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:

i) Total Energy Consumed

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

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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].

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

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

=56.10kW

$kWh_{savings}$= kW_{saved} x 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.

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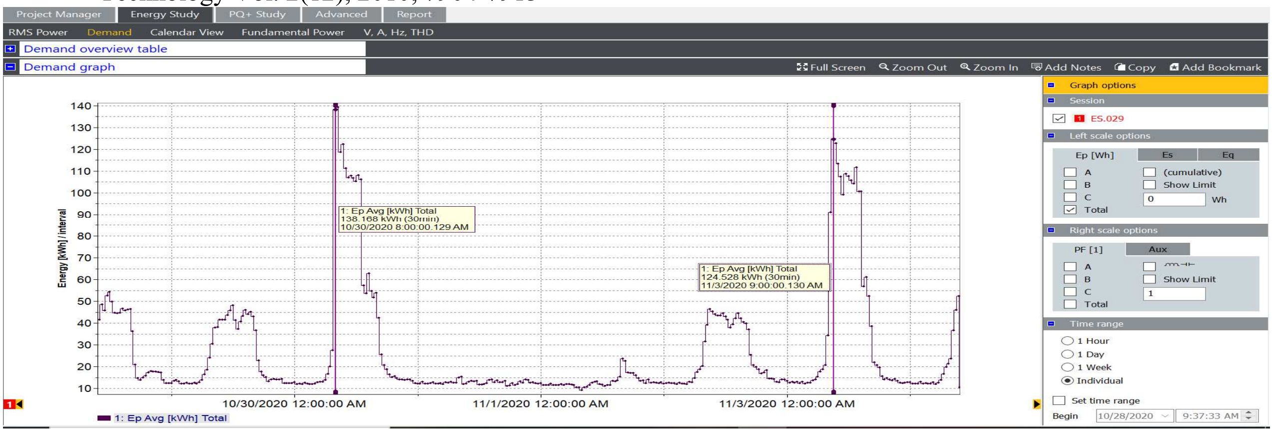

Fig. 2 Demand Graph showing the kWh consumption over 5 days study period

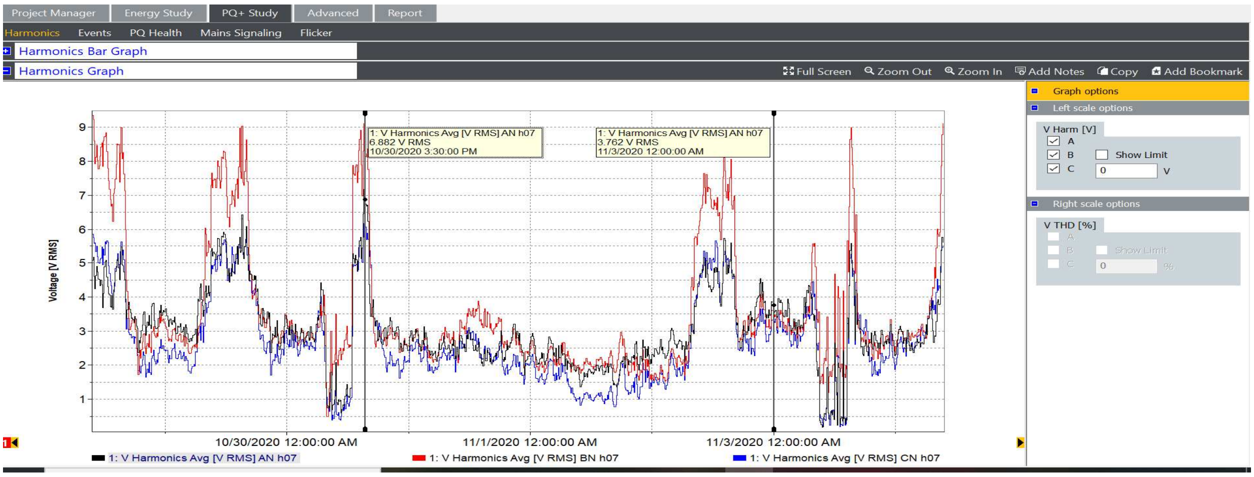

Fig. 3 Harmonics Graph over 5 days study period

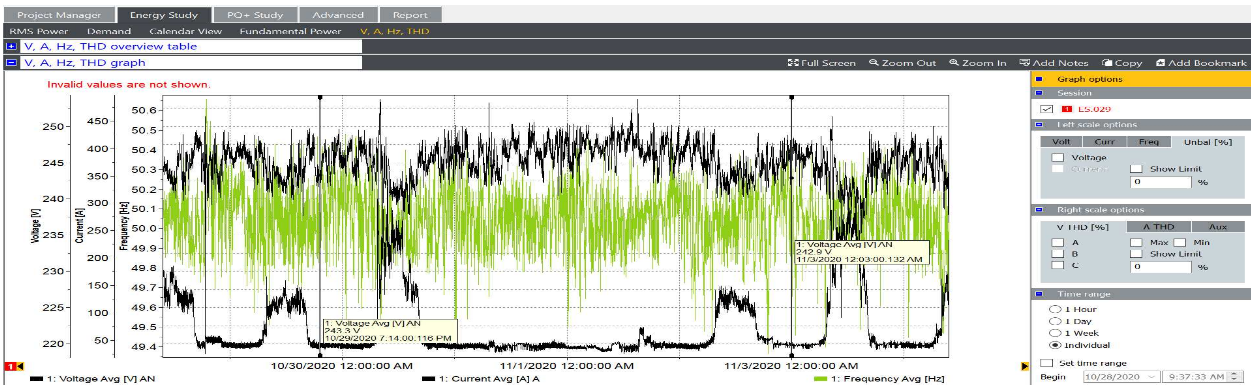

Fig. 4 Voltage, Current and Frequency graph within the study period