energy Generation

This is the production of the energy needed for industrial processes on site to avoid or reduce the quantity of energy purchased. Apart from reduced energy costs, generation at site can lead to improved quality and security of energy supplied, and a better demand response management [12]. This idea is slowly gaining popularity in the industrial sector due to the introduction of renewable energy technologies such as solar PV generation and Feed-in Tariffs by governments which enables such producers to input extra energy produced into utility grids. There are several technologies available for onsite generation and the choice on which one to be adopted by companies is depends on:

i) The location of the plant.
ii) Feed-in tariffs existence.
iii) Availability of waste products to be used as fuel for generation.

The most common technology for onsite generation in industrial plants is cogeneration which is the production of power and useful heat simultaneously in a manufacturing process. Excess electricity produced is sold to the utility whereas excess heat can be used in cooling systems such as heat pumps [12].

2.6.3 Choice of Supplier and Tariff

This involves the choice of the most suitable and economically viable supplier based on the energy the needs and the prevailing market trends. The choice of supplier and tariff complexity is mainly influenced by the country in which the manufacturing plant is located. For example, in industrialized countries, there is de regulation and liberalization of electricity market as far as transmission and distribution is concerned while in most developing countries the electricity market is highly monopolized [12], [13].

For companies to be make informed decisions on the supplier and tariff choice, several skills, tools and time is needed i.e. expertise on energy consumption dynamics, energy consumption forecast, a good comprehension of market rules, reliable information on the available tariffs and options, and availability of personnel to perform energy market analysis. Different analysis methods have been proposed to enable companies to develop strategies for energy contracts renewal. For example, the use of statistical tools such as regression analysis and control charts [12].

There are several factors that affect cost of electricity in a manufacturing plant and can therefore be used in tariffs and supplier considerations:

i) Total Energy Consumed

Purchasing large amount of energy introduces the aspect of economies of scale hence lower cost per unit as illustrated in Table 2.1. However, industries can face challenges in adopting this due to segmentation of manufacturing processes into different sites and medium production volumes within a certain period which may not meet minimum amount consumption thresh hold for big consumers.

ii) Peak Demand

The maximum power demand by a consumer is often included in the electricity bills as an additional cost. Many suppliers use this to motivate companies to maintain their capacity requirement within manageable levels which in turn ease the pressure on the generation facilities. It is therefore necessary for companies to forecast energy consumption and load profile based on historical data and statistical analysis in order to avoid penalties and surcharges related to peak demand. The Monitoring of energy load profile and comparison of peak load values to the contractual values will help companies to come up with energy saving opportunities as summarized in Table 2.2.

Table 2.2: Energy Saving Opportunities Based on Peak Demand [12].

Peak Load	**Saving Opportunity**
Always Exceeds contractual value	Negotiate for a higher peak load value to avoid surcharges
Occasionally exceeds contractual value	Align operational practices and scheduling to contractual requirements
Always below contractual value	Negotiate for a lower peak load value to achieve energy savings

iii) Demand Response and Dynamic Price Systems

Demand response concept is referred to as changes in consumer demand of electricity in relation to changes in the price of electricity. It is also considered to be changes in demand of electricity because of incentives by the supplier due to reduced energy usage or usage of electricity during high wholesale market prices/off peak hours [13]

Suppliers often send cost signals to consumers to control their demand and flatten the demand curves as possible to enhance systems efficiency and reliability. Different methods are available to help companies and energy suppliers to calculate the variation in the amount of energy not supplied versus the expectations, because of implementation of demand response initiatives e.g. Monte Carlo simulation [14].

Energy Consumers can respond to price variation by:

a. Reducing the amount of electricity consumed during peak hours
b. Shifting part of electricity consumption from peak hours to off peak hours.
c. Partially supplying electricity demand during peak periods by onsite generation

iv) Power Factor Correction

Power factor correction and control is a popular practice in Manufacturing plants. This is always done to avoid penalties and fines from the suppliers and to achieve energy efficient distribution systems in an industrial plant. Power factor correction is usually implemented by introducing capacitors in systems to provide the reactive energy demand by loads such as motors. However, a Life Cycle Cost (LCC) assessment should be conducted to give a justification why a certain number of capacitors should be installed while taking into consideration external factors that affect their efficiency such as temperature.

2.6.4 Distribution and Transformation of Energy

Transformation of energy is the process of changing energy from one form to another that is more usable in an efficient manner while minimizing the losses involved. In Manufacturing industries, the main energy consuming machine are motors and Lighting loads To ensure energy efficient process, an industrial audit should check the efficiency of motors by comparing the energy input to the output. This can further reveal areas of energy wastage and help define Energy Conservation opportunities to achieve energy efficient systems.

Motors operate by converting electrical energy to mechanical energy. During this conversion, there are energy losses involved and this is what should be kept at minimum. Companies should select motors with the highest level of manufacturer's guaranteed efficiency. However, this is not enough since when in operation, the apparent efficiency is what comes into play. The apparent efficiency is the product of motor power factor and minimum efficiency. From this, it is evident that energy consumption of a system varies with the power factor. It is therefore necessary to attain a good power factor value in the network for high motor efficiency [15]. The main aim of increasing motor efficiency is to reduce energy consumption, which will in turn reduce CO_2 emissions and reduce environmental degradation.

Since Electric drive systems form the largest part of electrical energy consumption in industrial processes, improvement of motor efficiency will result in big energy savings which is important if industries are to remain competitive in business.

2.6.4.1 Energy Efficient Electric Motors

The concept of energy efficient electric motors has increasingly gained popularity over the last few years. This is because in the industrial sector, electric motors are the largest energy consumers. Previous research has however shown that out of the total number of electric motors purchased every year, only about 15% are energy efficient motors [15].

The efficiency of an electric motor can mainly be improved by reduction of the motor losses. This can be achieved by design, materials, and construction improvements in the motors. This will in turn result to 2-6% improvement in efficiency, leading to an approximate 25% losses reduction.

A small gain in motor efficiency can lead to significant energy savings and reduction of operating costs of motor [15].

Although energy efficient motors are higher in purchase costs (15-30%), this can be recovered in 2-3 years through savings in energy and operational costs [15]. Since these high efficiency motors have proven to be durable and reliable over time, they should be an important consideration as far as energy saving efforts are concerned in the industrial sector. They should be considered in new installations, replacement of faulty motors, major industrial equipment modifications or for underloaded or oversized motors. The efficiency of a motor is the ratio of mechanical output to the electrical input. This is expressed as [15]:

Efficiency = Output/Input= output/ (output + losses) ……………………………………...…. (2.2)

Electric motor losses [16] are classified as:

i) **Core Losses**-This is the energy needed to magnetize the core material and includes losses due to eddy currents that flow within the core. These losses can be reduced using thinner steel laminations and by lengthening the core to reduce magnetic flux densities.
ii) **Windage and Friction Losses-**These losses are due to bearing friction and air resistance. These losses can be reduced by improving the bearing selection, air flow and fan design. Losses reduction leads to reduced cooling requirements hence smaller fan.
iii) **Stator Losses-**These load losses are because of heating due to current flow through the resistance of the stator winding. Also referred to as I^2R losses and can be reduced by increasing the volume of wire in the stator.
iv) **Rotor Losses**- These load losses appear as I^2R heating in the rotor. These losses can be reduced by increasing the size of conductors in the rotor which will in turn lower the resistance.
v) **Stray Load Losses**- These losses are due to leakage fluxes induced by load currents within the motor.

When evaluating motors from different manufacturers in terms of efficiency, it is important that uniform efficiency definition is used. These definitions include:

i) **Nominal or Average expected efficiency**-This is the average full load efficiency value obtained through testing a sample population of the same motor model.
ii) **Expected minimum or guaranteed minimum efficiency**-most motors are guaranteed to have efficiencies that equal or exceed the full load value.
iii) **Apparent Efficiency-** This is the product of motor power factor and minimum efficiency.
iv) **Full load efficiency**-This term is not commonly used in motor specification as motors are not normally operated on full load.

v) **Calculated efficiency**- This refers to an average expected efficiency that is based on a relationship between design parameters and test results.

National Electrical Manufacturers Association (NEMA) instituted a nameplate labelling standard for polyphase induction motors in the 1 to 125hp size range. The full load motor nameplate efficiency is represented based on nominal and minimum efficiencies as shown in Table 2.3

Table 2.3: NEMA Motor Nameplate Efficiency Marking Standards [17].

Nominal Efficiency (%)	**Min Efficiency (%)**	**Nominal Efficiency (%)**	**Min Efficiency (%)**
98.0	97.6	88.5	86.5
97.8	97.4	87.5	85.5
97.6	97.1	86.5	84.0
97.4	96.8	85.5	82.5
96.8	96.2	84.0	81.5
96.5	95.8	82.5	80.0
96.2	95.4	81.5	78.5
95.8	95.0	80.0	77.0
95.4	94.5	78.5	75.5
95.0	94.1	77.0	74.0
94.5	93.6	75.5	72.0
94.1	93.0	74.0	70.0
93.6	92.4	72.0	68.0
93.0	91.7	70.0	66.0
92.4	91.0	68.0	64.0
91.7	90.2	66.0	62.0
91.0	89.5	64.0	59.5
90.2	88.5	62.0	57.5
89.5	87.5	59.5	55.0

From Table 2.3 above, it’s evident motors with efficiencies that fall within a given band, have essentially the same efficiencies. The nameplate nominal efficiency represents a value that may be used to compare the energy consumption of a group of motors.

The amount of savings that can be achieved by the use of energy efficient motors is determined by the size of the motor, Annual hours of use, load factor of the motor, improvement in efficiency and the utility's power and energy rates.

An energy efficient motor consumes fewer units of energy input (kW) to provide the same output as a standard efficiency motor. The difference between the efficiencies of the two motors can be used to determine the reduction in input power in kW , the annual kWh savings and the total annual cost savings for two similar motors, operating at the same load, with varying efficiencies as below shown in equations 2.3, 2.4 and 2.5 [17].

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$ ……………………………………..……………….(2.3)

Where:

h_p=Motor Nameplate Rating

L =Load factor

E_{std} = Standard Motor Efficiency under actual load conditions

E_{he} = Energy Efficient Motor Efficiency under actual load conditions

$kWh_{savings} = kW_{saved} \times$ Annual Operating hours……………...…………….………………………. (2.4)

Total Savings= (kW_{saved} x 12 x monthly demand charge) + ($kWh_{savings}$ x energy charge) …. (2.5)

It should be noted that before transformation of energy, distribution takes place first. Distribution of energy is the process of delivering energy to its point of use in the most efficient way while minimizing the losses involved. In an industrial set up, the distribution network should allow minimum losses and attain maximum system efficiency. During an Energy audit, the power network on the facility will be studied to identified areas of wastage within the facility.

2.6.4.2 Lighting Technologies

Lighting loads form a significant part of manufacturing Industries Power Consumers.

There are three main types of lighting Technologies available: Fluorescent Tubes Lamps (FTL), Compact Fluorescent Lights (CFL) and Light Emitting Diodes (LEDs).

Fluorescent lamps are commonly used in offices, buildings, shops, street lighting, supermarkets, etc. A fluorescent lamp contains mercury vapor, which when exposed to electricity gets excited to produce short wave UV light that in turn cause a phosphor coating inside the lamp to glow, resulting into illumination. During this conversion, heat is released in the process, which makes these lamps less efficient in terms of energy consumption. Apart from energy wastage related o the use of these lamps, another disadvantage is the environmental impact with the mercury vapor residue, which needs a carefully managed recycling process to minimize contamination [18].

Compact Fluorescent lamps is another type of lamps commonly used in offices and houses due to their small size as compared to tubular fluorescent lamps. It however has the same disadvantage of environmental impact like tubular fluorescent lamps, due to the use of mercury to produce light [18].

The most recent invention in lighting technologies is the se of Light Emitting Diodes (LEDs). These lamps create light by electroluminescence in a semiconductor material. This is a process by which a semiconductor material emits lights when electric current is passed through it.When electricity is connected to an LED, electrons start moving at the junction of the N-type and P-type semiconductors within the diode. When there is a jump over of electrons at the p-n junction, the electron loses a portion of its energy in terms of photons(light). The amount of energy lost defines the color of light produced [18].

Over the last decade, Manufacturing industries and general energy consumers have been shifting from Fluorescent tubes lighting to LED technology as far as lighting is concerned. This is because apart from Energy savings, LED technology offers the following advantages of long life, unlimited switching, flexible design, high luminous efficiency, compactness, dimmability, negligible heat transfer and variability [19]. Findings have showed that energy savings by LEDs is approximately 32% compared to CFLs [20].

2.7 Research Gap

From the reviewed literature, it is evident that energy auditing is not a new concept. Energy auditing of industry has also been extensively researched. However, the main research gap is that most of the research papers offer theoretical energy conservation measures, and for case studies, the recommendations given are not backed by economic evaluation, to give a justification of why the ECOs identified should be adopted. As a result of this, energy audit exercises have not yielded the expected results due to organizations' management reluctance to adopt the proposed ECOs due to lack of economic feasibility of the same.

Another gap is that most energy audits are usually carried out as a one-time event, with no measures put in place to monitor the effectiveness of the Energy conservation measures adopted. This project seeks to address these gaps as summarized in Table 2.4.

Table 2.4: Research Gaps Summary

Author	Study	Year	Observations	Research Gap
Aedah M J Mahdi	Energy Audit as a step to effective Energy Management	April 2018	*A programmable thermostat recommended for the building to control heating depending on the temperature to save on consumption.	*Expected energy saving not quantified. *Economic evaluation not undertaken
Gopi Srinath, N. Uday Kumar	Energy Audit as a tool for Improving system efficiency in Industrial sector	June 2014	*Savings on energy consumed by replacing of industrial motors by more efficient ones	*The investment is evaluated based on payback period only. No mention of IRR and NPV
Olatunde Ajani Oyelaran, Yau Yusuf Twada, Olawale Monsur Sanusi.	Energy Audit of an Industry: A Case Study of Fabrication Company	August 2016	*Electrical data collected by use of meters for a sample section. *ECOs recommendation made based on Payback period calculation only	*Lack of real time data acquisition for accuracy and consistency. *No monitoring put in place to check whether the expected results after ECOs implementation have been achieved.

2.8 Literature Review Conclusion

Energy is undoubtedly a limited resource whose use should be monitored and controlled. To be able to do this, a facility/plant should be first aware of the consumption details, hence the need of an energy audit. An energy audit gives visibility into the energy situation of a plant, with indication of areas that are the largest consumers, the machines in these sections, their efficiency and factors that affect the energy performance of such machines. The result of this study will give an insight into possible Energy conservation measures to be implemented to achieve an energy efficient manufacturing process and production of market competitive goods.

CHAPTER THREE: METHODOLOGY

3.1 Introduction of the Facility

Schneider Electric is a French multinational_corporation that specializes in the manufacturing of electrical and Power Products equipment, having its headquarters in France.

Schneider Electric Kenya is a subsidiary of Schneider electric Global and it's located at Power Technics Complex on Mombasa Road, Nairobi. The office serves as the headquarters of Schneider Electric East Africa. It houses an average of 200 staff with an office space of approximately 2,632 square meters. The complex is for general office use and Manufacturing plant. The main power consumer on the building, is the manufacturing plant and lighting.

The facility comprises of several buildings and sections, with the most important being the manufacturing plant, whose energy profile is to be analyzed. The manufacturing plant has various sections which include the sheet metal area, Paint line, Panel Assembly, Quality Control and Testing and finally the packaging section. The paint line and the welding sections operate for only 3 days in a week, while the rest of the sections operate throughout the week.

The complex also has the following additional buildings and facilities, some of which are shown on Figure 3.1.

i) An outsourced cafeteria.

ii) A generator room

iii) A borehole pumps

iv) Gate house.

v) Car park and grounds.

The facility is generally occupied between 8 a.m. to 5 p.m. every Monday to Friday.

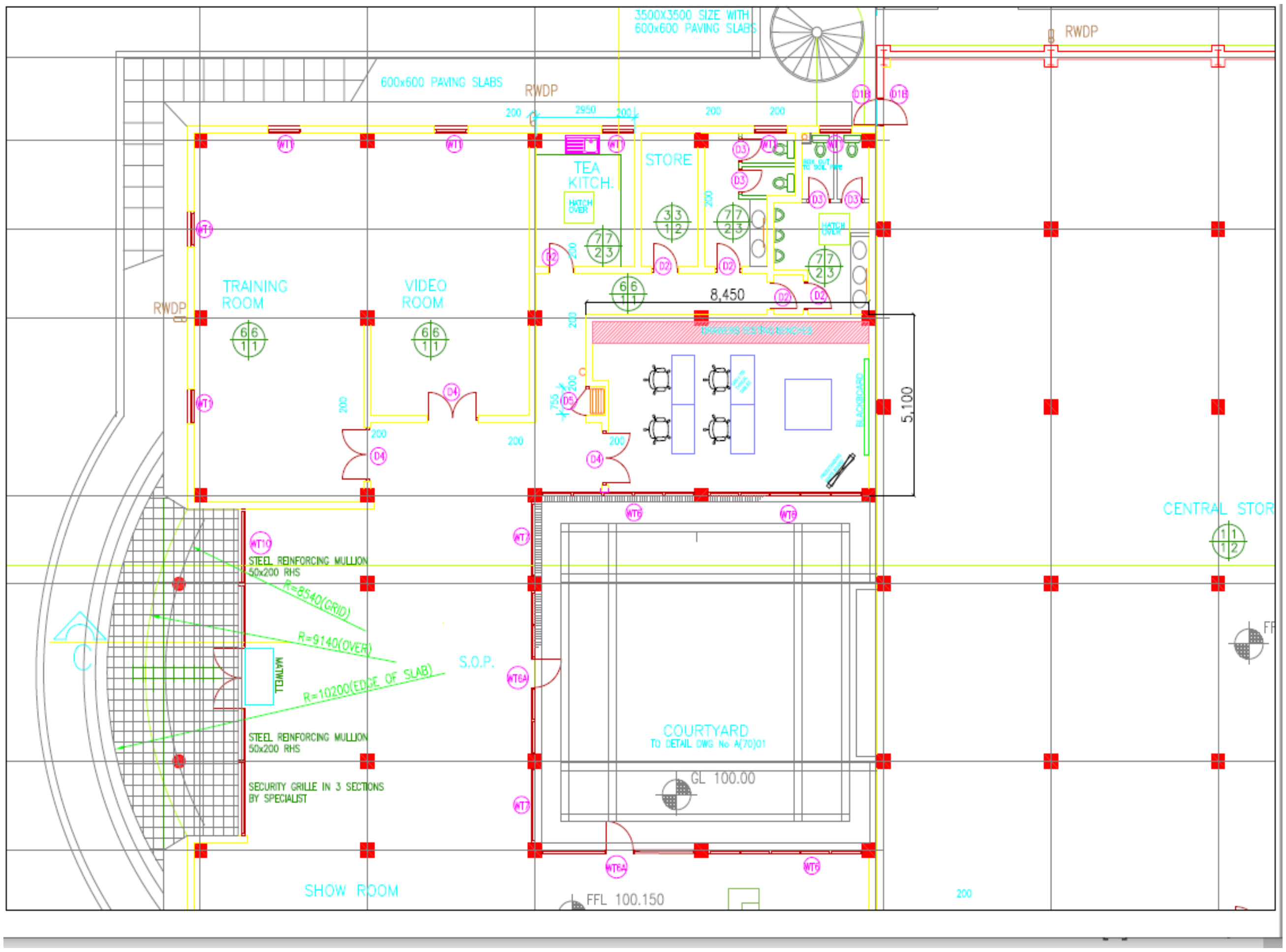

Figure 3.1: Schneider Electric Manufacturing Plant Layout [21]

3.2 Sources of Energy

The main source of energy at Schneider Electric Building Kenya is electricity from the grid. The electricity is supplied at 11kV by an underground cable that feeds an 11kV Switchgear which in turns feeds a 1000KVA 11kv/0.415kv transformer. The supply is metered by Kenya Power at 415V 3-phase 4-wire (tariff CI1).

There are three generators that provide backup power whenever there's an outage as shown in Figures 3.2, 3.3 and 3.4.

i) 675KVA generator is the main generator that automatically comes on during the day whenever there's an outage to support the entire load, apart from the painting line.

ii) 100KVA generator to support the load during an outage at night. This load mainly comprises of Lighting as there's no manufacturing activities that goes during this time.

iii) 500kVA diesel-fueled standby generator is dedicated to serve the paint line which is estimated to consume approximately half of the total energy consumption of the manufacturing plant. This is usually started manually whenever an outage occurs when the painting process is ongoing. The paint line is usually run for 2 or 3 days in a week, depending on the production requirements.

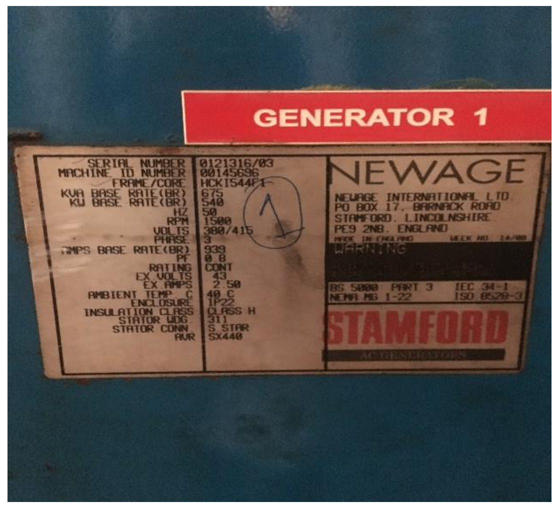

Figure 3.2: 675KVA Backup Generator

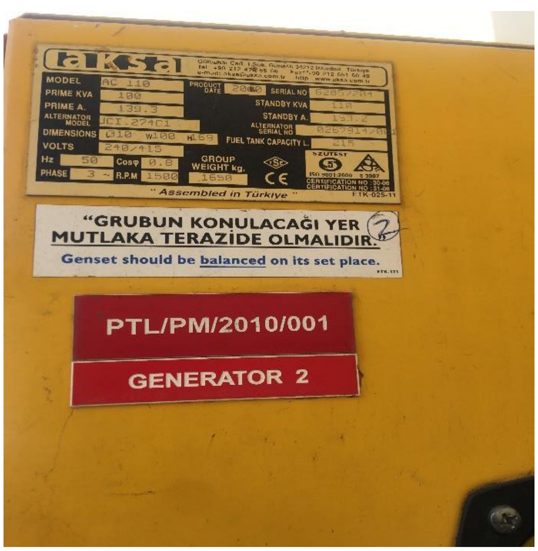

Figure 3.3: 100KVA Backup Generator

Figure 3.4: 500KVA Backup Generator

3.3 Energy Audit Preparation

To maintain clear focus of the main project objective of establishing ways of reducing energy consumption in the plant, an energy audit will be performed. In this case, the energy conservation measures that are feasible from operation perspective are evaluated. A prior discussion will be held with industrial operations director to study and analyze energy data to establish ways of minimizing energy consumption within the facility.

The first step will be to conduct interviews with industrial operations personnel, assess the energy bills and a brief inspection of the facility under study. The facility inspection is also aimed at:

i) Establishing the historical data on energy consumption.
ii) Understanding how power is distributed within the facility.
iii) The loads that are supplied.
iv) The transformation of energy within the facility.
v) The time of use of different machines and office spaces.
vi) The main Energy indicators of the facility.

Since the facility did not have a Single Line Diagram (SLD), my first task was to develop the SLD, which is represented in Figure 3.5.

During the preliminary audit, I also managed to assess the electricity bill of the plant, which revealed an average monthly electricity bill for the entire facility and also average monthly electricity bill for the paint line as shown in Table 3.1 and Table 3.2 respectively. From these tables, it is evident that the paint line consumes nearly half of the facility’s energy requirements, hence it will be my main area of focus during the energy audit and ECOs identification.

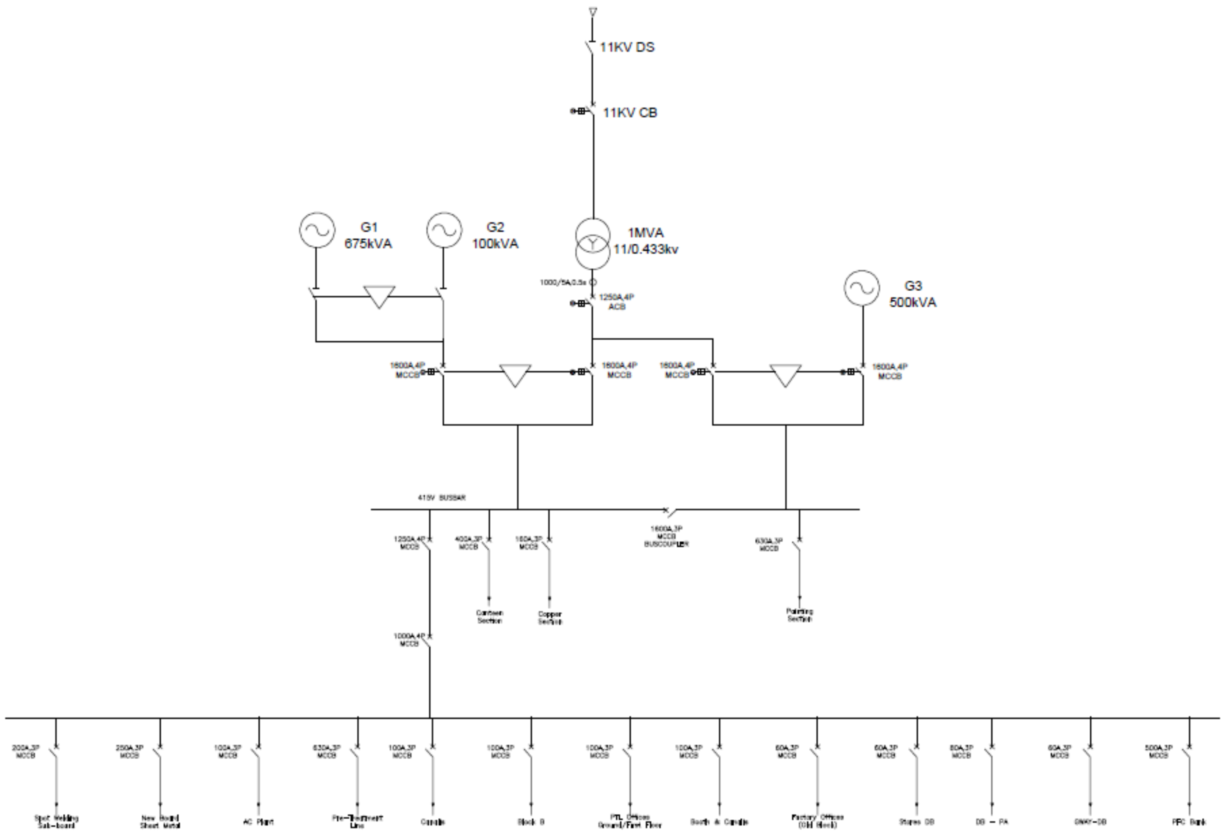

Figure 3.5: SEKL Power Distribution Single Line Diagram

Table 3.1: Schneider Electric Average Monthly Electricity Bill [21]

	Consumption(kWh)	**Unit Rate (Kshs/kWh)**	**Total (Kshs)**
High Rate Consumption	30,335.00	12	364,020.00
Low Rate Consumption	9,229.00	12	110,748.00
Maximum Demand (KVA)	567.00	800	453,600.00
Fuel Energy Cost	39,564.00	2.5	98,910.00
Total Energy Cost (KES)			**1,027,278.00**

A discussion with the operation personnel indicated that there's a specific meter at the incomer to the paint line to measure its consumption. Data collection from the meter revealed that the paint line energy consumption is approximately half of the total energy required in the facility as shown in Table 3.2.

Table 3.2: Schneider Electric Average Monthly Paint Line Consumption [21]

Average Consumption per day	1664kWh
Operation /week	3 days
Total Consumption in a week (1664*3)	4,992kWh
Total Consumption in a month (4992*4)	**19,968kWh**

The data on Tables 3.1 and 3.2 are based on CI1 Tariff:

i) CI1-Applicable to Commercial and Industrial consumers metered at 415V and Consumption Exceeds 15000 units:
ii) Energy charge of Kshs. 12.00 per unit consumed
iii) Energy Charge of Kshs. 6.00 per unit of supply consumed during off peak hours
iv) Demand Charge of kshs.800 per KVA

From this information, the paint line will be my main area of focus during the energy audit and Energy conservation/efficiency measures recommendations. The main power consuming loads in the paint line include motors, compressors, and Air dryers.

As part of energy audit preparation, I also prepared the datasheets for the main machines in the manufacturing Line. The manufacturing plant is divided into the following main sections:

i) Sheet Metal area`
ii) Painting Line
iii) Assembly Area

The motor datasheet in Table 3.3 was used to collect data of the main utilities during the energy audit. This data was then used to evaluate the potential energy savings that can be achieved by changing the motor starting schemes or even replacing the less efficient motors with the highly efficient ones. For example, the use of a soft starter will reduce the in-rush currents registered during motor starting, which will in turn lower the peak demand, which is a factor in electricity bills.

Table 3.3: Motors Datasheet [22]

Sr. No	Description	UOM	Data
1	No of the Motor		
2	Year of Manufacture/purchase/Installation		
3	Frequency Converter Available		
4	Mechanical Nominal Power	kw	
5	Method of starting		
6	No of Poles		
7	Synchronous Speed	rpm	
8	Full-load Efficiency	%	
9	Full load Amperage	A	
10	Full load Power Factor		
11	Operating Hours/Day	Hrs.	
12	Operating Hours/annum	Hrs.	
13	Power Consumption/day	Kwh	
14	Power Consumption/annum	Kwh	
15	Unit Rate of Power	Kes	
16	Total Expenditure per annum	Kes	

3.4 Energy Audit Tools

During the Energy audit, specialized tools will be needed for data collection, logging and analysis.

3.4.1 Fluke 1738 Three Phase Power Quality Logger

This power logger was used to conduct energy, power quality and load studies. When connected to power input points of an electrical network, it automatically captures and logs power, current, voltage and events such a dip, inrush currents and swells.

This information is represented in terms of high-resolution RMS load profiles and waveform snapshots.

Figure 3.6: Fluke 1738 Power Quality Logger [23]

3.4.2 Extech LT300 Lux Meter

This light meter was used to measure the illumination of various office rooms and the manufacturing plant to verify if the lighting needs are sufficiently met, over provisioned or under provisioned for. For this project, I used it to determine the brightness or lumens produced by the existing fluorescent tubes in order to determine the equivalent LED for replacement.

Figure 3.7: Extech LT300 Lux Meter [24]

3.4.3 Fluke 323 True RMS Clamp Meter

This meter was used to take current and Voltage measurements and check the continuity of circuits in tight areas that cannot be accessed by the power logger. It's sim and compact size is favorable for use in tough environmental conditions.

Figure 3.8: Fluke 323 True RMS Clamp Meter [25]

3.5 Economic Evaluation of Energy Conservation Opportunities

After the identification of Energy Conservation, I conducted economic evaluation of the identified ECOs. For this, I will apply the following economic evaluation formulas [26]:

3.5.1 The Net Present Value

$$NPV = CF_0 + \frac{CF_1}{(1+Rd)} + \frac{CF_2}{(1+Rd)^2} + \text{---} + \frac{CF_n}{(1+Rd)^n} \quad \text{.....(3.1)}$$

Where:

NPV is the Net Present Value

$CF_0 \ldots CF_n$ is the net cash flows within the project duration

R_d is the rate of discount

3.5.2 The Payback Period

The payback period is the length of time required for the revenues from a project to equal the invested amount. A project with the shortest payback period is the most attractive.

$$SPP = \frac{Capital\ Cost}{Annual\ Savings} \quad \text{.....(3.2}$$

Where SPP is the Simple Payback Period

3.5.3 Internal Rate of Return

The IRR is the discount rate (or interest rate) at which the cumulative net present value of the project is equal to zero.

$$IRR = R1 + \frac{NPV1*(R2-R1)}{NPV1-NPV2} \quad \text{.........(3.3)}$$

Where:

R1 = Lower interest rate

R2 = Higher interest rate

NPV1 = Higher Net Present Value (derived from R1)

NPV2 = Lower Net Present Value (derived from R2

3.6 Conceptual Framework

The conceptual Framework provided a visual illustration of how the various variables in the project relates to one another. This was summarized in Figure 3.9.

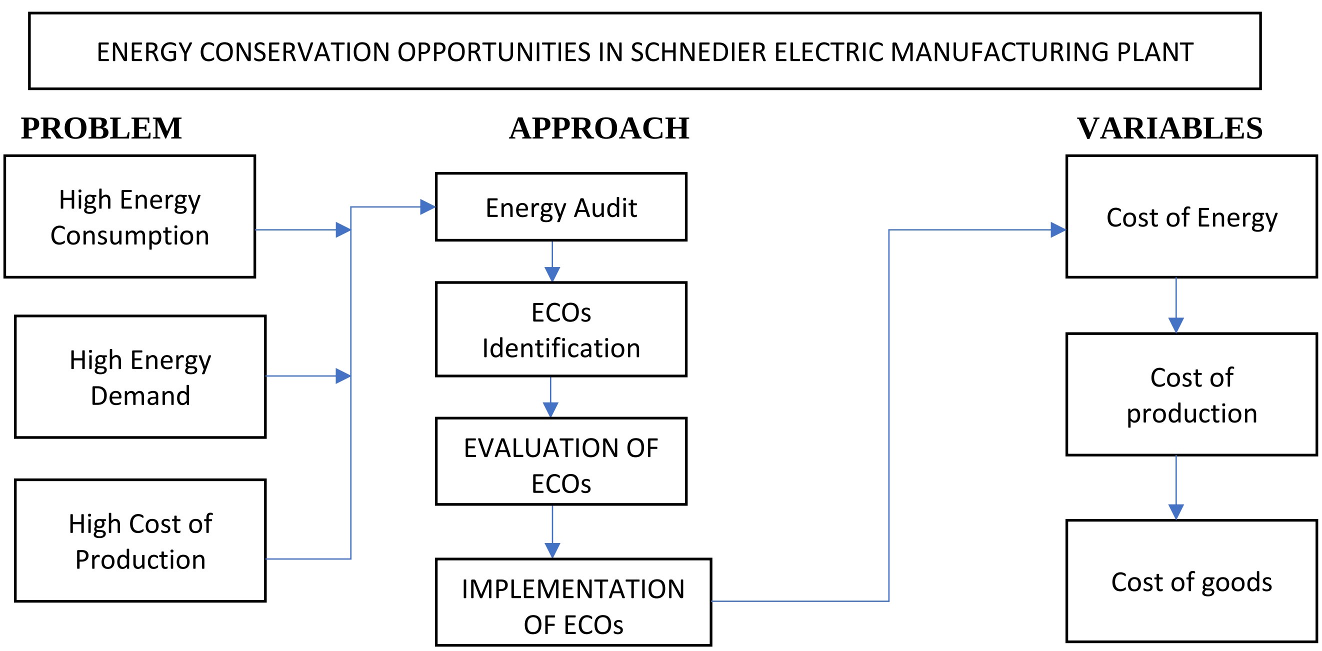

Figure 3.9: Project Conceptual Framework

3.7 Summary of Methodology

The methodology comprised of the following major activities.

i) Preliminary interview with operations personnel to establish the energy demand of the manufacturing plant, the daily production, the energy systems in the production process and the main energy consumers.

ii) Establish the main energy Indicators for the manufacturing plant.

iii) Visit to the selected sites of the plant i.e. Main Switchroom, Generator rooms, Paint line and assembly line.

iv) Review of past electricity bills for the plant.

v) Collection of data, mainly for the paint line (which consumes approx. 50% and welding area).

vi) Data Analysis

viii) Evaluation of energy efficiency and Conservation potentials.

ix) Economic evaluation of the identified Energy Conservation Opportunities.

x) Reporting of the results of energy audit including recommendations.

CHAPTER FOUR: RESULTS AND ANALYSIS

4.1 Historical Data

As part of the Energy Audit, historical data of the facility's Electricity Bill, for 12 months, was studied and the results are as are shown in Table 4.1. The bills were validated by the readings from the smart meter located at the metering panel of the facility.

Table 4.1: Schneider Electric Kenya Monthly Electricity Consumption Trends

Month	Total Consumption (kWh)	Max Demand (kW)	Max Demand (KVA)	Load Factor (%)	Power Factor	Electricity Cost (Kshs)	Consolidated Cost (Kshs/kWh)
Jan-20	39,564	546	567	10.0	0.96	1,230,665.00	31.11
Feb-20	45,394	567	583	11	0.97	1,348,382.00	29.70
Mar-20	45,973	563	568	11	0.99	1,307,327.00	28.44
Apr-20	41,304	546	567	11	0.96	1,249,915.00	30.26
May-20	36,671	530	536	10	0.99	1,132,356.00	30.88
June-20	45,879	571	577	11	0.99	1,340,543.00	29.22
July-20	47,507	573	579	12	0.99	1,340,543.00	28.22
Aug-20	54,900	598	607	13	0.99	1,540,607.00	28.06
Sep-20	53,638	598	607	13	0.99	1,525,106.00	28.43
Oct-20	35,197	564	572	9	0.99	1,184,741.00	33.66
Nov-20	41,827	567	574	10.2	0.99	1,288,363.00	30.80
Dec-20	48,404	539	544	12.5	0.99	1,406,540.00	29.06

Observations

i) The Total Consumption of the facility varies between 35 ,000 kwh to 54,000 kwh. The variation can be attributed to the fluctuation in the production quantity at the factory, with the month of October having the lowest consumption**,** with the lowest load factor and the highest consolidated cost.

ii) The Power Factor of the manufacturing plant is at an average of 0.98. This is good, given that the ideal power factor should be 1. Also, since the manufacturing plant has a lot of inductive loads such as motors and compressors, the power factor of 0.98 means that some actions have been put in place to improve the power factor and is working out just fine.

iii) Apart from the period between September and October which have a month to month variation of 34%, it can be seen in monthly comparisons that the electricity consumption was relatively flat during the year. There is a month to month variation margin of between 10-15% which is within the acceptable limits.

iv) The load factor of the facility varies from 9% to 13%. The load factor represents the actual energy usage versus the peak demand. The monthly load factor is calculated by equation 4.1.

$$Load\ Factor = \frac{Monthly\ consmption(kW)}{Peak\ Load\ in\ kW\ X\ 30\ days\ in\ a\ month\ x24\ hrs\ in\ a\ day.} \quad \text{....................} (4.1)$$

It is desirable that consumers should have a higher load factor. From table 4.1, the load factor of Schneider electric facility is very low. This can be improved by lowering the peak demand, e.g. by load scheduling.

The load factor can also be reduced by identifying periods of peak demand and making necessary changes in the network to achieve peak clipping.

v) The Consolidated cost of the facility ranges from 28 to 31 Kshs/kWh of energy consumed. This is very high, given that the energy charge is Kshs. 12 per unit. This means that the demand charge and other costs contributes to more than half of the energy bill. To change the situation an in-depth analysis of the plant’s loads, their schedule of operation and causes of high peaks at instances can help define measures to be put in place to improve the situation.

$$Consolidated\ Cost = \frac{Monthly\ Electricity\ Bill\ (Kshs)}{Monthly\ Energy\ Consumption\ (kWh)} \quad \text{....................} (4.2)$$

4.2: Data Collection and Analysis of the overall Consumption

Data collection on the overall energy consumption of the facility was conducted. This was done using Fluke 1738 Power logger, which was connected to the main Incomer, on the Low Voltage side of the Transformer.

The study was captured within 5 days (three working days and 2 Non-working days) and the results are as shown in Figure 4.1 to Figure 4.5.

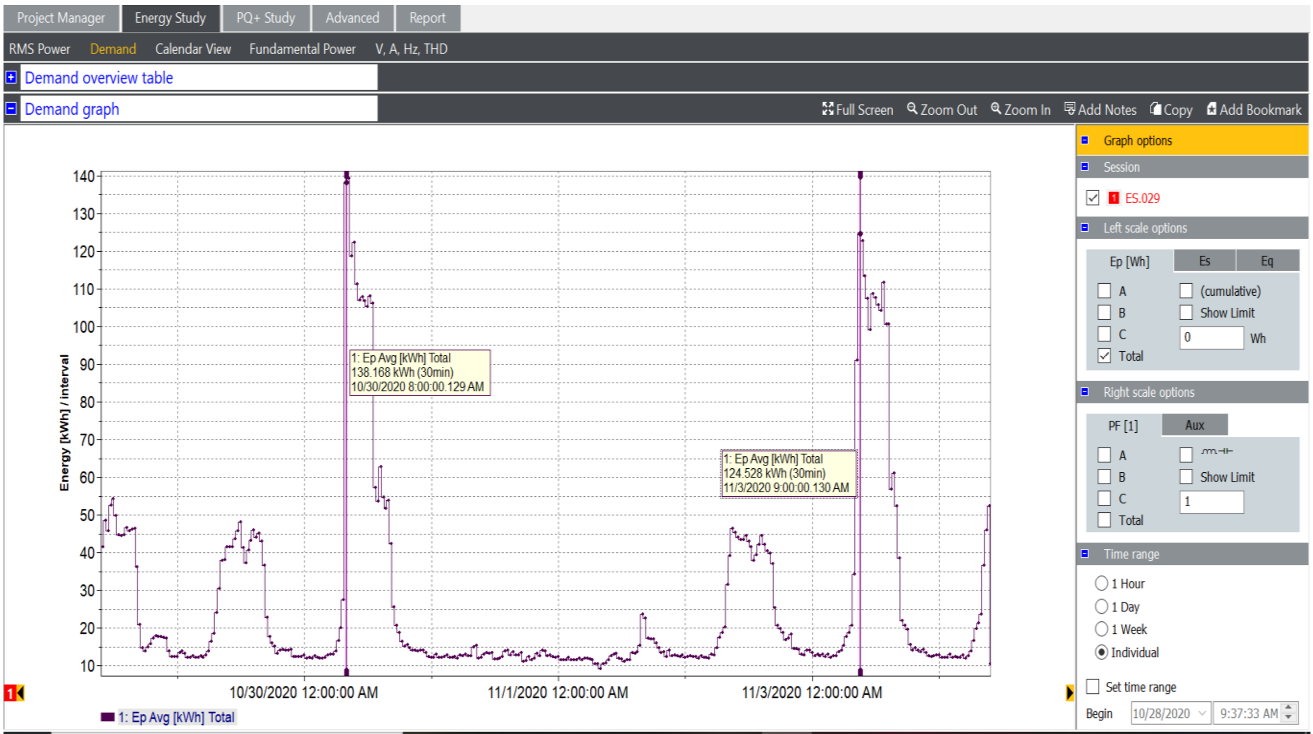

Figure 4.1: Demand Graph showing the kWh consumption over 5 days study period

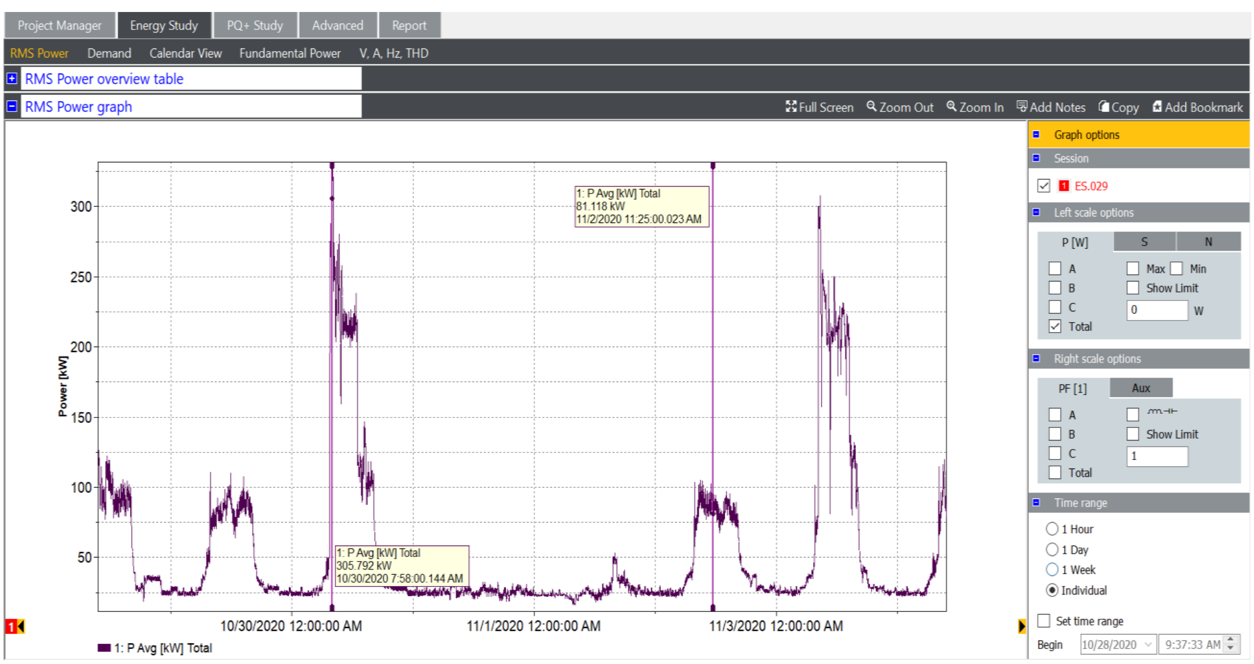

Figure 4.2: RMS Power Graph showing the kW consumption over 5 days study period

The graphs in figures 4.1 and 4.2 show that the peak load is registered between 7:30 to 8:00 a.m. when manufacturing activities starts and then reduces gradually as the day progress and drops to the lowest at 5 p.m. when manufacturing activities stop. The graph then remains constant throughout the night as during that time, the main load is only the security lights. The spikes registered during startup of the manufacturing activities can be attributed mainly to the large inductive loads such as the heaters and ovens that are started at this time and the motor starting schemes that are in place. This if corrected can lead to a reduced maximum demand, KVA.

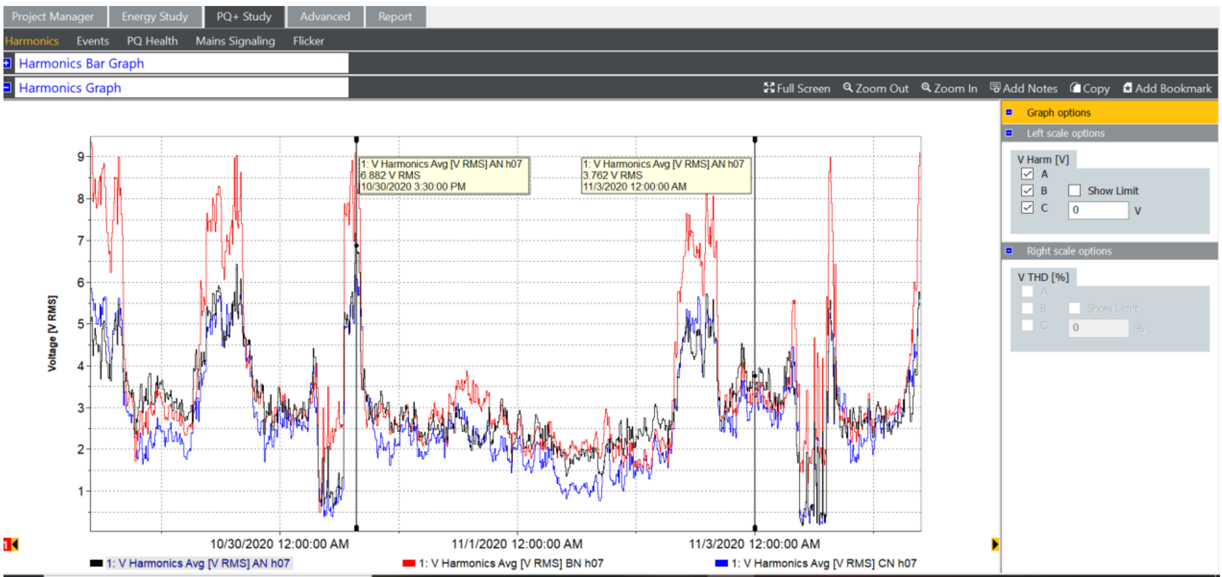

Figure 4.3: Harmonics Graph over 5 days study period

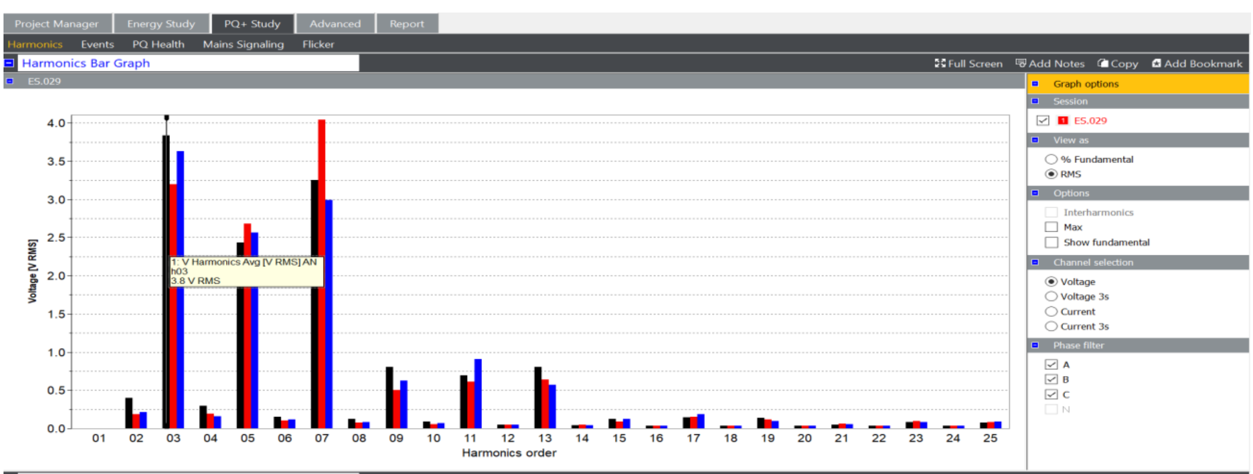

Figure 4.4: Harmonics Order over 5 days study period

From Figure 4.3, it can be deduced that the highest harmonics levels occur between 11:00 a.m. to 1:00pm during weekdays. This could be attributed to the presence of nonlinear loads in the network such as personal computers, welding machines, Variable Frequency Drives (VFDs) that start to operate within this period.

Figure 4.4 shows that the highest harmonics registered are the 3^{rd} and 7^{th} order harmonics. Example of effects of harmonics in a power network are reduced power factor. Harmonics increases the apparent power required by the system while the active power remains the same. This means that more current will be drawn by the system, increased conductor and core losses and derating of equipment in the system such as transformers, motors and generators.

Harmonics can be reduced by introduction of reactors in the AC/DC lines. Harmonics of low order (5^{th}, 7^{th} and 11^{th}) can be eliminated by use of passive harmonic filters consisting of capacitors and inductors that are meant to trap a certain harmonic frequency.

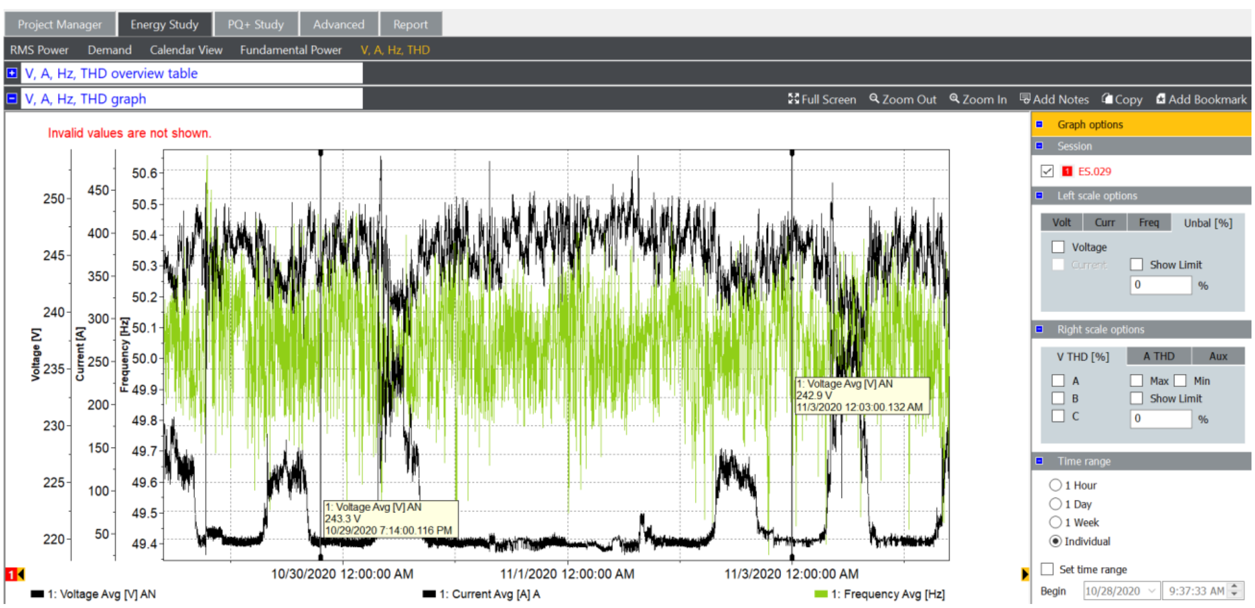

Figure 4.5: Voltage, Current and Frequency graph within the study period

From Figure 4.5, the following can be deduced:

- The frequency of the power supply is between 49.5 to 50.7Hz. this is within the acceptable limit of 45-52Hz, as provided for by the Kenya Electricity Grid Code.

- The supply voltage is between 223 to 253V. The voltage is lowest between 8:00 a.m. to 10:00 a.m., with the current being the vice versa (highest during this period). This can be attributed to the starting of motors, which draws high in rush currents.

4.3 IDENTIFIED ENERGY CONSERVATION OPPORTUNITIES

4.3.1 Tariff Migration

Schneider Electric Manufacturing Plant is currently on CI1 Tariff as has been shown from the Power bills. The plant can consider moving from to Commercial and Industrial tariff CI1 to Commercial and Industrial CI2.

CI1 tariff is applicable to Commercial and Industrial consumers for supply provided and metered at 415V and Consumption Exceeds 15000 units and is charged as below.

- Energy charge of Kshs.12.00 per unit consumed
- Energy Charge of Kshs. 6.00 per unit of supply consumed during off peak hours
- Demand Charge of Kshs.800 per KVA

CI2 tariff is applicable to Commercial and Industrial consumers for supply provided and metered at 11000V per post-paid billing period and is charged as below.

i) Energy charge of Kshs.10.90 per unit consumed
ii) Energy Charge of Kshs. 5.45 per unit of supply consumed during off peak hours
iii) Demand Charge of Kshs.520 per KVA

From the above data, it is evident that CI2 tariff is more economical as its Energy and demand charges are relatively lower as compared to CI1 tariff.

The expected cost savings as a result tariff migration will be:

i) Savings on Demand Charge = 800-520 = Kshs. 280 per maximum KVA demand
ii) Savings on Energy Charge = 12-10.90 = Kshs. 1.10 per unit of energy consumed

These savings computations are exclusive of other energy charges such as ERC Levy, REP Levy, Fuel Energy Cost, Warma levy, Inflation adjustment, Foreign Exchange Rate Fluctuation Adjustment and VAT.

4.3.2 Time of Use Tariff

Time of use tariff has been designed by energy suppliers to provide incentives to consumers to use more energy at off peak times. The utility company, Kenya power, who's Schneider electric's power supplier has defined off peak period as in Table 4.2.

Table 4.2: Kenya Power Off-Peak Tariff Periods

Day	Start (hrs.)	End (hrs.)
Weekdays	00:00	06:00
	22:00	00:00
Saturday/holiday	00:00	08:00
	14:00	00:00
Sunday	00:00	00:00

Since the paint line consumes nearly half of the total power consumption of the facility, operating it during off peak hours will yield some energy savings. The cost savings associated with the shift, with CI1 tariff will be:

Savings on Energy charge = 12-6 = Kshs.6 per unit of energy consumed.

4.3.3 Replacement of Existing Fluorescent Tube Lamps with LEDs

A study of the existing lighting Fixtures was conducted during the energy audit. The results show that the facility has done a relatively good job of replacing previously existing Fluorescent Tube Lamps (FTL) with Light Emitting Diodes (LEDs).

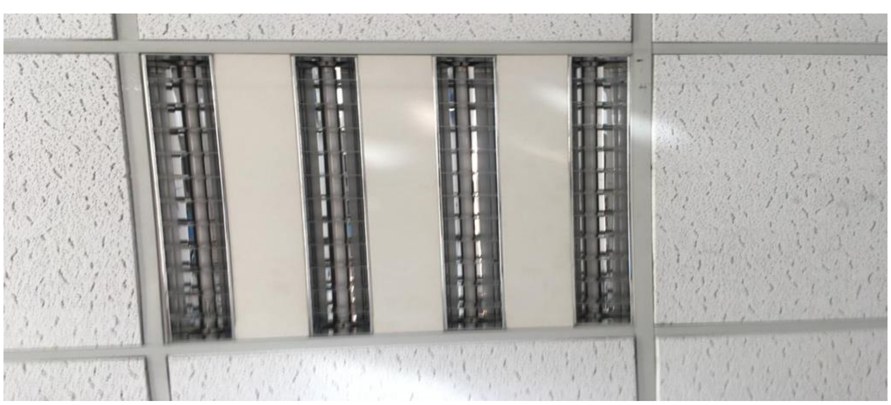

Figure 4.6: Existing Ceiling Fluorescent Tube Lamps

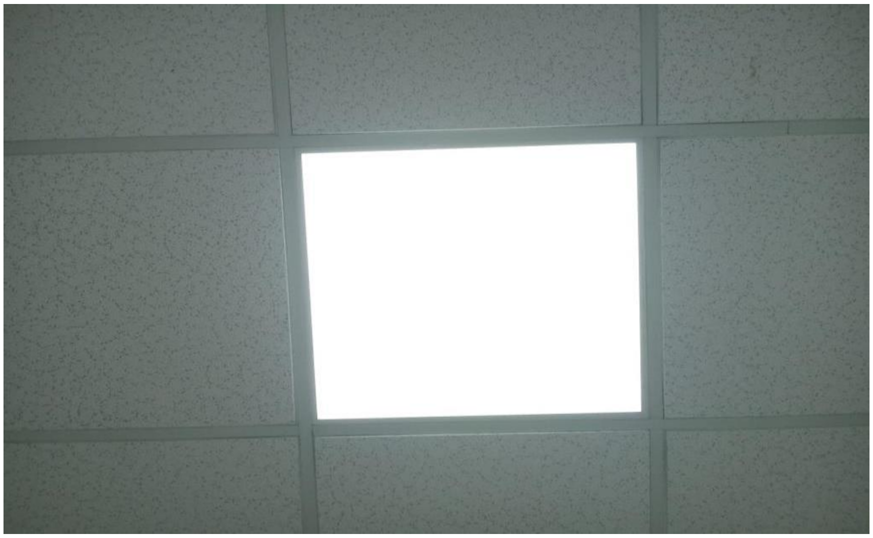

Figure 4.7: Existing Ceiling LED Lamps

However, some offices and areas in the facility still have FTLs (shown in Figure 4.6) that were enumerated as shown in Table 4.3

Table 4.3: Fluorescent Tubes Lighting Fixtures Installed in SEK Manufacturing Plant

SR. NO.	Lamp Location	Lamp Type	Qty	Fixture Rating (W)	Power Rating (W)
1	Marketing Office	4 x14W Fluorescent	18	56	1,008
2	ITD Office	4 x14W Fluorescent	6	56	336
3	IT Office	4 x14W Fluorescent	6	56	336
4	Sales Office	4 x14W Fluorescent	11	56	616
5	PA Office	4 x14W Fluorescent	4	56	224
6	Finance Office	4 x14W Fluorescent	5	56	280
7	Meeting room next to PA	4 x14W Fluorescent	5	56	280
8	Corridors	4 x14W Fluorescent	10	56	560
Total					**3, 304**

To determine the equivalent LED to be used to replace the FTL, Table 4.4 was used.

Table 4.4: Fluorescent Tubes Lighting Fixtures LED Equivalent

Fluorescent Tube Light Wattage	LED Equivalent Wattage
70 Watt	24 Watt
58 Watt	22 Watt
35 Watt	18 Watt
20 Watt	9 Watt

Table 4.4 shows that to replace the 56W FTL, a 22W LED will be required. This shows that LEDs are more efficient in terms of energy consumption. Other advantages of LEDs over FTLs include dimmability, long life, variability, unlimited switching, high luminous efficiency, negligible heat transfer and flexible design. Based on these values, the energy savings realized was calculated and the results were as shown in Table 4.5.

Table 4.5: Energy Savings by Replacing FTL with LED Computation Sheet

SR. NO.	Lamp Location	Qty	FTL Fixture Rating (W)	Equivalent LED Rating (W)	Annual kWh consumption using FTL	Annual kWh consumption using LED	Annual Energy Savings (kWh)
1	Marketing Office	18	56	22	3,144.96	1,235.52	1,909.44
2	ITD Office	6	56	22	1,048.32	411.84	636.48
3	IT Office	6	56	22	1,048.32	411.84	636.48
4	Sales Office	11	56	22	1,921.92	755.04	1,166.88
5	PA Office	4	56	22	698.88	274.56	424.32
6	Finance Office	5	56	22	873.60	343.20	530.40
7	Meeting room 1	5	56	22	873.60	343.20	530.40
8	Corridors	10	56	22	1,747.20	686.40	1,060.80
Total							**6,895.20**

The energy savings was calculated based on 12hrs of lighting of each lamp for 5 days every week, with a total of 52 weeks in a year.

4.3.4 Energy Saving through Solar PV Generation.

Schneider Electric Manufacturing plant solely depends on Electricity from the national grid to meet its energy requirement, apart from the backup generators that are engaged during an outage. The facility can consider supplementing its energy needs by generating some of the energy at site using Solar PV. An analysis of the solar radiation potential of Nairobi city was carried out to establish how much energy can be harnessed from Solar PV plant. Figure 4.8 shows historical data of monthly sunshine hours of Nairobi city in 2019.

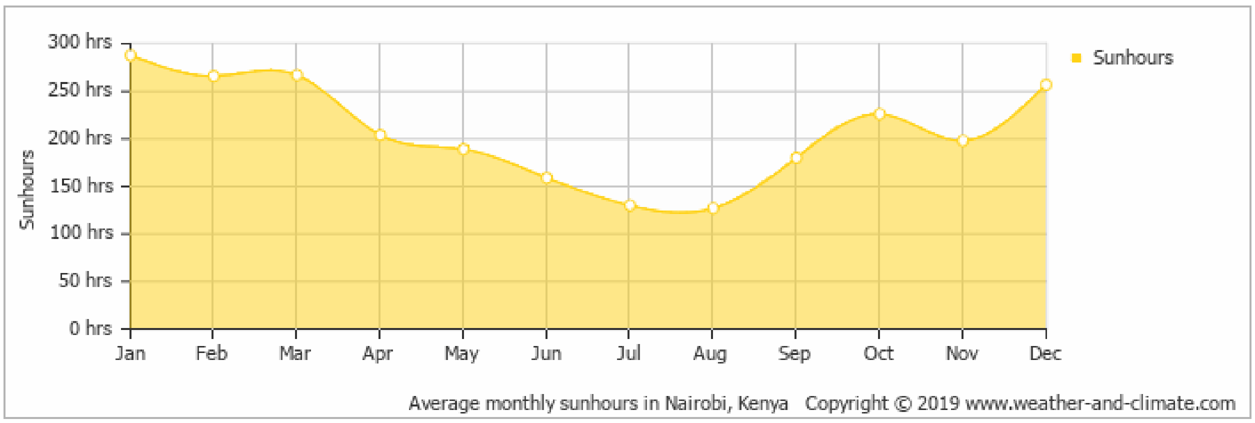

Figure 4.8: Nairobi City Monthly Sunshine hours in 2019

Figure 4.8 shows that:

i) January has on average the highest Sunshine hours
ii) August has on average the lowest Sunshine hours
iii) The average annual number of sunshine hours is 2,495 hrs.

The sunshine hours graph shows that Nairobi has relatively good number of sunshine hours that can support Solar PV Generation.

Based on the energy consumption graph in Figure 4.2, A based load graph was drawn as shown in Figure 4.9.

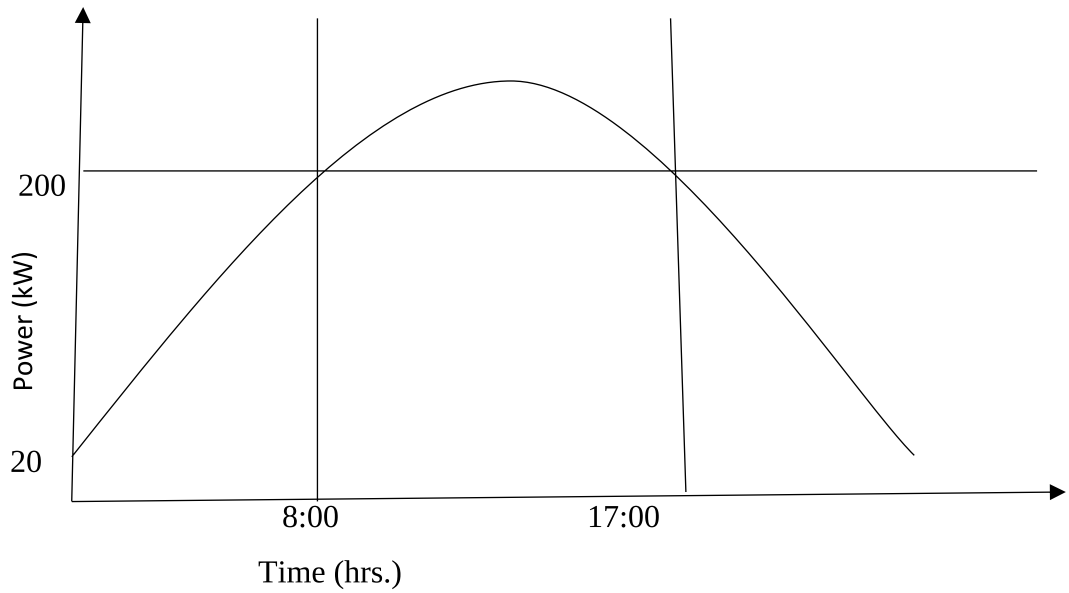

Figure 4.9: Schneider Electric Base Load Graph

The proposal is to design a solar PV grid tie system to support the lowest load at any given time, which is 20kW, to avoid injecting excess power into the grid. The 20kW generated from the PV system will not only supplement the electricity demand from the grid but will also clip the peak demand at the start of manufacturing activities, hence a lower demand curve. These two aspects will directly impact the plant's electricity costs.

With the PV plant capacity of 20kW, space factor of 0.85 and panel efficiency of 15% and plant efficiency of 80%, the shade free area on the roof top required for mounting of the solar Panels was calculated as shown in equation 4.3. [27]

$$Capacity\ of\ a\ PV\ Plant\ (kW) = \frac{\text{Space factor x shade free area (m}^2\text{)}}{\text{Panel Efficiency}} \qquad (4.3)$$

$$20 = \frac{0.85 \text{ x shade free area}}{15}$$

Shade free area required = 352.94 m²

The space available at the roof top of schneider electric manufacturing plant is sufficient to support the solar panels as shown in Figure 4.10

Figure 4.10: Schneider Electric Premises

The Energy output of the Solar PV Plant will be as presented in equation 4.4

$$Daily\ Energy\ Output\ (kWh) = \text{Plant capacity x plant efficicency x avg dailty sun hr} \ldots (4.4)$$

Average daily sun hours calculated from Figure 4.8 is = 2345/365 = 6.4 hour

$$Daily\ Energy\ Output\ (kWh) = 20 \text{ x } 0.85 \text{ x } 6.4$$

$$Daily\ Energy\ Output\ (kWh) = \mathbf{108\ kWh}$$

The annal energy generated from the Solar PV Plant = 108kWh x 365 days

= **39,420kWh**

4.3.5 Replacing existing motors with energy efficient motors

During the Energy Audit, information was collected about the existing standard efficient Motors and the typical results populated in Table 4.6. The proposal is to replace the motors with the equivalent motors with 87.5% efficiency, 89% efficiency and 90.5% efficiency for motors 1, 2 and 3 respectively. The energy savings because of this replacement based on 75% load factor, for each of the motors, is calculated using equation 4.5.

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$……………………………………………………(4.5)

Motor 1

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$

$= 15 \times 0.75 \times 0.746 \times (\frac{100}{0.86} - \frac{100}{0.875})$

= 16.73kW

Motor 2

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$

$= 30 \times 0.75 \times 0.746 \times (\frac{100}{0.875} - \frac{100}{0.89})$

= 32.33kW

Motor 3

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$

$= 50 \times 0.75 \times 0.746 \times (\frac{100}{0.885} - \frac{100}{0.905})$

= 69.86kW

Total kW saved = 16.73 + 32.33 + 69.86 = **118.92kW**

$kWh_{savings} = kW_{saved} \times$ Annual Operating hours

= (16.73*6*3*52) + (32.33*6*3*52) + (69.86*6*3*52)

= **111,309.12kWh**

When selecting motors for replacement, apart from the efficiency, the following major factors should be considered.

i) **The method of coupling-** The motor should be easily coupled to machine that. There should be no modification on the equipment to accommodate the motor as this could affect its performance. For these motors, they form part of Pre-treatment line and the ease with which they will fit in the system is a big consideration.

ii) **The Physical Size of the Motor-** Since these motors are part of a system, they should be able to fit within the available space within the line.

iii) **The Power Rating of the Motor-** This is the Power output of the motor to the machine and should not be altered if the machine design requirements are not changing.

Table 4.6: Existing Standard Efficiency Motors Datasheet

Sr. No	**Description**	**UOM**			
1	No of the Motor		**1**	**2**	**3**
2	Year of manufacture/purchase/Installation		1995	1995	1995
3	Frequency (Hz)		50	50	50
4	Mechanical Nominal Power	kW	11	22	37
5	Horsepower Rating		15	30	50
5	Method of starting		DOL	VSD	VSD
6	No of Poles				
7	Synchronous Speed	rpm	970	970	980
8	Full-load Efficiency	%	86	87.5	88.5
9	Full load Amperage	A	24.2	44.7	71
10	Full load Power Factor		0.81	0.83	0.86
11	Operating Hours/Day	Hrs.	6	6	6
12	Operating Hours/annum	Hrs.	936	936	936
13	Power Consumption/day	kWh	66	132	222
14	Power Consumption/annum	kWh	10,296	20,592	34,632
15	Unit Rate of Power	Kes	12	12	12
16	Total Expenditure per annum	Kes	**123,552**	**247,104**	**415,584**

4.3.6 Paint line Operational Proposed Best Practices

The results of the energy audit revealed that the main power consumers in the Manufacturing Plant Paint line are:

i) The Pre-treatment line, with two heating zones (1&2). Each of these zones must attain 60°c before starting operation. The heating elements are each rated at 130kW.

ii) Two Ovens, one used for water drying the equipment and the other for curing. The water drying ovens must attain 140°c and the curing one must attain 200°c before use. The two ovens are each rated at 150kW and 180kW.

Currently, the practice is to switch on the heating zones and the ovens simultaneously. Since this section has a big number of motor loads and heating coils, the high spike witnessed during the start of manufacturing activities could be attributed to the large inrush current drawn by the motors during start up. To clip this peak, the proposal is to delay the startup of heating zone 2, one hour after heating zone 1 and oven 2, 30 minutes after oven 1.

When Heating zones 1 and 2 are switched on at the same time, they draw a large amount of current calculated as calculated in equation 4.6.

$P = \sqrt{3} VI\ Cos\ \theta$ ………………………………………………………………………………….. (4.6)

$$260kW = \sqrt{3}\ x\ I\ x\ 240V x\ 0.98$$

$$I = \mathbf{638.23\ A}$$

When one of the heating zones is started like an hour before the other, the energy drawn during the switching on is half i.e. **319.115A**

The relationship between active energy and apparent is as shown in Figure 4.11.

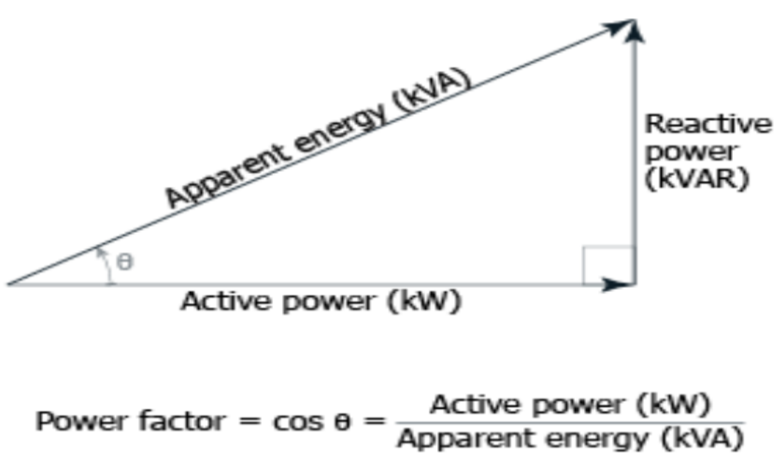

Figure 4.11: Power Triangle

The apparent Power when both heating zones are switched on at the same time was calculated by equation 4.7.

$$\text{Apparent Power} = \frac{\text{Active Energy}}{\text{Cos } \theta} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.7)$$

$$= \frac{260}{0.98} = \mathbf{265.30\ KVA}$$

When one heating zone is turned on before the other, the apparent power will be:

$$= \frac{130}{0.98} = \mathbf{132.65\ KVA}$$

The Saving in apparent power with this operational change is **132.65KVA.**

Similarly, if the ovens are scheduled to start at different times as compared to both starting at the same time, the KVA Saving will be:

$$\text{Apparent Power Saving} = \left(\frac{330}{0.98}\right) - \left(\frac{150}{0.98}\right)$$

= 336.73 – 153.06 = **183.70 KVA**

Taking the average of Apparent Power saving for the two adjustments i.e. 158 KVA, a cost benefit analysis is then performed to establish the viability of this investment.

4.4 TECHNO-ECONOMIC EVALUATION OF ENERGY CONSERVATION OPPORTUNITIES

4.4.1 Tariff Migration

Schneider Electric manufacturing facility is currently metered at 415V, CI1 Tariff. The proposal is to migrate to CI2 tariff, with lower energy and demand charges. An analysis was carried to compare the annual energy costs associated with CI1 and CI2 Tariffs and are represented in Tables 4.8 and 4.9. From this, the Annual Energy savings associated with the shift from CI1 Tariff to CI2 Tariff is as shown below.

Annual Energy Cost Savings = Kshs. 11,939,896.00 – Kshs. 9,423,528.40

= Kshs. 2,516,367.60

Migration from CI1 Tariff to CI2 Tariff requires modification of the electrical network equipment to accommodate the new installation. This will include the purchase of a new transformer and 11kV metering panel. There is also a facilitation and commissioning fee that will be paid to Kenya Power. This capital Investment cost associated with the shift from CI1 Tariff to CI2 Tariff represented in Table 4.7.

Table 4.7: Tariff Migration Electrical network equipment modification Cost

Item No	Description	Qty	Unit Rate	Total Cost
1	1000KVA Transformer 11/0.415kV	1	1,750,000	1,750,000
2	11kV Metering Panel	1	2,340,000	2,340,000
3	Installation	1	1,000,000	1,000,000
4	Facilitation Fee paid to Kenya Power	1	1,200,000	1,200,000
	Total			**6,290,000**

Table 4.8: Total Annual Energy cost based on CI1 Tariff

Month	Total Consumption (kWh)	Energy Charge	Max Demand (KVA)	Demand Charge	Electricity Cost (Kshs)
Jan-20	39,564	12	567	800	928,368.00
Feb-20	45,394	12	583	800	1,011,128.00
Mar-20	45,973	12	568	800	1,006,076.00
Apr-20	41,304	12	567	800	949,248.00
May-20	36,671	12	536	800	868,852.00
June-20	45,879	12	577	800	1,012,148.00
July-20	47,507	12	579	800	1,033,284.00
Aug-20	54,900	12	607	800	1,144,400.00
Sep-20	53,638	12	607	800	1,129,256.00
Oct-20	35,197	12	572	800	879,964.00
Nov-20	41,827	12	574	800	961,124.00
Dec-20	48,404	12	544	800	1,016,048.00
Total					**11,939,896.00**

Table 4.9: Total Annual Energy cost based on CI2 Tariff

Month	Total Consumption (kWh)	Energy Charge	Max Demand (KVA)	Demand Charge	Electricity Cost (Kshs)
Jan-20	39,564	10.90	567	520	726,087.60
Feb-20	45,394	10.90	583	520	797,954.60
Mar-20	45,973	10.90	568	520	796,465.70
Apr-20	41,304	10.90	567	520	745,053.60
May-20	36,671	10.90	536	520	678,433.90
June-20	45,879	10.90	577	520	800,317.30
July-20	47,507	10.90	579	520	818,906.30
Aug-20	54,900	10.90	607	520	914,050.00
Sep-20	53,638	10.90	607	520	900,294.20
Oct-20	35,197	10.90	572	520	681,087.30
Nov-20	41,827	10.90	574	520	754,394.30
Dec-20	48,404	10.90	544	520	810,483.60
Total					**9,423,528.40**

The Payback period of this Investment is thus calculated as:

$$\text{Payback Period} = \frac{\text{Capital Cost of Instalation}}{\text{Annual Savings}} \qquad (4.8)$$

= 6,290,000/2,516,367.60

= 2.499yrs

The Payback period of the Investment will be **2 years** and **6 months.**

4.4.2 Time of Use Tariff

Since the paint line of the manufacturing facility consumes nearly half of the total energy, the proposal is to have it operate during weekends, on Saturday between 14:00hrs to 22:00hrs and on Sundays between 10:00hrs to 18:00hrs.

However, there will be a cost associated with this shift, since this will mean a few employees working over the weekend, which is not within the normal operation hours of the company.

The extra cost incurred in terms of compensation of the manpower working during the weekends, according to the analysis done by the manufacturing supervisor will be Kshs. 20,000 per month. From Table 3.2, the average monthly consumption of the paint line is 19,968 kWh. The savings realized per month by running it during the off-peak hours (taking into consideration that the facility's consumption is above the monthly threshold consumption is 40,003kWhwith High-rate consumption threshold of 30,477kWh and low rate consumption threshold of 9526kWh) will be:

Energy cost savings per month = (19,968-9,526) *6 = **Kshs. 62,652**

Monthly Expense = Kshs. 20,000

Overall monthly income = 62,652 – 20,000

=**Kshs. 42,652**

Overall Net income/ annum = Kshs. 511,824

Since the net income per month for the project is positive, the project is viable. The project would also make more savings with higher production volumes, which would necessitate longer working hours during off-peak period and hence more units of energy consumed to spread the costs incurred to realize a more positive cash flow.

4.4.3 Energy Saving by Replacing FTL with LEDs

The annual energy savings made by replacing Fluorescent Tube Lamps with LEDs is 6,895.20kWh as shown on Table 4.5.

Annual energy cost saving = 6,895.20 x 12

= Kshs. 82,742.40

Cost of 22W LED is = Kshs. 2,750

Total cost of investment = 2,750 *65

=Kshs. 178,750

$$\text{Payback Period} = \frac{\text{Capital Cost of Instalation}}{\text{Annual Savings}} \qquad (4.9)$$

= 178,750/82,742.40

= **2.1yrs**

4.4.4 Energy Saving through Solar PV Generation.

4.4.4.1 Design of a grid tie Solar PV system [27]

The architecture of the solar system will be as represented in Figure

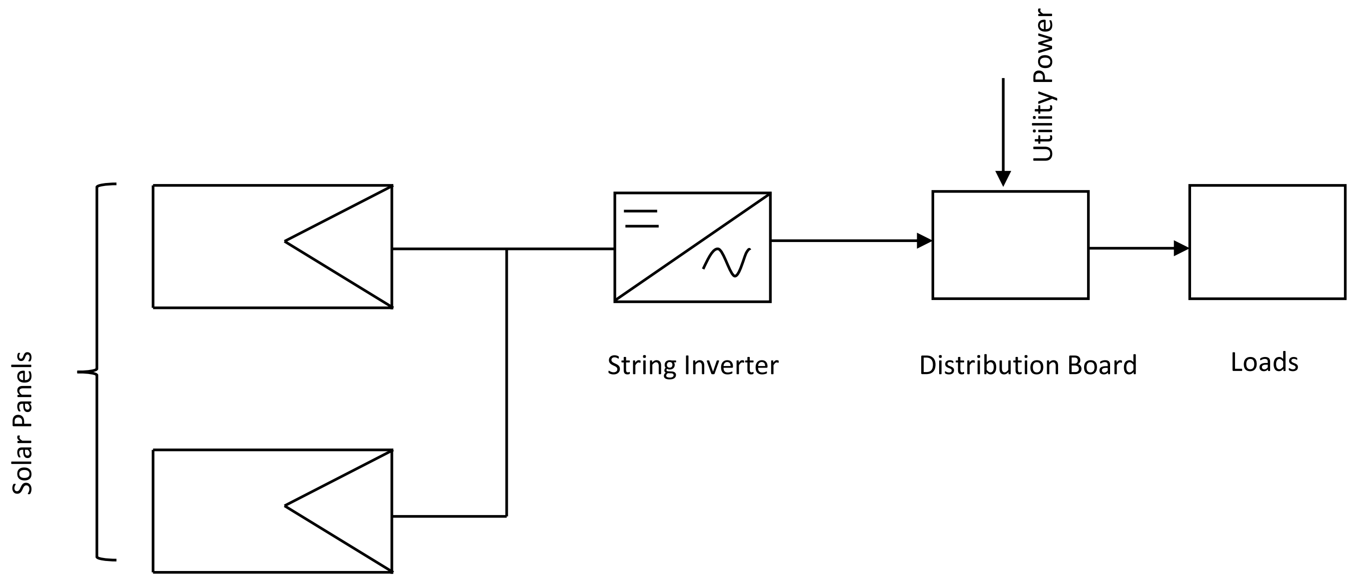

Figure 4.12: Grid Tie Solar PV Plant Architecture

Selecting a 320wp solar panels for this application, the number of solar panels was calculated using Equation 4.10.

$$No. of\ solar\ panels = \frac{\text{Plant capacity (kW)}}{\text{Rated Power of selected panels kW)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.10)$$

$$No. of\ solar\ panels = \frac{20\text{kW}}{0.32\text{kW}}$$

=63 Panels

The optimal combination of the PV array is 4 strings of PV Panels each having 16 panels. So, the actual number of solar panels required is **64**.

Selecting a 36kW inverter, with 98.5% efficiency, the number of inverters required will be:

$$No.of\ Inverters = \frac{\text{Plant capacity (kW)}}{\text{Rated AC Output of the selected Inverter (kW)}x\ inverter\ efficiency} \ldots\ldots\ldots\ldots(4.11)$$

$$No.of\ Inverters = \frac{\text{20kW}}{\text{36kW x 0.985}}$$

$$=1\ \text{Inverter}$$

The physical size of the D.C cable from the solar panels to the inverter is given by:

$S = 0.3$ Lx Im$/\Delta$V……………………………………………………………...… (4.12)

Where S – Required wire size

L – Length of wire

Im – Maximum current in Amperes

ΔV – Maximum allowable voltage drop

The approximate length of the DC Cable required (from the roof top) to the Inverter location in the building is 5metres

Maximum design current, Im = S.C Current of PV Panel x No. of strings x safety factor…. (4.13)

= 8.96 x 4 x1.25 = 44.8A

S= (0.3 x 5 x 44.8)/0.5

S= 134.40mmsq

Diameter of the cable, D = √4S/π…………………………………………………... (4.14)

=√ (4 x 134.40/π)

= 13.08mm

The size of the DC Cable to be selected is **134.40 mm sq**, with a diameter of **13.08mm.**

The size of AC Cables, from the inverter to the loads was calculated by using equations 4.15, 4.16 and 4.17

Inverter Input (kW) = Rated power of selected PV Panels x number of PV Panels………… (4.15)

= 320 x 64

$= 20.17kW$

Inverter Output Power (kW) = Inverter input x Inverter efficiency………………………… (4.16)

$= 20.17 \times 0.985 = 19.86kW$

Inverter Input Power = $\sqrt{3}\, VI\, Cos\, \theta$………………………………………………………… (4.17)

$20.17 \times 10^3 = \sqrt{3}\ x\ 240x\ I\ x\ 0.8$

$I = 60.65A.$

Based on Electrical Engineering centre cable sizing chart, for this application, we will need 6mmsq 4 core cable, with a voltage drop of 7.9mV/A/m.

4.4.4.2 Cost Benefit analysis of a grid tie Solar PV system

The total cost of all the components needed for the grid tie solar PV solar system is summarized in Table 4.10.

Table 4.10: Grid Tie Solar PV Plant Implementation Costs

Item No	**Description**	**Qty**	**Unit Rate (Kshs)**	**Total Amount (Kshs)**
1	Schneider electric Conext CL36kW string Inverter	1	288,600	288,600
2	Luminous 320W/24V (72 Cells) Solar Panels	64	13,000	832,000
3	Schneider electric NSX MCCB C60N 4P 63A Breaker	1	6,500	6,500
4	Schneider electric Acti 9 3P+N RCD 300mA	1	5,850	5,850
5	Schneider electric Acti 9 IC60N MCB 1P 32A D CURVE	4	300	1200
6	35mmsq 4 core DC Cable	5	2500	12,500
7	6mmsq 4 core AC Cable	30	600	18,000
8	Installation	2	130,000	260,000
9	Miscellaneous	1	50,000	50,000
	Total			**1,474,650**

The energy generated from the Solar PV Plant is 39,420kWh per year. This will result in the following cost savings:

Energy Cost Saving/annum = (39,420 x 12) +(20 x 800 x12)

=Kshs. 665,040

$$\text{Payback Period} = \frac{\text{Capital Cost of Instalation}}{\text{Annual Savings}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.18)$$

$$\text{Payback Period} = \frac{1474650}{665040} = 2.2 \text{ years}$$

For this Investment, the Payback period is not enough to establish the viability since it does not consider the time value of money. As such, the Net Present Value of the project was calculated.

Assuming the capital cost of the investment will be financed by a local bank, at an interest rate of 7% (According to world bank March 2021), a monthly maintenance cost of Kshs. 10,000 (considering 5% inflation after every 5 years) an inverter replacement after every 10 years), a summary of the project’s cash inflows and outflows was evaluated as represented in Table 4.11 and consequently the Project’s NPV for a lifetime of 25 years was determined as shown in equation 4.19.

The net present value for a discount rate 7% was thus calculated as:

$$NPV = CF_0 + \frac{CF_1}{(1+rd)} + \frac{CF_2}{(1+rd)^2} + \text{---} + \frac{CF_n}{(1+rd)^n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (4.19)$$

$$= \frac{-930}{(1+0.07)} + \frac{545}{(1+0.07)^2} + \frac{545}{(1+0.07)^3} + \frac{545}{(1+0.07)^4} + \frac{545}{(1+0.07)^5} + \frac{539}{(1+0.07)^6} + \frac{539}{(1+0.07)^7} + \frac{539}{(1+0.07)^8} + \frac{539}{(1+0.07)^9} + \frac{545}{(1+0.07)^{10}} + \frac{244.10}{(1+0.07)^{11}} + \frac{532.70}{(1+0.07)^{12}} + \frac{532.70}{(1+0.07)^{13}} + \frac{532.70}{(1+0.07)^{14}} + \frac{532.70}{(1+0.07)^{15}} + \frac{526}{(1+0.07)^{16}} + \frac{526}{(1+0.07)^{17}} + \frac{526}{(1+0.07)^{18}} + \frac{526}{(1+0.07)^{19}} + \frac{526}{(1+0.07)^{20}} + \frac{230.45}{(1+0.07)^{21}} + \frac{519.05}{(1+0.07)^{22}} + \frac{519.05}{(1+0.07)^{23}} + \frac{519.05}{(1+0.07)^{24}} + \frac{519.05}{(1+0.07)^{25}}$$

= -869.16+ 476.02 + 444.88 + 415.78 + 388.58 + 359.16 + 335.66 + 313.70 + 293.18 + 277.05 + 115.97 + 236.53 + 221.05 + 206.59 + 193.07 +178.17 + 166.52 +155.62 + 145.44 +135.93 + 55.66 + 117.16 + 109.50+102.33+ 95.63 = **4,470.02**

NPV= **4,470**

The NPV of the project is a positive value. This shows that the project is viable hence should be considered by the management of schneider electric a one of their energy costs saving initiatives.

Table 4.11: NPV Computation of Grid tie Solar PV Plant

Year	Investment (KES x1000)	Savings (KES x1000)	Expenses (KES x1000)	Cash Flow (CFi) (KES x1000)
1	-1,475	665.00	120.00	-930.00
2	0	665.00	120.00	545.00
3	0	665.00	120.00	545.00
4	0	665.00	120.00	545.00
5	0	665.00	120.00	545.00
6	0	665.00	126.00	539.00
7	0	665.00	126.00	539.00
8	0	665.00	126.00	539.00
9	0	665.00	126.00	539.00
10	0	665.00	126.00	539.00
11	0	665.00	420.90	244.10
12	0	665.00	132.30	532.70
13	0	665.00	132.30	532.70
14	0	665.00	132.30	532.70
15	0	665.00	132.30	532.70
16	0	665.00	139.00	526.00
17	0	665.00	139.00	526.00
18	0	665.00	139.00	526.00
19	0	665.00	139.00	526.00
20	0	665.00	139.00	526.00
21	0	665.00	434.55	230.45
22	0	665.00	145.95	519.05
23	0	665.00	145.95	519.05
24	0	665.00	145.95	519.05
25	0	665.00	145.95	519.05

4.4.5 Replacement of Existing Motors with Energy Efficient Motors

Taking into consideration the energy savings when standard efficiency motors are replaced by highly efficient one, as calculated in article 4.3.5, the total monetary energy savings will be given by:

Total Energy Savings= (kW_{saved} x 12 x monthly demand charge) + ($kWh_{savings}$ x energy charge)

= ((118.92/0.98) *12*800) + (111,309.12 *12)

= **Kshs. 2,500,640.05**

The capital cost of replacing the motors is tabulated in Table 4.12

Table 4.12: Energy Efficient Motor Capital Investment Computation

Motor No.	Description	Unit capital cost	Installation cost	Total Cost
1	11kW 3-phase induction Motor with 87.5% efficiency	56,500	20,000	76,500
2	22kW 3-phase induction Motor with 87.5% efficiency	85,500	20,000	105,500
3	37kW 3-phase induction Motor with 90.5% efficiency	125,000	20,000	145,000
	Total			**327,000**

$$\text{Payback Period} = \frac{\text{Capital Cost of Instalation}}{\text{Annual Savings}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.20)$$

$$= 327{,}000/2{,}500{,}640.05$$

$$= 0.13 \text{ x}24$$

$$= 3.12$$

The Payback Period for the project is **3 months.** The project is extremely attractive given that the payback period is less than 6 months.

4.4.6 Paint line operational Best Practices

The energy demand from the grid is shown to reduce by 158KVA by implementing some changes in the operation sequence of the paint line as demonstrated in 4.3.6.

Demand Charge saving/month= 158 x 800

=Kshs. 126,400

To effective this operational change, one operating personnel must report to work one hour earlier to schedule the starting of the heating zones and oven so as not to interfere with the start of manufacturing activities. This will necessitate an overtime compensation of Kshs. 20,000 in a month.

The net monthly energy saving = 126,400-20,000

= Kshs. 106,400

From this, the plant will save **Kshs. 106, 400 per month**, which translates to Kshs**. 1,276,800 per annum**. This is a viable Energy Conservation Opportunity, given that there is no initial capital investment nor modification of any equipment in the electrical distribution network. This, when undertaken will be a quick win for the plant.

4.4.7 Summary of Results and Analysis

Table 4.13: Results and Analysis Summary

Identified Energy Conservation Opportunities	Energy saving/annum	Capital Investment (Kshs)	Expenses /annum	Energy Cost Saving (Kshs)/annum	Net Energy saving	PBP (yrs.)	NPV
Tariff Migration		6,290,000		2,516,367		2.5	
Time of use Tariff			240,000	751,824	511,824		
Replacement of FTL with LEDs	6,895 kWh	178,750		82,742.40		2.1	
Solar PV Generation	39,420 kWh	1,474,650	120,000	665,040		2.2	4,470
Replacement of existing motors with energy efficient Motors	111,309 kWh	327,000		2,500,640		0.13	
Paint line operational best Practices	158KVA		240,000	1,516,800	1,276,800		

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The project report has addressed the three main Objectives defined. An energy audit was carried out to obtain the results indicated herein. ECOs were Identified and economic evaluation for each of them undertaken. Through this, the project has demonstrated that there exists an unexploited energy saving potential in manufacturing Industry.

Schneider Electric Manufacturing plant has previously carried out energy audits, but the recommendations have mostly not been put into action due to insufficient demonstration of cost benefit analysis to convince management to invest in the recommended ECOs. This project has evaluated the potential energy savings associated with tariff migration, adjusting the time of use of energy to benefit from off peak period rates, replacement of FTL s with LEDs, introduction of Solar PV generation to supplement power from grid and also improving system efficiency by replacing some of the motors with energy efficient motors. The results obtained have further indicated that replacement of motors have a payback period of 3 months, making this the most viable project amongst the five possible considerations. The use of solar PV to supplement energy needs of the plant on the other hand gives a positive Net Present Value hence making it also a viable project, although the with a high initial capital investment.

5.2 Recommendations

i) Manufacturing Industries should be encouraged to establish Energy Management departments, headed by an Energy Manager to constantly monitor their energy situation, define energy policies, carry out regular Energy audits, represent the organization in energy associations and regularly prepare and submit reports on energy management to the organization and other Government bodies whenever needed. This will make Energy management in industries a continuous Improvement process and not a one-time event as has been the norm.

ii) The utility company in Kenya should enlighten its consumers, especially Commercial and Industrial consumers on the need for energy efficiency. This will not only reduce energy costs but also ease the pressure on generation facilities and increase reliability of distribution systems.

iii) Employees in Manufacturing industries should be educated about tariff structures and motivated to reduce electricity use during peak hours. Industries should have an electricity-saving programmed shifts that helps to schedule some activities to off-peak hours.

iv) Finally, there's need for long term commitment by the Government of Kenya, through policies, to promote energy efficiency in Manufacturing Industries.

REFERENCES

[1] R. M. Nachiappan, N. Muthukumar, (2016). Continuous Improvement in Energy efficiency, A case study at Automotive components manufacturing processes.

[2] Energy Live News by US Energy Information Administration (EIA) https://www.energylivenews.com/2020/01/08/global-energy-use-projected-to-nearly-double-by-2050/

[3] Geoffrey A. Mabea, Rafael E. Macatangay, John Mutua. (2018, Jan 01). 60 Years Electricity Reform Progress in Kenya.

[4] Ministry of Energy. Feed-in-Tariffs policy for wind, biomass, small hydros, geothermal, biogas and solar,1st revision, Jan 2010.

[5] Catrina Godinho, Anton Eberhard, (April 2019). Learning from power sector reform, The case of Kenya.

[6] Approved Tariffs Aug-2018.pdf by ERPA https://www.epra.go.ke/wp-content/uploads/2018/06/Approved-Tariffs-Aug-2018.pdf.

[7] Gopi Srinath, N. Uday Kumar. (2014, June). "Energy Audit as a Tool for Improving System Efficiency in Industrial Sector". Journal of Engineering Research and Applications. Vol. 4, Issue 6 (Version 6), pp.06-11

[8] Olatunde Ajani Oyelaran1, Yau Yusuf Twada, Olawale Monsur Sanus. "Energy Audit of an Industry: A case study of a fabrication company". Aceh International Journal of Science and Technology. ISSN: 2088-9860. Available: http://jurnal.unsyiah.ac.id/aijst

[9] Mitrovic, B. and Muller, M.R. Energy impacts of productivity improvements in manufacturing**.** Proceedings of the Twenty-fourth National Industrial Energy Technology Conference, Houston, TX, April 16-19, 2002.

[10] Davidson, O. 2006. Energy for sustainable development: an introduction. In: Winkler, H (Ed.), Energy Policies for Sustainable Development in South Africa, Option for the Future. Energy Research Centre, Cape Town, South Africa.

[11] Morvay, Z.K. and Gvozdenac, D.D. 2008. Applied industrial energy and environmental management. John Wiley and Sons Ltd, United Kingdom.

[12] Miriam Benedetti, Vittorio Cesarotti, Vito Introna (2015). Improving Energy Efficiency in Manufacturing Systems.

[13] Cesarotti V, Di Silvio B, Introna V (2007). Evaluation of electricity rates through characterization and forecasting of energy consumption.

[14] Samadi M, Javidi MH, Ghazizadeh MS (2013). The effect of Time-Based Demand Response.

[15] Gajendra Singh, N K. Sharma, P Tiwari, Pankaj Mishra (2012, June). “Energy Efficient Industrial Motors”. International Journal of Engineering, Science and Technology Vol. 2(12), 2010, 7904-7913

[16] Gilbert A. McCoy, Todd Litman, John Douglass, Washington State Energy Office Olympia Washington (1990). Energy Efficient Electric Motor Selection Handbook.

[17] NEMA, (1997): Scope of electric motors subject to efficiency standards: Energy Policy Act-1992.

[18] J. M. Avella*, T. Souza, J. L. Silveira, Laboratory of Optimization of Energy Systems (LOSE), Department of Energy, College of Engineering of Guaratingueta, Institute of Bioenergy Research (IPBEN), São Paulo State University (UNESP) (2016). A Comparative Analysis between Fluorescent and LED Illumination for Improve Energy Efficiency at IPBEN Building.

[19] W.R. Ryckaert, K.A.G. Smet, I.A.A. Roelandts, M. Van Gils, P. Hanselaer (2012). Linear LED tubes versus fluorescent lamps: An evaluation.

[20] Tharanga Wickramarathna (2014). Economic feasibility of Replacing conventional Lighting devices with LEDs in Sri Lanka.

[21] Schneider Electric Plant Archives.

[22] Own Interpretation.

[23] https://www.fluke.com/en/product/electrical-testing/power-quality/1736-1738//.Accessed on 21st March 2021

[24] http://www.extech.com/products/LT300- Accessed on 21st March 2021

[25] https://www.fluke-direct.com/product/fluke-323-true-rms-clamp-meter- Accessed on 21st March 2021

[26] R. Panneerselvam. Engineering-economics.13th Printing January

[27] Md. Fahim Hasan Khan (May 2019). Designing a grid Tie Solar PV System.

LIST OF APPENDICES

Response to Panelists Comments

SR. NO	**Comments**	**Response**	**Page Number**
1	Amend the Recommendations to be more academic than to the specific facility.	• Recommendations amended	62
2	How did you validate your results?	• Smart metering is being done at the facility, meaning that the power bills are valid**.** • Past studies have shown a positive NPV after 25yrs lifecycle of solar PV and so is the study under this project.	36
3	How does the Schneider factory under study compare to other Schneider factories in the rest of the world in terms of energy efficiency?	• The manufacturing plant is almost 30yrs old (formerly known as Power Technics) and as such, most of the technologies and equipment in place are old and some have become obsolete. Since its acquisition in 2015, Schneider electric has embarked on modernization and implementation of energy Conservation measures to make it more energy efficient as other Schneider entities.	2

Permission to Collect and Disseminate Data from Schneider Electric

Life Is On | Schneider Electric

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University of Nairobi.
School of Engineering
Dept of Mechanical and Industrial Engineering

Reference: Project of Maureen Adhiambo Ogendo

Dear Sir/Madam,

I want to confirm by this letter that the project proposed by Maureen Adhiambo is interesting for us and I give my validation to proceed.

The project is: ENERGY CONSERVATION OPPORTUNITIES IN MANUFACTURING INDUSTRY: A CASE STUDY OF SCHENEIDER ELECTRIC KENYA MANUFACTURING PLANT.

The Research Objectives are:

i) Detailed Analysis of the energy situation of the Manufacturing plant through a Level III Energy Audit.
ii) Carry out an Economic Evaluation of three major Energy saving Opportunities identified.
iii) Make Recommendations of the most viable Energy Conservation measures for adoption by the company

With my best regards

Philippe MASSON
Industrial Operations Director

String Inverter Datasheet

Technical Specifications

Conext™ CL36 String Inverter

Device short name	Conext™ CL36 (IEC Standard)
DC Side	
Max. PV input voltage	1100 V
Start up voltage	250 V
Nominal input voltage	585 V
MPPT voltage range	200 - 1000 V
MPPT voltage range for nominal power	500 - 850 V
No. of MPPTs	3
Max. number of PV strings per MPPT	3 / 3 / 2
Max. PV input current	88 (33A/33A/22A)
Max. current for input connector	12 A
Max. DC short circuit current	96A (36A/36A/24A)
DC connectors / DC max. current per input	MC4 / 12 A (mating part included)
DC fuses (included)	8 pairs (+), string monitoring included
DC switch / DC SPD	Yes / Type II surge arrester
Max. Inverter backfeed current to the array	0 A
AC Side	
Nominal AC output power	36 kW
Max. AC output power (PF=1)	36 kW
Max. AC output apparent power	36 kVA
Max. AC output current	53.5 A
Nominal AC voltage	400 Vac (3ph/ N/ PE or 3ph/PE)
AC voltage range	310 - 480 V
Nominal grid frequency	50 Hz / 60 Hz
Grid frequency range	45 - 55 Hz / 55 - 65 Hz
THD	< 3% (Nominal power)
DC current injection	< 0.5 % In
Power Factor	> 0.99 at nominal power, (adj. 0.8 leading -0.8 lagging)
AC connection	4 wire grounded WYE or ungrounded DELTA
Protection	
Protection	Anti-islanding protection, DC reverse connection protection, AC short circuit protection, Leakage current protection, AC Type II
System data	
Max. efficiency	98.5 %
Euro. efficiency	98.3 %
Isolation method	Transformerless
Ingress protection rating	IP65
Night power consumption	< 2 W
Operating ambient temperature range	-25 °C - 60 °C (> 45 °C derating)
Allowable relative humidity range	0 - 100 % (condensing)
Cooling method	Smart forced air cooling
Max. operating altitude	4000 m (> 3000 m derating)
User interface	Graphic LCD and Easy Config tool
Communication	RS485
DC connection type	MC4 (Max. 6 sq mm)
AC connection type	Screw Clamp terminal (Max. 50 sq mm Cu type cable)
Mechanical Specifications	
Part number	PVSCL36E
Dimensions (W x H x D)	525 mm x 740 mm x 240 mm
Mounting method	Vertical mounting through Wall bracket
Weight	48 kg

Solar Panels Datasheet

LUMINOUS

Solar Panel

Two common types of PV Panels are:

Polycrystalline Cell Type

Polycrystalline Cells are effectively a slice cut from a block of silicon, consisting of a large number of crystals. They have a speckled reflective appearance and you can see the thickness of the slice. These cells are less expensive to produce and more suited for Indian conditions.

Monocrystalline Cell Type

Monocrystalline Cells are cut from a single crystal of silicon. In appearance, they will have a smooth texture and you will be able to see the thickness of the slice. These are slightly expensive to produce.

Luminous has both Monocrystalline and Polycrystalline PV modules with performance warranty of up to 25 Yrs. They are certified for compliance to IEC standard

Range available with us are from 10 Watt to 320 Watt catering to wide range of applications from rural to urban projects.

Features	Benefits
Best in class conversion efficiency	Higher cell efficiency means optimum output
Anti reflective coating and back surface field (BSF)	More light absorption
Optically, mechanically and electrically tested	Frame reduces resistance and thus improves cell efficiency
Advance EVA encapsulation	Multi layer encapsulation provides better module protection
Strong light weight Aluminum frame design	Offers high torsion resistance against wind load and snow loads
Compliance to IEC standards	Consumers can have confidence that the product is safe, reliable and of good quality

Technical Specifications of Poly PV Panels (Suitable for 12V System)

Model	Wattage, Wp	Voltage at Max Power, Vmax (V)	Open Circuit Voltage Voc (V)	Current at Max, Power imax (A)	Short Circuit Current isc (A)	Dimensions (mm) LxWxT
12V 10W	10	17.8	21.8	0.57	0.61	340x280x22
12V 20W	20	17.8	21.8	1.13	1.2	535x380x22
12V 37W	37	18.1	21.8	2.05	2.22	435x670x34
12V 40W	40	18.2	22	2.2	2.4	485x670x34
12V 60W	60	18.2	22	3.3	3.55	635x670x34
12V 75W	75	18.2	22	4.13	4.45	785x670x34
12V 80W	80	18.2	22	4.45	4.62	935x670x34
12V 100W	100	18.2	22	5.5	5.92	1035x670x34
12V 125W	125	18.2	22.1	6.98	7.4	1265x670x34
12V 150W	150	18.3	22	8.2	8.9	1480x680x34
12V 200W	200	18.0	22	11.12	12.12	1321x991x34

Technical Specifications of Poly PV Panels (Suitable for 24V System)

Model No.	Wattage Wp	Voltage at Max Power, Vmax	Open Circuit Voltage, Voc	Current at Max Power, Imax	Short Circuit, Isc	Module Efficiency (%)	Number of Cells
LUM-200	200	29.00	36.20	6.89	7.47	14.02	60 (LUM-230 to LUM-260)
LUM-250	250	30.20	37.42	8.31	8.85	15.60	
LUM-24250	250	36.3	43.90	6.88	7.51	14.65	72 (LUM-24285 to LUM-24305)
LUM-24300	300	35.90	44.50	8.36	8.83	15.50	
LUM-24305	305	36.20	44.70	8.43	8.89	15.75	
LUM-24320	320	38.95	46.08	8.22	8.96	-	

Technical Specifications of Mono PV Panels

Model	Wattage, Wp	Voltage at Max Power, Vmax (V)	Open Circuit Voltage Voc (V)	Current at Max, Power imax (A)	Short Circuit Current isc (A)	Dimensions (mm) LxWxT
12V 5W	5	18	22.5	0.29	0.31	320x180x22
12V 20W	20	18	22.5	1.15	1.23	480x340x22
12V 125W	125	18	23.1	6.88	7.1	1265x670x34
12V 150W	150	18	23.2	8.0	8.55	1480x680x34

Data at standard test conditions (STC) Power Tolerance : 0/+5%
STC (1000W/m^2), AM1.5, cell temperature 25 °C. Best in class AAA Solar Simulator (IEC60904-9) used. Power measurement accuracy:±3%

For more than 24V systems, you may connect multiple panels in series to achieve desired system voltage.

Solar

IEEE PAC Conference Paper

2021 IEEE PES/IAS PowerAfrica

Energy Conservation Opportunities in Manufacturing industry - A Case Study of Schnedier Electric Manufacturing plant in Nairobi

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***Abstract*— One of the main pillars of the modern industry is the uninterrupted supply of energy at an affordable cost. In Kenya, the installed generation capacity is made up of 29.4% hydro, 29.8% geothermal, 26.1% thermal, 11.9% wind, 0.9 biomass and 1.8% solar [According to Power Africa study done in August 2019]. Electricity bills have a fuel cost, which is mainly a component of fossil fuels. The fossil fuels are getting more expensive progressively, which in turn increases the cost of energy and subsequently the cost of production of goods. This paper represents the potential Energy Conservation Opportunities in Schneider electric manufacturing plant in Nairobi, the techno-economic evaluation of the ECOs and recommendations of the most viable ECOs based on their economic feasibility.**

Keywords*— *Energy Management, Sustainability, Energy Audit, Energy efficiency, Energy Conservation Opportunities.

I. INTRODUCTION

Energy is extensively used in the industrial sector in different forms and to drive various processes. The industrial sector uses electricity for operating motors and machinery, lights, computers, and office equipment, and for facility heating, cooling, and ventilation.

In the last decade, energy management and sustainability has gained popularity due to; increase in fuel prices, depletion of fossil fuels, global warming, economic crisis, and strict international environmental and energy policies. These factors have forced companies to reduce their energy consumption by cutting down on wastages and adopting efficient use of energy practices [1]. As such, Manufacturing industry have also not been left behind, given that it accounts for 90% of industry energy consumptions, which translates to 51% global energy use [2].Various energy conservation measures have been adopted by industries to cut on their consumption such as the use of energy efficient motors, soft starters for motor starting, variable speed drives, use of LED Lighting, onsite generation to reduce losses, implementation of energy management programs etc. These initiatives have greatly improved the energy situation in the industrial sector. However, a significant share of the potential to improve energy efficiency – more than half located in industry remains untapped.

II. ENERGY SAVING CONSIDERATIONS IN MANUFACTURING INDUSTRY

From the Physical Economic Index, an energy auditor can develop a conceptual framework to identify and classify energy conservation measures in manufacturing plants. Thus, the two main variants in the physical economic index, i.e. specific energy consumption and specific cost of energy can be influenced by measures performed with regards to the following factors [3]:

i) Contractual Purchasing Conditions
ii) Onsite Energy Generation
iii) Choice of Supplier and Tariff
iv) Transformation of Energy

Contractual Purchasing Conditions

This includes all actions towards attaining compliance claims and provisions of the chosen energy purchasing contracts to avoid fines and surcharges. In most large industrial firms, the capability to comply to contractual purchasing conditions heavily depends on the commitment of the organization, culture and attitude to energy saving programs put in place.

Onsite Energy Generation

This is the production of the energy needed for industrial processes on site to avoid or reduce the quantity of energy purchased. Apart from reduced energy costs, generation at site can lead to improved quality and security of energy supplied, and a better demand response management [3]. This idea is slowly gaining popularity in the industrial sector due to the introduction of renewable energy technologies and Feed-in Tariffs by governments which enables such producers to input extra energy produced into utility grids.

Choice of Supplier and Tariff

This involves the choice of the most suitable and economically viable supplier based on the energy needs and the prevailing market trends. The choice of supplier and tariff complexity is mainly influenced by the laws of the country in which the manufacturing plant is located [3], [4]. There are several factors that affect cost of electricity in a manufacturing plant and can therefore be used in tariffs and supplier considerations:

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i) Total Energy Consumed

Purchasing large amount of energy introduces the aspect of economies of scale hence lower cost per unit.

ii) Peak Demand

The maximum power demand by a consumer is often included in the electricity bills as an additional cost. Many suppliers use this to motivate companies to maintain their capacity requirement within manageable levels which in turn ease the pressure on the generation facilities. Energy saving opportunities in this aspect is as shown in Table I.

TABLE I. ENERGY SAVING OPPORTUNITIES BASED ON PEAK DEMAND [3].

Peak Load	Saving Opportunity
Always Exceeds contractual value	Negotiate for a higher peak load value to avoid surcharges
Occasionally exceeds contractual value	Align operational practices and scheduling to contractual requirements
Always below contractual value	Negotiate for a lower peak load value to achieve energy savings

iii) Demand Response and Dynamic Price Systems

Demand response concept is referred to as changes in consumer demand of electricity in relation to changes in the price of electricity. It is also considered to be changes in demand of electricity because of incentives by the supplier due to reduced energy usage or usage of electricity off peak hours [4].Suppliers often send cost signals to consumers to control their demand and flatten the demand curves as possible to enhance systems efficiency and reliability. Different methods are available to help companies and energy suppliers to calculate the variation in the amount of energy not supplied versus the expectations, because of implementation of demand response initiatives e.g. Monte Carlo simulation [5].

Energy Consumers can respond to price variation by:

a. Reducing the amount of electricity consumed during peak hours
b. Shifting part of electricity consumption from peak hours to off peak hours.
c. Partially supplying electricity demand during peak periods by onsite generation.

iv) Power Factor Correction

Power factor correction and control is a popular practice in Manufacturing plants. This is always done to avoid penalties and fines from the suppliers and to achieve energy efficient distribution systems in an industrial plant. Power factor correction is usually implemented by introducing capacitors in systems to provide the reactive energy demand by loads such as motors. However, a Life Cycle Cost (LCC) assessment should be conducted to give a justification why a certain number of capacitors should be installed while taking into consideration external factors that affect their efficiency such as temperature [5].

v) Transformation of Energy

Transformation of energy is the process of changing energy from one form to another that is more usable in an efficient manner while minimizing the losses involved. In Manufacturing industries, the main energy consuming machine are motors. To ensure energy efficient process, it important to make sure that the losses incurred during this process are maintained at minimum and efficiency at maximum [6].

III. PROJECT EXECUTION

Schneider Electric is a French multinational corporation that specializes in the manufacturing of electrical and Power Products equipment.

Schneider Electric Kenya is a subsidiary of Schneider electric Global and it's located at Power Technics Complex on Mombasa Road, Nairobi. The office serves as the headquarters of Schneider Electric East Africa. It houses an average of 200 staff with an office space of approximately 2,632 square meters. The main power consumer on the facility, is the manufacturing plant. The plant has various sections which include the sheet metal area, Paint line, Panel Assembly, Quality Control and Testing and finally the packaging section.

Fig. 1 Schneider Electric premises

The main source of energy at Schneider Electric Building Kenya is electricity from the grid. The electricity is supplied at 11kV and is metered at 415V 3-phase 4-wire (tariff CI1). There are three generators that provide backup power whenever there's an outage:

a) 675KVA which supports the entire load when there's an outage, apart from the painting line.
b) 100KVA generator to support the load during an outage at night.
c) 500kVA diesel-fueled standby manually Operated generator is dedicated to serve the paint line which estimated to consume nearly half of the total energy consumption of the manufacturing plant

IV. METHODOLOGY

A Preliminary interview with operations personnel was conducted to establish the energy demand of the manufacturing plant, the daily production, the energy systems in the production process and the main energy consumers.

After, a level III Energy Audit was conducted to establish the Energy situation of the manufacturing plant. For this, Fluke 1738 Power Logger was used. The results were then analyzed to establish Energy Conservation Opportunities, through Techno-economic evaluation, taking into consideration Payback Period, NPV and IRR.

V. RESULTS AND DISCUSSION

Historical Data

An analysis of the facility's electricity bill in 2020 revealed:

a) The Total Consumption of the facility varies between 36 ,000 kwh to 54,000 kwh. The variation can be attributed to the fluctuation in the production quantity at the factory.
b) The Power Factor of the plant is at an average of 0.98 which is good. Since the manufacturing plant has a lot of inductive loads such as motors, the P.F of 0.98 means that some actions have been put in place to improve it and is working out just fine.
c) There is a month to month variation margin of between 10-15% which is within the acceptable limits.
d) The load factor of the facility varies from 9% to 13%. The load factor represents the actual energy usage versus the peak demand. It is desirable that consumers should have a higher load factor. This can be improved by lowering the peak demand and by identifying periods of peak demand and making necessary changes in the network to achieve peak clipping.

Data Collection and Analysis of the overall consumption

A study on the overall energy consumption of the facility was conducted. This was done using Fluke 1738 Power logger, which was connected to the main Incomer, on the Low Voltage side of the Transformer.

The study was captured within 5 days (three working days and 2 Non-working days) and the results are as shown in Fig. 2.

The graph in Figure 2 show that the peak load is registered between 7:30 to 8:00 a.m. when manufacturing activities starts and then reduces gradually as the day progress and drops to the lowest at 5 p.m. when manufacturing activities stop. The graph then remains constant throughout the night as during that time, the main load is only the security lights. The spikes registered during startup of the manufacturing activities can be attributed to motor starting mechanisms in place.

From Fig. 3, it can be deduced that the highest harmonics levels occur between 11:00 a.m. to 1:00pm during weekdays. This could be attributed to the presence of nonlinear loads in the network such as personal computers, welding machines etc. Harmonics increases the apparent power required by the system while the active power remains the same. This means that more current will be drawn by the system, increased conductor and core losses and derating of equipment in the system such as motors and generators.

Harmonics can be reduced by introduction of reactors in the AC/DC lines, or passive harmonic filters consisting of capacitors and inductors that are meant to trap a certain harmonic frequency.

From Fig. 4, the following can be deduced:

a) The frequency of the power supply is between 49.5 to 50.7Hz. this is within the acceptable limit of 45-52Hz, as provided for by the Kenya Electricity Grid Code.
b) The supply voltage is between 223 to 253V. The voltage is lowest between 8:00 a.m. to 10:00 a.m., with the current being the vice versa (highest during this period). This can be attributed to the fact that most of the plant loads come on within this time when manufacturing activities start.
c) The supply voltage is between 223 to 253V. The voltage is lowest between 8:00 a.m. to 10:00 a.m.

Identified Energy Conservation Opportunities

Use of Variable Speed Drives (VSDs) in Motor lines

Table II. shows the details of the motor loads within the manufacturing plant.

TABLE II. PAINT LINE MOTOR LOADS

Equipment	Rating	Quantity	Efficiency
Compressor1	37kW	1	85%
Compressor2	45kW	1	75%
Pumps	22kW	2	72.5%
Motor Line 1	15kW	4	80%
Motor Line 2	22kW	4	75%
Motor Line 3	7.5kW	2	80%

The speed and Torque of induction motors is proportional to the frequency and voltage of its supply. Since most utility supplies are at constant Voltage and frequency, this means that the speed and torque of motors are also constant regardless of the load demand [6].VSDs when used in motor networks can modify incoming electricity supply and its voltage and frequency depending on the load requirements. As such, with a decrease in load, comes a decrease in the electricity supply needed by the motors to operate the equipment connected to them [6]. When pumps or fans are operated at reduced speeds, significant maintenance savings are realized due to reduced wear on seals, bearings, shafts, etc. Productivity increases from reduced downtimes and reduced waste from optimized process Control.

The Energy Savings Achieved by introducing VSDs in the Manufacturing plant was calculated as below.

In the absence of VSDs, the energy consumption of the motor is.

Energy cost = Power Requirement x No of hours of operation/annum x cost of electricity per kWh (1)

=22kW x (8*3*50) hrs/ annum x 0.3USD/kWh

=7920 USD

To determine the potential savings from a control method, a load profile must be developed. For this example, the following load profile is determined as shown in Table III.

TABLE III. LOAD PROFILE OF 22kW MOTOR

Flow	Duty Cycle
100%	20%
75%	40%
50%	40%

The weighted Power Requirement with VSD in the network is calculated as in Table IV.

TABLE IV. WEIGHTED MOTOR POWER REQUIREMENT WITH VSD.

% Flow	% Duty Cycle	Power Required (kW)	Weighted Power (kW)
100	20	22 (1.00) = 22.0	22.0 (0.2) = 4.4
75	40	22 (0.55) = 12.1	16.5 (0.4) = 6.6
50	40	22 (0.25) = 5.5	11.0 (0.4) = 4.4
		Average Annual Power	15.4 kW

Energy cost using VSD = Power Requirement x No of hours of operation/annum x cost of electricity/kWh. (2)

=15.4kW x (8*3*50) hrs /annum x0.3USD/kWh

=5544 USD

Energy Cost Saving/annum = 7920 − 5544

=2376 USD

Percentage Energy Cost Saving = (2376/7920) *100%

Percentage Energy Cost Saving = 30%

Pay Back Period

The cost of a 22Kw is approximately 2000 USD

Payback period= Capital Cost/Annual Savings. (3)

$\frac{2000}{2376}$ x12 months/year =10.1 months

The Payback period of the Investment will be **10 months**.

Replacing of standard Efficiency Motors with high Efficiency Motors

Replacing the 37kW motor with a 90% efficient motor and 0.6 load factor will result in the following energy savings [7], [8].

$kW_{saved} = h_p \times L \times 0.746 \times (\frac{100}{Est} - \frac{100}{Ehe})$. (4)

$= 37kW \times 0.6 \times (\frac{100}{0.88} - \frac{100}{0.9})$

=56.10kW

$kWh_{savings} = kW_{saved} \times$ Annual Operating hours. (5)

= 56.10 x (8*3*50) = 67,320 kWh

Total Savings= (kW_{saved} x 12 x monthly demand charge) + ($kWh_{savings}$ x energy charge) (6)

=(56.10kW/0.98) x12x 8) + (67,320 kWh *0.15)

= 15,593.51 USD

The Capital cost of the 30kW 90% efficient motor is 5,000 usd in Kenya.

Pay Back Period

Payback period= Capital Cost/Annual Savings. (7)

= $\frac{5000}{15593.51}$ x12 months/year =3.8

The Payback period of the Investment will be **4 months**.

VI. CONCLUSION

The energy savings achieved by use of VSDs in a motor line is 30%. However, the introduction of VSDs should be done in line with Thermal considerations of motor operation. As the motor speed decreases, the amount of cooling available from the motor's ventilation system is reduced, so motor torque must be limited at reduced speed to avoid overheating.

The energy savings achieved by replacing standard efficiency motor goes hand in hand with the motor loading. This is because if a motor has a significantly higher rating than the load it's driving, the motor operates at a partial load. When this happens, the efficiency of the motor is reduced.

REFERENCES

[1] R. M. Nachiappan, N. Muthukumar, (2016). Continuous Improvement in Energy efficiency, A case study at Automotive components manufacturing processes.

[2] Energy Live News by US Energy Information Administration (EIA) https://www.energylivenews.com/2020/01/08/global-energy-use-projected-to-nearly-double-by-2050/

[3] Miriam Benedetti, Vittorio Cesarotti, Vito Introna (2015). Improving Energy Efficiency in Manufacturing Systems.

[4] Cesarotti V, Di Silvio B, Introna V (2007). Evaluation of electricity rates through characterization and forecasting of energy consumption.

[5] Samadi M, Javidi MH, Ghazizadeh MS (2013). The effect of Time-Based Demand Response.

[6] Scout Rouse of Energy@work, Dan Dederer of Enertech Solutions Inc (2015). Variable Frequency Drives. Energy Efficiency Reference Guide.

[7] Gajendra Singh, N K. Sharma, P Tiwari, Pankaj Mishra (2012, June). "Energy

[8] Efficient Industrial Motors". International Journal of Engineering, Science and Technology Vol. 2(12), 2010, 7904-7913

[9] Gilbert A. McCoy, Todd Litman, John Douglass, Washington State Energy Office Olympia Washington (1990). Energy Efficient Electric Motor Selection Handbook.

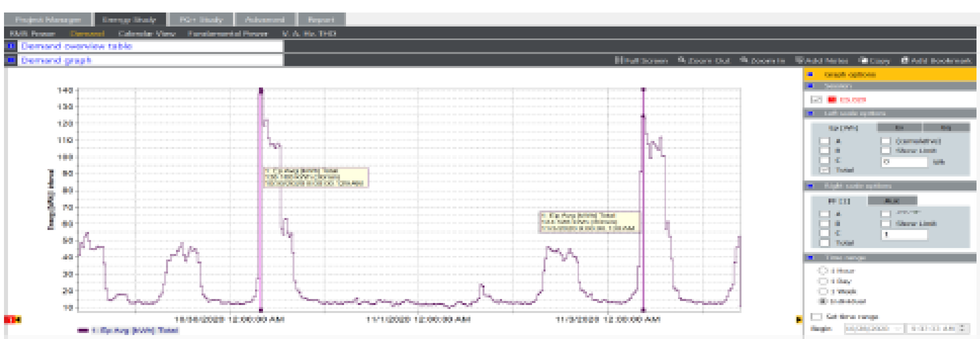

Fig. 2 Demand Graph showing the kWh consumption over 5 days study period

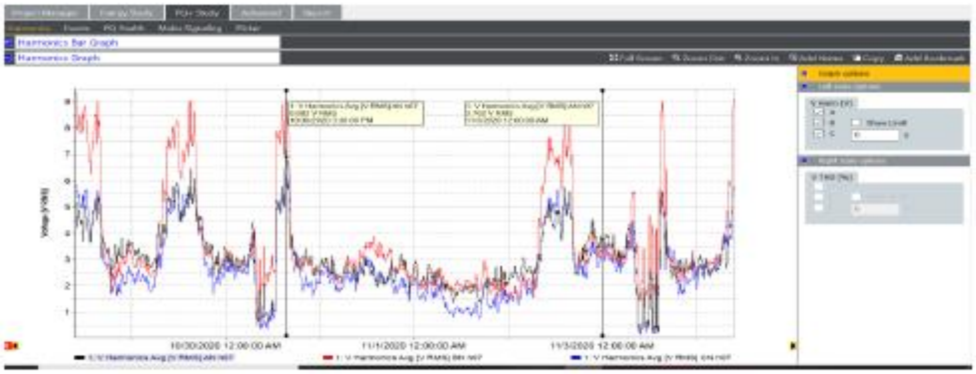

Fig. 3 Harmonics Graph over 5 days study period

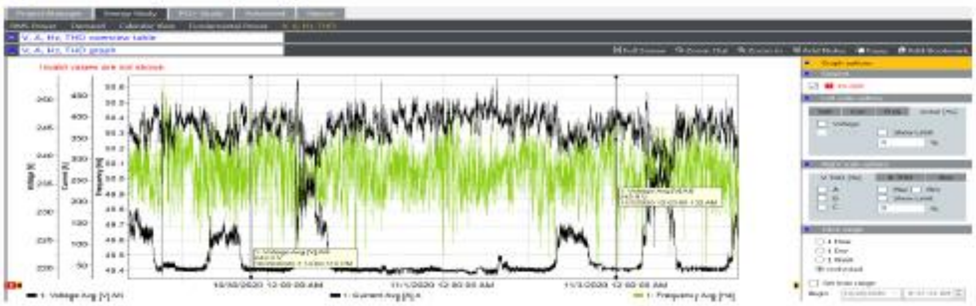

Fig. 4 Voltage, Current and Frequency graph within the study period

EVALUATION OF ENERGY CONSERVATION OPPORTUNITIES IN MANUFACTURING INDUSTRY

A CASE STUDY OF SCHNEIDER ELECTRIC MANUFACTURING PLANT IN NAIROBI

By: Maureen Adhiambo (F56/34186/2019)

Master of Science in Energy Management

Project Originality Report

Signed

Student	Maureen Adhiambo	Mourgo	22/08/2021
Supervisor	Dr. Peter Moses Musau		22/08/2021
Dean	Prof. Ayub Gitau	....	24.08.21

Report Details

Submission date: 13-Jul-2021 06:04AM (UTC+0300)
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