ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Electrical and Computer Engineering

ENERGY CONSERVATION AND EFFICIENCY IMPROVEMENT IN SUGAR FACTORIES

(CASE STUDY: FINCHAA SUGAR FACTORY)

A thesis Submitted to the School of Graduate Studies of Addis Ababa Institute of Technology, Addis Ababa University

In partial fulfillment of the Requirement for the Degree of

MASTERS OF SCIENCE IN ELECTRICAL ENGINEERING

(ELECTRICAL POWER ENGINEERING)

By: Bahru Oljira (GSE/1062/07)

Advisor: Dr. Getachew Bekele (PhD)

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Addis Ababa, Ethiopia

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APPROVED BY BOARD OF EXAMINERS

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DECLARATION

I hereby declare that the work presented in this thesis is my original work, has not been presented for a degree or otherwise anywhere else and all the sources of materials used for the thesis have been duly acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

Dr.Getachew Bekele (PhD) _______________

Advisor's Name Signature

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ABSTRACT

Like any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials in a sugar factory. Energy has the highest potential for cost reduction by ensuring energy efficiency and conservation. The energy costs are rising steadily and availability of fuel is becoming scarce. Electrical energy and thermal energy are the primary energy types used for sugar processing and the benefits of energy efficiency and conservation are commonly accepted in the sugar industry. Cogeneration power plants using bagasse in sugar factories produce steam and electricity for use in the sugar processing and also export the excess power to the grid. For the generation of excess power there is continuous analysis required for the economical balance for input and output power. The success of cogeneration depends on efficient use of energy.

The thesis work tries to identify the way energy is being used, mainly targeted at identifying practical, sustainable and economically viable energy saving opportunities in different sections of the factory, i.e. electrical systems, major drive motors, lightings, captive power plants, resulting from a compressive study and analyses of technical parameters through energy audit methodology. The study involved using a wide range of sophisticated, portable, diagnostic and measuring instruments to generate refined data. International Motor Selection and Saving Analysis (IMSSA) software and RETScreen energy efficiency model tools are used to facilitate in complex analyses to give a more reliable basis for evaluation of performance, energy saving measures and economic/financial viability.

The study conducted (energy conservation and efficiency improvement) on electrical systems, major drive motors and lightings identify recommendations, which identified an annual electricity saving potential of 4,303MWh. This works out around 15% of the total base case electricity consumption with fuel cost saving of 77,883 USD Analyzed with RETScreen Energy Efficiency model. The power quality parameters like voltage unbalance, total harmonic distortions and frequency are measured at PCC/MCC and compared against the IEEE-519 standard and they are found to be well within the limit, but power factor at some MCC are less than optimum.

The second part of the study focuses on the steam generation and distribution system. The study conducted in the steam generation unit shows the steam generation units during the study (boiler 1, boiler 3 and boiler 4), have very low efficiency (on average 63.59%) when compared to the minimum acceptable efficiency of boiler that uses bagasse as a fuel (70 %).

The determined low efficiency is caused by large quantity of heat losses particularly due to excess air and moisture in the fuel, i.e. bagasse that should be transferred to steam. The investigation on the steam distribution systems also shows there is significant amount of losses due to deteriorated steam distribution line thermal insulation and steam leakages.

The study conducted on both steam generation units (boilers), thermal losses due to deteriorated insulation of steam lines and steam leakages identified energy conservation measures of annual saving potential of 17,807ton of bagasse which could avoid additional fuel/FO utilization and enhance generation of electricity that significantly reduce grid electricity dependency of the factory.

Keywords: Cogeneration, energy audit, energy saving opportunities, energy conservation, efficiency improvement, energy conservation measures, power quality.

ACRONYMS

A	Area
AAS	Actual Air supplied
Aunb	Current unbalance
Vunb	Voltage Unbalance
APFC	Automatic power factor corrector
CFL	Compact Fluorescent Lamp
CPP	Captive Power Plant
CRI	Color Rendering Index
E	IL luminance
EA	Excess Air
ECM	Energy Conservation Measures
EEU	Ethiopian Electric Utility
FO	Furnace Oil
FSF	Finchaa Sugar Factory
FTL	Fluorescent Tube Lamp
GCV	Gross Calorific Value
GLS	General Lighting service
HID	High Intensity discharge
HT	High Tension
HV	High Voltage
HPMV	High Pressure Mercury Vapour
IMSSA	International Motor Selection and Saving Analysis

IEC	international Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
IRR	Internal Rate of Return
LT	Low Tension
MCC	Motor Control Center
MH	Metal Halide
NCV	Net Calorific Value
PCC	Point of Common Coupling
PF	Power Factor
TEFC	Totally Enclosed Fan Cooled
TCD	Tone Cane per Day
THD	Total Harmonic Distortion
TPH	Tone per Hour
USD	United States Dollar
VFD	Variable Frequency drive

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1. INTRODUCTION

1.1 Background of the study

Energy is a one of major inputs for the economic development of any country. In case of developing country like Ethiopia, the energy sector assumes critical importance in view of the ever increasing energy needs, requiring huge investment to meet them. The industry sector plays a significant role in global energy consumption. Currently many sugar factories in the world are producing or co-generating additional power for transfer to the grid or for use in ancillary industry in addition to satisfying their own demand. However, sugar industry in Ethiopia is facing challenges to cut down the cost of production mainly due to imported additional fuel with hard currency to meet their energy demand. And highly depend on national grid electricity.

The energy consumption in sugar industries are classified as energy consumption by process equipment's and energy consumption by cogeneration auxiliaries [1]. The main source of energy for sugar industries are steam and electricity. Bagasse is being used as fuel to the boilers to generate the high pressure steam which in turn drives the turbine to generate both electricity and low pressure steam. Low pressure steam is used for sugar production process requirements.

Many sugar factories are using sugarcane bagasse with some additional fuel to meet their energy requirements. The usage of this additional fuel can be avoided by modernization and energy conservation in sugar plants [**2**].The various means through which the sugar industries are attempting to save energy and/or fuel are;

- Efficient production of steam,
- Efficient use of electrical and mechanical energy
- Efficient use of steam

This can be achieved through, maximum generation of steam per unit of bagasse or fuel, maximum generation of power set per unit of steam, minimum consumption of power, minimum consumption of process steam, minimum line losses both on account of steam and power transmission, maximum heat recovery through reclamation flue gas, a hot condensate, flashing etc.[2].

The energy costs are rising steadily and the availability of fuel is becoming scarce. Therefore the conservation of energy in sugar industry has become a matter of great significance.

Adoption of energy conservation and efficiency measures is imperative for the sugar industry to generate electricity for own use and for export to the national grid [**3**].The use of bagasse improves the amount of electricity generated in the country and reduces greenhouse gases. The idea is to encourage the adoption of renewable energy sources as alternatives to the conventional fossil fuels that are mainly used. The success of cogeneration schemes depends on maximizing the energy output and minimizing the energy expenditure in the sugar processes.

Indian sugar mills in different countries have acknowledged importance of implementing high efficiency grid connected cogenerating power plants for generating exportable surplus power through systematic assessment of energy conservation potential [4].

An energy conservation measure should be initiated with an energy audit in a sugar factory to achieve the most economical reduction of energy costs in order to save the maximum energy at the lowest cost [**2**].The manner in which the total energy utilization at the plant is managed between different stages is determined by energy measurements, to be able to draw up an energy balance for the plant.

1.2 Energy audit and Measurements

An energy conservation measure should be initiated with an energy audit in factory to achieve the most economical reduction of energy costs in order to save the maximum energy at the lowest cost. Industrial energy audit is an effective tool in defining and pursuing comprehensive energy management program. In any industry, the three top operating expenses are often found to be energy (both electrical and thermal), labour and materials.

Energy audit means the verification, monitoring, and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption [5].

The manner in which the total energy utilization at the plant is managed between different stages is determined by energy measurements, to be able to draw up an energy balance for the plant.

So proper measurement in a regular basis and during energy audit between different stages is important for improving energy efficiency and conservation in industrial facilities.

1.3 Energy conservation and Energy efficiency

Energy conservation and energy efficiency are separate, but related concepts. Energy conservation is achieved when growth of energy consumption is reduced in physical terms. Energy conservation, therefore, is the result of several processes or developments, such as productivity increase or technological progress. On the other hand energy efficiency is achieved when energy intensity in specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels. Promotion of energy efficiency will contribute to energy conservation and is therefore an integral part of energy conservation promotional policies

[6].

Energy efficiency is often viewed as a resource option like coal, oil or natural gas. It provides additional economic value by preserving the resource base and reducing pollution. For example, replacing incandescent with CFL lamps means using only ¼th of the energy to light a room. Pollution level also reduced by the same amount. Very simply, energy efficiency means using less energy to perform the same function.

1.4 Problem statement of the thesis work

In recent years there is an increasing trend in setting up new sugar factory and capacity enhancement of the existing ones in Ethiopia. Thus, the industry has the potential to support grid in addition to satisfying its own energy need (by cogeneration). But the success of cogeneration schemes depends on maximizing the energy output and minimizing the energy expenditure in the sugar processes. Like another factories in our country, sugar factories have also problems of proper energy utilization.

Finchaa sugar factory has power generation Capacity of 31MW, 7MW from existing plant and 24MW from the new plant with an intention of satisfying its electricity demand which was complemented from national grid before expansion and export surpass electricity to the national grid. However,

- The factory additional fuel/FO utilization is increasing which is imported fuel with hard currency,
- Unable to export intended amount of electricity to the grid and still highly depend on grid electricity/imported electricity.

Hence, this thesis work aimed at examining the way energy is being used in the factory, and identifying energy conservation opportunities including possibilities of efficiency improvement in steam generation unit so as to come up with actions to be taken to minimize energy wastage, reduce additional fuel utilization and preparing feasible energy saving recommendations and action plans.

1.5 Objective of the study

1.5.1 General Objective

The primary objective of the thesis is examining the way energy is being used in the factory, and identifying energy conservation opportunities including possibilities of efficiency improvement so as to come up with actions to be taken to minimize energy wastage and preparing feasible energy saving recommendations/energy conservation measures and action plans.

1.5.2 Specific objectives

- To identify types & cost of energy used by the factory.
- To understand how energy is being used and possibly wasted.
- To indicate better energy conserving opportunities.
- To examine energy consuming systems of the factory so the improvements can be quantified in terms of both energy and cost.
- To identify and analyze improved operational techniques and / or new equipment that could substantially reduce energy use and which ones are cost-effective for the factory.
- To evaluate economic and technical practicability of energy saving opportunities and recommending the feasible measures.

1.6. Scope and limitation of the study

The scope of this thesis work includes, assessment of factory electrical systems, major electrical drives (motors), lighting systems, boilers, steam distributions systems. But assessment of derived mechanical loads such as pumps, compressors and steam utilization are beyond the scope of the study.

The investment cost of the recommended Energy Conservation measures (ECM) are estimated by referring from project database of RETScreen/case study of efficiency projects applied somewhere in the world, factory inventory and from IMSSA database.

1.7. Methodology

The study will cover an in-depth study of factory electrical system, motors, power supply quality, lightings, FO/ Bagasse Boiler assessment, steam distribution system and other major energy consuming equipment. It involve carrying out various measurements and analysis covering major energy consuming sections, to realistically assess losses, inefficiencies and potential for energy savings.

1.7.1. Approach

To conduct the study, the following methods and approach are used:

- Literature review on sugar manufacturing process, energy performance assessment of sugar factory, and energy conservation opportunities in sugary factory.
- Data collection: energy consumption (electricity and steam), primary energy data (FO and bagasse), imported and exported electricity from/to the grid and production data are collected from the factory.
- Briefing/awareness session with plant technical division, walk through tour with technical staff conducted.
- On site/field measurements of electrical systems, major drives, lighting level, flue gas measurements and steam distribution lines surface temperature are measured and leakage test are conducted by using diagnostic and measuring instruments, And
- Data’s are analyzed using RET Screen 4 energy efficiency and International motor selection and saving analysis (IMSSA)

1.7.2. Instruments

A wide array of latest, sophisticated, portable, diagnostic and measuring instruments are used to support the assessment and analysis.

The specialized instruments used during the study and their description is given listed in table 1.1:

Table 1. 1: List of instruments used

s no	Description	Functions
1	Power analyzer/ Chauvin 8335A	Three phase power and harmonic analyzer
2	Clamp on A/fluke	To measure instant power
3	Lux meter	Illumination level
4	Combustion/flue gas analyzer	O_2, CO, and CO_2 measurements
5	Thermography/infrared camera	Thermal imager
6	Ultrasonic leak detectors	To detect steam and air leakage
7	Humidity meter	To measure humidity

1.7.3. Software tools

RETScreen 4 energy efficiency model and Motor Master + international (IMSSA) are used for analysis.

1.8. General Factory description

Finchaa sugar factory is one of the leading state owned sugar manufacturing plant located in Western part of Ethiopia, Oromia regional state Horro Guduru Wollega which is around 350km from capital Addis Ababa and around 60km from Shambu town zone capital (9.6^{o}N, 37.1^{o}E). The construction of the factory was completed in 1999. The factor mill had a capacity of crushing 4,500 tons of cane per day. And then Finchaa has expanded the sugar factory to a capacity of 12,000 TCD on November 2012.

This sugar factory also installed captive generation systems. Leftover of cane (bagasse) after juice is executed, is used to generate steam and electricity. Power generation Capacity of 31MW by two existing 3.5MW each turbine generators and two expanded plant 12MW each turbine generators with an intention of satisfying its electricity demand which was complemented by the national grid before expansion and export surpass electricity to the national grid.

1.9. Literature review

The thesis work compulsory inclusive knowledge of comprehensive energy audit, improving/optimizing energy use efficiency in sugar industry, management of power quality and parameters in industrial systems, improving power factor, assessment of thermal energy loss in industry from different research works. This literature review section includes, brief of energy audit, improving energy efficiency in sugar industry, assessment of power quality and energy loss in major driving in industrial systems.

Vishal N Patel, MM Madhikar [1] provides information on scope of energy audit, scope of energy audit in sugar industry and energy conservation. The scope of energy audit in sugar industry should include the study of improve the power factor ,replace lights by efficient light, install VFD drive in spray pump, install of Automatic temperature controller in cooling tower system, reduce overloading of certain pump and install planetary gear drive in place of worm gear drive. some areas has found in Sugar plant for increasing plant productivity .It also identified that Energy conservation must consider as important factor for cost reduction.

A N Pathak [2] provides knowledge on suggestive measures for minimizing energy and heat losses in Indian sugar industries. The suggestions are enumerated to achieve the target of effective electrical energy conservation, heat and fuel through modernization of equipment’s and technology. The work also addresses, use of alternative sources of energy like solar energy, bioenergy etc. for power generation and utilization of byproducts of sugar industry by value addition, to increase the profitability of the sector.

S.P. Nangare, R.S. Kulkarni [3] provides information on the generation of surplus power effectively through continuous analysis required for the economical balance for input and output power. The system analysis and results are calibrated under one process known as Energy Audit.

This recovers the wastage of power through steam & heat and non-control of feed air tapping it at each interval can generate surplus power.

G R Narasimha Rao and M Nagarajan [4] this work provides knowledge on a comparison of specific energy consumption of inefficient sugar plants and efficient sugar plants with reference to major energy consuming equipment's/section of the plants.

EBRD thematic factsheet [5] Improving industrial energy efficiency, provides information on advantages of energy efficiency investments. If energy efficiency investments are assessed and implemented properly, the returns can be high and the technical risks relatively low. Such investments can help reduce energy consumption and may also have other positive implications, such as improved product quality. Benefits can also be gained through environmental improvements and from the demonstration effect on the business community.

More than ever, companies are facing increased competitive pressures to produce high quality products at comparable or lower cost. With rising energy prices, companies are pressured to bring energy costs in line with standards of best practice.

Assefa Alena, Omprakash [6] provided intensive knowledge on cogenerations of energy from sugar factory bagasse. The work deals with bagasse and its properties focuses on determining the quality and quantity of bagasse that has been used by Wonji shoa sugar factory as a fuel for boilers with respect to conventionally accepted standards. The outcome of the study indicates the bagasse produced by the factory fulfills all the requirements as a boiler fuel both in quality and quantity wise, during milling time and stoppage of mill without the supply of any additional fuel.

The study focus also on steam generation and utilization unit. The study conducted in the steam generation units (boilers) has very low efficiency (on average 56%) when compared to minimum accepted efficiency of boiler that uses bagasse as a fuel 70%. The low efficiency manifested by large quantity of heat losses that should be transferred into steam. The investigation in steam utilization shows it operates without problems. In general the outcomes of the study proves that the shortage can be solved by improving the efficiency of the steam generation unit. The proposed solutions to the problems are optimization of excess air supply in the combustion chambers, application of bagasse drying system, increasing the capacity of evaporators, efficient operations, maintenance of boilers and its accessories.

Charles Mbohwa [7] this work provides practical information. Identifies energy management best practices necessary to increase the efficiency of the cogeneration processes. Adoption of energy conservation and efficiency measures is imperative for the sugar industry to generate electricity for own use and for export to the national grid. Such as,

Improving Boiler Efficiency: The boiler efficiency can be increased through efficient heat recovery and excess air control in the boilers. Boiler efficiencies can usually be increased by adding heat recovery equipment such as economizer or more air heater surfaces. For every 10^{o}C higher final gas temperature, the boiler will produce about 1% less steam per ton of bagasse [6]. Modern improvements to bagasse boilers makes it possible to achieve complete combustion with ± 27% excess air, thereby maintaining an oxygen level in flue gas at ± 4.0 %. Under these conditions, a boiler with 160^{o}C final gas will be operating at > 85% lower calorific value (LCV) efficiency on bagasse of 50% moisture. One of the main thrust of energy efficiency in the sugar industries is to increase energy export.

Jatin Gupta [10] provides information on energy-efficient technologies and production measures applicable to the textile industry. The work also includes analysis of an audit conducted on motors of different horsepower in a textile plant and includes energy saving and cost information available. For some measures this report also provides range of savings and payback periods found in under varying conditions. The thesis report analysis is done only on rewound induction motors for its efficiency improvement.

Assefa Alena, Omprakash [6] by optimizing excess air in the combustion chamber at Wonji shoa sugar factory, the boiler efficiency increases 4-6 %. The gain in the above efficiency due to optimization of excess air will lead to save 1.56 tons of bagasse per hour after generation of the same quantity of steam as before.

2. Sugar Manufacturing process and Energy use

2.1. Sugar manufacturing process

The natural sugar stored in sugar cane is separated from the plant material through sugar manufacturing process. The sugar manufacturing process normally comprises of, juice extraction, juice clarification, evaporation, centrifuging and drying and packaging. These processes involves,

- Cane is weighted first, and then it is converted into small pieces by passing through fiberizer where cane is turned into small thin fibrous form and then enter into mill set through carrier.
- This prepared cane is now crushed in mills .after passing through three mills hot water of temperature 60 °C to 70°C is added in fourth mill to take out as much as possible in leaving Bagasse. The Bagasse is used as fuel in Boiler to produce steam.
- The produced steam is used for prime mover of power turbines, mills and Fiberizer. The juice is collected at Mills and is called "Mixed Juice". It is pumped out to auto weighing Tank.
- This "Mixed Juice " is now allowed to pass Juice heater where it is being heated at 60 °C to 70°C for clarification ,Juice is mixed with milk of lime and SO2 gas simultaneously .Here PH of juice is maintained at 6.9 to 7.1.This juice is called sulphited juice. This sulphited juice is heated again to 100-105°C and it is pushed to settler vessels called clarifier where all Mud is settled down and clear juice is obtained on upper part of chamber.

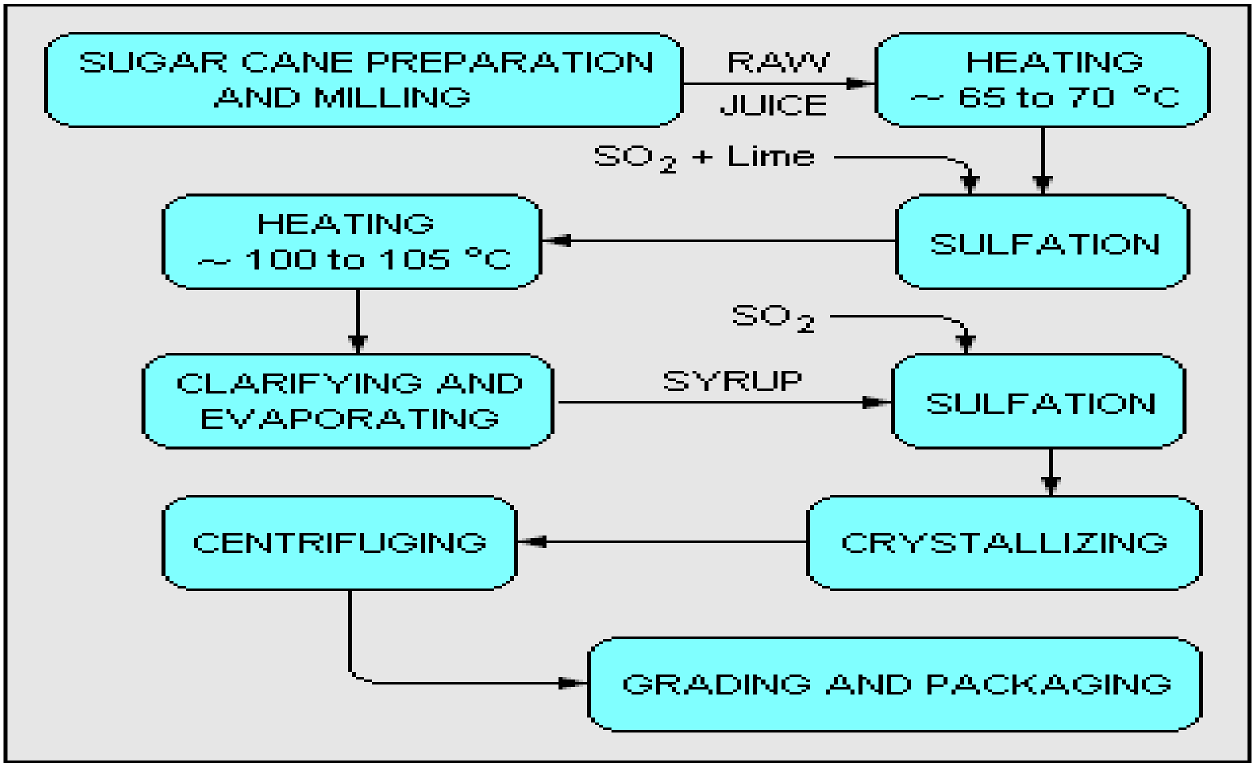

Figure 2. 1: Sugar manufacturing process [1]

- The muddy juice now is pumped to filter where mud is taken out from the juice again sent to “Mixed Juice” and mud separated is known as “Filter Cake” which is used as manure in the syrup is again passed through SO_2 gas where PH is maintained at 4.9 to 5.1.
- Now this Sulphited syrup is sent to supply tanks of pan station. After boiling under vacuum at “pan”, small grain is formed with molasses that is called Masscult.
- After dropping from pan, this Massecuite are allowed to cool in crystallizer and then pumped out to centrifugal machines.
- At centrifugal machines sugar and molasses are separated now the sugar is passed through hopper to get it free from moisture and Hot and Cold air is applied through blower.
- The separated molasses is collected in storage tanks.
- This sugar is separated in separate grade by passing through grader of different mesh and finally from grader sugar filled in gunny bags and weighted and sends to go-downs [1].

2.2. Factory energy consumption profile

2.2.1 Energy description of the factory

The preliminary data collected from the factory has been done to determine specific energy consumption of the factory to analyze energy utilization of the factory and identify energy efficiency improvements potential through benchmarking strategy with similar industry in the world. (To determine strategy for efficiency improvement for the factory).

The factory major energy consumption is electricity and steam (for process) which is generated from bagasse (by product from sugar manufacturing process) and Heavy furnace fuel (HFO). The energy data (electricity generated, steam produced, electricity imported and exported from/to national grid), cane crashed and sugar produced for the year 2016/2017 is collected from the factory using developed data collection worksheet for the purpose of energy utilization analysis and efficiency improvement potential.

2.2.2 Energy consumption profile

The major source of energy in the factory for sugar manufacturing process is electricity and steam. The factory has two steam turbine generators (cogeneration power plant) 3.5MW each from existing plant and two 12MW each from new plant which is commissioned on 2014 with intention of satisfying the factory demand from the two existing units (2x 3.5 MW) plants and one from the 12MW new plant. And to export to the national grid from the remaining 12MW unit.

The month wise electricity generated from both plants, electricity imported and exported to the grid on 2016/2017 (for the last one year) during production period of the factory from October 2016 to June 2017 is given on the following table.

Table 2. 1: 2016/2017 production period electricity profile of the factory

Month 2016/17	Electricity generated(kWh)	Electricity imported (kWh)	Electricity exported (kWh)	Import export balance(kWh)
October	-	234,482	-	234, 482
November	1,460,900	3,455,690	51,341	4,865,249
December	2,560,784	2,355,695	205,089	4,711,390
January	2,239,205	1,619,712	619,493	3,239,424
February	1,255,359	339,202	916,157	678,404
March	2,052,489	512,902	1,539,584	1,025,807
April	1,732,724	1,159,789	574,935	2,317,578
May	1,418,500	3,178,450	19,316	4,577,634
June	78,100	3,131,079	-	3,209,179
July	-	-	-	-

The import and export balance of electricity indicated on above table is electricity consumed by the plant. The trend of the electricity consumption of the plant is indicated below on the following graph (figure 2.3).

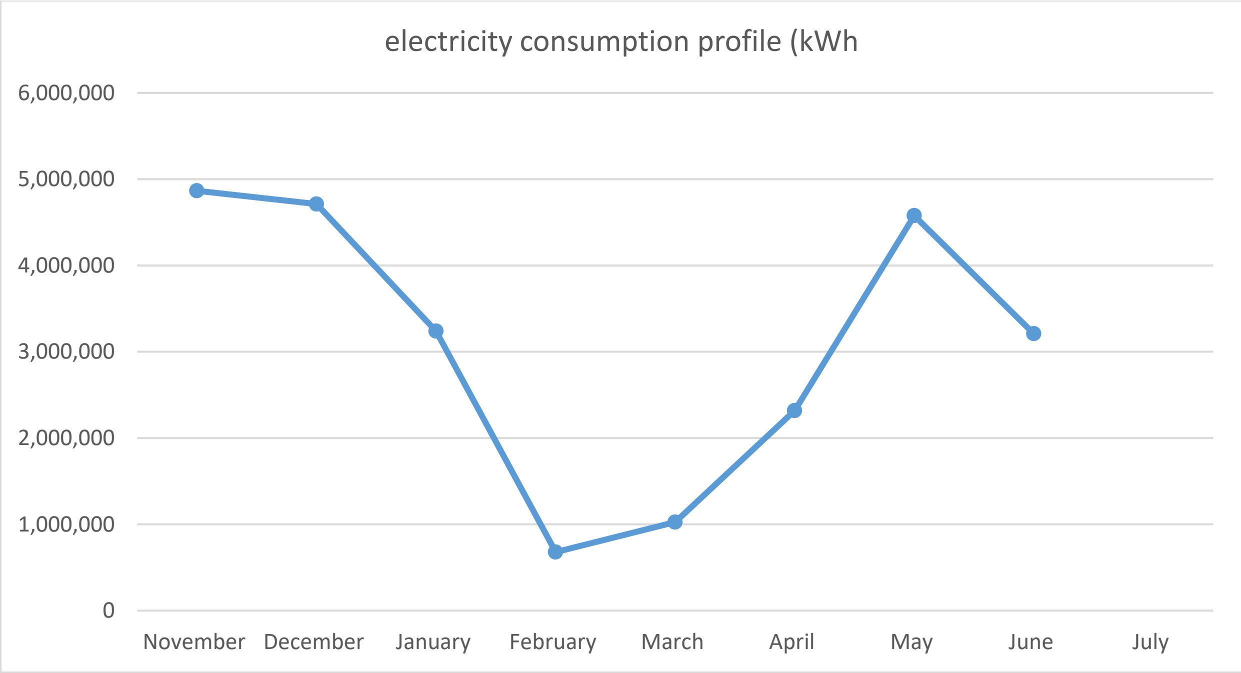

Figure 2. 2: FSF Electricity consumption profile (Oct. 2016 - July 2017)

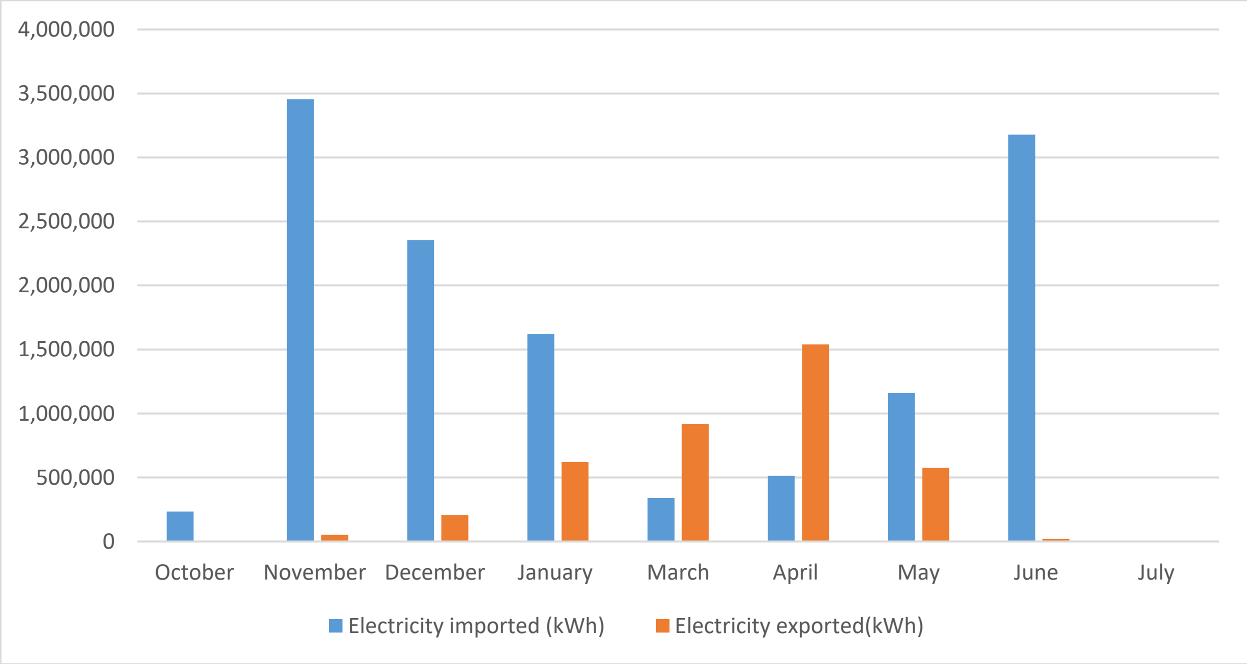

Figure 2. 3: FSF Electricity import and export (Oct. 2016 - July 2017)

Bagasse produced, furnace fuel consumed and electricity imported from the grid is indicated on the following table 2.2. (Data from quality control department of FSF).

Table 2. 2: 2016/17 bagasse produced, HPFO consumed and electricity imported

Months	Bagasse produced (quintal)	HFO consumed (Litters)	Imported electricity(KWh)
October	-	-	-
November	417, 769	92,415	3,404,349
December	576,400	0	2,150,606,
January	628,757	0	1,000,219
February	495,142	13,780	-576,955
March	507,987	92,415	-1,026,682
April	423,087	25,073	584,854
May	295,236	356,817	3,159,134
June	151,642	368,675	3,131,079
July			
Yearly/total	3,496,020	949,175	11,826,604

Sugar produced, steam produced and electricity consumed in kWh per month during production period of the factory is indicated in the following table 2.3.

Table 2. 3: Sugar production and major energy consumption

Months	Steam produced (quintal)	Electricity consumed(kwh)	Cane crashed (quintals)	Sugar produced(quintal)
October	-			
November	627,190	3,404,349		129,400
December	905,100	2,150,606,		225,428
January	962,870	1,000,219		260,089
February	781,860	-576,955		208,865
March	627,190	-1,026,682		207,596
April	456,120	584,854		151,325
May	233,870	3,159,134		89, 692
June	140,460	3,131,079		42,157

Yearly/total	4,898,160	9,675,998	12,370,332	1,224,860

The months of October and July are considered as the production moths (from October to July) of the factory in a year, but the there are no production registered in those months.

2.2.3 Specific energy consumption of the factory and benchmarking

Bench marking can be useful for understanding energy consumption patterns in industrial sector and for taking measures to improve energy efficiency. Energy benchmarking for an industry is a process in which the energy performance of an individual plant or an entire sector of similar plant is compared against a common metric that represents ‘standard’ or ‘optimal’ performance. It may also entail comparing the energy performance of a number of plants against each other [13].

Since benchmarking is used for comparison across a number of plants or sectors, there are two important features they should have. First, they are applied to plants or sectors of different sizes and outputs, the metric used should be common irrespective of plant size. The most common

metric used is energy intensity which measures 'energy use per unit of output’ (specific energy consumption). The second, the benchmarking approach should be used in a wide range of facilities so as to compensate for differences in production at similar facilities. The specific energy consumption of major industry sectors in India and global bench mark is indicated in the following table.

Table 2.4 Specific Energy Consumption of some industries in India and global benchmarks [24].

Industry	Specific energy consumption in Giga joule/tone (GJ/ton)	
	India	World
Iron and steel	25.5 – 34.2	16.5 – 18.5
Cement	3.0 – 3.4	2.9 – 3.0
Fertilizer (Urea)	27.2 – 28.5	24.0 – 28.5
Pulp and Paper	31.0 – 51.0	25.0 – 30.0
Chlor Alkali (Caustic Soda)	7.8 – 8.6	7.1 – 7.5
Aluminum	75.6 – 83.2	70.5 – 73.0
Sugar	0.7 – 0.9	0.6 – 0.7

The specific energy consumption of FSF is computed from the data obtained which is about 0.8 GJ/ton. The specific energy consumption of the FSF is higher compared to India sugar industry and much higher compared to global benchmarks i.e. 0.6 to 0.7 GJ/ton. Hence, this indicates that there is a potential for energy conservation and efficiency improvement in the sugar factory.

In sugar industry the energy intensity (specific energy consumption) could be measured in two ways.

- Steam to cane ratio (steam % cane crashed)
- Electricity consumption (kWh) per ton of cane crashed [1].

The steam to cane ratio is 26 – 45% range and electricity consumption is 22 – 37kWh/Mt As it can be determined form the energy and production data of the factory the specific energy consumption during production period of 2016/17 steam to cane ratio and electricity consumption per ton of cane crashed is estimated 0.58 and 78kWh/ton respectively.

Amount of steam generated per each ton of wet bagasse could be also one indicator. According to different sources, the average practice is about 2.3 tons of steam per ton of bagasse burned [11]. In this factory it is far from this figure. Which is estimated about 1.5.

2.2.4 The factory unit cost of energy

Understanding unit cost of energy is a vital factor for financial analysis and economic viability of energy conservation and efficiency measures. The cost of energy of FSF is obtained from the utility bill and fuel inventory. Electricity and steam are the two forms of energy used for sugar processing. Bagasse and FO (furnace oil) imported from outside are used to generate steam. Where electricity is produced from the captive power plant/cogeneration power plant and also complemented by grid electricity. The average cost of electricity from the grid is about 0.0181USD/kWh (average cost of grid electricity) and electricity generated by the CPP plant is estimated about 0.066USD/kWh (estimated-CPP- FO + bagasse). The cost of furnace oil is 0.5USD/liter (obtained from the factory inventory).

Output, energy consumption, imported and exported electricity are supplied from the factory, The unit cost of electricity and furnace oil/FO considered for all financial analysis in this study is 0.0181USD/kWh, 0.5USD/liter respectively.

3. Electrical systems and energy saving opportunities

At the industrial end users premises, plant network elements like transformers at receiving end substations, switchgear, lines and cables, load-break switches, capacitors causes losses, which affect the input-received energy [14]. However losses in such systems are meager and unavoidable. Whenever the power reaches the industry, it meets the transformer. The energy efficiency of the transformer is generally very high. A typical network efficiency including transformer is 95% and motor efficiency is about 90%. Another 30% (i.e. 70%efficiency) is lost in the mechanical system which includes coupling/drive system, a driven equipment such as pump and flow control Valves/throttling etc.

Usually after power generation at the power plants it is transmitted and distributed over a wide network and the standard efficiency is around 83%. Thus the overall energy efficiency becomes 50% [14]. (0.83 x 0.95 x 0.90 x 0.70 = 0.50, i.e. 50% efficiency).

3.1 The factory electrical system description

Finchaa sugar factory (FSF) plant generate electricity from both existing and new expanded plant (2x3.5MW and 2x12MW respectively) with a plan of satisfying its own demand for sugar production and exporting surpass to the national grid (EEU). But during this assessment only the existing plant generates electricity (2x3.5MW) and receives the remaining demand from the national grid through single feeder of 66kV line. The 66kV line is stepped down to 11kV by 16MVA single transformer at the substation and distributed to the plant.

The factory electrical system is shown in figure 3.1 and figure 3.2 below

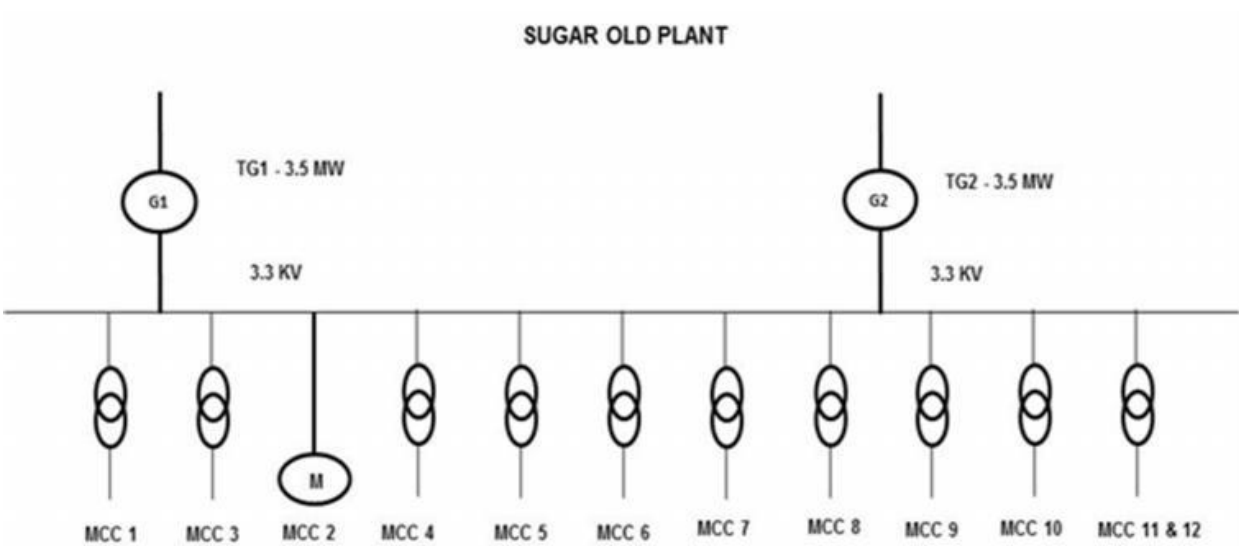

Figure 3. 1: single line diagram of old sugar plant.

The existing power plant of FSF has installed captive generation system as economic measure. The generation capacity of the power plant is 7MW by two 3.5MW each turbine generator. With the generating voltage of 3.3kV feed into 3.3kV bus bar and supplied to LT distribution transformers 3.3kV/380V to supply different MCCs (motor control centers) of old plants and HT old cane knife driver/motor at MCC2.

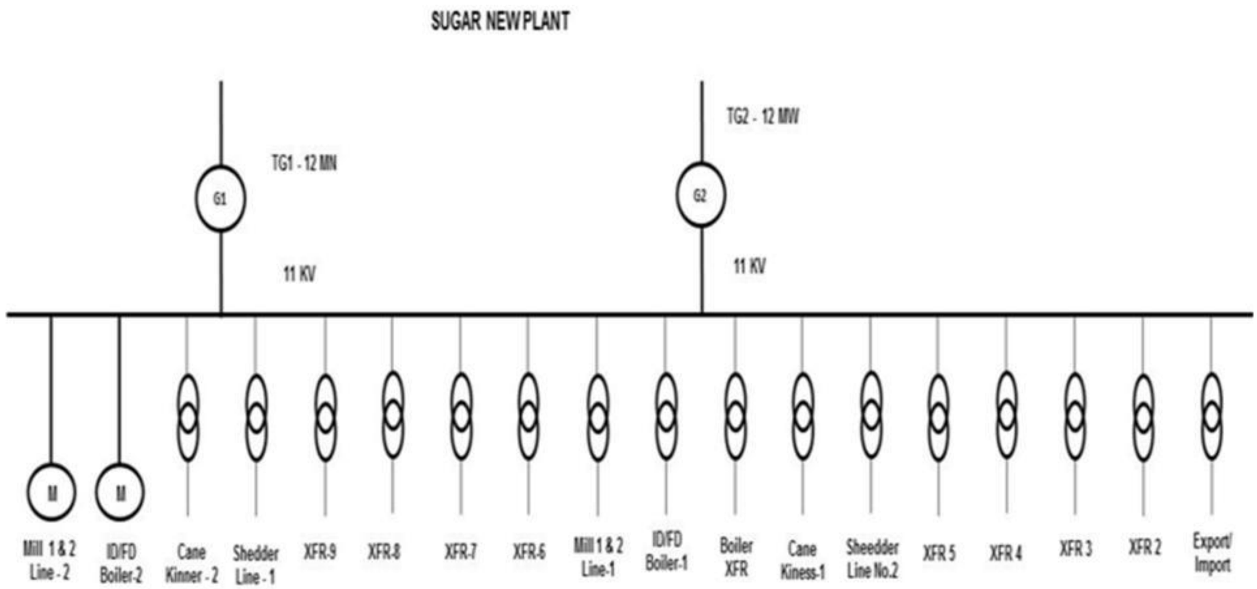

Figure 3. 2: single line diagram of new sugar plant

The new power plant of FSF has also installed captive generation system as economic measure with Power generation capacity of 24MW by two 12MW each turbine generator. With the generating voltage of 11kV feed into 11kV bus bar and supplied to LT distribution transformers to supply different MCCs (motor control centers) of new plants and HT sugar mills and boilers ID/FD fans. In addition to satisfying its own demand with this capacity the plant was exporting some surpass electricity to the grid with an intention of exporting 10MW. But during this study the plant was importing electricity from the grid to satisfy its own demand.

3.2. Plant electrical system measurement and analysis

Measurement and analysis of an electrical power system may uncover energy waste, fire hazards and equipment failure [14]. Facility/energy managers increasingly find that reliability centered maintenance can save energy, money and down time. Hence, the electrical system trouble approach could be used as indicated in Table 3.1 which provides technical recommendations.

Table 3. 1: trouble shooting of electrical power system [14]

System problem	Common causes	Possible effects	Solutions
Voltage unbalances among the three phases	Improper transformer tap settings, Single-phase, not balanced among phases, poor connections, bad conductors, transformer ground faults	Motor vibration, premature motor failure A 5% unbalance causes a 40% increase in motor losses.	Balance loads among phases.
Voltage deviations from rated voltages (too low or high)	Improper transformer settings, incorrect section of motors.	Over-voltages in motors reduce efficiency, power factor and equipment life, increased temperature	Correct transformer settings, motor ratings, motor input voltages
Poor connections in distributions or at connected loads.	Loose bus bar, cable connections and corroded connections, loose or worn connectors	Produces heat, causes failure at connection site, leads to voltage drops and & voltage unbalances	Use infrared camera to locate hop-spots and correct
Low power factor	Inductive loads such as motors, transformers and lighting ballasts, non-linear loads such as most electronic loads.	Reduces current-carrying capacity of wiring, voltage regulation effectiveness, and equipment life.	Add capacitors to counter reactive loads.
Harmonics (non-sinusoidal voltage and/or current wave forms)	Office electronics, UPS, VFDs, high intensity discharge lighting, and electronic core-coil ballasts.	Over-heating of neutral conductors, motors, transformers, switch gear, voltage drop, low PF reduced capacity.	Take care with equipment selection and isolate sensitive electronics from noisy circuits.

During this assessment through comprehensive audit the electrical power measurement were conducted at the HT 11kv EEU (grid) incoming bus bar, the two existing generators incoming feeder (2x3.5MW generator turbine) main PCC, and MCCs to analyze the factory electricity demand and monitor power quality conditions (Harmonics, unbalance, power factor) to analyze their impact on energy performance efficiency mainly on LT motors using sophisticated Chauvin, C.A 8335, and fluke power quality analyzers.

3.2.1 Grid incoming 11KV power parameters measurement

The power parameters on 11kV incoming line were measured at HT level/11kV panel in the factory and parameters such as incoming voltage profile, Harmonics, variation in load current, kW, kVA, power factor with respect to time is given in **Appendix – 3/1.** The summary of the loading parameters of the 11kV grid (EEU) Incomer feeder measured for 24hrs is given in table 3.2

Table 3. 2: 11kV grid incoming measured power and quality conditions

Description	kV	I	MVA	MW	MVar	PF	%Uthd	%Ithd	Vunb	Aunb
Minimum	10.03		3.286	2.634	1.961	0.791	0.867	2.200	0.400	1.700
Average	10.42		3.849	3.140	2.222	0.814	1.115	2.724	0.488	2.397
Maximum	10.86		4.252	3.570	2.365	0.839	1.400	3.167	0.500	2.900

The grid incoming active power varies from 2.634MW~ 3.570MW, apparent power 3.286MVA~ 4.252MVA and reactive power 1.961MVar ~ 2.365MVar during the study on production day over 24hrs. The trend is given in figure 3.3 below:

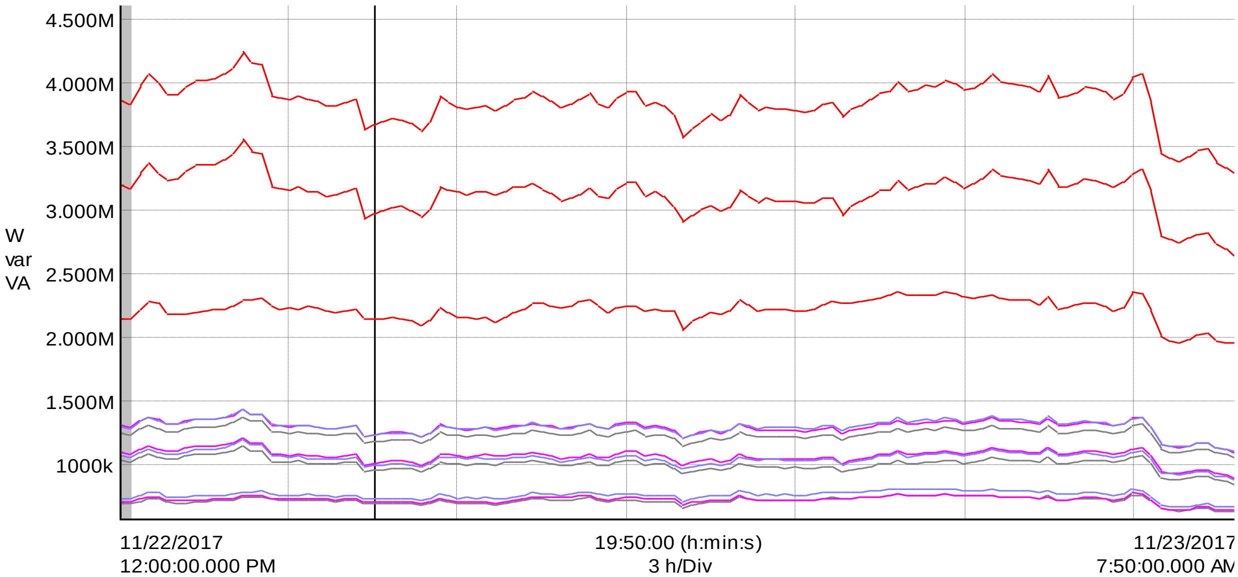

Figure 3. 3: EEU/grid incoming power trend.(C.A 8335 power and quality analyzer output)

Figure 3. 4: During Measurement of power and power quality on 11kV at HT side.

3.2.2 Existing (2x3.5MW) turbine generators bus bar parameters measurement

Power parameters and voltage conditions at the two existing steam turbine generators are measured at HT incoming panel is listed as follows. The Power parameters of Turbine No 1 generation Incomer panel were measured at the HT level/3.3kV, parameters such as incoming voltage profile, frequency, harmonics, variation in load current, kW, kVA, power factor with respect to time is given in **Appendix – 3/2.** The Summary of the loading parameters of the Turbine No 1 and No 2 generation Incomer feeders are given in table 3.3 below and in table 3.4 respectively.

Table 3. 3: Turbine 1 generator bus bar measured power and quality conditions.

Description	kV	I	MVA	MW	K Var	PF	%Uthd	%Ithd	f(Hz)
Minimum	3.23	290	1.808	1.695	-822.6	0.919	1.100	2.200	49.98
Average	3.27	521	1.980	1.889	-557.9	0.953	1.103	2.724	50.04
Maximum	3.29	581	2.307	2.250	-419.8	0.976	1.201	3.167	50.07

Table 3. 4: turbine 2 generator bus bar measured power and quality conditions

Description	kV	I	MVA	MW	K Var	PF	%Uthd	%Ithd	f(Hz)
Minimum	3.26	290	1.493	1.386	-822.6	0.909	1.100	2.200	49.98
Average	3.01	521	2.645	1.889	-557.9	0.923	1.103	2.724	50.02
Maximum	3.31	581	3.107	2.250	-419.8	0.946	1.201	3.167	50.06

The existing turbine generator 1 active power varies from 1.695MW~ 2.250MW, apparent power 1.808MVA~ 2.307MVA during the study on production day over 24hrs. The trend is given in figure below

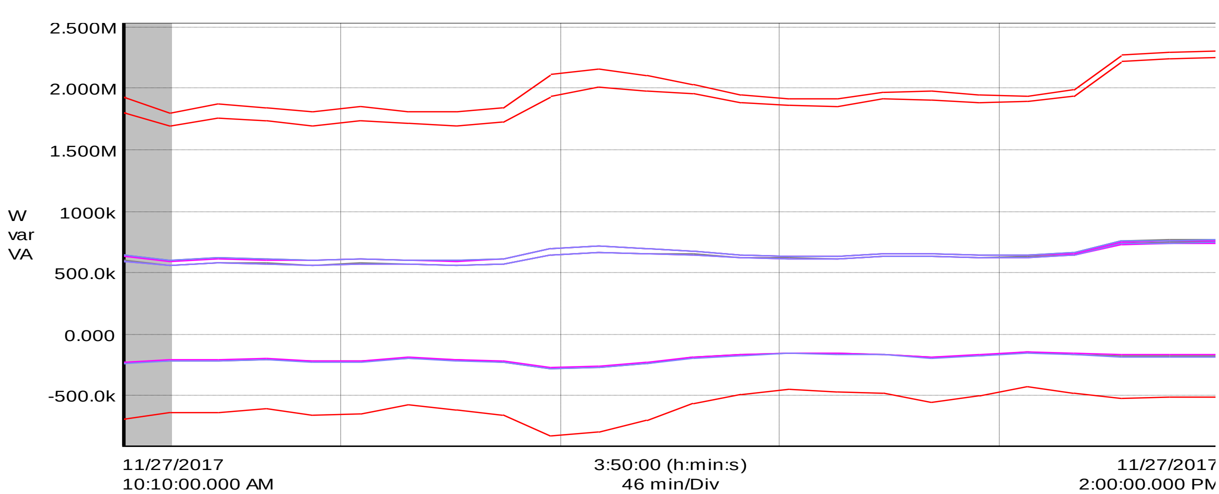

Figure 3. 5: Turbine 1 Existing generator power generated trend.

The real power (kW) trend of the turbine 1/existing generator 1 is indicated on the following figure 3.6 below.

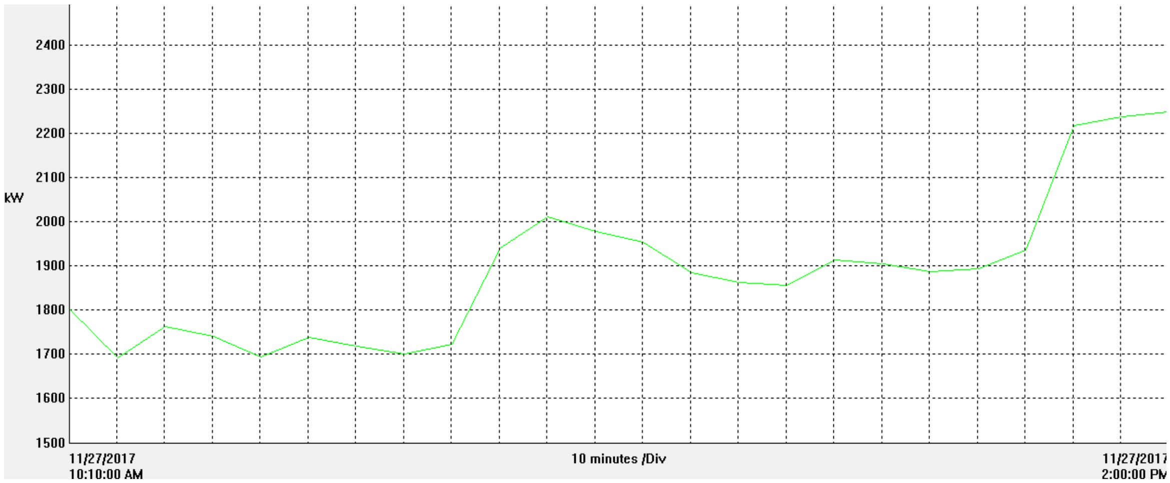

Figure 3. 6: Existing turbine 1 (one) kW generation trend.

3.2.3 Existing boiler 1 MCC11, (ID, OFA and FD fans) measurement

The Power parameters of existing boiler no 1 ID, OFA & FD fans MCC11 (Incomer panel) were measured at the HT, parameters such as incoming voltage profile, variation in load current, kW, kVA, power factor with respect to time is given in Appendix **– 3/3.** The Summary of the loading parameters of the existing boiler No 1 ID OFA & FD fans Incomer feeder are given in table 3.5 it is observed that the ID fan (450HP) is provided with VFD.

Table 3. 5: MCC11 measured loading parameter

Description	kV	I	kVA	KW	kVar	PF	%Uthd	%Ithd	Vunb	Aunb
Minimum	0.000		0.000	0.000	0.000	0.902	0.100	0.00	0.100	0.600
Average	0.3757		499.512	454.07	207.87	0.908	3.801	14.197	0.128	0.707
Maximum	0.4038		560.804	510.19	232.81	0.910	4.200	15.901	0.400	0.800

The load on MCC11 panel (existing boiler no 1 ID, OFA and FD fans) varies between 0(due to interruption) to 510.19kW during assessment on production. The apparent power also varies between 0 ~ 560.804kVA and reactive power 0.000 ~ 232.81kVar. (The plant was suddenly down during this measurement)

The trend of MCC11 monitored power is given in figure 3.7

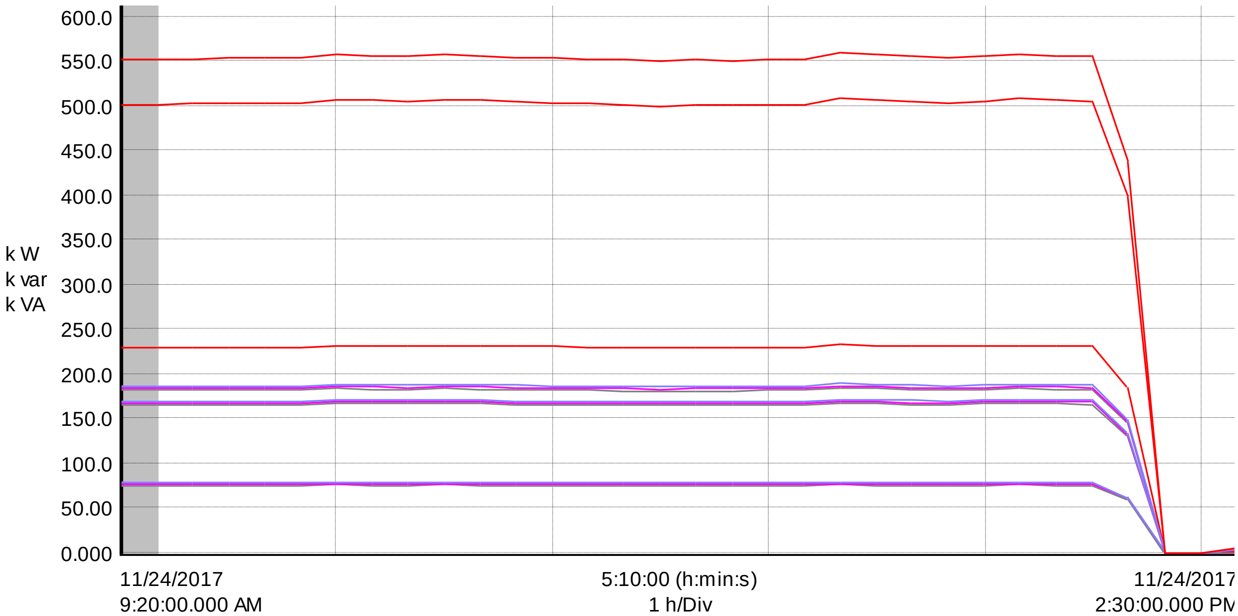

Figure 3. 7: MCC11 loading parameters trend

The trend of power parameters monitored at this motor control center was falls to zero due to sudden plant stoppage.

3.2.4 Power quality

In addition to having deleterious effect on the life of end use equipment the power quality problems have an impact on energy utilization. Harmonics and voltage unbalances are the two types of power quality problems assessed in this work by using power and harmonic analyzer to compare with existing industry standards (IEEE-519) and see their impact on energy performance if there is any deviation.

Harmonics occurs as spikes at intervals which are multiples of the main (supply) frequency and these distort the pure sine wave form of the supply voltage and current [**14**]. Harmonics are multiples of the fundamental frequency of an electrical power system. If, for example, the fundamental frequency is 50Hz, then the 5th harmonic is five times that frequency, or 250Hz. Likewise, the 7th harmonic is seven times the fundamental or 350Hz, and so on for higher order harmonics.

When harmonic current flow in a power system, they are known as "poor power quality" or "dirty power". This leads into voltage drop, low power factors and reduced capacity [**15**]. Other causes of poor power quality include transients such as voltage spikes, surges, sags, and ringing. Because they repeat every cycle, harmonics are regarded as steady state cause of poor power quality.

During this study the total harmonic distortion (THD) of voltage and current were also monitored at PCC, MCC levels as well as at the load end. The main industry standard used for harmonics in a power system is referred to IEEE – 519. Table 3.6 summarizes the total harmonic distortion as observed at the incomer level of the feeders.

Table 3. 6 summary of measured total harmonic distortion level at PCC, MCC/HT feeders

Descriptions	% THD (V)/ %Uthd	%THD (I)/ %Ithd
12MW EEU/grid incoming/ average	1.115	2.724
3.5MW existing generator 1 feeder / average	1.103	2.724
3.5 MW existing generator 2 feeder/ average	1.103	2.724
MCCs average	3.22	8.91

The trend of monitored %THD (total harmonic distortion) level with Power quality analyzer (output trend) is shown in figures below.

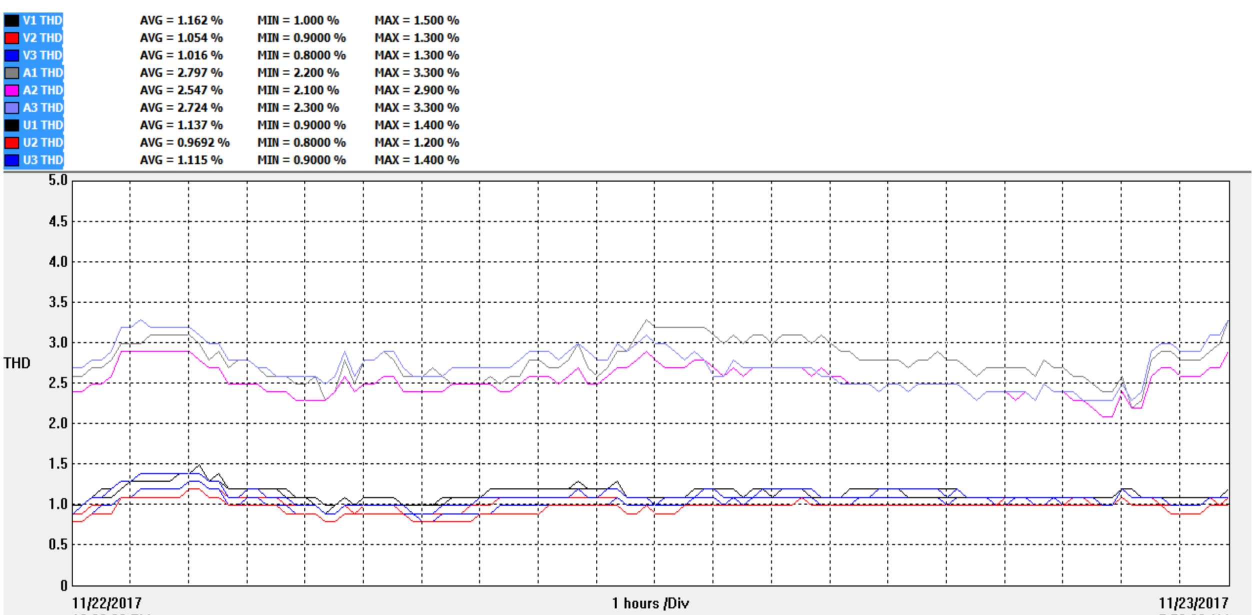

Figure 3. 8: 11kV EEU/grid incoming harmonic distortion trend.

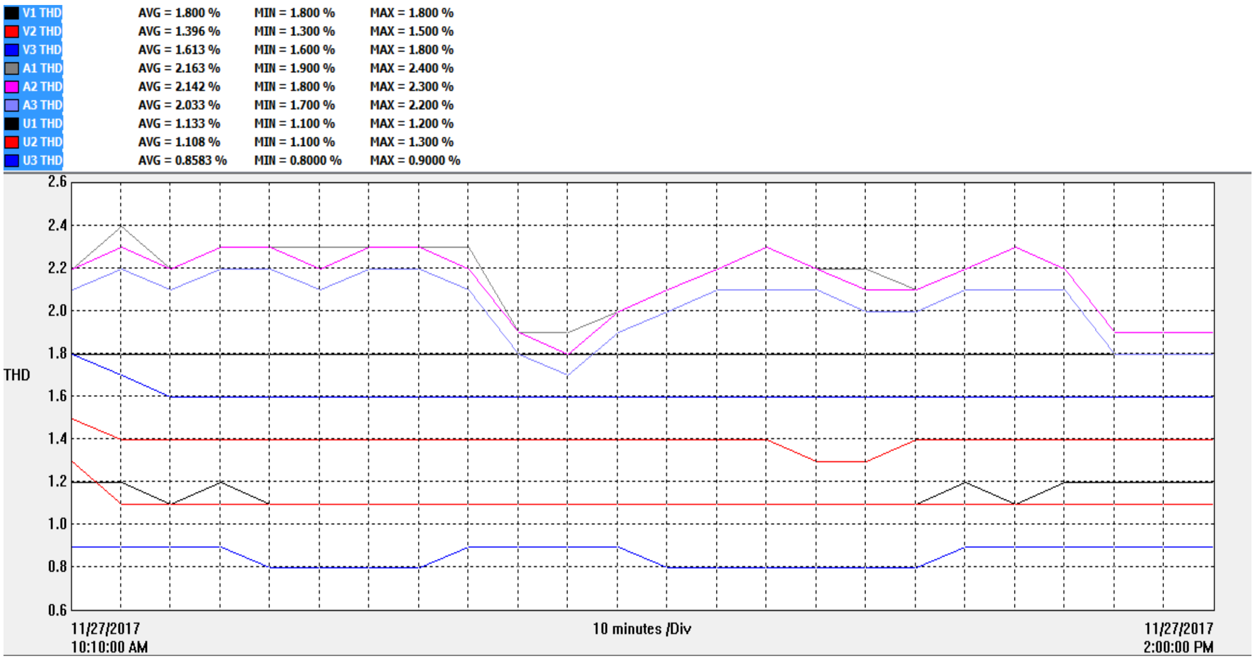

Figure 3. 9:1 3.5MW generator 1 feeder harmonic distortion trend.

As per IEEE-519, the % voltage distortion should be below 5.0%. Total harmonic distortion of current (%THD- I) should be below 15.0% and as observed from the analysis at the main incomer at the Transformer, the % THD (V) and % THD (I) is well within the limit as specified in IEEE – 519 standard.

Another power quality aspect analyzed in this study is voltage unbalance. The common causes of voltage unbalances in any industry could be, improper transformer tap settings, single-phase loads not balanced among phases, poor connections, bad conductors, and transformers ground or faults capacity. A 5% voltage unbalance causes a 40% increase in motor losses [14]. Motor vibration and premature motor failures are also other possible effects of voltage unbalance. The voltage unbalance in FSF is also checked at PCC, MCCs and at motor terminals as well and compared against IEEE- 519 standard. The trend of the unbalances at 11kV PCC and 3.3kV feeder are given in the following figures.

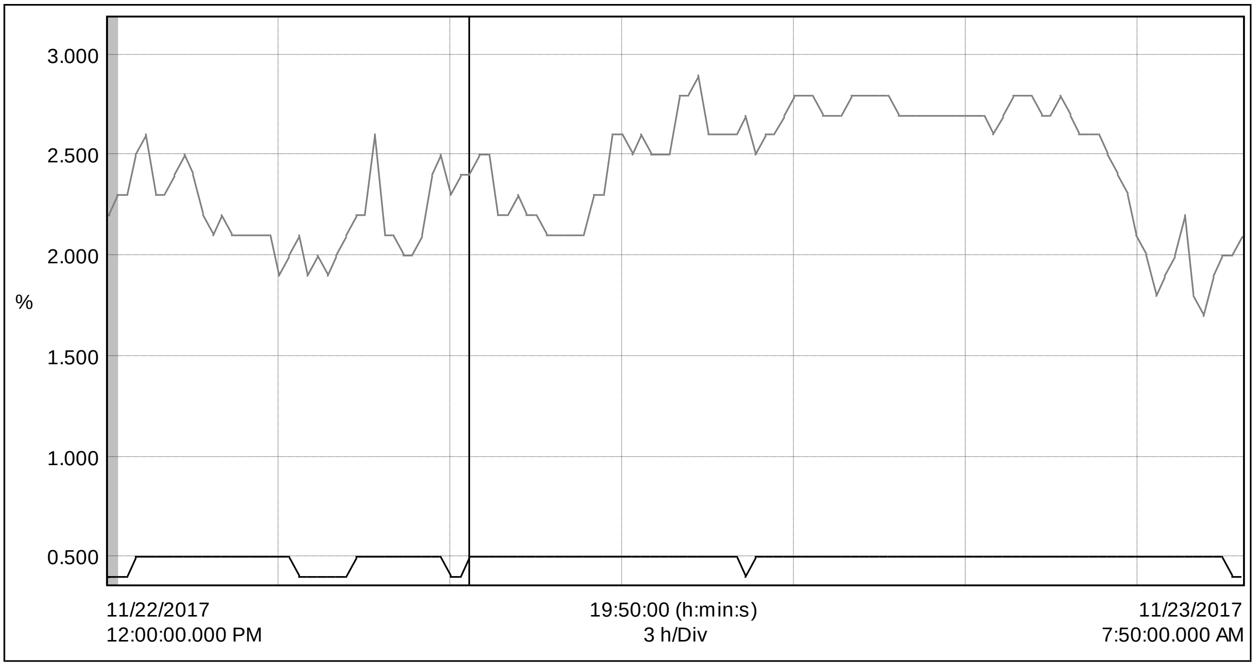

Figure 3. 10: 11kV EEU/grid incoming unbalance trend.

The average voltage unbalance is about 0.5% and the average current unbalance is about 2.4%. As observed from the trend/analysis at the main incomer the measured unbalance is well within the limit as specified in industry standard.

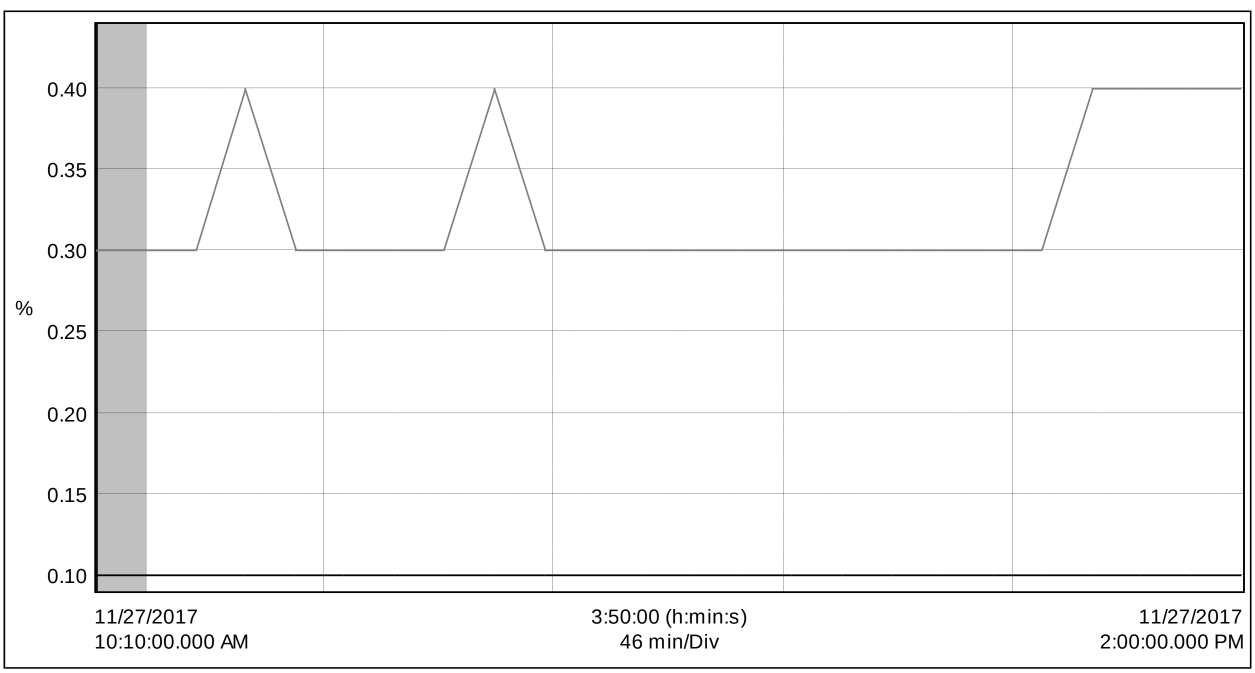

Figure 3. 11: 3.5MW generator feeder unbalance trend.

In this case also the trend/analysis at the main incomer indicates that the measured unbalance is well within the limit as specified in industry standard.

3.2.5 Power factor management and Automatic power factor controllers

A low power factor contributes toward high distribution losses. The maximum demand can also be reduced at the plant level by using capacitor banks and maintaining the optimum power factor. Capacitor banks are available with microprocessor based control systems. These systems switch on and off the capacitor banks to maintain the desired power factor of system and optimize the maximum demand thereby [14].

Many of the industries desire to maintain power factor near to unity with the objective of minimizing the maximum demand as well as availing PF incentives offered by distribution companies. When the loads in industries are fluctuating, it becomes difficult to maintain near unity PF with fixed capacitor banks. At low loads there is a possibility of PF going into leading side which can create high voltages at the motor terminals. In such cases the maximum demand will also rise. To overcome this situation automatic power factor controllers (APFC) are deployed. Power factor controllers are typically panel mount and used like a panel mount meter, indicating the power factor at the point of supply.

Figure 3. 12: Automatic power factor control relay [14]

Power factor controllers are programmable and range from quite simple to very complex. A simple power factor controller monitors the displacement power factor. The controller displays power the factor on a digital display and compares the measured power factor with desired power factor. If the power factor is less than the desired power factor, another bank of capacitors is switched on via relay output on the controller. If the power factor is leading, or is the above a threshold point, a bank of capacitor is switched off. Typically, the number of outputs will range from 6 to 14 relays. There are a number of other options that can be included in such as harmonic current alarms and low current thresholds to prevent capacitors being connected under very light loads [14].

In industrial distribution systems the major loads are resistive and inductive. Resistive loads are incandescent lighting and resistance heating. In case of pure resistive loads, the voltage (V), current (I), resistance (R) relationships are linearly related. Typical inductive loads are A.C. motors, induction furnaces, transformers, and ballast-type lighting. Inductive loads require reactive power in addition to active/working power to create and maintain electro-magnetic fields.

During this study the power factor is measured at PCC, MCC levels in both existing and new sugar plant. The trend of power factor measured at PCC level is given in the following pictures.

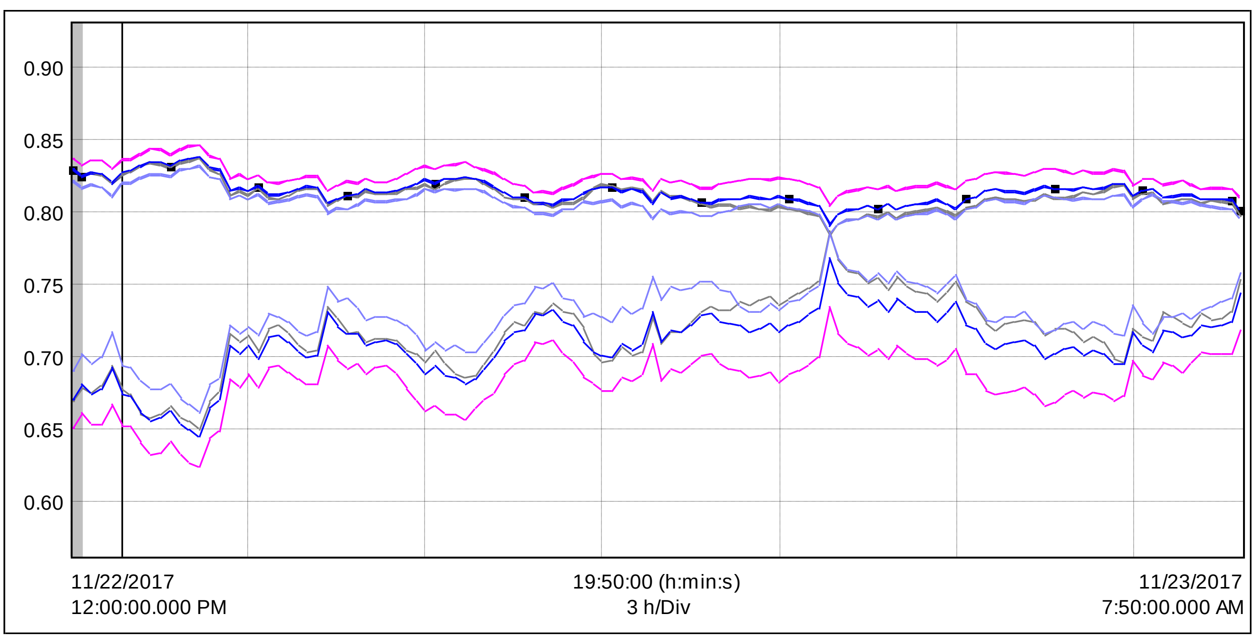

Figure 3. 13: 11kV grid incoming power factor trend

The power factor measured at 11kV PCC level varies between 0.791~ 0.839pf with an average of 0.814. (11kV PCC average power foctor is indicated with line with dotes figure 3.13).

The power factor measured at one of 3.5MW existing generator trend is also shown in the following figure.

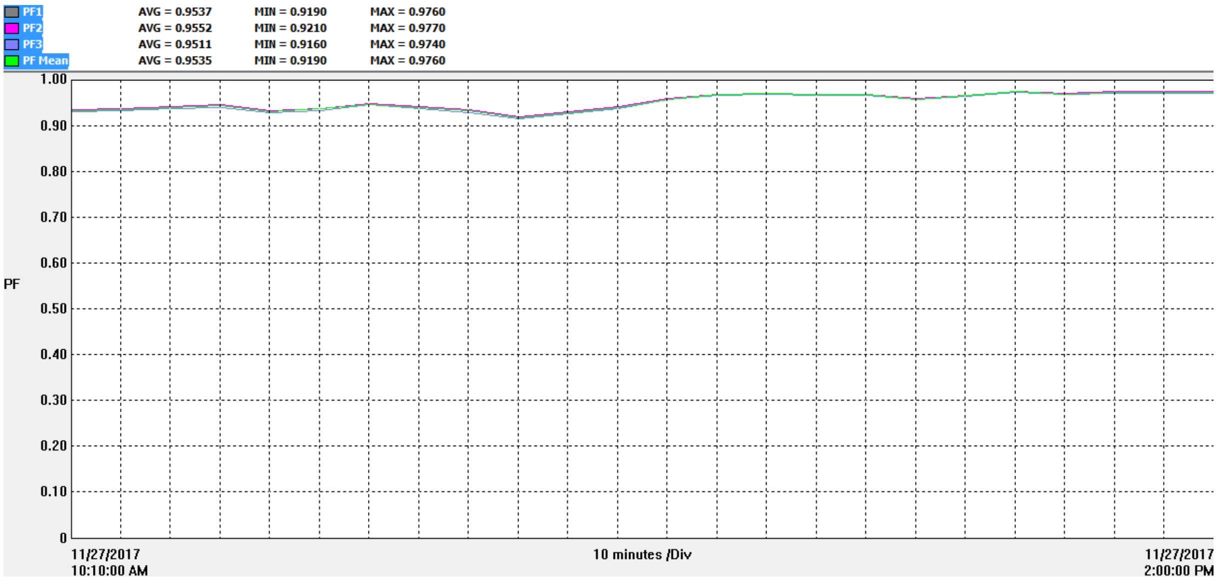

Figure 3. 14: 3.5MW existing generator trend /feeder power factor trend

The power factor measured at 3.5MW existing generator1 varies between 0.91~ 0.961pf with an average of 0.943. This indicates that the power factor at existing generator feeder is maintained well within the limit.

The power factor is monitored at old sugar plant MCCs with another power analyzer and the summary of measurement is presented in table 3.7

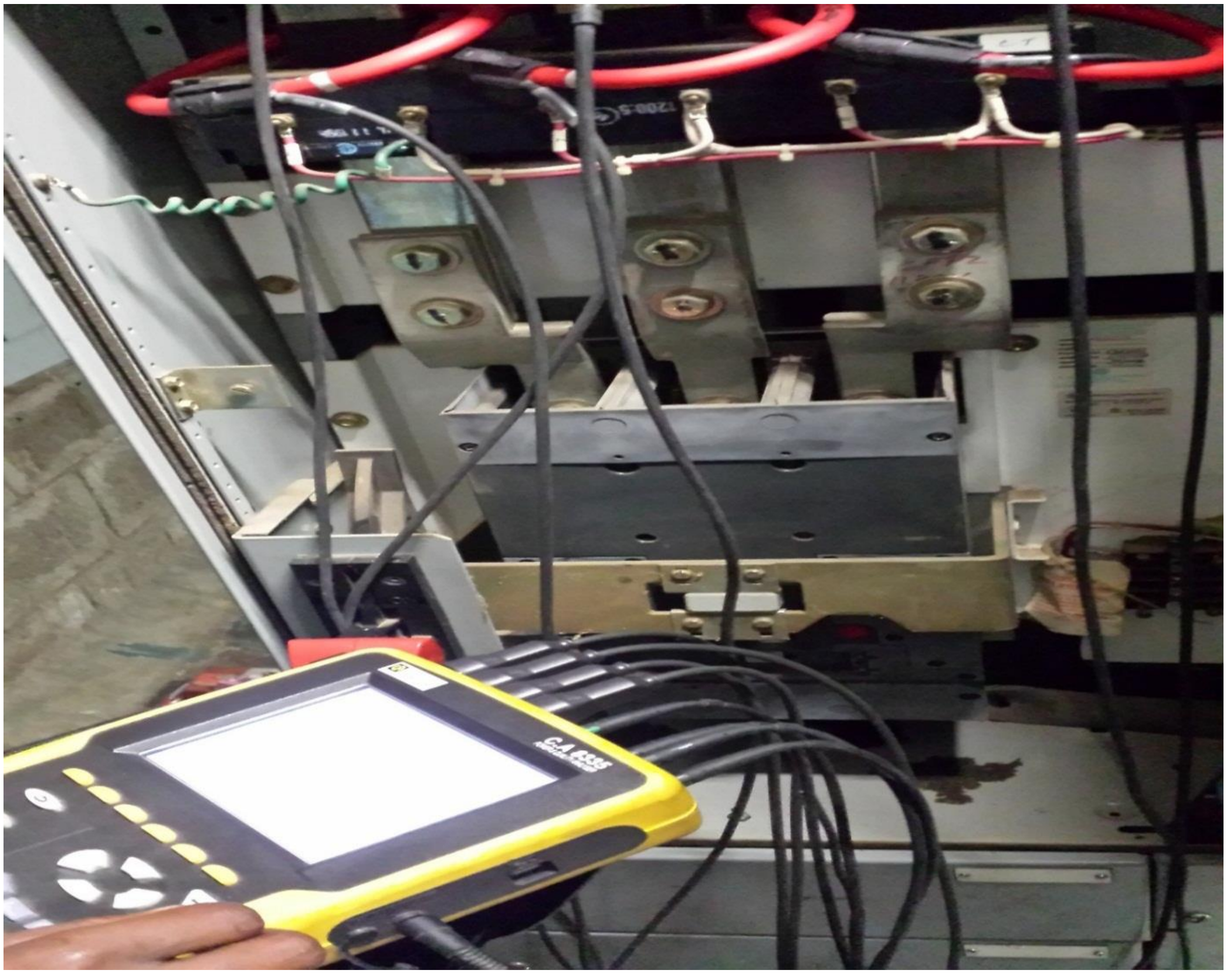

Figure 3. 15: During Measurement of power and power quality of some MCCs in old plant

Table 3. 7 summary of measured parameters at old sugar plant MCCs

Descr.	kV	I	kVA	kW	kVar	PF	%Uthd	%Ithd	Vunb	Aunb
MCC4	0.389	102.38	68.81	41.25	38.49	0.689	1.712	2.413	1.100	2.600
MCC5	0.391	285.82	195.06	139.6	132.94	0.768	2.611	3.112	1.003	1.707
MCC8	0.395	260.02	231.01	198.91	117.48	0.861	1.981	2.762	1.013	2.091
MCC9	0.399	98.73	68.232	53.971	232.81	0.791	1.561	2.212	0.400	0.800

3.3. Observation and Analysis

As observed from electrical measurement system on PCCs/MCCs indicates, the following observation is deduced:

- The average power factor measured at 11kV grid incoming PCC is 0.814, which is less than optimum.
- Other power quality parameters such as, voltage and current (THD), voltage unbalance and frequency variations are well within the IEEE-519 standard.
- The average power factor measured at 3.5MW existing generator turbines are well within the limit. Other power quality parameters such as, voltage and current (THD), voltage unbalance and frequency variations are well within the limit.
- The average power factor measured at MCC4, MCC5, MCC8, MCC9 are less than optimum, which is 0.803pf.

3.3.1 Energy conservation measures

The maximum demand can also be reduced at the plant level by installing capacitor banks and APFC, similar to some new plant MCCs, then maintaining the optimum power factor. These systems switch on and off the capacitor banks to maintain the desired power factor of system and optimize the maximum demand thereby [15].

Based on the observations/ findings during the assessment conducted on the electrical system of the plant, one of the energy conservation measures (ECM) identified is Installation APFC control panel and additional kVAr banks in New plant PCC/MCCs. Maintaining PF to optimum level of 0.95 will reduce significantly the distribution losses. Hence, 1225kVAr capacitor bank and APFC need to be installed at 11kV PCC/MCC panels (300kVAr in 4 MCCs). The selection has been done by Blakley Electrics/green power spreadsheet. (www.blackleyelectrics.gps)

3.3.2 Energy and Cost saving analysis with RETScreen

Saving analysis is done with RETScreen Version 4 energy efficiency model after selection has been done. And the saving outputs are:

Energy and cost saving analysis:

- Reduction in demand is 0.532MW, the demand is reduced from 3907kVA (original load) to 3348kVA (corrected load) the reduction in demand is about 560kVA.
- Energy savings = 2,442MWh, 13.4%
- Energy cost saving : 44,205USD
- Incremental initial cost = 157,500USD

Financial analysis:

- Pre-tax IRR asset % 36.2%
- Simple pay back year 3.6
- Equity pay back year 3.1

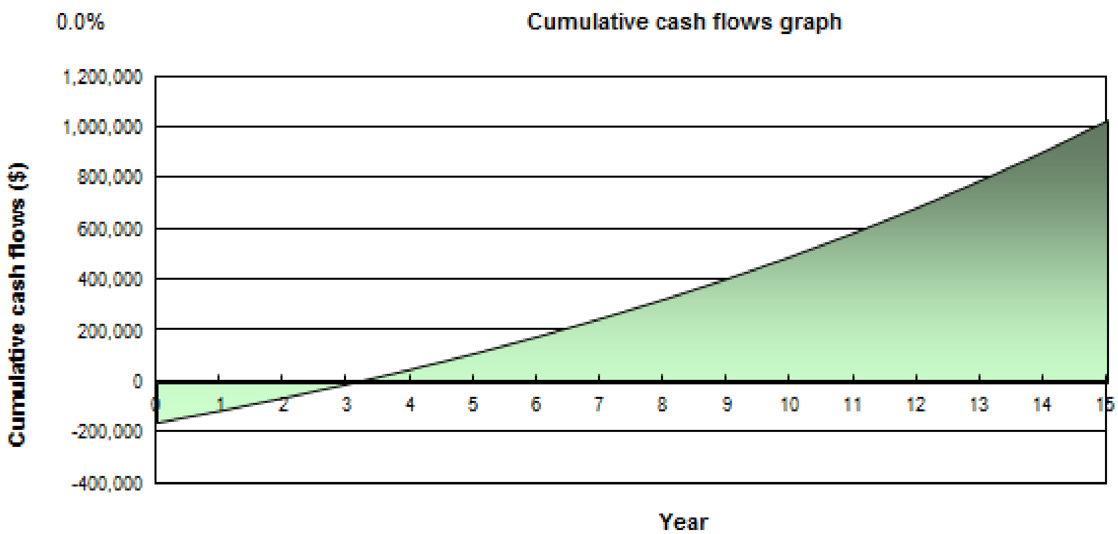

Figure 3. 16: financial analysis output of installation of APFC at 11kV PCC/MCC

Installation of APFC control panel and additional kVAr banks in old sugar plant MCC panel's room is another ECM identified that could save significant amount of energy there by reducing maximum demand. Maintaining PF to optimum level of 0.95 at identified old MCC panels with low power factor on table 3.7 reduce the distribution losses. Hence, 150kVAr capacitor bank/APFC need to be installed at MCC panels. Saving analysis is done with RETScreen Version 4 energy efficiency model. And the saving outputs are:

Energy and cost saving analysis:

- Reduction in demand is about 90kW

- Energy savings = 427Mhr, which is about 18.4% of base case electricity consumption.
- Energy cost saving : 7,725USD
- Incremental initial cost = 25,714USD

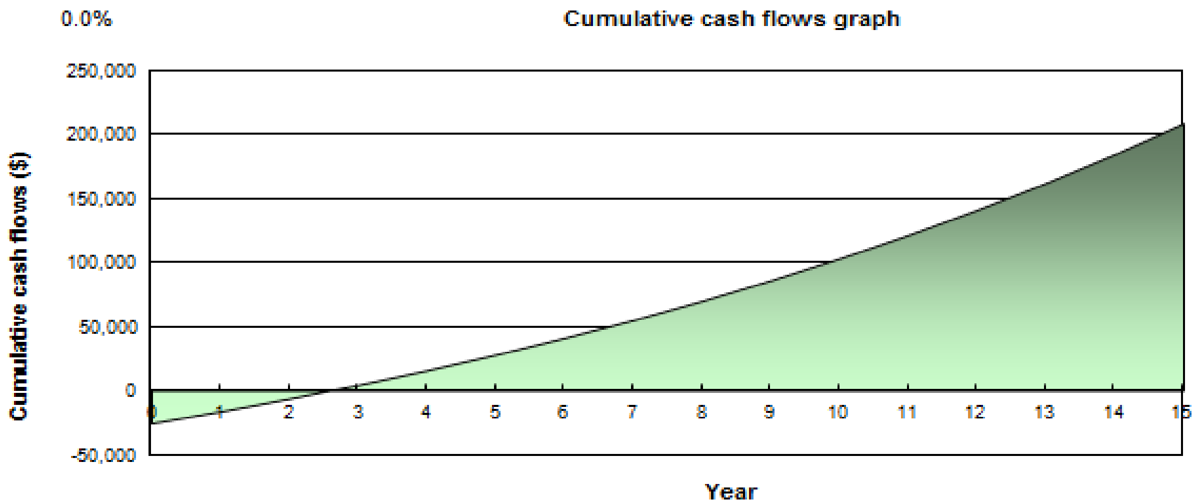

Figure 3. 17: financial analysis output of installation of APFC at old plant MCC

Financial analysis:

- Pre-tax IRR asset % 42.8%
- Simple pay back year 2.9
- Equity pay back year 2.6

3.4. Electric motors and their Energy performance Assessment

Motors convert electrical energy into mechanical energy by interaction between the magnetic fields set up and in their stator and their rotor windings. Industrial electric motors can be classified as induction motors, direct current motors or synchronous motors. All motors types have the same operating components.

The two parameters of importance in a motor are efficiency and power factor. The efficiencies of induction motors remain almost constant between 50% to 100% loading [17].

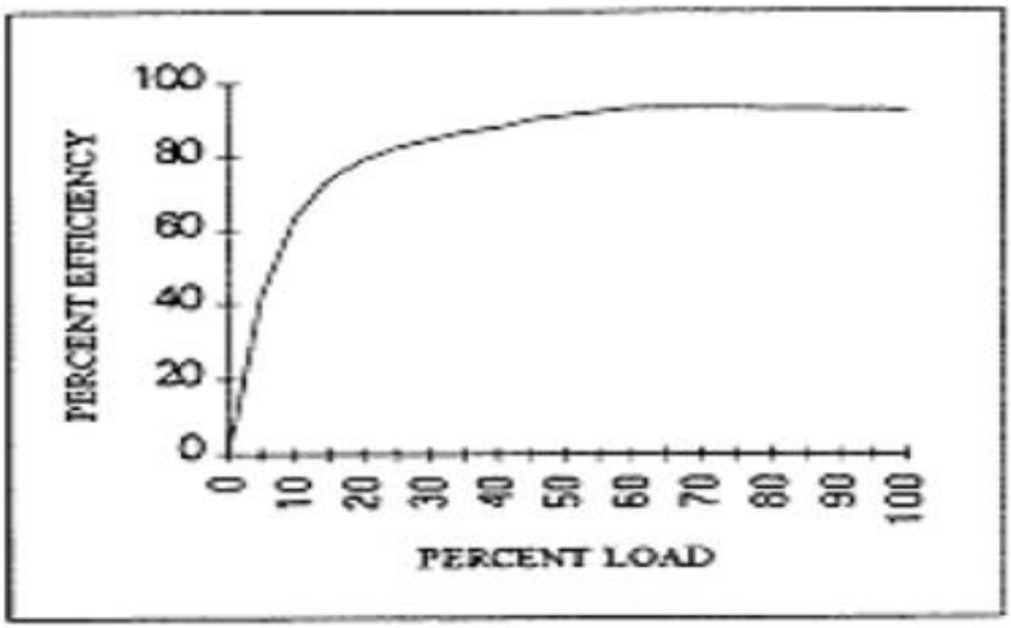

Figure 3. 18: Motor Efficiency Vs. loading [17]

With motors designed to perform this function efficiently; the opportunity for savings with motors rests primarily in their selection and use. When a motor has a high rating than that required by equipment, motor operates at part load. In this state, the efficiency of the motor is reduced. Replacement of under loaded motors with smaller motors will allow a fully loaded smaller motor to operate at a higher efficiency. This arrangement is generally most economical for larger motors, and only when they are operating at less than one-third to one-half capacity, depending on their size [17].

3.4.1 Motor Efficiency

Two most important attributes relating to motor efficiency of electricity use by A.C. induction motors are efficiency (η), defined as ratio of the mechanical energy delivered at the rotating shaft to the electrical energy input at its terminals, and power factor (PF). Motors, like other inductive loads are characterized by power factor less than one. As a result, the total current draw needed to deliver the same real power is higher than for a load characterized by a higher PF. An important effect of operating with a PF less than one is that resistance losses in wiring upstream of the motor will be higher, since these are proportional to the square of the current. Thus, both a high value for η and a PF close to unity are desired for efficient overall operation in a plant [12].

High speed motors are normally more efficient than lower speed motors. Efficiency is also a function of motor temperature. Totally, enclosed fan cooled (TEFC) motors are more efficient than screen protected, drip-proof (SPDP) motors. Also, as with most equipment, motor efficiency increases with the rated capacity. The efficiency of a motor is determined by intrinsic losses that can be reduced only by changes in motor design. Intrinsic losses are of two types: fixed losses- independent of motor load, and variable losses- dependent on load.

Part-load performance characteristics of a motor also depend on its design. Both η and PF fall to very low levels at low loads. Figure 3.19 shows the effect of load on power factor and efficiency. It can also be seen that the power factor drops sharply at part loads. The figure shows the effect of speed on power factor.

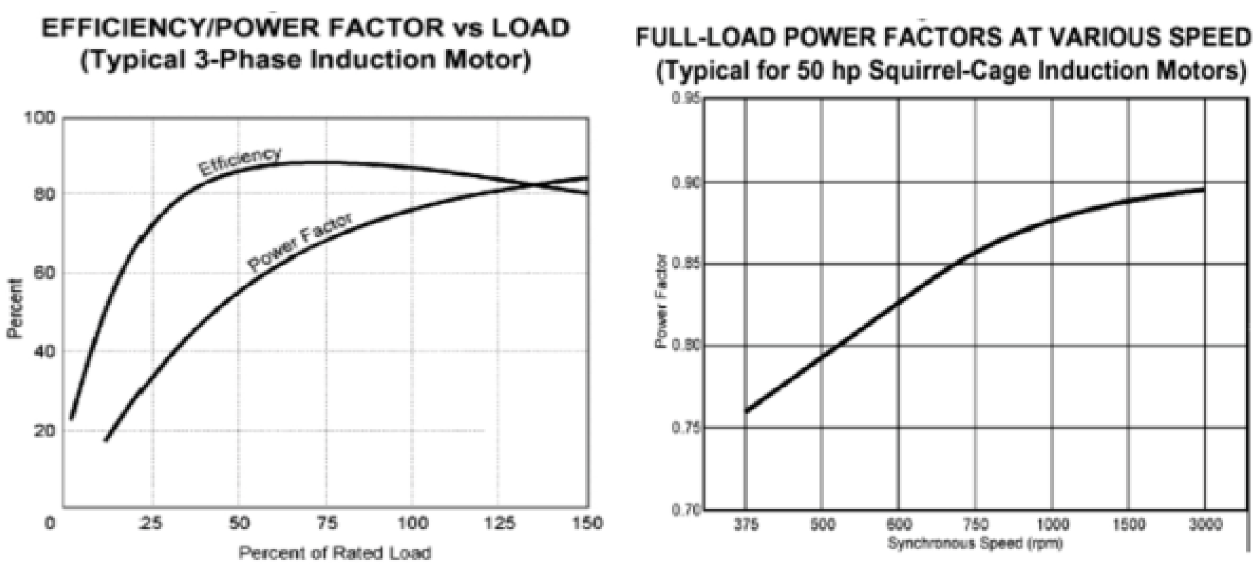

Figure 3. 19: % loads vs. power factor, efficiency and speed vs. power factor [12]

3.4.2 Motor selection and energy efficient motors

The primary technical consideration defining motor choice for any particular application is the torque required by the load, especially the relationship between the maximum torque generated by the motor (break-down torque) and the torque requirements for start-up (locked rotor torque) and during acceleration periods [19]. The duty/load cycle determines the thermal loading on the motor. One consideration with TEFC motors is that the cooling may be insufficient when the motor is operated at speeds below rated value. Ambient operating conditions affect motor choice;

special motor designs are available for corrosive or dusty atmospheres, high temperatures, restricted fiscal space, etc.

Energy efficient motors (EEM), are the ones in which, design improvements are incorporated specifically to increase operating efficiency over motors of standard design **[17].** Design improvements focus on reducing intrinsic motor losses. Improvements included the use of lower-loss silicon steel, a longer core (to increase active material), like thicker wires (to reduce resistance), thinner laminations, smaller air gap between stator and rotor, copper, instead of aluminum bars in the rotor, superior bearings and smaller fan etc.

3.5. Measured loading parameters of major drivers (motors)

The factory (FSF) has several LT (400v) motors in each section of the plant and the measurements were taken during the operation of the plant at major drivers' incomer MCC panels. Studies on major LT motors involve measurements of electrical load parameters namely, volts, amperes, PF, THD, kW drawn.

Figure 3. 20: During measurement of motor input power and nameplate data collection

3.5.1 Loading parameters of major drivers in boiling house

Table 3. 8: Loading parameters of major drivers in boiling house

Description	V	I	Kw	KVA	KVar	Pf	%Uthd	%Athd
MCC8 sugar drier ID fan	385.7	60.9	29.8	40.7	27.7	0.732	2.01	2.81
MCC8 Cane wash pump	390.5	161.3	87	109	65.7	0.79	1.5	2.3
MCC8 final molasses transfer pump	391.5	13.61	9.2	9.23	0.67	0.996	1.12	2.41
MCC9A continuous centrifugal	-	-	-	-	-	-	-	-
MCC9 C continuous centrifugal 2	380.4	78	38	52	35.49	0.77	1.56	2.21
MCC9 B continuous centrifugal 3	381							
MCC10 massacuite pump	389	12.91	2.21	8.5	8.2	0.26	1.63	3.86

5.2.2 Loading parameters of major drivers in clarification

Table 3. 9: Loading parameters of major drivers in clarification

Description	V	I	KW	KVA	KVar	Pf	%Uthd	%Athd
MCC 6 $7, weigh juice pump	391.9	203.2	118.1	138	71.3	0.855	1.4	1.65
Condensate vacuum pump	387	14.6	7.35	9.8	6.3	0.75	1.4	2.6

3.5.3 Loading parameters of major drivers in cane preparation

Table 3. 10 Loading parameter of major drivers in cane preparation

Description	V	I	KW	KVA	KVar	Pf	%Uthd	%Athd
MCC5 main cane carrier	388.1	57.9	27.9	38.9	27.1	0.717	2.95	3.01
MCC5 cane elevator	388.6	60.3	26.2	40.6	30	0.645	1.91	2.61
MCC5 inter carrier 2	389.6	26.85	10.15	18.13	15.02	0.559	2.91	3.59
MCC5 inter carrier 3	388.5	26.87	10.24	16.73	13.23	0.612	2.90	3.00
MCC4 cane feeder table 1	388.2	48.20	28.27	32.43	15.88	0.871	1.51	1.93
MCC4 feed table 1 lever	387.8	27.09	6.49	18.19	16.99	0.356	1.71	2.41
MCC 5 B continuous centr cont.	409.00	113.9	65.11	80.70	47.61	0.806	1.01	1.33

3.5.4 Loading parameters of major drivers at cooling tower

Table 3. 11 Loading parameter of major drivers in cooling tower

Description	V	I	Kw	KVA	KVar	Pf	%Uthd	%Athd
MCC1 CT water supply pump	382.3	41.6	24.12	27.57	13.35	0.874	0.941	1.43
New CT circulation water pump 3	410	356	126.9	162.0	100.6	0.780	2.30	5.89
New CT circulation water pump 4	410	223	132	158.7	87.8	0.833	1.34	1.92
New CT injection pump 1	404	419	239.2	293.6	170.2	0.814	1.21	1.62
New CT injection pump 3	405	430	251.3	301.9	140.5	0.713	0.981	1.40
Condenser CT fan no 1	413	64.9	29.8	46.4	35.5	0.642	0.91	1.02
Condenser CT fan no 2	410	72.8	34.2	51.7	38.7	0.661	1.00	1.10
Bearing cooling water pump	402	183	127	127.4	9.10	0.996	1.31	1.61

3.5.5 Loading parameters of major drivers at boilers Auxiliaries

Table 3. 12 loading parameter of major drivers at boilers Auxiliaries

Description	V	I	Kw	KVA	KVar	Pf	%Uthd	%Athd
New boiler no 4 feed water pump	411	288.7	205.1	205.5	12.2	0.998	1.07	1.591
Exist. boiler no 1 feed water pump	382.3	182.1	120.3	120.6	8.5	0.997	2.21	5.23
Exist. Boiler no 1 OF fan	386	153.4	102.4	102.6	6	0.998	1.06	1.91
Exist. Boiler no 1 FD fan	386.1	145	75.5	97	60.8	0.776	1.11	2.04

3.6. FSF Motor load survey: Methodology

The factory has massive population of LT motors. Load survey of LT motors is taken to methodologically identify improvement options. Representative LT motor drives among the motor population, for analysis. The criteria considered are:

- Utilization factor i.e. hours of operation with preference given to continuously operated drives.
- Sample representative basis, where one drive motor analysis can be reasoned as representative for the population. Example. cooling tower fans,

- Conservation potential basis, where drive motors with inefficient capacity controls on the machine side, fluctuating load drive systems, etc. are considered.

In the assessment of motor loading in the FSF, since the power measurement is conducted by using hand held power meter (fluke) and power quality analyzer, the most accurate method which is by power measurement method is used. Therefore motor loading is estimated by using the following equation;

% loading of the motor can be estimated by the following relation:

$$\%\text{loading} = \frac{input\ power(kw)\ drawn\ by\ the\ motor\ at\ existing\ load}{nameplate\ fullload\ in\ kW\ rating/\text{Nameplate rated efficiency}}\ \text{x100} \ldots\ldots\ldots\ldots (3.6)$$

Motor efficiency:

Efficiency (η) of the motor is given by:

Efficiency (η) of the motor is given by: the ratio of mechanical output to electrical power input is usually expressed as,

$$\eta = \frac{nameplate\ rated(kW)x\ load}{Pi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

Where:

η = efficiency operated in %

Load = output power as a % of rated power.

Pi = measured three-phase power in kW

By using above equations (3.6) and (3.7) the summary of major drivers in each plant section is summarized in tables.

Table 3. 13: Estimated efficiency, %loading summary of major drivers in boiling house

Description	Input power(kW)	Nameplate power(kW)	Nameplate (RPM)	Output power(kW)	Efficiency(η) (%)	Loading (%)
MCC8, SDI	29.8	93	1480	28.27	94.86	30.4

MCC8, CWP	87	110	1420	78.3	90	71.3
MCC8,	9.2	15	2800	7.8	84.78	52.1
MCC9C2	38	75	1480	32.26	84.9	43.1
MCC10msct	1.46	22	2910	1.241	85	5.64

Table 3. 14: Estimated efficiency, %loading summary of major drivers in clarification

Description	Input power(kW)	Nameplate power(kW)	Nameplate (RPM)	Output power(kW)	Efficiency(η) (%)	Loading (%)
MCC6,w j p	29.8	93	1480	28.27	94.86	30.4
MCC8, CWP	87	110	1420	78.3	90	71.3

Table 3. 15: Estimated efficiency, %loading summary major drivers in cane preparation

Description	Input power(kW)	Nameplate power(kW)	Nameplate (RPM)	Output power(kW)	Efficiency(η) (%)	Loading (%)
MCC5, mcc	27.9	75	2960	24.7	88.7	33
MCC5,Can.elev	26.2	50	1420	78.3	84.9	44.5
MCC5, inter	10.15	30	1470	7.8	84.8	28.7
MCC4,cfeed	28.27	37	1480	32.26	85.07	65
MCC5B, cnt	65.1	90	1480	1.241	84.3	61

Table 3. 16: Estimated efficiency, loading summary of major drivers in cooling tower

Description	Input power(kW)	Nameplate power(kW)	Nameplate (RPM)	Output power(kW)	Efficiency(η) (%)	Loading (%)
MCC1,CTws	24.12	30	1470	24.7	84.5	68

New CT circ.	126.9	200	1480	119.9	94.5	60
Inject. pump	239.2	315		226.8	94.8	72
Condens. ct						

Table 3. 17: Estimated efficiency, loading summary of major drivers in boilers auxiliary

Description	Input power(kW)	Nameplate power(kW)	Nameplate (RPM)	Output power(kW)	Efficiency (%)	Loading (%)
Exist boiler wp	52	250	1470	24.7	91	19
Exist boiler OF	102.4	185	1480	92.16	90	50
Exist boiler FD	75.5	110	1480	67.95	90	61.8

3.7. Energy saving opportunities in electric motors

Motor load assessment is aimed not only as a measure to identify motor efficiency areas but equally importantly, as a means to check combined efficiency of the motor, driven machine and controller if any. The margins in motor efficiency may be less than 10% of consumption often, but the load assessment would help to bring out savings in driven machines/ systems, which can give 30 – 40% energy savings [19]. With the aim of optimizing energy use efficiency of the motor drives in the industry the following energy saving opportunities in major drive motors are discussed below.

3.7.1. Reducing under loading

One of the most common practice contributing to sub-optimal motor efficiency is that of under-loading. Under loading results in lower efficiency and power factor, and higher-than- necessary first cost for the motor and related control equipment. Under loading is common for several reasons. Such as;

- Original equipment manufacturers tend to use a large safety factor in motors they select.
- Due to under-utilization of the equipment.
- Selection of a larger motor to enable the output to be maintained at the desired level even when input voltages are abnormally low.

- Selection of a large motor for an application requiring high starting torque where special motor, designed for high torque, would have been suitable.

Hence, Careful evaluation of the load would determine the capacity of the motor that should be selected or to be replaced.

Another aspect to consider is the incremental gain in efficiency achievable by changing the motor. Larger motors have inherently higher rated efficiencies than smaller motors. Therefore, replacement of motor operating at 60 – 70% of capacity or higher is generally not recommended. However, there are no rigid rules governing motor selection: the saving potential needs to be evaluated on a case-to-case basis [19]. When downsizing, it may be preferable to select an energy efficient motor, the efficiency of which may be higher than that of a standard motor of higher capacity.

3.7.2. Replacing existing standard efficiency motors with higher efficiency

Energy efficient motors cover a wide range of ratings and the full load efficiencies are higher by 3 to 7% than standard efficiency motors. In which design improvements are incorporated specifically to increase their operating efficiency [12]. Higher energy efficiency motors are last longer and may require less maintenance. Figure 3.7 below indicates energy efficiency of standard versus higher efficiency of typical three phase induction motors.

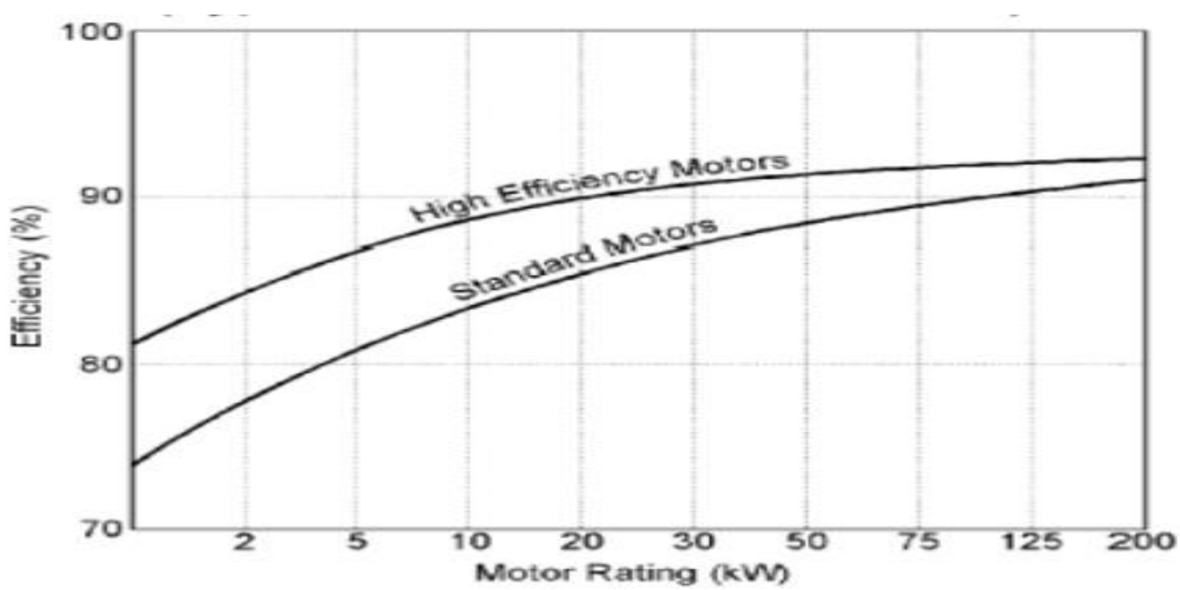

Figure 3. 21: standard versus higher efficiency typical 3 phase induction motors [12]

Replacing existing standard efficiency LT motor population could significantly ensure optimal use of energy. But while planning to replace standard efficient motors with higher energy efficiency motors the incremental gain in efficiency achievable by changing the motor has to be taken into account. Larger motors have inherently higher rated efficiencies than smaller motors. Therefore, replacement of standard efficiency motor has to take into consideration the financial gains. However, there are no rigid rules governing motor selection: the saving potential needs to be evaluated on a case-to-case basis [19].

The costs of energy efficient motors are higher than those of standard motors. The higher cost will often be paid back rapidly through reduced operating costs, particularly in new applications or end-of-life motor replacements. But replacing existing motors that have not reached the end of their useful life with energy efficient motors may not always be financially feasible, and therefore it is recommended to only replace these with energy efficiency motors when they fail [12].

Saving analysis with software tools: (IMSSA) and RETScreen 4

Motor master+ international is used to select and evaluate motor saving analysis of replacing the existing standard efficiency motors in old plants with energy efficient one/higher energy efficiency. LT motors in the old plant are low efficient and evaluated for replacement with new higher efficiency.

IMSSA examine its database and display a report motors ranked in descending order of full load efficiency. The motor saving analysis enables you to identify the most cost effective alternative when making new purchase, repair versus replacement or replacing existing. The IMSSA select and analyze the motor one by one. Hence, in this study IMSSA is just used to select available efficient motors and their cost one by one, that is compatible with motors to be replaced.

In this work motors considered to be replaced, according to their estimated, loading and efficiency are selected and analyzed as follows with Motor Master + international.

- (Boiling house, clarification, cane preparation, cooling tower and boilers auxiliary with less than 50% loading ratio and standard efficient, selection is done with IMSSA and saving analysis done with RET screen 4 energy efficiency model)

IMSSA Analysis for MCC9C2, continuous centrifugal pump: (loading and efficiency is given on table 3.6.1)

IMSSA, Motor sector: finds the most efficient motor for this pumping application and create performance and purchase information for the motors selected:

Inputs to motor selector windows are:

- motor type: IEC Design N
- motor size: 75kW (nameplate data)
- speed/poles (rpm): 1500rpm (nameplate data)
- degree of protection: IP55
- Voltage: 400V are the main input to and then the available motors of selected manufacturers or all are appeared in descending order of their full-load efficiency value.

As indicated below in figure 3.7B motor selector displays 52 available motors in IMSSA data base provided by different manufacturers. Among 52 available motors IC – premium efficient motor of (95.2%) manufactured by WEG manufacturer is selected.

To replace this existing motor with premium efficiency motor of 75kW, the total cost is about 5,759USD (US dollar) [28]. [WEG, All-purpose low Voltage Motors, Price List, 2015]

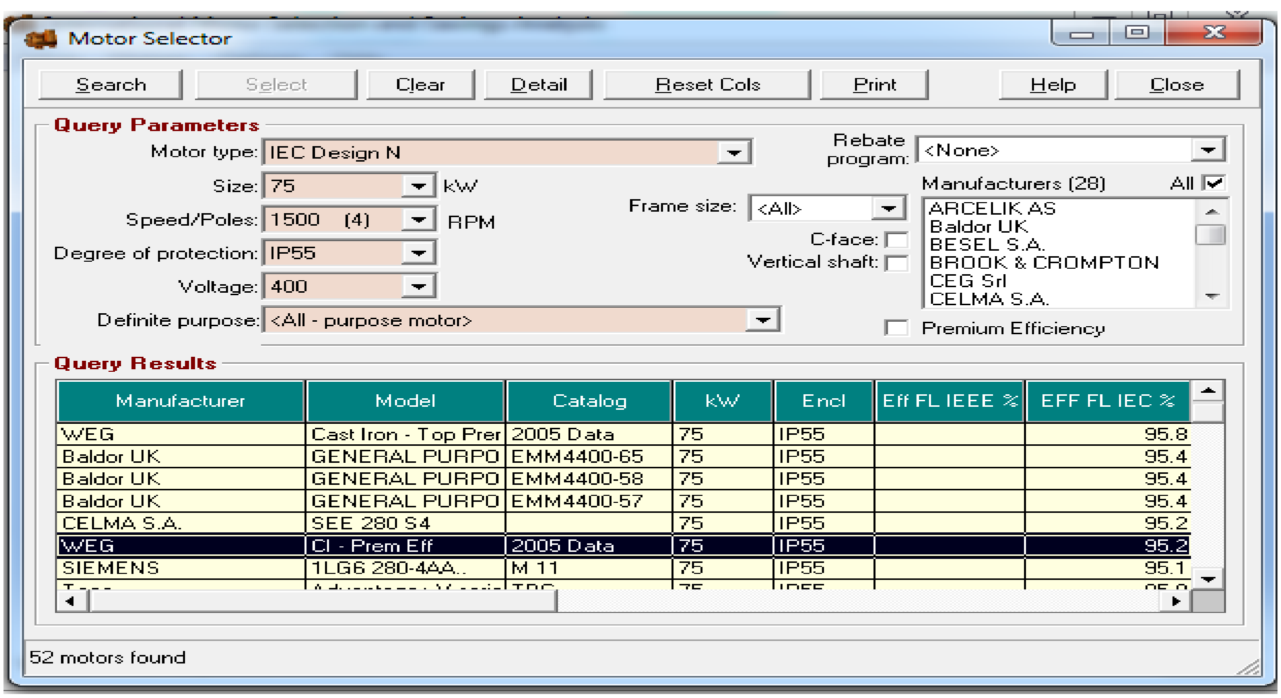

Figure 3. 22: IMSSA Energy efficient motor sector output

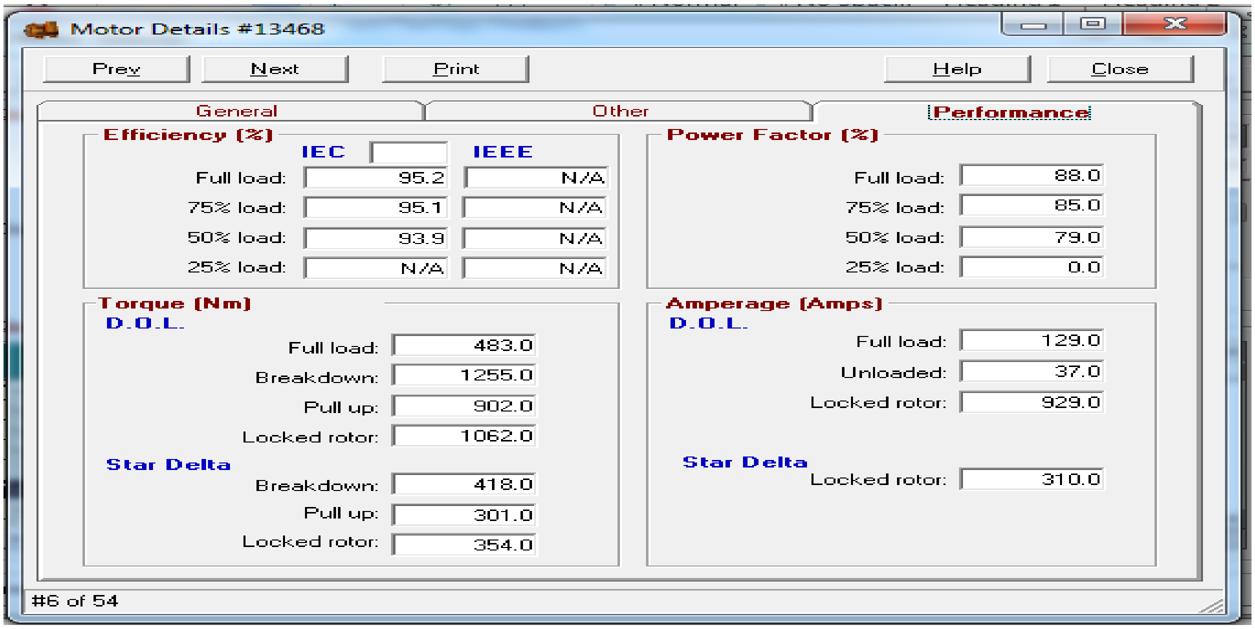

Figure 3. 23 IMSSA selected efficient motor performance characteristics

The total saving analysis from replacing all considered existing standard motors is done by RETScreen version 4 energy efficiency model.

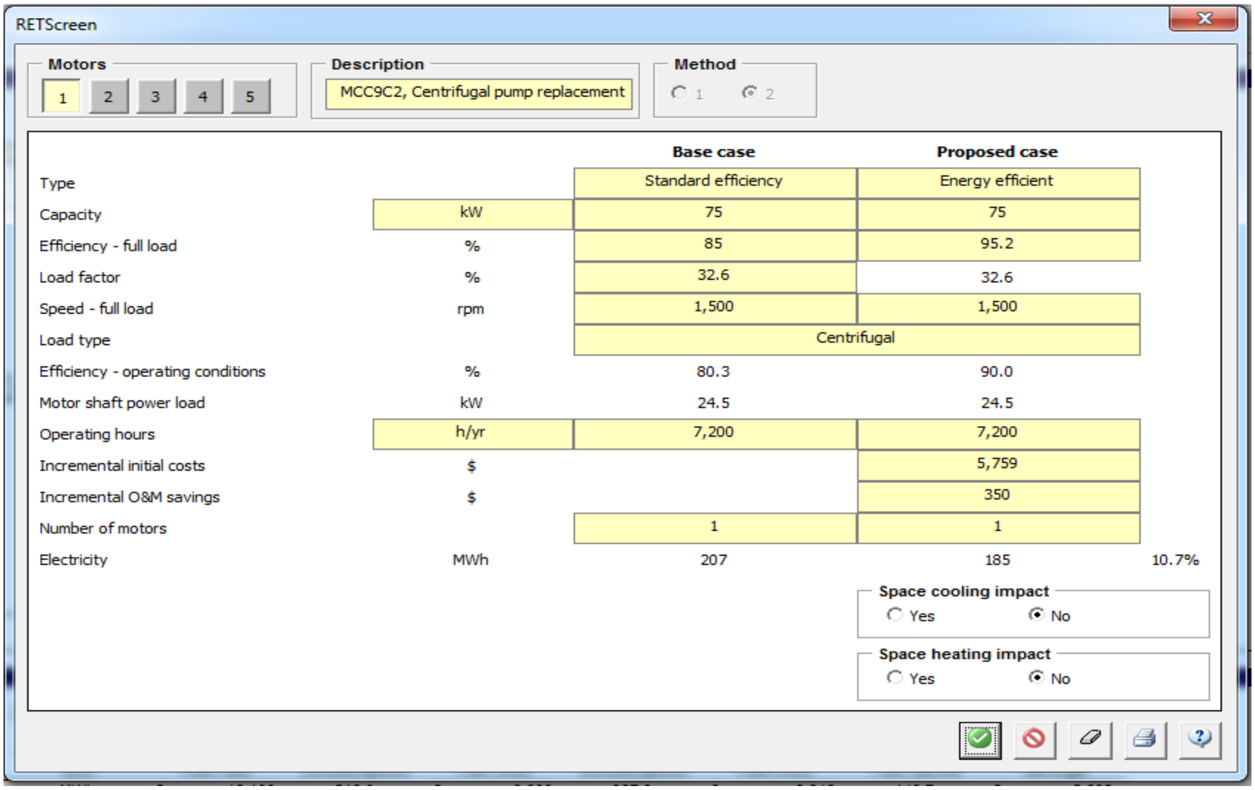

Figure 3. 24: RETScreen 4 Energy saving analysis output of 75kW motor

Figure 3.7C is the output of Energy saving analysis of replacing existing 75kW centrifugal pump with energy efficient pump selected from IMSSA data base.

The output indicates, 10.7% of electricity could be saved by replacing existing standard efficiency motor of 75kW pump with premium efficiency pump of 95.2%. The energy consumption is reduced from 207MWh to 185MWh which is about 22MWh a year of electricity could be saved.

The RET screen financial analysis output is;

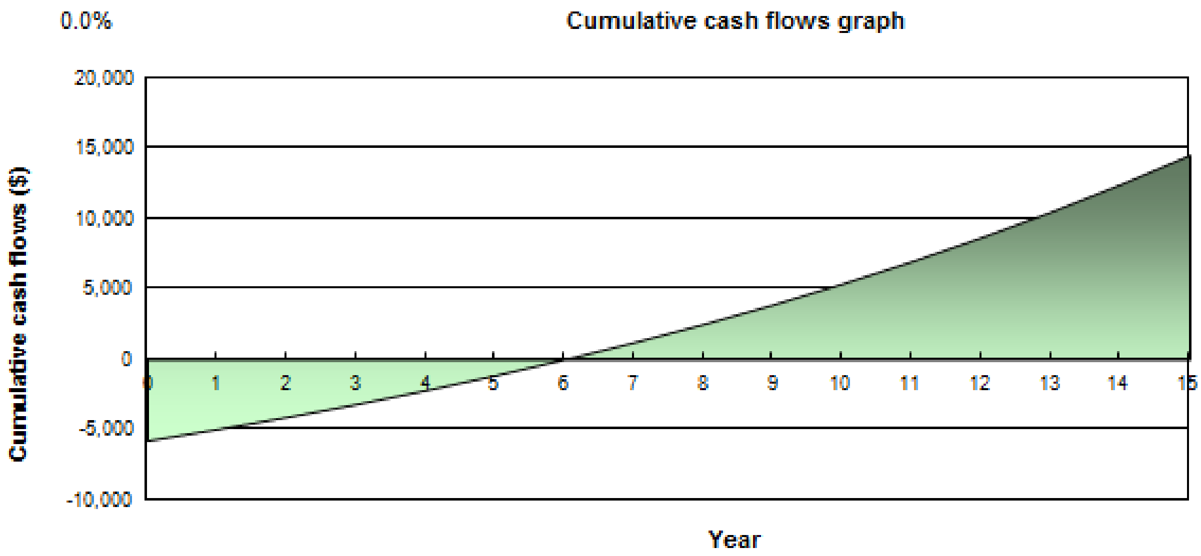

Figure 3. 25: RETScreen 4 Financial analysis output of 75kW motor

• Pre-tax IRR - assets	%	17.6%
• Simple payback	year	7.7
• Equity payback	year	6.0

This indicates that the payback period of this investment is about 7.7years. With equity payback period of about 6.0 years and asset pretax internal rate of return of 17.6%.

The analysis of replacing existing standard efficiency motors and low loading ratio indicated above is; (two, 75kW centrifugal pump. Two, 75kW main cane carrier. Three, 30kW inter carrier. Two, 37kW cane feeder table 1)

The output indicates, 10.3% of electricity could be saved by replacing 4 existing standard efficiency motor of 75kW, two 37kW and three 30kW old standard efficiency with energy efficient. The energy consumption is reduced from 1,513MWh to 1,357MWh which is about 156MWh a year of electricity could be saved. And the financial analysis output is;

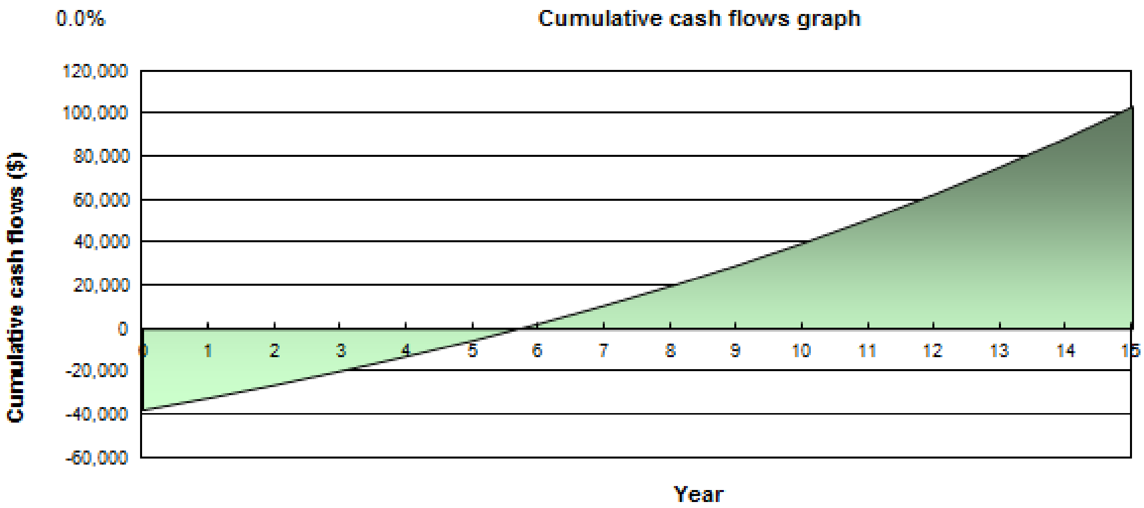

Figure 3. 26 RETScreen 4 Financial analysis output of group of motors to be replaced

Financial viability		
Pre-tax IRR - assets	%	18.8%
Simple payback	year	7.2
Equity payback	year	5.7

This indicates that the payback period of this investment is about 7.2years. With equity payback period of about 5.7 years and asset pretax internal rate of return of 18.8%.

From this it can be understood that replacing existing motor is financial not viable especially with existing grid electricity tariff of 0.0181$/kWh. Hence it is suggested to replace motors when they are aged/burned out by comparing with cost of rewinding.

3.7.3. Operating in star mode

Motor which consistently operate at loads below 40% of their rated capacity, could be operated in in star mode. This involves change from the standard delta operation to permanent star operation by re-configuring the wiring at the terminal box and resetting of the overcurrent relay. This leads to a voltage reduction by a factor of $\sqrt{3}$. Motor is electrically downsized by 1/3rd in star mode operation, but performance characteristics as a function of load remain unchanged [19]. Hence, full load operation in star mode gives higher efficiency and power factor than partial load operation in delta mode. This mode of operation is effective and inexpensive. However, motor operation in star mode is possible only for applications where the torque-to speed requirement is lower at reduced load [19].

During this assessment in old plant of FSF there are motors operating below 40% of their rated capacity identified in boiling section, in juice clarification, cane preparation, cooling tower. But consistent operation with this rated capacity has to be well examined for changing mode of their operation to ensure efficiency.

3.7.4. Power factor correction

Induction motors are characterized by power factors less than unity, leading to lower overall efficiency (and higher overall operating cost) associated with a plant's electrical system. Capacitors in parallel (shunted) with the motor are typically used to improve the power factor. The impact of PF correction included reduced kVA demand and hence, reduced utility demand charges, reduced I^2R losses in cables upstream of the capacitor and (hence, reduced energy charges), reduced voltage drop in the cables (leading to improved voltage regulation), and an increase in the overall efficiency of the plant electrical system [12].

In the new FSF plant, some a bank of capacitors are installed at new MCC, with automatic power factor controller and the details are not available to see the size of capacitor bank. But as power factor is monitored at motor terminals, and new plant MCCs, with Chauvin power quality analyzer, the PF is well maintained at optimum level which is ≥ 0.9 at some new plant MCCs and motor terminals. In old plant there is an opportunity to conserve energy either by installing power factor corrector at motor terminals or MCCs considered in plant electrical system above.

3.7.5. Proper maintenance

In addition to ensuring operation reliability and reduce machine downtime, preventive maintenance has significant impact on energy consumption of electrical motors in industry. Inadequate maintenance of motors can significantly increase losses and lead to unreliable operation [12]. For example, resistance losses in the motor, which rise with temperature, would increase. Improper lubrication can cause increased friction in both the motor and associated drive transmission equipment. As it is indicated in different literatures, the energy saving associated with proper maintenance are significant that could be 2-25% of total energy motor drive system use.

During this study, in the FSF there is no proper preventive maintenance practices observed. Dust are observed in motor ventilating ducts, no scheduled monitoring of loading conditions of the motors, no periodically checking of alignments of the motors and drive equipment etc. Hence, to achieve significant savings indicated in proper maintenance practices and to help proper motor operation in FSF;

- regular inspection of motors for wear in bearings and housings (to reduce frictional losses) and for dirt/dust in motor ventilating ducts (to ensure proper heat dissipation) mainly in production area and boiler auxiliaries motor drives. This includes monitoring adequate lubrication of motors as per manufacturer's recommendations and Checking periodically for proper alignment of the motor and the driven equipment.
- Since the factory has large number of motors, monitoring loading conditions to ensure that the motor is not over or under loaded also could contribute much for efficient operation. And Inspecting regularly the connections at the motor and starter to be sure that they are clean and tight [17].

3.7.6. Proper rewinding

Burn-out motors are usually rewound in industry. The impact of rewinding on motor efficiency and power factor can be easily assessed if the no-load losses of a motor are known before and after rewinding. Maintaining documentation of no-load losses and no-load speed from the time of purchase of each motor can facilitate assessing of this impact [19]. Careful rewinding can sometimes maintain motor efficiency at previous levels, but in most cases, losses inefficiency result. Rewinding can affect a number of factors that contribute to deteriorated motor efficiency: winding and slot design, winding material, insulation performance, and operating temperature. For example, a common problem occurs when heat is applied trip old windings: the insulation between lamination can be damaged, thereby increasing eddy current losses.

In some cases efficiency of motors could be increased after rewinding [15]. This can be done by changing the winding design, though the power factor could be affected in the process, using wires of greater cross section, slot size permitting, would reduce stator losses thereby increasing efficiency. However, it is generally recommended that the original design of the motor be preserved during the rewind, unless there are specific, load related reasons for redesign.

Large populations LT motors are rewound in FSF workshops. But there are observed problems in the workshops during removing of old insulation, selecting appropriate size of conductors and maintaining the previous history of the motors. Hence, maintain proper documentation of the motors and careful rewinding with preserving the original design of the motors minimizes impact of the motor rewinding on motor efficiency in FSF.

3.8. Lighting systems

3.8.1. General Lighting Description

Based on the construction and operating characteristics, the lamps can be categorized into three groups, incandescent, fluorescent and high intensity discharge lamps (HID). HID lamps can be further classified as sodium vapour, mercury vapour, and metal halide lamps [20]. There are basic parameters and terms in lighting system to quantify light, light source etc. these are; luminous flux, luminous intensity, illumination, luminance etc.

Luminous flux: which describe the quantity of light emitted by a light source. It is a measure of a lamp's economic efficiency ant its unit is **lumen (lm)**.

Illuminance (E): is the quotient of the luminous flux incident on an element of the surface at a point of surface containing the point, by the area of that element. **LUX (lx)** is the metric unit of measure for illuminance of a surface.

Luminous efficacy (lm/W): is the ratio of luminous flux emitted by a lamp to the power consumed by the lamp. It is a reflection of efficiency of energy conversion from electricity to light form. Unit: lumens per watt (lm/W).

Color rendering index (CRI): is a measure of effect of light on the perceived color of objects. To determine CRI of a lamp.

Installed Load efficacy: is the average maintained illuminance provided on a horizontal working plane per circuit watt with the general lighting of an interior. Unit: lux per watt per square meter (lux/W/m^2). The following table 3.8.1 the lamp features of different lamps.

Table 3. 18: luminous performance characteristics of commonly used luminaries [20].

Type of lamp	Lumen/Watt		Color rending index	Typical application	Typical life (hours)
	Range	Aver age			
Incandescent	8 - 18	14	Excellent (100)	Homes, restaurants, general lighting, emergency lighting.	1000
Fluorescent lamps	46 -60	50	Good w.r.t coating (67 -77)	Offices, shops, Hospitals, homes,	5000
Compact fluorescent lamps (CFL)	40 - 70	60	Very good (85)	Hotels, shops, homes, offices	8000 – 10000
High pressure mercury (HPMV)	44 - 57	50	Fair (45)	General lighting in a factories, garages, car parking, flood lighting	5000
Halogen lamps	18 - 24	20	Excellent (100)	Display, flood lighting, stadium exhibition grounds, construction areas	2000 – 4000
High pressure sodium (HPSV) SON	67 - 121	90	Fair (22)	General lighting in a factories, ware houses, street lighting	6000 – 12000
Low pressure sodium (LPSV)	101 -175	150	Poor (10)	Roadways, tunnels, canals, street lighting	6000 – 12000

Metal halide lamps	75 - 125	100	Good (70)	Industrial bays, spot lighting, flood lighting, retail stores.	8000
LED lamps	30 - 50	40	Good (70)	Reading lights, desk lamps, night lights, spot lights, security lights, signage lighting etc.	40,000 – 1,00,000

Different types of lighting fixtures are retrofitted in the FSF in different sections of the existing and new plant. In the existing plant, general lighting service fixture are old installed since establishment of the plant. The retrofitted lightings are, fluorescent tube lamps (FTL), GSL, sodium lamps, and mercury lamps. The illumination levels were also measured using lux meter and they are not sufficient in some section of the plant. Summary of lighting fixtures in FSF are listed in the following table 3.19

Table 3. 19: Details of observed lighting fixtures in FSF.

Types of lamps	Ratings, W	No of fixtures	Total, kw	Retrofitted areas
Sodium lamps/HP	400	43	17.2	Plant area, milling, workshop
Mercury vapor	400	183	73.2	Milling, old boiler, power h.
Mercury lamps	150	150	22.5	Milling,
Mercury lamps	175	41	7.175	Boiler/ upper drum area.
Fluorescent lamps	40	694	27.76	Offices, PCC/MCC rooms.
Sodium lamps/HP	200	39	7.8	Milling, warehouse
GLS	60	41	2.46	Offices, workshops.

Figure 3. 27: 400w mercury vapor lamp in boiler house

3.8.2. General Observation and Energy Conservation Opportunities

During the study, the lighting fixtures used in the old plant and new plant were counted (as indicated above) and their working condition were assessed, most lighting illuminations level were inefficient in the critical areas of the old plant.

Based on the observations during detailed assessment conducted through detailed energy audit conducted in the unit, the following major energy conservation measures (ECMs) have been identified. And the details are discussed below.

3.8.2.1 Lighting Maintenance

Maintenance is vital to lighting efficiency. Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce total illumination by 50 percent or more, while lights continue drawing full power [21]. The following basic maintenances includes;

- Cleaning of lamps and fixtures,
- Cleaning and repainting interiors.

- Re lamping
- Clean or repaint small rooms every year and larger rooms every 2 to 3 years. Dirt collects on surfaces, which reduces the amount of light they reflect.

In FSF there is observed drop in illumination level due to lack of proper maintenances of lighting systems that can improved by implementing these basic maintenance practices.

3.8.2.2 Use Natural Day Lighting

The utility of using natural daylighting instead of electric lighting during the day is well known, but being increasingly ignored especially in modern air-conditioned office spaces and commercial establishments like, hotels, shopping plazas etc. industrial plants generally use daylight in some fashion, but improperly designed day lighting systems can result in complaints from personnel or supplementary use of electric lights during daytime. Increasing levels of daylight within rooms can reduce electrical lighting loads. Day lighting differs from other energy efficiency measures because its features are integral to the architecture of a building, and so it is applied primarily to new buildings and incorporated at the design stage [20]. However, existing buildings can be cost-effectively refitted with day lighting systems. Various day lighting systems are available on the market; some of which can be supplied as kits to retrofit an existing building. Day lighting can be combined with lighting controls to maximize its benefits. Because of its variability, day lighting is usually combined with artificial lighting to provide the necessary illumination on cloudy days or after dark. Day lighting technologies include properly placed and shaded windows, atria, angular or traditional (flat) roof lights, clerestories, light shelves, and light ducts.

Day lighting is most appropriate for those areas that are used in daytime hours by people. In office spaces, day lighting may save between 30 and 70% [12]. The savings will vary widely depending the facility and buildings. Some problems associated with day lighting in industrial buildings have been identified due to the structure of the building. Various companies offer day lighting technologies.

3.8.2.3 Task lighting and De-lamping

Task lighting implies providing the required good illuminance only in the actual small area where the task is being performed, while the general illuminance of the shop floor or office is kept at a lower level; e.g. Machine mounted lamps or table lamps. Energy saving takes place because good task lighting can be achieved with low wattage lamps. The concept of task lighting if sensibly implemented, can reduce the number of general lighting fixtures, reduce the wattage of lamps, save considerable energy and provide better illuminance and also provide aesthetically pleasing ambience [12]. In some industry, lowering of lighting fixtures has resulted in improved illuminance and also reduction in 15 to 30% of the fixtures. De lamping is an effective method to reduce lighting energy consumption. In some industries, reducing the mounting height of lamps, providing efficient luminaries and then de-lamping has ensured that the illuminance is hardly affected [21]. De-lamping at empty spaces where active work is not being performed is also a useful concept. De-lamping some off the lumps during no activities in some plant area of FSF, for example in warehouse, compressor room, riverside pump control sections can make significant savings.

3.8.2.4 Electronic ballasts

Conventional electromagnetic ballasts (chokes) are used to provide higher voltage to start the tube light and subsequently limit the current during normal operation. Electronic ballasts are oscillators that convert the supply frequency to about 20,000Hz to 30,000Hz.[21]. The basic functions of electronic ballast are:

- To ignite the lamp
- To stabilize the gas discharge
- To supply power to the lamp

The losses in electronic ballasts for tube lights are only about 1Watt, in place of 10 to 15 Watts in standard electromagnetic chokes.

The additional advantage is that the efficacy of the tube lights improves at higher frequencies, resulting in additional savings if the ballast is optimized to provide the same light output as with the conventional choke. Hence saving of about 15 to 20 Watts per tube light can be achieved by use of electronic ballasts. With electronic ballast, the starter is eliminated and the tube light lights up instantly without flickering.

3.8.2.5 Lighting controllers

Automatic control for switching of unnecessary lights can lead to good energy savings. This includes timers, dimmers, daylight linked switches, infrared and ultrasonic occupancy sensors. Significant energy savings can be made by deploying the automatic controllers in lighting systems but they need to be evaluated in terms economic significance. Occupancy sensors can save up to 20% of facility lighting energy use [12].

3.8.2.6 Replacement of mercury lamps with metal halide lamps

In a mercury vapour lamp electromagnetic radiation is created from discharge within mercury vapour, but the regime is different than that found in the normal fluorescent lamp [12]. During operation, the pressure within the lamp is in the range of 200 – 400kPa (compared only with 1 Pa). The energy from this discharge vaporizes the mercury to get the main discharge going. The mercury vapour lamp produces a much greater proportion of visible light than fluorescent lamp and gives off a bluish white light. Phosphor coating can be given to improve the colour rendering index.

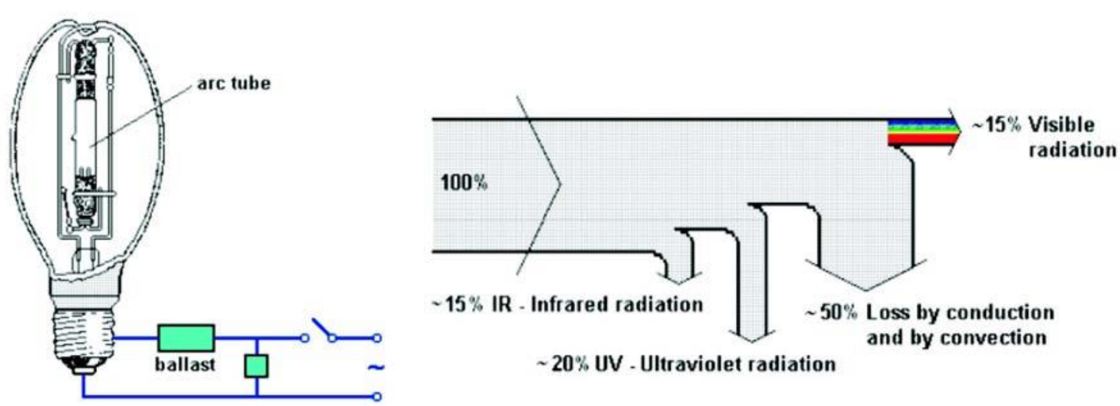

Figure 3. 28: Mercury Vapour lamp and energy flow diagram

Metal halide lamp can be considered as a variant of high pressure mercury vapour lamp (HPMV). In addition to mercury vapour and argon, this lamp contains metal hide. The halides can be a mixture of rare earth halides, usually iodides or a mixture of sodium and scandium iodide. The mercury vapour radiation is augmented by that of the metals [21]

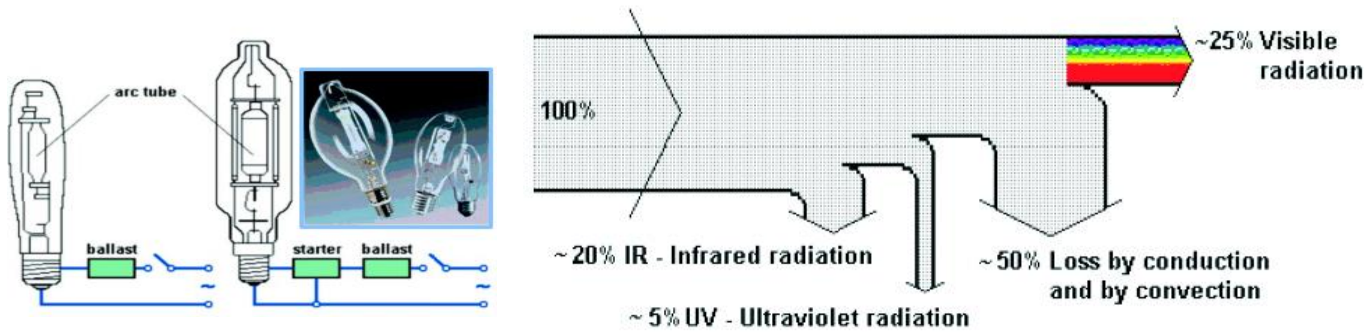

Figure 3. 29: Metal halide lamp and energy flow diagram

It is observed that plant uses mercury vapour lamp for lighting in production area. The existing lamps consume 400W and 175W power and ballast consumes 15W power. The lumens per watt of mercury vapour lamp are low and also the life is short as indicate in table 8.3.1 above. The total 183 and 65 fixtures are present in the plant. Hence replacing HPMV lamps with MH lamps provide the following major benefits in addition to energy conservation opportunity:

- Uniform light output for wide range of supply voltages.
- A color rendering index of MH lamp is 70 higher than HPMV.
- Less heat generation, hence load on ACs reduces.
- Higher lumen output per watt (about 100) as indicated above.
- Better typical life hours.
- Lessen demand

RET screen Analysis:

The analysis made to replace existing 400W, HPMV with 250W, MH indicates that, 45% of electricity could be saved which is about 145MWh annually. The interesting feature of RETscreen in analyzing lighting is that once you define the space type, for example in this case it is production area/manufacturing, then the software provided suggested illumination level, which is about 300lux. And then, once you enter rating of the lamp and number of fixtures intended to be replaced i.e. 183 then the suggested number of fixtures to be replaced is 161 MH.

Table 3. 20: Summary of energy savings from replacing existing HPMV by MH lamps

Description	Unit	Existing/HMVL	Proposed/MHL
Wattage of lamp	watt/ W	400/175	250/100
Design lumen(approx.)	Lumen	20000	20000
Number of lamps to be replaced	Number	183	161
Average operating hour/day	Hours	12	12
Operating day/year	Days	365	365
Energy savings	kWh/year		145,000kwh
Energy cost	$/kWh		0.0181
Energy cost savings	$/year		2176.18
Initial retrofit cost/lamp(approx.)	$/USD		28.5
Initial investment cost	$/USD		5215.5

The financial analysis output is:

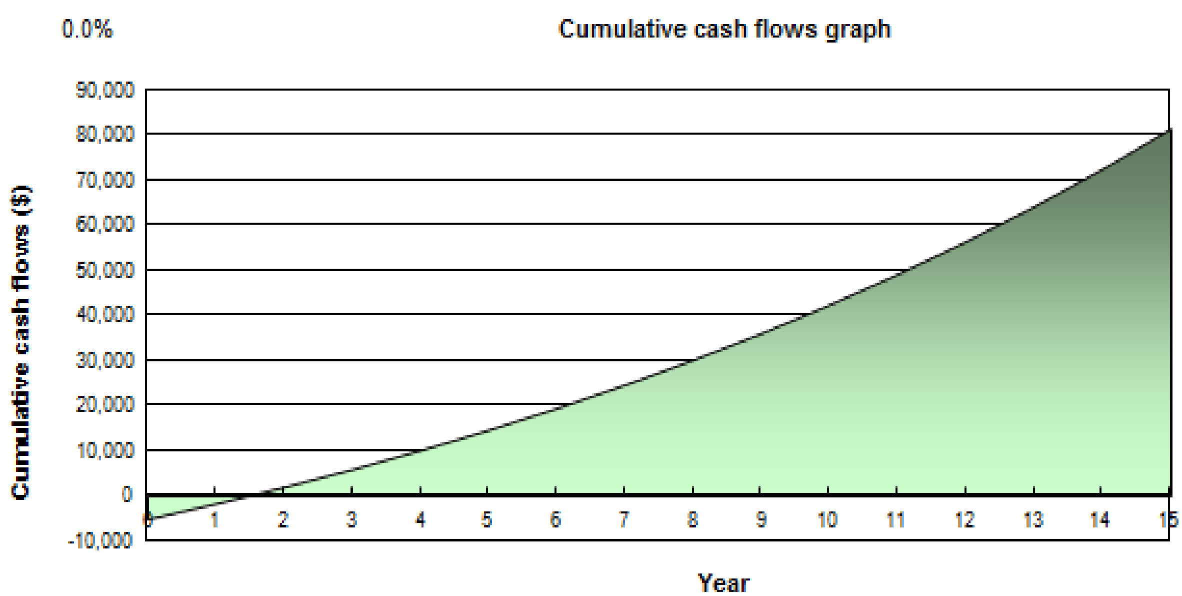

Figure 3. 30 RETScreen 4 Financial analysis output of Replacing HPMV with MH

Financial viability		
Pre-tax IRR - assets	%	72.9%
Simple payback	year	1.6
Equity payback	year	1.5

3.8.2.7 Replacement of FTL electromagnetic ballast with FTL electronic ballast

Fluorescent tube lamps works by the fluorescence principle. A fluorescent lamp is a glass tube containing a small trace of a glass such as mercury vapour (for a white color), carbon dioxide (for green), neon (for red color) etc. [20]. With special fluorescent/phosphorescent coating on the interior surface of the tube. It contains two filaments, one at each end of the tube and when the electrical supply is switched ON, the contacts of the starter open and the filament glow to heat up the gas contained inside the tube. Ballast is needed to start and operated fluorescent lamps, because of the characteristics of a gaseous arc. Fluorescent lamps are about 3 to 5 times as efficient as standard incandescent lamps and can last about 10 to 20 times longer.

Different types of fluorescent lamps their references are: Linear tube (T2, T5, T8, and T12), U-bent tubes (T8, T12) and Circular tubes (T5, T9).

Linear tubes

- T12 - 38 mm (1.5” diameter)
- T8 – 25mm (1” diameter)
- T5 – 16mm (5/8” diameter)
- T2 – 6mm (1/4” diameter)

These four types of lamps vary in diameter (ranging from 1.5 inches that is 12/8 of inch for T12 to 0.625 or 5/8 of an inch diameter for T5 lamps). Efficacy is another area that distinguishes one from another. T5 and T8 lamps offer a 5% increase in efficacy over 40Watt T12 lamps, and have become the most popular choice for new installations.

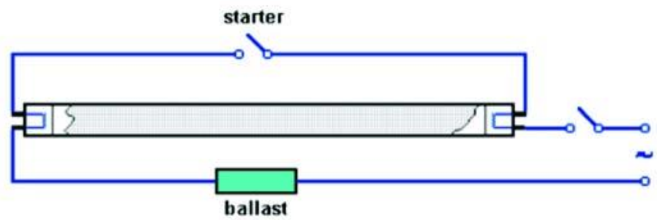

Figure 3. 31: Fluorescent Tube Lamp [21]

The losses in electronic ballasts for tube lights are only about 1Watt, in place of 10 to 15 Watts in standard electromagnetic chokes [21]. Fluorescent tube lights/T12 of 40W FTLs with electro mechanical ballasts consume more energy.

About 844 numbers such lamp fittings were found in different locations of the plant. Fluorescent tube lights of 36W (electromagnetic ballast) are counted (in offices, PCC, MCC and other rooms) are proposed to be replaced with 28W (electronic ballast) FTLs. Electronic ballasts help in instantaneous starting of lamps and have improved regulation for varying input voltage.

Major features of T5 FTL with electronic ballasts are:

- Uniform light output for wide range of supply voltages
- Instant start and flicker free operation.
- Improves the power factor almost close to unity.
- Increased lamp life (as indicated above)
- Higher lumen output per watt

RET screen Analysis:

The analysis made to replace existing 40W magnetic ballast with 28W, electronic ballast indicates. In the analysis number of operating hours per day is estimated about 18hours by considering the nature of operating the lamps during the production period.

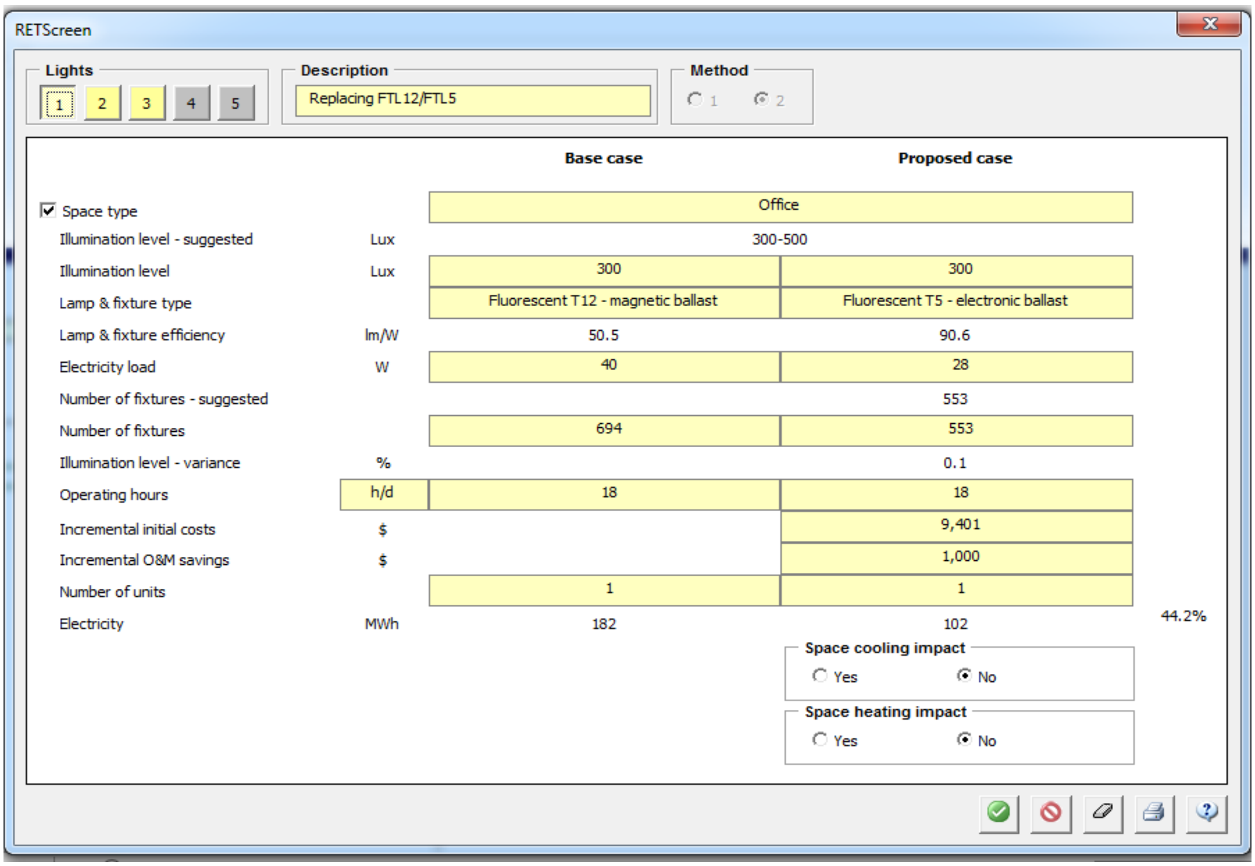

Figure 3. 32: RETScreen 4 energy saving analysis output of replacing T12 with T5

The financial analysis output is:

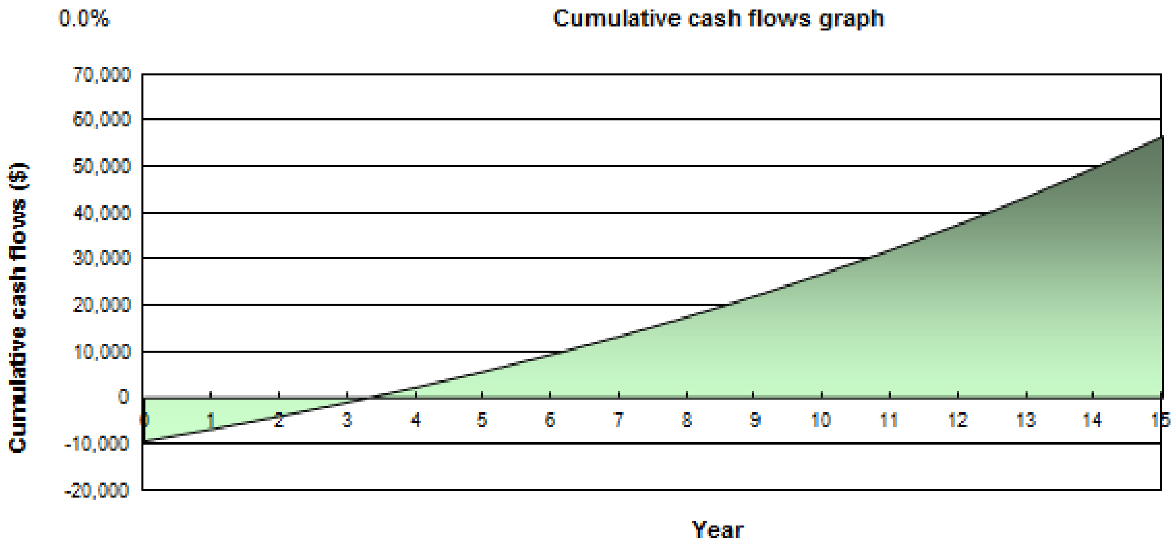

Figure 3. 33: RETScreen 4 Financial analysis output of Replacing T12 with T5

Financial viability		
Pre-tax IRR - assets	%	34.0%
Simple payback	year	3.8
Equity payback	year	3.3

Hence, replacing existing FTL lamps with new electronic ballast FTL is preferable to be replaced in phase manner.

Table 3. 21: Summary of energy savings from replacing existing T12 by T5 FTL

Description	Unit	Existing/FTL	Proposed/FTL
Wattage of lamp	watt/ W	40	28
Design lumen(approx.)	Lumen	3200	2900
Number of lamps to be replaced	Number	694	694
Watt loss per ballast	Watt	12	2
Average operating hour/day	Hours	12	12
Operating day/year	Days	365	365
Energy savings	kWh/year		80,000kWh
Energy cost	$/kWh	0.0181	0.066

Energy cost savings	$/year		2407.45
Initial retrofit cost/lamp(approx.)	USD		
Initial investment cost	USD		9401

3.8.2.8 Replacement of GLS with Compact Fluorescent Lamps CFL fixtures

Incandescent lamp also known as GLS (general lighting service lamp). The lamp include the filament, the bulb, the fill gas or vacuum and the cap. It produce light by means of a wire or filament heated to incandescence by the flow of electric current through it. The filament is enclosed in an evacuated glass bulb filled with gas such as argon, krypton, or nitrogen that helps to increase the brilliance of lamp and to prevent the filament from burning out.

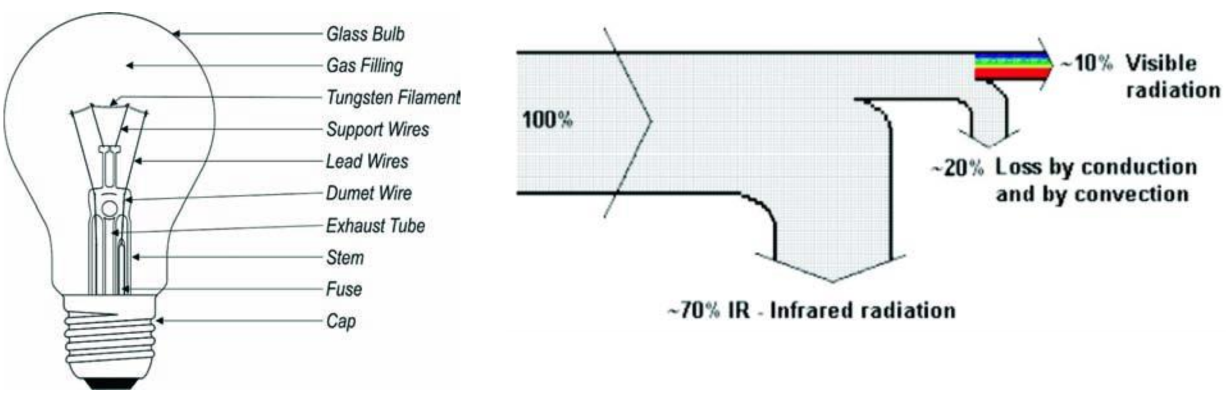

Figure 3. 34: incandescent lamp and energy flow diagram [21]

CFL lamps are compact versions of the linear or circular fluorescent lamps and operate in a very similar ways. The luminous flux depends on temperature. CFL's use less power and have a longer rated life compared to an incandescent lamp. They are designed to replace an incandescent lamp and can fit into existing light fixtures formerly used for incandescent.

During this assessment/study about 41 numbers of 60W GLS light fixtures are found in different locations of the plant. The fixtures could be replaced with 14W CFL without major compromise in illumination levels. The life of CFL fixture is very high when compared to GLS lamps and the power consumption is also very less.

Major features of CFL Compared to GLS lamps:

- Very efficient compared to GSL lamps
- Longer rated life compared to GSL/incandescent/
- Can fit into existing CFL fixtures
- Almost same lumen output with GSL (as indicated above on table: 3.8.1)

RET screen Analysis:

The analysis made to replace existing 60W GLS with CFL lamps;

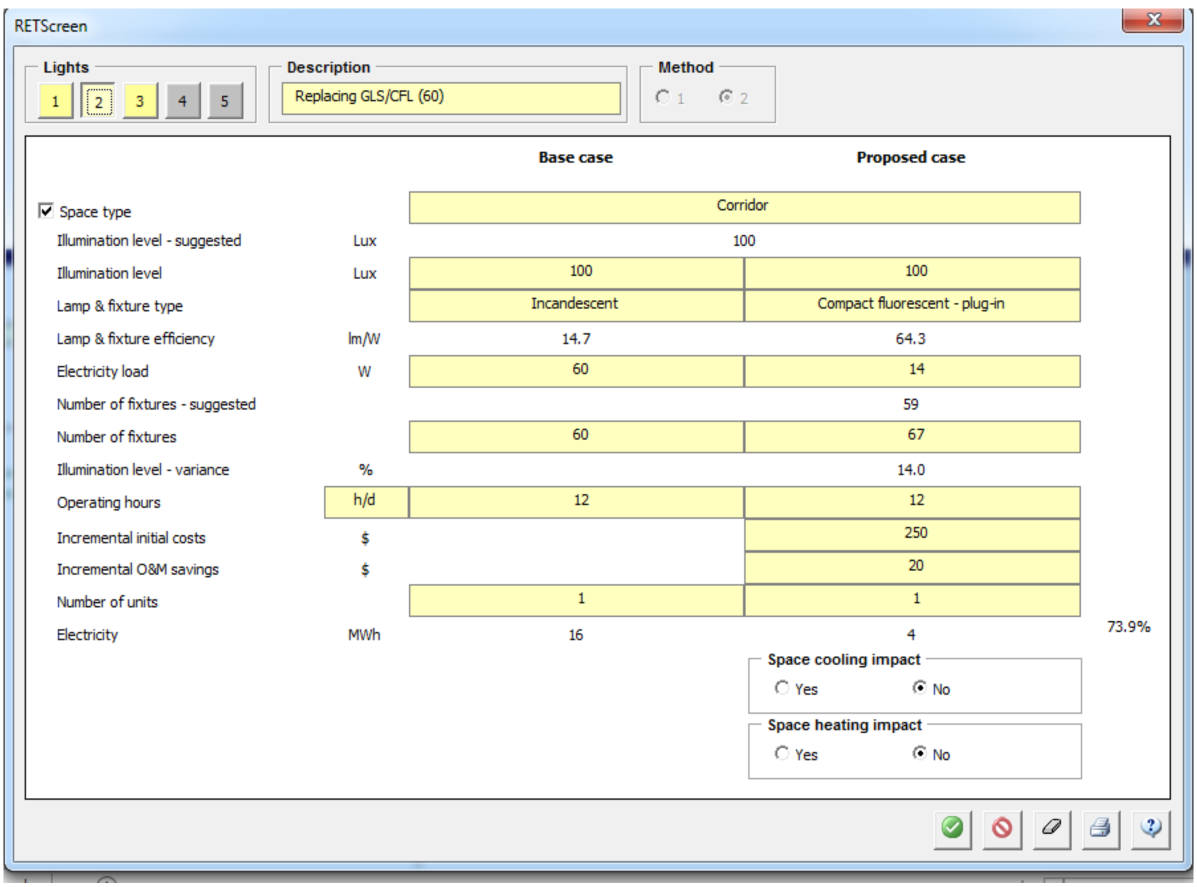

Figure 3. 35: RETScreen 4 energy saving analysis output of replacing GLS with CFL

The financial Analysis output is;

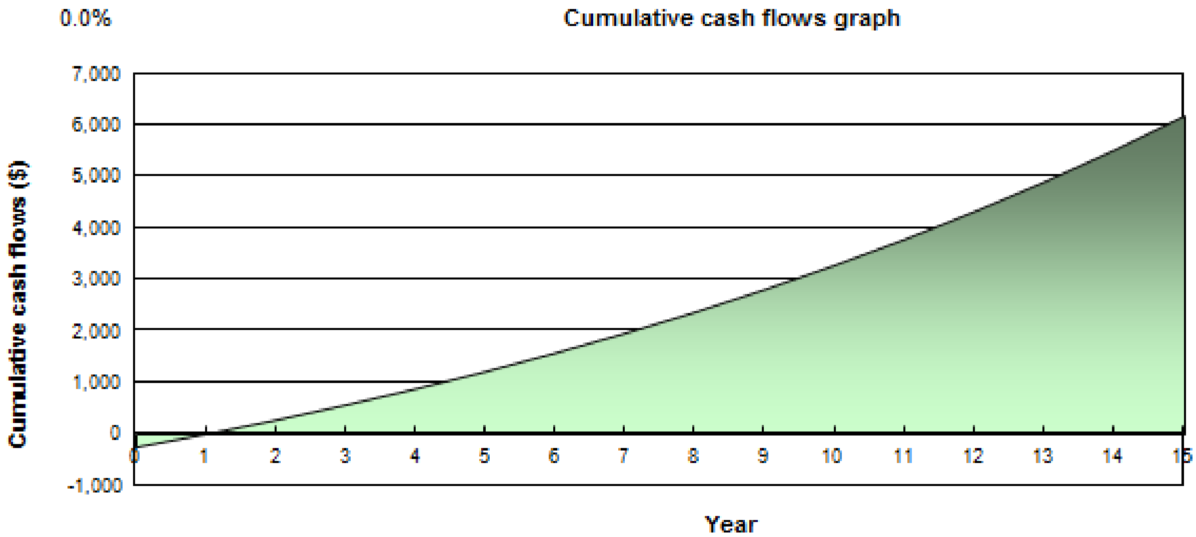

Figure 3. 36: RETScreen 4 Financial analysis output of replacing GLS with CFL lamp

Financial viability		
Pre-tax IRR - assets	%	109.7%
Simple payback	year	1.0
Equity payback	year	1.0

Table 3. 22: summary of energy saving from replacing existing GLS by CFL

Description	Unit	Existing/GSL	Proposed/CFL
Wattage of lamp	watt/ W	60	14
Design lumen(approx.)	Lumen	800	900
Number of lamps to be replaced	Number	60	67
Average operating hour/day	Hours	12	12
Operating day/year	Days	365	365
Energy savings	kWh/year		8,260kwh
Energy cost	$/kWh	0.5	0.5
Energy cost savings	$/year		4,160

Initial retrofit cost/lamp(approx.)	$ (USD)		
Initial investment cost	$ (USD)		250

4. Cogeneration Plant and Steam Distribution

4.1 Cogeneration plant Description

Cogeneration or combined heat and power (CHP) is defined as the sequential generation of two different forms of energy from a single primary energy source, typically mechanical energy and thermal energy. Mechanical energy is used either to drive an alternator for producing electricity, or rotating equipment such as motor, compressors, pump or fan for delivering various services. Thermal energy can be used either for direct process applications or for indirectly producing steam, hot water, hot air for dryer or chilled water for process cooling.

Cogeneration provides a wide range of technologies for application in various domains of economic activities. Along with the saving of fossil fuels, cogeneration also allows to reduce the emission of greenhouse gases (particularly CO_2 emission) [22]. The production of electricity being on-site, the burden on the utility network is reduced and the transmission line losses eliminated. Cogeneration makes sense from both macro and micro perspectives. At macro level, it allows a part of the financial burden of the national power utility to be shared by the private sector; in addition, indigenous energy sources are conserved. At the micro level, the overall energy bill of the users can be reduced, particularly when there is simultaneous need for both power and heat at the site, and a rational energy tariff is practiced in the country [22].

Steam turbine cogeneration systems involve different types of configurations with respect to mode of power generation such as extraction, back pressure or a combination of back pressure, extraction and condensing. Depending on power and steam load variations in the plant the entire system is dynamic. A performance assessment would yield valuable insights into cogeneration system performance and need for further optimization [22].

4.1.1 Boiler and Turbine

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or steam. The steam under pressure is then usable for transferring the heat for power generation to turbines and then to sugar manufacturing process. The quantity of the steam produced is indicated in tons of water, evaporated to steam per hour. Maximum continuous rating (MCR) is the hourly evaporation that can be maintained for 24 hours.

The boiler system comprises of feed water system, steam system and fuel system. The feed water system provides water to the boiler and regulates it automatically to the steam demand. Various valves provide access for monitoring, maintenance and repair. The steam system collects and controls the steam produced in the boiler. Steam is directed through a piping system to the turbine. Throughout the system, steam pressure is regulated using valves and checked with steam pressure gauges. The fuel system includes all equipment used to provide bagasse and/or furnace fuel to generate the necessary heat.

The water supplied to the boiler that is converted into steam is called feed water. The sources of feed water are condensed steam returned from the processes called condensate, and Make up water (treated raw water) which come outside of the boiler room and plant process. In addition to economizer, to increase efficiencies, besides the economizer for preheating the water an air heater is installed to preheat the combustion air.

The plant has two captive power plants, existing and new. On existing power plant, two double drum, natural circulation balance draft boilers of each having capacity of 65TPH. And the new plant has two boilers of each capacity 110TPH.

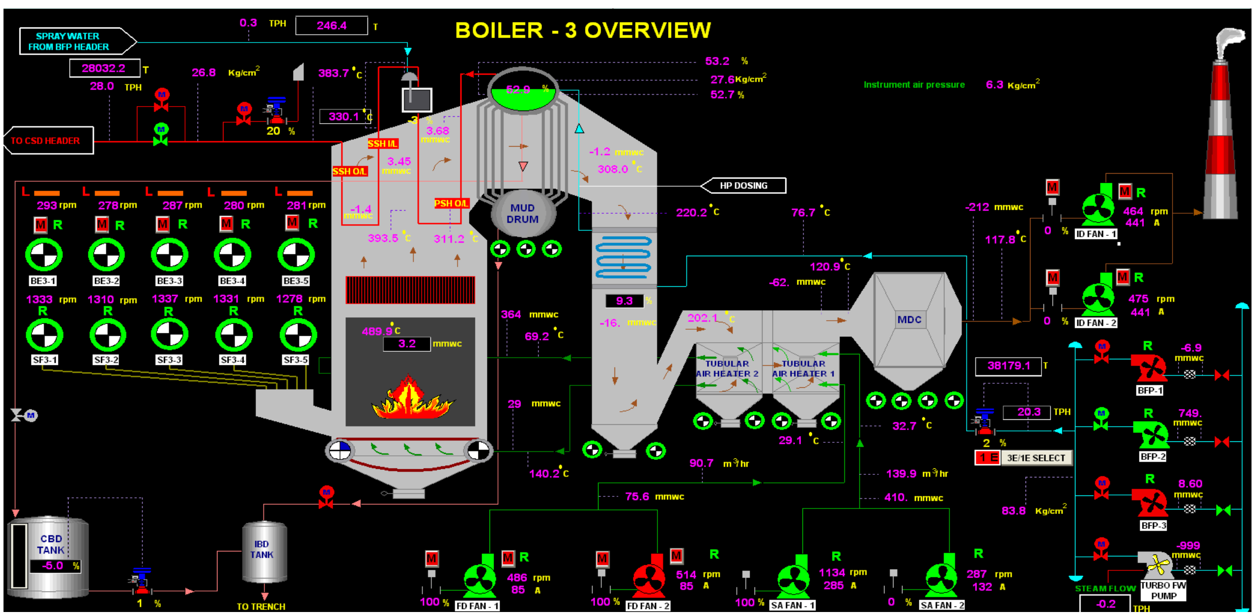

Figure 4. 1: overview of new boiler no 3

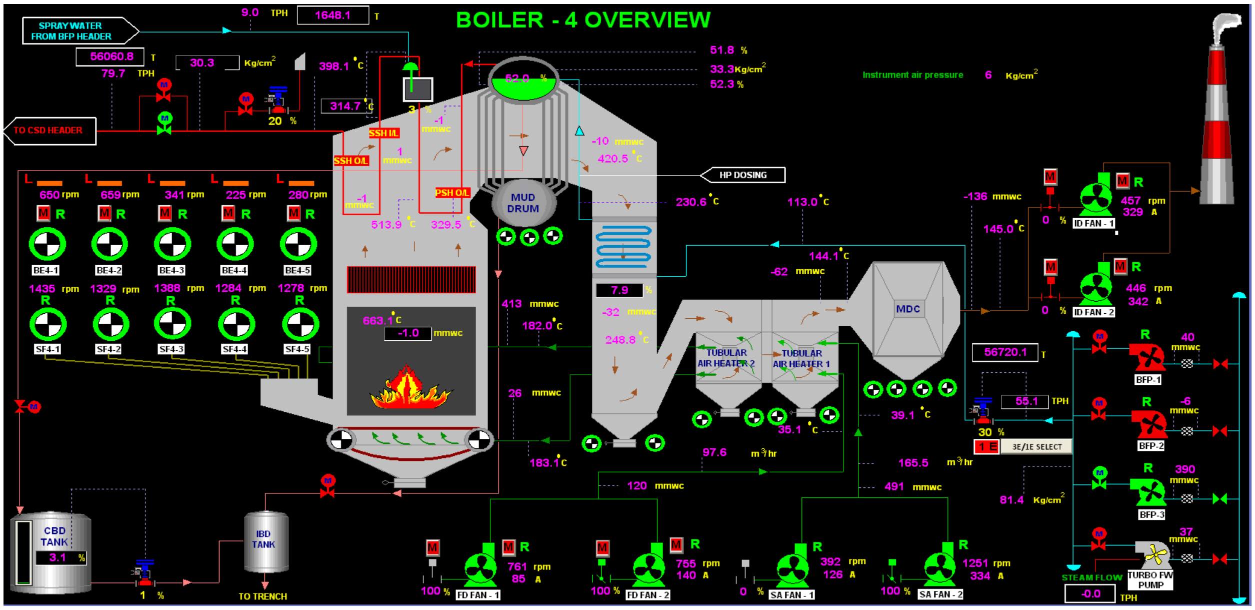

Figure 4. 2: overview of new boiler no 4

Steam piping, feed water piping, economizer, air preheater, and external fittings including funs are the main components of the boilers.

Table 4. 1: New and existing boilers specifications.

Description	Existing boilers (no 1&2)	New boilers (no 3&4)
Type	Natural circulation	Natural circulation
Capacity TPH	65	110
Steam pressure, kg/cm^2	32	32
Steam temperature ^{o}C	400±10	420
Feed water temperature C	105	105
Efficiency	-	-
Fuel	Bagasse and HFO	Bagasse and HFO

The steam generated from both two existing boilers and two new boilers is fed into common header and supplied to both existing and new plant turbines with capacity of 7MW(3.5MWx2) and 24MW(12MWx2) respectively for power generation. During this study/assessment only the existing power plant was operating. Due to this the power demand of the factor is supplemented from the grid/EEU incoming. The design specifications of the turbines are described in the following table

Table 4. 2: Design specification of FSF steam turbines

Description	Existing plant turbines	New plant turbines
Mark	Dresser rand	BHEL
Type	Back pressure	Extraction cum condensing
Rating (MW)	3.5	12
Turbine speed (rpm)	5970	7150
Gen. speed (rpm)	1500	1500
Inlet steam pressure kg/cm^2	28	29.6
Inlet Steam temperature, ^oC	390	398
Exhaust flow rate, TPH	46.9	-

4.1.2 Description of Power plant auxiliaries

4.1.2.1 Pumps associated with boiler

The feed water system is one of component of boiler system. The feed water system provides water to the boiler and regulates it automatically to meet the steam demand.

For existing plant (2 x 3.5MW), the boiler feed water system consists of two boiler feed water pumps. For a new plant (2 x 24MW), consist of three boiler feed water pumps and three condensate extraction pumps. The details are given in the following table 4.3

Table 4. 3: Details of pumps associated with boiler

Particulars	Existing boilers 1 and 2	New boilers 3 and 4	
	Boiler feed water pump	Boiler feed water pump	Condensate extraction pump
Flow, m^3/h	97.61	130	107
Head, m	530	980	130
Motor drive, kW	275	475	75

4.1.2.2 Fans associated with boiler

The boiler combustion air and flue gas system consists of Forced draft (FD) fans, secondary air (SA) fans and induced draft (ID) fans to maintain proper draft in the boiler. The fan specification of both existing boilers and the new boilers is given in table 4.4 and 4.5

Table 4. 4: Details of funs associated with boiler 1 and 2

Particulars	Induced draft fan	Forced draft fan	Secondary air fan
Flow, m^3/h	226700	73420	44200
Pressure, mmWC	211	211	998
Motor rating, kW	75	75	75

Table 4. 5: Details of funs associated with boiler 3 and 4

Particulars	Induced draft fan	Primary air fan	Secondary air fan
Flow, m^3/h	97300	45400	47560
Pressure, mmWC	400	1875	1325
Motor rating, kW	171	286	198

4.2 Energy Performance Assessment of Boilers

In cogeneration system, efficiency of individual components like boiler, steam turbine, is addressed in certain cases specifically where performance deterioration is suspected. A performance assessment would yield valuable insights into cogeneration system performance and need for further optimization [24].

The performance parameters of a boiler like evaporation ratio and efficiency deteriorate with time due to poor combustion, heat transfer fouling and poor operation and maintenance. Even for a new boiler, reasons such as deteriorating fuel quality, water quality etc. can result in poor boiler performance. Evaporation ratio trending and boiler efficiency test trends help to find out the deviation of boiler efficiency from the rated values and target problem areas for corrective action. Hence it is necessary to find out the current level of efficiency for performance evaluation, which is a prerequisite for energy conservation action in industry [24]. It is an indicator for tracking day-to-day and season to season variations in boiler efficiency and energy efficiency improvements.

The efficiency of boiler is quoted as the % of useful heat available, expressed as a percentage of the total energy potentially available by burning fuel. This is expressed on the basis of gross calorific value (GCV). Most standards for computation of boiler efficiency, including Indian standard IS 8753 and British standard, BS845 are designed for spot measurement of boiler efficiency. Invariably, all these standards do not include blow down as a loss in the efficiency determination process.

Thermal efficiency of a boiler is defined as the percentage of heat input that is effectively utilized to generate steam. There are two methods of assessing boiler efficiency.

a) **Direct method**: where the energy gain of the working fluid (water and steam) is compared with the energy content of the boiler fuel.
b) **Indirect or loss method**: where the efficiency is the difference between the losses and the energy input.

4.2.1. Direct method of Evaluating Boiler efficiency

This method needs only the useful output (steam) and heat input (i.e. fuel) for evaluating the efficiency of boiler. This can be determined by using the formula:

$$\text{Boiler efficiency} = \frac{Heat\ Output}{Heat\ input}\ x\ 100$$

Parameters to be monitored for the calculation of boiler efficiency by direct method are:

- Quantity of steam generated per hour (Q) in kg/hr.
- Quantity of fuel used per hour (q) in kg/hr.
- The working pressure (in kg/cm^2(g)) and superheat temperature (^{o}C), if any
- The temperature of feed water (^{o}C)

  Type of fuel and gross calorific value of the fuel (GCV) in kcal/kg of fuel

$$\text{Boiler efficiency } (\eta) = \frac{Q\ x\ (hg-hf)}{q\ x\ GCV}\ x\ 100$$

Where, h_g – enthalpy of saturated steam in kcal/kg of steam

h_f - enthalpy of feed water in kcal/kg of water

The calorific value may be gross or net and accordingly, the efficiency is reported is referred to as efficiency on GCV or NCV basis. This method needs few instruments for monitoring and easy to evaluate efficiency quickly. But the reported efficiency gives only values with respect to design but does not indicate an improvement and also fuel measurements are prone to errors [24].

4.2.2. Indirect method of evaluating boiler efficiency

The efficiency of a boiler can be measured easily by measuring all the losses occurring in the boiler. This method is called indirect method also called heat loss method. The efficiency can be measured easily by measuring all the losses occurring in the boilers. The efficiency is arrived at, by subtracting the heat loss fractions from 100 [23]. An important advantage of this method is that the errors in measurement do not make significant change in efficiency. A detailed procedure and formulas to determine types of losses indicated below in boiler is given on **appendix4/1**

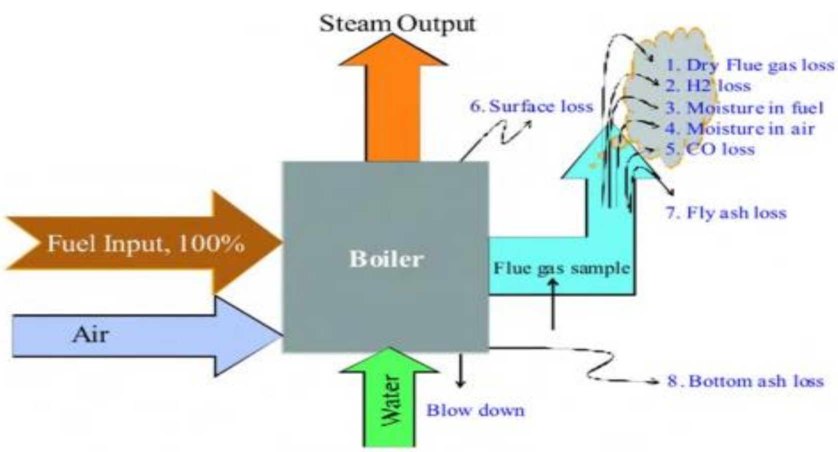

Figure 4. 3: various types of losses occur in a boiler.

Efficiency = 100 – (1+2+3+4+5+6+7+8)

After flue gas analysis is conducted using **combustion analyzer**. The indirect or heat loss method boiler efficiency analysis method is used to indicate efficiency and energy efficiency improvement opportunities.

In order to calculate the boiler efficiency by indirect method, all losses that can occur in the boiler must be established. These losses are conveniently related to the amount of fuel burnt.

Many formulas have been proposed to determine the calorific value of bagasse; amongst the better known the more reliable are that of Pritzelwitz van der Horst of Java and that of Hessey of Australia [11]. But, for all the gross calorific value (GCV) and net calorific value (NCV) can be assumed 2200kcal/kg and 9185.7kcal/kg. The gross calorific value (GCV) and Net calorific value of fuel oil which is substitute of bagasse is 10,000kcal/kg and 9,300kcal/kg respectively.

The result of experiment done on the higher heating value of bagasse at moisture content of 50% indicate the higher heating value ranging from 8396 to 8894KJ/kg which is within the standard range [9].

The proximate and ultimate analysis of bagasse as fired can be assumed to be as given in the following table 4.6

Table 4. 6: Energy property of bagasse [11]

Proximate analysis	% by weight	Ultimate analysis	% by weight
Fixed Carbon	7.0	Carbon	23.7
Volatiles	42.5	Hydrogen	3.0
Moisture	49.0	Oxygen	22.8
Ash	1.5	Moisture	49
		Ash	1.5

4.3. FSF Boilers efficiency evaluation by indirect method

4.3.1. Boiler 3 measurement and efficiency evaluation

During this assessment the observed and flue gas measurement result of boiler 3 with combustion analyzer is given in the following tables.

Table 4. 7: operating parameters of boiler 3 during the study

Operating parameters	Existing boiler 3
Steam flow	57.7TPH
Steam temperature , ^oC	382.8
steam pressure kg/cm^2	26.4
Feed water temperature , ^oC	69.3

The measured flue gas parameters of boiler 3 during the study is given on the following table 4.8

Table 4. 8: Measured flue gas parameters of boiler 3 during the study

Parameters	New boiler 3
Oxygen % before economizer	11.00
CO_2 % before economizer	7.5
Flue gas temperature before economizer ^oC	220.2
Flue gas temperature after economizer ^oC	202.1
Flue gas temperature after air preheater ^oC	161
Ambient temperature ^oC	29.41
% of excess Air	110

Efficiency of the boiler can be determined as follows:

Step1: find theoretical air requirement: = [(11.6xC) + {34.8x (H_2 –O_2/8)} + (4.35xS)]/100 kg/kg

Theoretical air required for complete combustion is = 3.3kg/kg of bagasse

Step2: find % of excess air supplied (%EA) = O_2% / (21- O_2%) = 110%

Step3: find actual mass of air supplied (AAS) = {1+EA/100} x Theoretical Air

= {1 + 110/100} x 2.8 = 5.88kg/kg of bagasse

Step4: find Actual mass of dry flue gas = (0.237x44)/12 + (5.88x77/100) + (5.88-2.8)x23/100

= 0.869 + 4.527 + 0.708 = 6.104kg/kg of bagasse

Step5: determine all types of losses:

- %Heat losses in dry flue gas (L1)
- %Heat loss due to formation of water from H_2 in the fuel(L2)
- %Heat loss due to moisture in the fuel (L3)
- %Heat loss due to moisture in air (L4)
- %Heat due to partial conversion C to CO (L5)
- %Heat loss due to radiation and unaccounted(L6)

Boiler 3:

- L1, %Heat losses in dry flue gas (L1) = $\{m \times C_p \times (T_f - T_a)/GCV\} \times 100 = 8.10$
- L2, %Heat loss due to formation of water from H_2 in the fuel(L2)

  $= 9 \times H_2 \times \{584 + C_p (T_f - T_a)\} /GCV \times 100 = 7.84$
- L3, %Heat loss due to moisture in the fuel (L3) = $M \times \{584 + C_p(T_f - T_a)\}/GCV \times 100$

  $= 14.51$
- L4, %Heat loss due to moisture in air (L4) = $\{AAS \times humidity \times C_p(T_f - T_a)\}/GCV \times 100$

  $= 0.29$
- L5, %Heat due to conversion C to CO (L5) = $\{((\%CO \times C)/(\%CO_2+\%CO)) \times (5654/GVC)\} \times 100 = 0.432$
- L6, %Heat loss due to radiation and unaccounted ~= 5%. Heat loss due to radiation and some other loss which cannot be determined easily are accounted about 6% of the heat loss. [11]

Boiler 3 efficiency by indirect method = 100 – (L1+L2+L3+L4+L5+L6)

= 100–(8.10+7.84+14.51+0.29+0.432++5) = 63.83

Table 4. 9: summary of heat balance of new boiler 3

Input/output parameter		Kcal/kg of bagasse	% losses
Heat input	=	2,200	100
Losses in boiler			
Dry flue gas, L1	=	178.2	8.10
Loss due to H_2 in fuel, L2	=	172.48	7.84

Loss due to moisture in fuel, L3	=	319.22	14.51
Loss due to moisture in air, L4	=	6.38	0.29
Partial combustion of C to CO, L5	=	9.46	0.43
Loss due to radiation and unaccounted, L6	=	110	5
Boiler efficiency = 100 – (8.10+7.84+14.51+0.29+0.432+5) = 63.83			

4.3.2. Boiler 4 measurement and efficiency evaluation

During this assessment the observed parameters and flue gas measurement result of boiler 4 with combustion analyzer is given in the following tables respectively.

Table 4. 10: Operating parameters of boiler 4 during the study

Operating parameters	New boiler 4
Steam flow	79.7TPH
Steam temperature , ^{o}C	398.1
steam pressure kg/cm^2	30.3
Feed water temperature , ^{o}C	86.4

Table 4. 11: Measured flue gas parameters of boiler 4 during the study

Parameters	New boiler 4
Oxygen % before economizer	11.00
CO_2 % before economizer	7.5
Flue gas temperature before economizer ^{o}C	269
Flue gas temperature after economizer ^{o}C	248.8
Flue gas temperature after air preheater ^{o}C	144
Ambient temperature ^{o}C	29.1
% of excess Air	110

Efficiency of the boiler can be determined as follows: Boiler 4

Step1: find theoretical air requirement: = [(11.6xC) + {34.8x (H_2 –O_2/8)} + (4.35xS)]/100 kg/kg

Theoretical air required for complete combustion of bagasse = (2.8kg/kg of bagasse)

Step2: find % of excess air supplied (%EA) = O_2% / (21- O_2%) = 110%

Step3: find actual mass of air supplied (AAS) = {1+EA/100} x Theoretical Air

= {1 + 110/100} x 2.8 = 5.88kg/kg of bagasse

Step4: find Actual mass of dry flue gas = (0.237x44)/12 + (5.88x77/100) + (5.88-2.8)x23/100

= 0.869 + 4.527 + 0.708 = 6.104kg/kg of bagasse

Step5: determine all types of losses:

- %Heat losses in dry flue gas (L1)
- %Heat loss due to formation of water from H_2 in the fuel(L2)
- %Heat loss due to moisture in the fuel (L3)
- %Heat loss due to moisture in air (L4)
- %Heat due to partial conversion C to CO (L5)
- %Heat loss due to radiation and unaccounted

4.3.3 New Boiler 4 efficiency: indirect method

- L1 , %Heat losses in dry flue gas (L1) = {m x C_p x (T_f –T_a)/GCV} x100 = 7.65
- L2, %Heat loss due to formation of water from H_2 in the fuel(L2)
  = 9 x H_2 x {584 + C_p (T_f –T_a)}/GCV x 100 = 7.80
- L3, %Heat loss due to moisture in the fuel (L3) = M x {584 + C_p(T_f –T_a)}/GCV x 100
  = 14.44
- L4, %Heat loss due to moisture in air (L4) = {AAS x humidity x C_p (T_f –T_a)/GCV}x100 = 0.27
- L5, %Heat due to conversion C to CO (L5) = {((%CO x C)/(%CO_2+%CO)) x (5654/GVC)} x 100 = 0.313
- L6, %Heat loss due to radiation and unaccounted = 5%. Heat loss due to radiation and some other loss which cannot be determined easily are accounted about 6% of the heat loss. [11].
  Boiler 4 efficiency by indirect method = 100 – (L1+L2+L3+L4+L5+L6)

= 100 – (7.65+7.80+14.44+.27+0.313+5) = 65.52

Table 4. 12: summary of heat balance for new boiler 4

Input/output parameter		Kcal/kg of bagasse	% losses
Heat input	=	2,200	100
Losses in boiler			
Dry flue gas, L1	=	168.3	7.65
Loss due to H_2 in fuel, L2	=	171.6	7.80
Loss due to moisture in fuel, L3	=	317.68	14.44
Loss due to moisture in air, L4	=	5.94	0.27
Partial combustion of C to CO, L5	=	6.89	0.313
Loss due to radiation and unaccounted, L6	=	110	5
Boiler efficiency = 100 – (7.65+7.80+14.44+0.27+0.313+5) = 65.52			

4.3.4. Existing Boiler 1 measurement and efficiency evaluation

During this assessment the observed parameters and flue gas measurement result of existing boiler 1 with combustion analyzer is given in the following tables. 4.3.3a and 4.3.3b respectively.

Table 4. 13: Operating parameters boiler 1 during study

Operating parameters	Existing boiler 1
Steam flow	24.5TPH
Steam temperature , ^oC	329
steam pressure kg/cm^2	27.04
Feed water temperatur	--

Table 4. 14: Measured flue gas parameters of boiler 1 during study

Parameters	Existing boiler 1
Oxygen % before economizer	10.89
CO_2 % before economizer	8.53
Flue gas temperature before economizer ^oC	330.1
Flue gas temperature after economizer ^oC	203.6
Flue gas temperature after air preheater ^oC	182.8

Ambient temperature ^{o}C	30.1
% of excess Air	107.71

Step1: find theoretical air requirement: = [(11.6xC) + {34.8x (H_2 –O_2/8)} + (4.35xS)]/100 kg/kg

Theoretical air required for complete combustion of bagasse = (2.8 kg/kg of bagasse)

Step2: find % of excess air supplied (%EA) = O_2% / (21- O_2%) = 107.71%

Step3: fins actual mass of air supplied (AAS) = {1+EA/100} x Theoretical Air

= {1 + 107.71/100} x 2.8 = 5.82kg/kg of bagasse

Step4: find Actual mass of dry flue gas = (0.237x44)/12 + (5.76x77/100) + (5.88-2.8)x23/100

= 0.869 + 4.44 + 0.68 = 5.99kg/kg of bagasse

Step5: determine all types of losses:

- %Heat losses in dry flue gas (L1)
- %Heat loss due to formation of water from H_2 in the fuel (L2)
- %Heat loss due to moisture in the fuel (L3)
- %Heat loss due to moisture in air (L4)
- %Heat due to partial conversion C to CO (L5)
- %Heat loss due to unburned carbon in the ash
- %Heat loss due to radiation and, (others) unaccounted

Existing Boiler 1:

- L1 , %Heat losses in dry flue gas (L1) = {m x C_p x (T_f –T_a)}/GCV x100 = 9.91
- L2, %Heat loss due to formation of water from H_2 in the fuel(L2)

  = 9 x H_2 x {584 + C_p(T_f –T_a)}/GCV x 100 = 8.01
- L3, %Heat loss due to moisture in the fuel (L3) = M x {584 + C_p(T_f –T_a)}/GCV x 100

  = 14.82
- L4, %Heat loss due to moisture in air (L4) = {AAS x humidity x C_p(T_f –T_a)}/GCV x100

= 0.36

- L5, %Heat due to conversion C to CO (L5) = {((%CO x C)/(%CO_2+%CO)) x (5654/GVC)} x 100 = 0.481
- L6, %Heat loss due to surface radiation and, others(unaccounted) = 5% [11]

Boiler 3 efficiency by indirect method = 100 – (L1+L2+L3+L4+L5+L6+L7)

= 100 – (9.91+8.01+14.82+0.36+0.481+0.81+5) = 61.42

Table 4. 15: summary of heat balance for existing boiler 1

Input/output parameter		Kcal/kg of bagasse	% losses
Heat input	=	2,200	100
Losses in boiler			
Dry flue gas, L1	=	244.2	9.91
Loss due to H_2 in fuel, L2	=	176.22	8.01
Loss due to moisture in fuel, L3	=	326.26	14.82
Loss due to moisture in air, L4	=	8.87	0.36
Partial combustion of C to CO, L5	=	10.58	0.481
Loss due to radiation and unaccounted, L6	=	110	5
Boiler efficiency = 100 – (9.91+8.01+14.82+0.36+0.481+5) = 61.42			

4.4. Energy conservation opportunities

The various energy efficiency opportunities in boiler system can be related to combustion, heat transfer, avoidable losses, high auxiliary power consumption, water quality and blow down [24]. Examining factors such as stack temperature, feed water preheating using economizer, combustion air heater, incomplete combustion, excess air control, radiation and convention losses, variable speed control for fans, blowers and pumps, etc. can indicate if a boiler is being run to maximize its efficiency.

4.4.1. Excess Air Control

By optimizing excess air in the combustion chamber the boiler efficiency increases 4 – 6% [9]. The table 4.4.1 gives theoretical amount of air required for combustion of various types of fuel. Controlling excess air to an optimum level always results in reduction flue gas losses, for every 1% reduction in excess air there is approximately 0.06% rise in efficiency. The optimum level of excess air of bagasse fired boiler is 20 – 35% [24]

Various methods are available to control the excess air [12]:

- Portable oxygen analyzers and draft gauges can be used to make periodic readings to guide the operator to manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible.
- The most common method is the continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow. A further reduction of 10 – 15% can be achieved over the previous system.
- The same continuous oxygen analyzer can have a remote controlled pneumatic damper positioner, by which the readouts are available in a control room.

During this study, FSF existing Boiler 1, new boiler 3, and boiler 4, efficiency is evaluated by indirect/loss method. The overall losses of each boiler is 61.42%, 63.83% and 65.52% respectively. And the average losses of the three boilers is estimated is about 63.59%. Most literatures indicate that the minimum bagasse boiler is 70% [24]. Hence, the factory captive power plant boiler is less efficient. The overall efficiency and major losses of the three boilers are summarized in the table below.

Table 4. 16: Overall efficiency and major losses in FSF boilers

Losses/major losses	Boiler 1	Boiler 3	Boiler 4
Dry flue gas loss %	9.91	8.10	7.65
Losses due to moisture %	14.82	14.51	14.44
Loss due to H_2 in fuel %	8.01	7.84	7.80
Overall loss %	61.42	63.83	65.52

Improving efficiency of the boilers can be achieved by minimizing major losses, dry flue gas losses and losses due to moisture in a fuel/bagasse. Keeping the excess air to optimum level, which is about 20 – 35% indicated above could improve overall efficiency of boilers by 5%. Hence heat loss due to dry flue gas is high.

Installing flue gas analyzer/combustion analyzer and based on oxygen percentage reducing the excess air by controlling FD air and secondary air flow. It will help to reduce the bagasse/ Furnace oil consumption and reduce the flue gas losses.

The fuel saved from this could be determined as:

Hence, 2016/17 bagasse consumption is 349,602ton and Fuel oil consumption is 949,175litre which is equivalent to 4,314ton of bagasse.

Improving boilers efficiency by 5% indicates that;

5% x 353,916ton = 17,696ton, of bagasse could be saved. Energy cost saved: 17,696x 0.2 x 0.5 x 1000 = 1,769,600USD

From these total bagasse equivalent consumption is 353,916ton and steam produced is 489,816ton. International practice indicates that 1ton of bagasse produce 2.3ton of steam [11]. Accordingly, the FSF bagasse consumption has to be 489,816ton/2.3 which is 212,965ton of bagasse.

Bagasse loss = 353,916ton - 212,965ton = **140,951ton**, this indicates = 60% utilization efficiency and the boilers average efficiency is estimated to be around 65%, hence, 5% is due to bagasse wastage before introduced into boiler. 5% x 353,930 = 17,697ton.

4.4.2 Application of bagasse drier:

As it can be seen from the boiler efficiency analysis above loss due to moisture content in a bagasse is significant. So bagasse drier can be applied to improve boiler efficiency significantly. Literatures suggest that improving moisture content of bagasse even from 50% to 40% can increase steam production by 15% [11].

The experimental test results and the operational data have clearly indicated that the energy potential of bagasse has been underutilized, research work done at Wonji shoa sugar factory. The result of the experiment shows currently, the drying of bagasse has taken much attention, as it is a power full tool to save bagasse energy in sugar industry [6]. In the bagasse draying, the gases, which is the gaseous products of combustion leaving the combustion chamber is employed as a heat source to remove the water from bagasse. In doing so large quantity of sensible heat that has been lost with the flue gases are recovered. By applying the bagasse drying system, the gain in system efficiency is calculated from the change of the stack gas and is found to be 10.4 % [6]. The calculation for the system assumes that there are no losses in the dryer. These are estimated to be about 4% losses in the dryer and are made as a correction on the final efficiency. The actual gain in system efficiency would then be, therefore, 6.4% and this leads to the savings of 2.2 tons / hr bagasse after generating the same quantity of steam [6].

Therefore, the application of bagasse drier should be seen carefully for future work. And beyond the scope of this study.

4.5. Steam Distribution system

The steam distribution system is the essential link between the steam generator and the steam user. Whatever the source, an efficient steam distribution system is essential if steam of the right quality and pressure is to be supplied, in the right quantity, to steam using equipment [26]. Installation and maintenance of the steam system are important issues, and must be considered at the design stage.

4.5.1 Steam Pipe insulation

The insulation of steam conveying pipes and the steam consuming equipment is very essential to retard the flow of heat from the system to environment. Broadly the purpose of steam pipe insulation is as follows;

- Conserve energy by reducing heat loss
- Facilitate temperature control of a process
- Prevent condensation of steam
- Prevent or reduce damage to pipe from exposure to fire or corrosive atmospheres
- Control surface temperature for personnel protection and comfort [12].

The following table 4.5 indicates the effect of insulating bare pipes, comparison of radiation losses (pipe surface temperature at 150 ^{o} C)

Table 4. 17: effect of insulation on steam pipes [12]

Pipe size in inch	Economic insulation thickness mm	Radiation losses (kW/m)	
		Insulated	Uninsulated
1/2	15	125	692
2	25	243	1820
4	40	298	2942
12	50	588	7614

Heat can be lost due to radiation from steam pipes. As an example while lagging steam pipes, it is common to see leaving flanges uncovered. An uncovered flange is equivalent to leaving 0.6 meters of pipe line unlagged. If a 0.15m steam pipe diameter has uncovered flanges, there would be a loss of heat equivalent to wasting 5 tons of coal or 3000litres of oil a year. This is usually done to facilitate checking the condition of flange but at the cost of considerable heat loss. The remedy is to provide easily detachable insulation covers, which can be easily removed when necessary. The various insulating materials used are cork, glass wool, rock wool and asbestos.

4.5.2 Economic Thickness of Insulation (EIT)

Insulation of any system means capital expenditure. Hence the most important factor in any insulation system is to analyze the thermal insulation with respect to cost. The effectiveness of insulation follows the law of decreasing returns. Hence, there is a definite economic limit to the amount of insulation, which is justified. An increased thickness is uneconomical and cannot be recovered through small heat savings. This limiting value is termed as economic thickness of insulation [29]. Each industry has different fuel cost and boiler efficiency. These value can be used for calculating economic thickness of insulation.

The steam generated is feed into common header and supplied to steam turbine for power generation and production process in FSF.

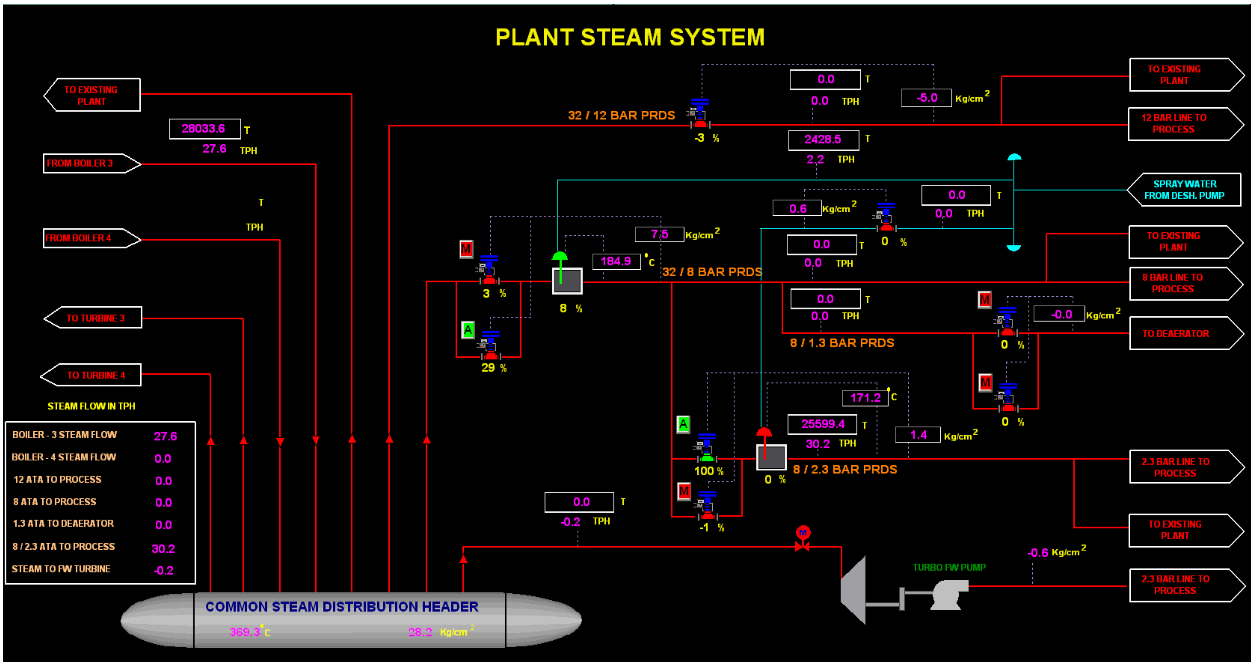

Figure 4. 4: Plant steam distribution system over view

The surface temperatures of the steam lines were measured by thermal imaging camera (FLUKE Ti125) to check the adequacy of insulation. From the boilers to the turbine section, the surface temperature was so high due to deteriorated insulations, at different places, including at common header, existing turbine sections etc. Inside the process plant also insulation was poor. For any steam lines, the temperature below 45°C (or ambient +5°C) is considered to be optimum [27].

Figure 4. 5: Some of main steam lines with deteriorated insulatio

Figure 4. 6: Photos during measurement of steam lines surface temperature

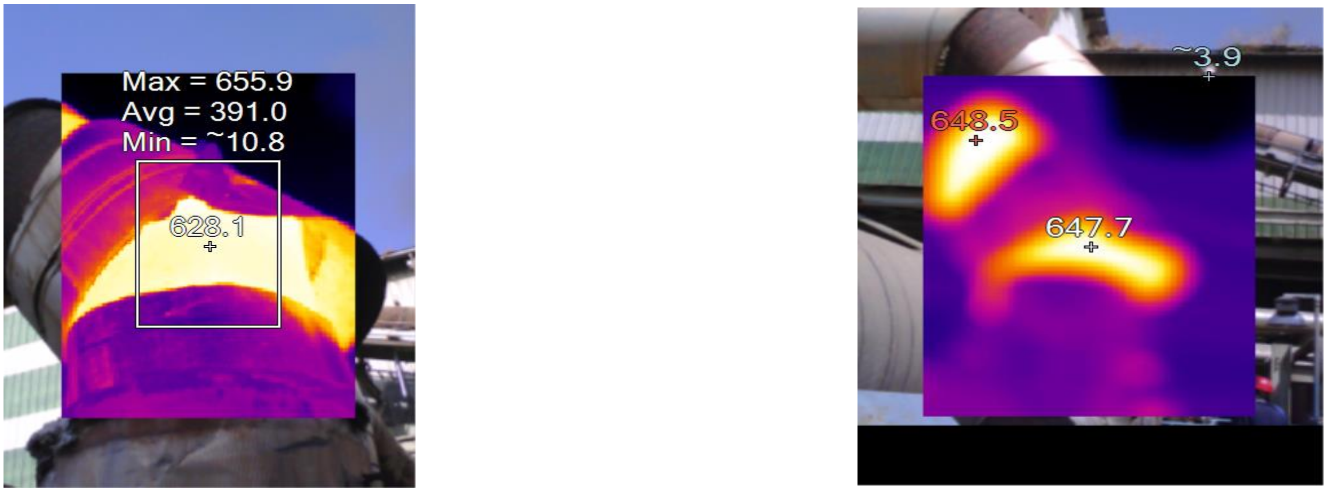

Figure 4.7: photos and measurement taken by infrared thermal imager on main steam lines

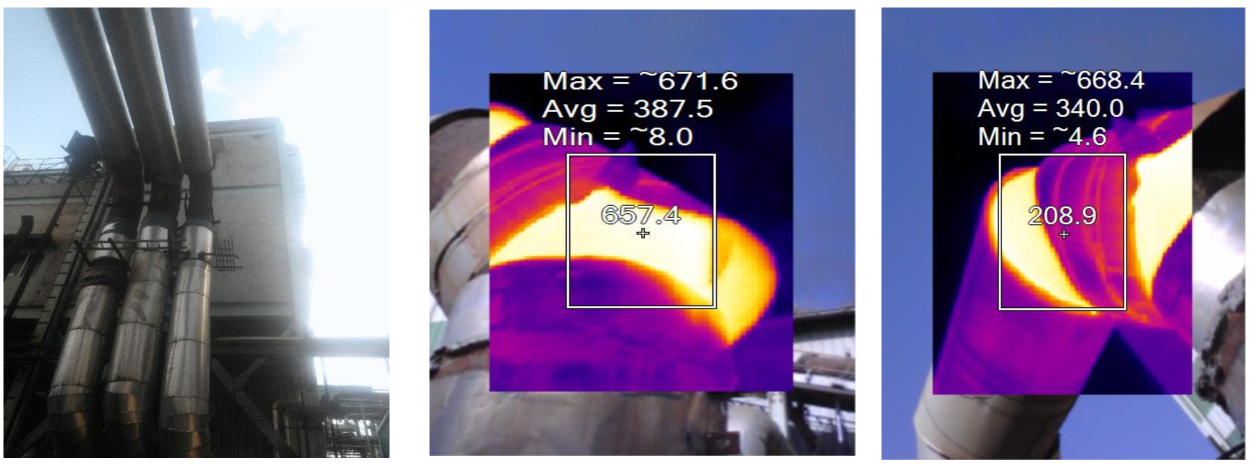

Figure 4. 8: photos and measurement taken by thermal imager on header

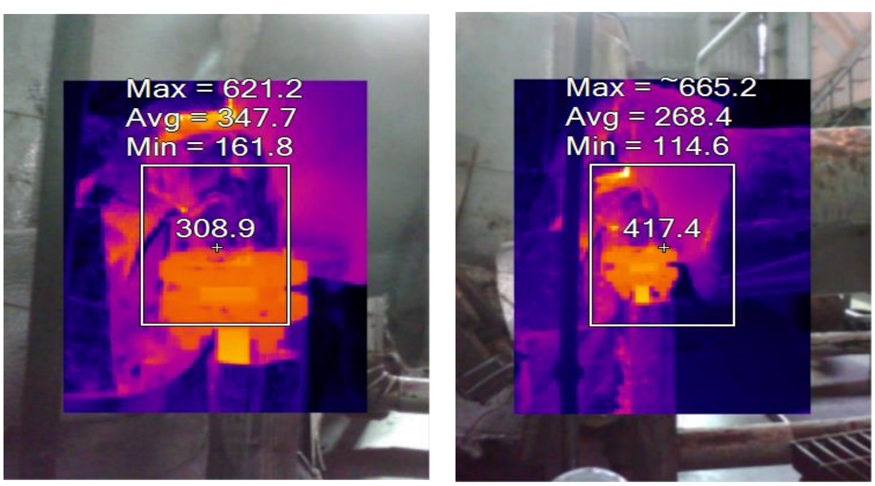

Figure 4. 9: photos and measurement taken by thermal imager at existing turbine section

Note: the measurement taken by thermal imager is in degree Fahrenheit

4.5.3. Heat loss due to poor insulation

The surface temperature of main steam lines, and process plant steam lines were measured are less than optimum. Various charts, graphs and references are available for heat loss computation. The surface heat loss can be computed with the help of a simple relation as a given below [29]. These equation can be used up to 200 ^oC surface temperature.

$S = [10 + (T_s – T_a)/20] \times (T_s – T_a)$…………………..4.5

Where: S = surface heat loss in kcal/hr-m^2

T_s = hot surface temperature in ^oC

T_a = ambient temperature in ^oC

Total heat loss/hr (H_s) = S x A, where A is surface area in m^2

Based on the cost of heat energy, the quantification of heat loss can be quantified as follows:

Equivalent fuel loss (H_f) (kg/hr) = (H_s x yearly hour of operation)/ (GCV x η_{boiler})

The measured average surface temperature of deteriorated steam lines with thermal imager is 196^oC steam, ambient temperature during measurement was 30.6 ^oC, 65mm insulating material (glass mineral wool), and 21.9m length which is estimated uninsulated lines (uninsulated) , diameter 150mm.

- Existing heat loss:

S = [10 + (Ts – Ta)/20] x (Ts – Ta)

Ts= 196 ^oC

Ta=30.6 ^oC

S = [10 + (196 – 30.6)/20] x (196 – 30.6) = 3,021.86kcal/hr-m^2

S_1= S = Existing heat loss = 3,021.86kcal/hr-m^2

Energy conservation measure is just insulating considered lines with glass mineral wool, 50mm (modified system),

Ts= 65 ^oC (surface temperature after insulation)

Ta=30.6 ^oC

S = [10 + (65 – 30.6)/20] x (65 – 30.6) = 403.17kcal/ hr-m^2

S_2= S = loss after insulator is provided, heat loss (403.17kcal/ hr-m^2). Therefore significant amount of energy could be saved by insulating this lines with proposed insulation.

Table 4. 18: summary of fuel saving from insulating steam lines

Fuel savings calculation		
	=	0.15m and 21.9m length
Surface area existing A1	=	3.14 x 0.15 x 21.9 = 10.3m^2
Surface area after insulation A2	=	3.14 x 0.345 x 21.9 = 23.72m^2
Total heat loss in existing system (S1 x A1)	=	3,021.86 x 15.03= 31,125.16kcal/hr
Total heat loss in modified system (S2 x A2)	=	403.17 x 23.72 = 9,563.19kcal/hr
Reduction in heat loss	=	31,125.16 – 9,563.19= 21,561.97kca/hr
No of hours operation in a year	=	(10 x 30 x 24) = 7,200
Total heat saving in (kcal/year)	=	21,561.97x 7,200 = 155,246,184
Calorific value of fuel (FO and bagasse)	=	10,000kcal/liter
Boiler efficiency (determined average)	=	63.59%
Price of fuel oil (USD/$)	=	0.5$/liter
Yearly fuel oil savings	=	155,246,184/(10,000 x 0.6359) 24,413.62litre/year or 110.97tone/year of bagasse

4.5.4. Steam trap and steam leakage

A steam trap is a valve device that discharges condensate and air from the line or piece of equipment without discharging the steam [28]. The three important functions of steam traps are:

- To discharge condensate as soon as it is formed.
- Not to allow steam to escape
- To be capable of discharging air and other incondensable gases.

Therefore steam traps is installed to obtain fast heating of the product and equipment by keeping the steam lines free of condensate, air and no condensable gases. There are three basic types of steam trap: Thermostatic (operated by changes in fluid temperature), Mechanical (operated by changes in fluid density), Thermodynamic (operated by changes in fluid dynamics).

Steam trap performance assessment is basically concerned with answering the following two questions:

- Is the steam trap is working correctly or not?
- If not, has the trap failed in the open or closed position?

Trap that fail 'open' result in a loss of steam and its energy [28]. Where condensate is not returned, the water is lost as well. The result is significant economic loss, directly via increased boiler plant costs, and potentially indirectly, via decreased steam heating capacity. Traps that fail 'closed' do not result in energy or water losses, but can result in significantly reduced heating capacity and/or damage to steam heating equipment.

During this assessment, an attempt was made to evaluate the performance of the traps by conducting survey on main steam lines and sub-lines/process steam lines. It was observed that at various place steam valves are partly open to remove condensate because of the failure of steam traps.

Steam losses due to steam leakage is observed mainly in process plant and detected with infrared leak detectors at flanged joints as well. Different size of steam flume are observed, estimated size (2mm to 6mm). These is detected and observed at more than four areas/places process steam lines. Of about 4bar pressures (observed at pressure gauges on those lines).

Figure 4. 10: During leak detectin using ultrasonic lead detector on steam lines

Figure 4. 11: Observed steam leakage in process plant

4.5.4.1. Avoiding steam Leakages

Steam leakage is visible indicator of waste and must be avoided. It has been estimated that a 3mm diameter hole on a pipeline carrying 7kg/cm^2 steam would waste 33KL of fuel oil per year. Steam leaks on high pressure mains are prohibitively costlier than on lower pressure mains. The plant should consider a regular surveillance program for identifying leaks at pipelines, valves, flanges and joints. Indeed, by plugging all leakages, one may be surprised at the extent of fuel savings, which may reach up to 5% of the steam consumption in smaller or medium scale industry or even higher in installations having several process departments. [24]

To avoid leaks it may be worthwhile considering replacement of flanged joints which are rarely opened in old plants by welding joints. Figure 4.10 provides a quick estimate for steam leakage based on plume length.

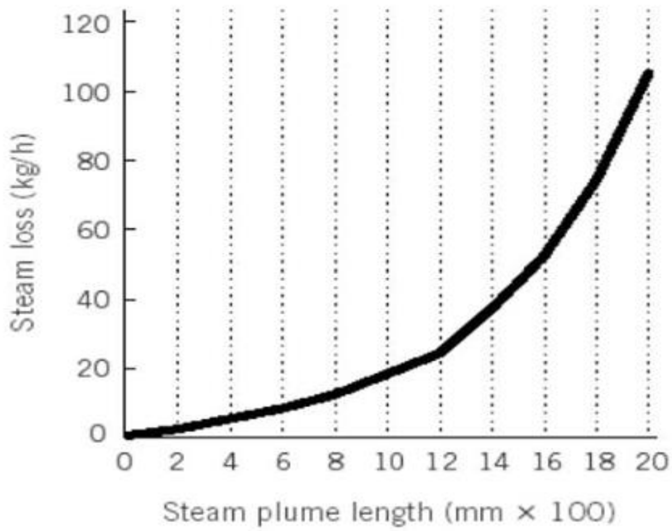

Figure 4. 12: steam losses vs. plume length [24]

4.6. Energy Conservation Measures

Thermal energy generation and distribution (i.e. steam generation and distribution) is suspected area of energy loss in the factory where energy conservation and efficiency improvement potential could be significant. Based on observation and assessment conducted on steam generation and steam distribution system, the following energy conservation measures (ECM) have been identified,

- Improving the efficiency of boilers by monitoring excess air to optimum level
- Providing proper insulation/maintaining insulation level of steam lines
- Minimizing steam leakage and
- Proper utilization of bagasse for boilers instead of furnace oil.

4.6.1. Improving the efficiency of the boilers by monitoring excess air to optimum level

The percentage of excess air of existing boiler 1, new boiler 3 and boiler 4 is 107.1%, 110% and 110% respectively. Excess air quantity is high compared to allowable excess air to bagasse fired boiler which is 20 -35%. The theoretical amount of air required for combustion of bagasse is about 3,2kg/kg of bagasse [9]. With 20-35% excess air required in all practical cases. But in this case i.e. FSF boilers, even though the theoretical amount of air required is estimated about

3.3kg/kg, amount of air introduced to the three considered boilers are 5.82kg/kg, 5.88kg/kg, and 5.88kg/kg of bagasse respectively. Hence, one of the reasons why the factory captive power plant boilers are less efficient is introduction of excess to the boilers.

Improving efficiency of the boilers can be achieved by minimizing major losses, dry flue gas losses and losses due to moisture in a fuel/bagasse. To keep the excess air to optimum level, which is about 20 – 35%, overall efficiency of boilers can be improved by about 5%.

4.6.1.1 Observation and Analysis

It is easy to monitor flue gas either by using portable combustion analyzer or by installing fixed analyzer and accordingly by following the oxygen percentage excess air can be reduced by controlling air supplied by FD fan and Secondary air fan. It will help to reduce the bagasse/furnace oil consumption and reduce the flue gas losses. Also it has potential to reduce the FD fan and secondary air fan power consumption.

Controlling excess air to an optimum level always results in reduction in flue gas losses, for every 1% reduction in excess air there is approximately 0.6 rise in efficiency [9]. Various methods could be implemented to control the excess air introduced to the boilers.

- Portable oxygen analyzer and draft gauges can be used to make periodic readings to guide the operator manually adjust the flow of air for optimum operation. Excess air reduction up to 20% is feasible [9].
- Using continuous oxygen analyzer with a local readout mounted draft gauge, by which the operator can adjust air flow. Which ensure further reduction of 10-15% can be achieved over using the portable analyzer and draft gauge.
- The same continuous oxygen analyzer can have a remote controlled pneumatic damper position, by which the readouts are available in a control room.

Hence, by implementing methods easily by using portable combustion analyzer which is about 3,500USD (estimated cost of combustion analyzer used for the study) improving the boilers efficiency from 3 – 5% is possible by accordingly by following the oxygen percentage excess air can be reduced by controlling air supplied by FD fan and Secondary air fan.

Improving boilers efficiency from 3-5% indicates that; 10,618ton to 17,696ton bagasse could be saved. (i.e. 5% x 353,916ton = 17,696ton, bagasse could be saved). This means even 3% improvement of boiler efficiency could avoid additional utilization of FO. With indicated investment which is very marginal.

The investment cost is less than one thousand dollar, hence the payback for this investment is very marginal.

4.6.2. Insulating steam pipes to avoid heat loss due to deteriorated insulation

The measured average surface temperature of steam lines (FSF steam distribution system) at different locations where insulations are highly deteriorated are high, on average it is about 196°C. Even the steam lines provided with relatively good insulation are about 65°C on average basis. The temperature below 45°C or (ambient +5°C) is considered to be optimum [29]. The ambient temperature during measurement was 30.6ºC, 65mm insulating material (glass mineral wool), and estimated 21.9m length (uninsulated).

4.6.2.1 Observation and Analysis

Providing the same insulation for about 21.9m length of indicated deteriorated insulation.

Hence, as indicated above by using heat loss estimation equation 4.5, the yearly fuel saving is estimated about 24,413.62liter/year of FO or 110.97tone/year of bagasse. The investment cost is estimated about 262.8USD (estimated from old inventory with plant personnel's), and cost saving is about 12,206.81USD with the simple pay back is less than one year.

4.6.3. Minimizing steam leakage

Steam losses due to steam leakage is observed mainly in process plant due to steam trap failures is observed and detected with infrared leak detectors at flanged joints as well. Different size of steam leakage are observed, at flanged joints, valves and etc. different size of steam leakage and different plume length are recognized and estimated. The estimated size of (2mm to 6mm). with an average of 4mm side and plume of different length.

4.6.3.1 Observation and Analysis

Maintaining flanged joints could significantly minimize/avoid steam leakage detected by ultrasonic leak detectors during the Assessment. The observed leakage analysis done with RET Screen; the analysis made by RETScreen is indicated below:

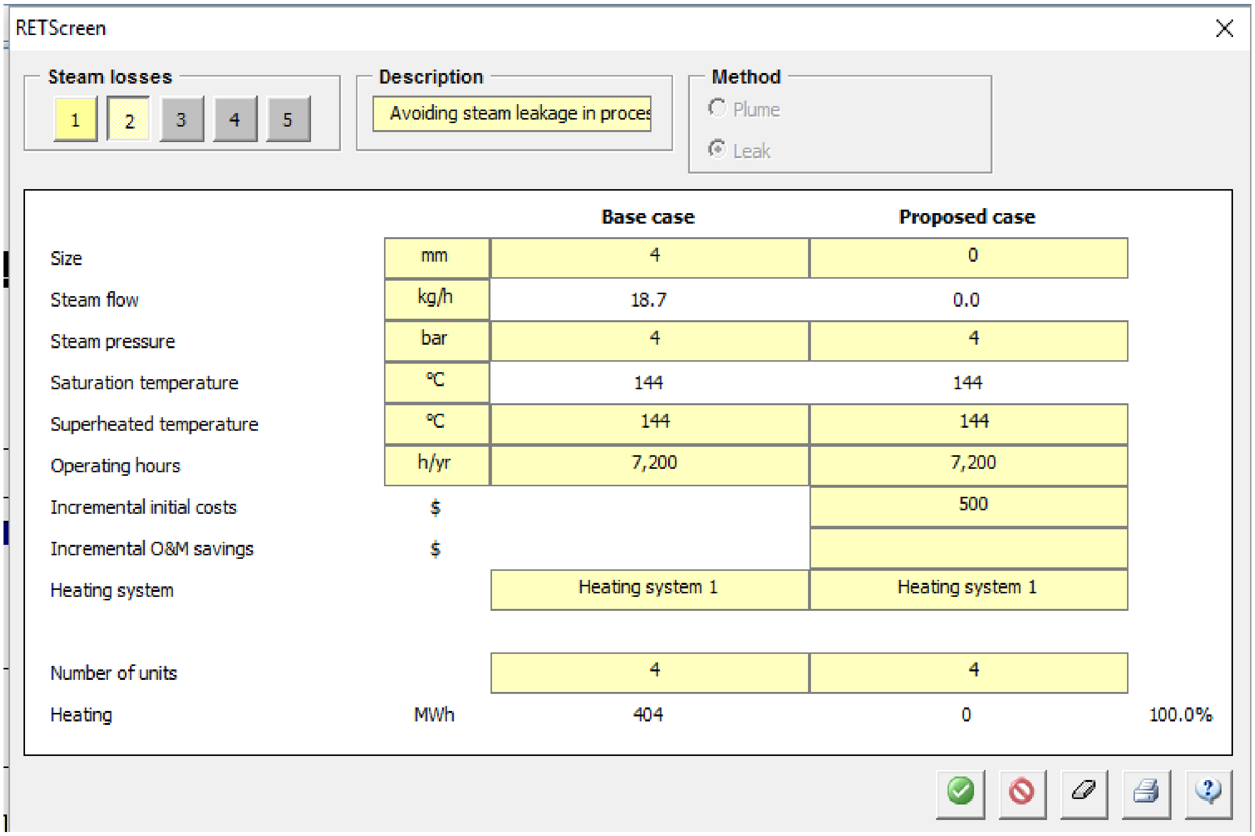

Figure 4. 13: RETScreen 4 Energy saving analysis output of Avoiding steam leakage

The output indicates that avoiding steam leakage of average size of 4mm causes to save 18.7kg of steam per hour and the plant operating hour which is estimated about 7200hours a year and the saving would be about 404MWh. The incremental initial cost is estimated about 500USD (estimated cost to replace some flanged joints and welding) for each units to avoid leakage and the total would cost be about 2000USD. The energy saving cost is about 7,312.4USD. The payback period is very marginal which is about 0.3 years.

5. Result Analysis and Discussion

The detail analysis of identified energy conservation measures/efficiency improvements are evaluated by RET Screen Version 4 energy efficiency model. These analysis includes, summary of energy that could be saved due to implementation of identified energy efficiency measures in each utility systems, electrical systems, motor drives, lighting systems and captive power plant, financial analysis, and emission analysis within the whole FSF facilities considered in the study. The RETScreen model allows to calculate heating impacts of lighting on your space heating and cooling.

The software enables to make analysis of both existing facility and energy conservation measures proposed to see what is already existing and what is proposed to be implemented. In the analysis the software enables to do analysis of part of the facility utility systems independently and also analysis of the whole plant. Hence, it enables to evaluate the proposals and options taking into account the financial soundness of the proposed measures.

In the RETScreen energy efficiency model there are 3 main sections;

Section 1. Fuel and schedules: where fuel exists, electricity, natural gas, biomass, etc. are specified. electricity is default fuel that cannot be changed in the RETScreen version 4 energy efficiency model. And in this case electricity which is default fuel, bagasse and FO are defined.

Section 2. Facility Characteristics (energy and cost): where equipment or utility systems and measures to be implemented in the factory i.e. FSF. Such as lightings, motors, boilers etc are considered.f

Section 3. This section is the summary section where energy use and savings are summarized. Also Energy conservation measures verification can be done in this section to see that what has been done in the project by bench marking energy use of particular application.

In the analysis the base case which is existing scenario is compared with proposed case. The software has project database which consists of different energy efficiency projects implemented in different countries and this helps me to estimate cost of different energy efficiency measures. Once energy efficiency analysis is done with the software, emission and financial analysis is done in parallel.

5.1 Analysis of Electrical Systems with RETScreen

In doing analysis with RETscreen energy efficiency model it is possible to do analysis of the whole plant or just one part of the plant or just one process in that plant. In doing energy efficiency analysis it important to consider possibility of minimizing the usage, maximize efficiency and then optimizing the supply. The energy efficiency measures analyzed takes into account the identified energy conservation measures in each section of the plant.

Project information and site reference is defined in start page of the software as follows.

Figure 5. 1 project information and site reference conditions defined on the RETSreen

The project name is Finchaa sugar factory efficiency project and the project location is Finchaa, Ethiopia, the Analysis type selected is method 1. And the climate data location is defined by nearby site, Shambu town.

In this model, i.e. RETscreen energy efficiency model of there are three main section as described in the above. The first section is fuel and schedules section.

The fuel available in the FSF is defined in this section with respective unit cost of energy,

EEM_select

RETScreen Energy Model - Energy efficiency measures project

Fuels & schedules ☑ Show data

Fuel	Fuel type 1	Fuel type 2	Fuel type 3	Fuel type 4	Fuel type 5	Fuel type 6
Fuel type	Electricity	Diesel (#2 oil) - L	Biomass			
Fuel consumption - unit	MWh	L	t			
Fuel rate - unit	$/kWh	$/L	$/t			
Fuel rate	0.018	0.500				

Schedule	Unit		Schedule 1	Schedule 2	Schedule 3	Schedule 4	Schedule 5	Schedule 6
Description			24/7					
				Occupied	Occupied	Occupied	Occupied	Occupied
Temperature - space heating	°C							
Temperature - space cooling	°C							
Temperature - unoccupied	+/-°C							
Occupancy rate - daily			h/d					
Monday			24					
Tuesday			24					
Wednesday			24					
Thursday			24					
Friday			24					
Saturday			24					
Sunday			24					
Occupancy rate - annual	h/yr		8,760					
	%		100%					
Heating/cooling changeover temperature	°C	16.0						
Length of heating season	d	0						
Length of cooling season	d	365						

Facility characteristics ☑ Show data

Figure 5. 2: Fuels and Schedules defined in RETSreen for the analysis

The available fuels are electricity with unit cost of 0.0181$/kWh, FO with unit cost of 0.5$/L and bagasse are the three fuels defined.

Schedules can be defined here, where heating and cooling needs to be considered. But in this analysis heating or HVAC system is not considered.

The next section is facility characteristics.

Facility characteristics ☑ Show data

Show: Fuel saved	Heating MWh	Cooling MWh	Electricity MWh	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr	Include measure? ☐
Heating system								
Boiler	0	-	-	0	0	0	-	☐
Cooling system								
Building envelope								
Ventilation								
Lights								
Replacing HPMV with MH lamps	-	-	144	5,216	2,612	0	2.0	☑
Replacing T12 with T5 (electronic ballast)	-	-	81	9,401	1,460	1,000	3.8	☑
Replacing GLS with CFL lamps	-	-	12	250	220	20	1.0	☑
Electrical equipment								
Hot water								
Pumps								
Fans								
Motors								
MCC9C2, Centrifugal Pump replacement	-	-	45	11,518	817	700	7.6	☑
MCC5/main cane carrier (2)	-	-	56	11,514	1,007	800	6.4	☑
MCC5/inter carrier (3)	-	-	21	6,423	375	300	9.5	☑
MCC4/cane feeder table 1 (2)	-	-	20	4,100	364	350	5.7	☑
Process electricity								
Improving power factor at New PCC/MCC	-	-	3,276	157,500	59,300	1,000	2.6	☑
improving power factor at old Plant MCC	-	-	648	25,714	11,729	500	2.1	☑
Process heat								
Process steam								
Steam losses								
Avoiding steam leakage in process	0	-	-	500	0	0	-	☑
Heat recovery								
Compressed air								
Refrigeration								
Other								
insulating steam pipes	0	0	0	263	0	12,207	0.0	☑
Total	0	0	4,303	232,398	77,883	16,877	2.45	

Start | Energy Model | Tools

Figure 5. 3: Electrical systems Facility characteristics defined for analysis with RETScreen

The electrical systems, defined are, lightings, motor/major drives, process electricity. And the base case is seen against proposed case. In the Analysis the operating hour is estimated about 7200hours.

And the output indicates that, the fuel saved which is electricity about 4,303MWh, of estimated incremental initial costs of 232,398$ and fuel cost savings of 77,883$. The incremental O&M savings is about 16,877$ and the overall simple payback period is about 2.45years.

The third section, summary section, it indicates how much fuel is utilized in base case and how much is used in proposed case.

Summary ☑ Show data

	Fuel		Base case		Proposed case		Fuel cost savings	
Fuel type	Fuel consumption - unit	Fuel rate	Fuel consumption	Fuel cost	Fuel consumption	Fuel cost	Fuel saved	Fuel cost savings
Electricity	MWh	$ 18.100	27,886.6	$ 504,748	23,583.7	$ 426,865	4,302.9	$ 77,883

Project verification Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Electricity	MWh	23,583.7	27,886.6	15%

Fuel consumption	Heating MWh	Cooling MWh	Electricity MWh	Total MWh
Fuel consumption - base case			27,887	27,887
Fuel consumption - proposed case			23,584	23,584
Fuel saved			4,303	4,303
Fuel saved - %			15.4%	15.4%

☐ Show data

See benchmark database

Benchmark		
Energy unit	MWh	
Reference unit	t	

Figure 5. 4: The summary section of the electrical systems output.

It indicates that the fuel consumed in base case is 27,888.6MWh and the fuel cost is about 504,748$ and the proposed case is fuel consumption is 23,583.7MWh and fuel cost is 428,885$. Fuel saved is about 4,303MWh and the fuel cost saved in this case is 77,883$.

The RETScreen energy efficiency model has project verification. In this analysis the fuel consumption variance is about 15%.

Financial Analysis of Electrical systems:

The financial analysis output of the RETscreen model for the electrical system is:

Financial Analysis

Financial parameters			
Inflation rate	%	7.0%	
Project life	yr	15	
Debt ratio	%		
Initial costs			
Energy efficiency measures	$	232,398	100.0%
Other	$		0.0%
Total initial costs	$	232,398	100.0%
Incentives and grants	$		0.0%
Annual costs and debt payments			
O&M (savings) costs	$	-16,877	
Fuel cost - proposed case	$	426,865	
Other	$		
Total annual costs	$	409,989	
Annual savings and income			
Fuel cost - base case	$	504,748	
Other	$		
Total annual savings and income	$	504,748	
Financial viability			
Pre-tax IRR - assets	%	50.4%	
Simple payback	yr	2.5	
Equity payback	yr	2.2	

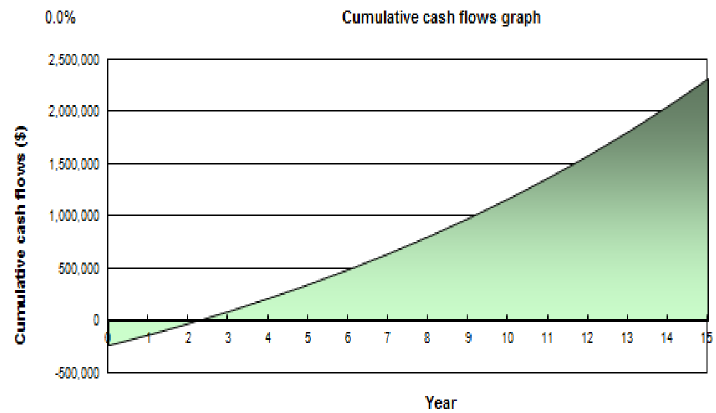

Figure 5. 5: RETScreen 4 Financial analysis output of FSF considered electrical systems

In these case, financial parameters, like inflation rate which is estimated about 7% (2016 inflation rate) and project life is defined. And the financial viability of the proposed energy conservation measures described in terms of assets pretax internal rate of return, simple payback period and equity payback as indicated in figure 5.5 above. Accordingly,

- Pre-tax IRR assets % 50.4%
- Simple payback period (years) 2.5 years
- Equity payback period (years0 2.2 years

Hence, as an investment payback period is 2.5 years and 2.2 years equity payback period indicates that the proposed measures are financial it is viable.

5.2 Analysis of Thermal Energy savings

The thermal systems (steam generation efficiency, maintaining steam distribution pipes and avoiding steam leakges), analysis is also done with RETScreen Energy efficiency model. And the facility characteristics considered in thermal systems are:

- Boiler, i.e. Improving/optimizing the efficiency of boilers by monitoring excess air to optimum level
- Providing proper insulation/maintaining insulation level of steam lines
- Steam losses, Minimizing steam leakage
- Proper utilization of bagasse for boilers instead of furnace oil.

The 2016/17 bagasse consumption was 349,602ton and Fuel oil consumption is 949,175litre which is used in the analysis. The boiler saving Analysis which is considered by using portable analyzer or installing fixed analyzer could improves boiler efficiency by 3 - 5%. This could save 10618ton to 17,696 ton of bagasse could be saved. Which is estimated about 15,844MWh of annual energy saved.

- Annual cost of energy saving is about 286,776.4USD.
- The incremental initial cost of this measure, 3500USD, therefore the simple payback period is very low less than 1year.

The saving Analysis output done for insulating steam pipes indicates that the yearly fuel saving is estimated about 24,413.62liter/year of FO or 110.97tone/year of bagasse.

- Annual cost of energy saving is about 12,206.81USD.
- The incremental initial cost of this measure, ECM is very low, 262.8USD.
- The investment cost is estimated about 262.8USD,
- The simple payback period is very marginal

The saving Analysis output done for Avoiding steam leakage by replacing identified damaged flanges indicates annual energy saving of 404MWh with the incremental initial cost estimated about 2000USD.

- The Annual cost of energy saving is about 7,312.4USD.
- The payback period is very marginal which is about 0.3 years.

The FO consumption of 2016/17 of the factory 949,175litre could be replaced by bagasse. Which is only about 5,300ton of bagasse. And the annual cost energy saved from this is about 474,588USD.

Generally, the amount of bagasse that could be saved by implementing the ECM indicated, which is about 10618ton to 17,696 ton could avoid additional use of FO and generate additional electricity that could significantly reduce electricity import from the national grid and reduce energy intensity and energy cost of the plant. The annual cost of energy saving from proposed ECM of thermal system is 780,883.21USD.

6. Conclusion and Recommendation

6.1. Conclusion

Electricity which is cogenerated and imported from the national grid/EEU, bagasse and imported furnace oil are the major energy source to the factory. The energy in the factory are mainly consumed by process equipment's and cogeneration auxiliaries like funs, pumps etc.

Benchmarking specific energy consumption of the factory with similar factories in the world which is 0.6 – 0.7GJ/ton indicates that there is potential to reduce the energy consumption of the factory. Efficient production of steam, efficient use of electrical and mechanical energy, efficient use of steam, minimizing energy and heat loss are vital to ensure competitiveness and minimize energy intensity of the factory. Energy conservation and efficiency improvement could enables the factory to significantly reduce imported oil consumption and enhance electricity export (to the grid) capacity of the factory and minimize grid electricity dependency.

Assessment of technical and financially viable to the factory energy conservation potential and optimizing efficiency through comprehensive energy audit uses sophisticated and diagnostic measuring instruments to realistically asses and identify energy conservation measures. These includes mainly;

- Maintaining plant power factor at optimum level PCC/MCCs
- Replacing efficient lightings
- Replacing inefficient major drives/motors
- Optimizing excess air to boiler to improve efficiency of boiler by 5%
- Utilizing bagasse properly instead of HFO
- Insulating deteriorated thermal insulation on steam lines
- Avoiding steam leakage in process plant

The selection and saving analysis is evaluated by using IMSSA (International Motor Selection and Saving Analysis) and RETScreen 4 energy efficiency model tools.

The summary of ECMs and saving potential is indicated on the table 6.1 below:

Table 6. 1: summary of recommended ECM and saving potentials

	Energy Conservation Measures (ECM)	Annual saving potential		Incremental initial cost/investment	Simple payback
		Energy	Energy cost		
		MWh /liter/t	USD ($)	USD ($)	Years
Electrical system					
1	Installation of APFC and capacitor banks in new plant PCC/MCCs	3,276MWh	55,300USD	157,500USD	2.6
2	Installation of APFC and capacitor banks in old plant identified MCCs	648MWh	11,729USD	25714USD	2.1
Motors					
3	Replacing old standard efficiency motors with low loading ration with efficient motors	142MWh	2,563USD	33,555USD	7.2
Lighting system					
1	Replacing HPMV lamps with MH lamps	144MWh	2,612USD	5,216USD	2.0
2	Replacing existing T12 existing FTL lamps in phase manner	81MWh	1,460USD	9,401USD	3.8
3	Replacing incandescent lamps with 14W CFL	12MWH	220USD	250USD	1.0
Boilers and steam system					
1	Improving boiler 1, 3& 4 efficiency through maintaining excess air at	17,696ton (949,175L)	286,776.4USD.	Marginal	< 1year

	standard level	(15, 844MWh)			(marginal)
2	Insulating steam pipes with proper insulation	24,413.62L	12,206.81USD.	262.8USD	< 1year (marginal)
3	Avoiding steam leakages by using suggested measure	404MWh	7,312.4USD.	2000USD.	< 1year (marginal)
4	Minimizing utilization of FO by proper utilization of bagasse	947,175L	474,588USD.	Marginal	< 1 year (marginal)
Total					

6.2. Recommendations

Energy efficiency and conservation should be viewed as new source of energy along with energy cogeneration. Identifying energy conservation opportunities including possibilities of efficiency improvement so as to come up with actions to be taken to minimize energy wastage and preparing feasible energy saving recommendations to reduce additional fuel/FO consumption and minimizing grid dependency, electricity from the grid was the objective of the thesis work. Energy audit is vital tool to understand more about the ways energy is being used in the factory, and help in identifying the areas where waste can occur and where scope for improvements exist. Hence, there has to be regular monitoring of energy and analysis of energy use in the factory.

Implementing the proposed recommendations identified in this thesis work will improve energy utilization efficiency of the factory that minimize dependency of imported fuel and enhance electricity export capacity of the factory to the grid. It's is recommended to implement low cost/no recommended ECMs first. This also ensure competitiveness and economic viability of the recommended ECM factory as well.

There has to be energy management unit that ensure energy management practices that provide a strategy of regulating and optimizing energy use, energy using systems and procedures. Operational practices and maintenance has to be taken care of because it is not only for the purpose of ensuring reliability but also ensuring energy efficiency and conservation in the factory. This has to be supported by internal energy management policy in factory.

Energy meters are provided at the main incomer i.e. PCC/MCC panels. But the plant should calibrate analog energy meters and rectify them to know section wise energy consumption and daily/monthly consumption trend that will help in identifying energy consumption trend.

6.3. Suggestions for future work

This thesis work reveals that there has to be future research works need to be taken into account also, to further conserve and optimize energy efficiency in the factory. These are:

- This study covers, electrical systems, motors, lightings and Steam generation units/boilers and steam distribution systems only. There could be significant scope of energy efficiency improvement and conservation in mechanical drive systems like pumps, compressors etc. and steam utilization as well that has to be investigated through detailed energy audit.
- Power quality parameters are monitored for existing condition and installing APFC and kVAr banks may cause harmonics that could be beyond the IEE-519 industry standard after implementing the recommended measures, so future work must integrate study of harmonics and study the distortion levels produced. Tuned harmonic filters consisting of a capacitor bank and reactors in series could be designed and adopted for suppressing harmonics.
- Boiler efficiency analysis indicates that loss due to moisture content in a bagasse is significant, about 14.5%. Literatures suggest that improving moisture content of bagasse even from 50% to 40% can increase steam production by 15%. Hence, future work must consider application of bagasse drier.

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Appendix