International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-9 Issue-6, April 2020

Internet of Things (IOT) based Advanced Energy Auditing on Sugar Industry Automation for Better Energy Conservation Measures

Yamanappa.N.Doddamani, U. C. Kapale

***Abstract:** This Paper is an investigation on methods involved for different energy auditing practices using the Internet of Things (IOT) technology. A practical sugar industry environment is emulated to get the overall power delivery at each stage of the sugar industry process. The sensors utilized at different sugar making process are discussed with the perspective of the power usage at each of the sugar processing stages. The Raspberry Pi based logging and analysis process is developed for the sugar industry. The sensors are connected to the power usage capability and the data collected are logged to be able to analyse the power delivery and carry out the energy auditing in the complete process. Python based UI for the complete energy auditing process is developed and the results are discussed in detail. The emulation carried out is found to replicate the complete process of sugar industry and the auditing is scaled up to match the specifications of the practical sugar industry. Suggestions regarding the power conservation measures are provided to be followed by the industry. The manual means of energy audit is removed to replace it with the automated energy audit as given in the graphical form. It is observed that the total cost for the energy audit is getting reduced except for the capital cost.*

***Keywords:** Internet of Things, Energy Auditing, Cloud Computing, Sugar Industry, Process Control*

I. INTRODUCTION

India being one of the leading sugar producers in the world needs a better automated sugar production technology with lesser energy consumption in every power delivery stage of the sugar production. The energy audit implementation in an industry is meant to develop the conservation strategy of energy in the plant. The total capital cost and the breakeven point of the industry's income is a crucial parameter considered in the economics of the company [1]. The energy demand that is prevailing in the industry and ever increasing demand, with increasing cost on energy, the leakage in the energy and depleting source of energy the purpose of auditing the energy is inevitable.

Revised Manuscript Received on April 30, 2020.
* Correspondence Author
Yamanappa.N.Doddamani , Research Scholar, VisvesvarayaTechnical University, Belagavi, , Karnataka, India. Email: yndabhi@rediffmail.com
U. C. Kapale*, Departement of Mechanical Engineering, . S. G. Balekundri Institute of Technology, Belagavi, Karnataka, India

The energy conservation strategies are the results of the energy audit procedure carried out in the industry. The automation of energy audit is prime in order to avoid human hours on the auditing process. Categorising the sections of the plant, by means of power specifications or the industry process, is carried out while conducting the energy audit survey in the plant. Among the total power that is used commercially in India almost 45% of the energy is used in industries [2-4]. It is observed that the energy saving capability of the sugar plant is about 35% [5-7]. Thus the need of the energy audit implementation and the conservation of energy in the sugar industry has a bigger scope with government encouraging the energy conservation initiatives. The government of India initiated the energy conservation act way back in 2001 establishing the Bureau of Energy Efficiency (BEE) later in 2002. Every industrial sector is concentrated to develop the conservation practice through this establishment. The processes in the sugar industry include juice extraction plant that comprise of unloading sugarcane, moving sugarcane in the conveyor belt, preparing the cane and juicing. The other processes are Juice purification followed by the evaporation and crystallization at the end. The cogeneration process using the bagasse which is the residue from the cane after the juice extraction is considered in the modern sugar industries [8-9].

This paper takes up the challenge of identifying the sections in the sugar industry which utilises higher power and audits the energy. The conservation tactics utilized in the sugar industry by using the data available from the energy audit is discussed and further suggestion is followed in the industry.

II. ENERGY AUDIT PURPOSE, PREREQUISITES AND PROCEDURE

The purpose of the energy audit in the sugar industry is the problem of lesser profit due different reasons including the transportation cost, sugar price, low output from the sugar industry from high amount of sugarcane. The cost cutting at every stage of the production is a primary need in order to improve profit in the sugar industry while Indian scenario is considered.

The power rating of the equipment used all over the sugar plant is as given in the table 1. The Sugar industry capable of handling 7500 tonnes of sugar cane with slings lifting 6 tonnes for every lift and frequenting 20 lifts per hour with three bridges with three trolleys. Electrical equipment with power delivery capacity for the specifications thus discussed is detailed in the following Table1.

Table I : Equipment Used in Sugar Industry and Corresponding Specifications

Equipment	Rating Induction Motor
Hoisting Drum Drive	35HP
Holding Drum Drive	35HP
Cross Travel Drive	10HP
Feeder Table	15HP
Cane Carrier	125 BHP
Rake Carrier	100BHP
Cane Chopper	200BHP
Cane Leveller	500BHP
Fibrizer	3MW
Mill Drive	850HP
Bagasse Elevator	75HP
Bagasse Carrier	100BHP
Return Bagasse Carrier	75BHP
Main Hoist Motor	25HP
Long Travel Motor	10HP
Cross Travel Motor	7.5HP
Roller	400HP
Mill and Pressure Feeder Drive	1000HP
Drum Drive for Vacuum Filter	3.7KW
Agitator Drive	2.2KW
Seed and Vacuum Crystallizer	15HP

The Table above is the power used in the sugar industry while the table below is the production from the bagasse based power generating plant. 8000KW alternator is available for the supply to the sugar industry.

Table II : Alternator Rating in Bagasse Cogeneration Plant

Equipment	Alternator
Diesel Generating	500KW
Bagasse Power Generating Plant	8000KW

The choice of both the electric and hydraulic sugarcane handling system by using in the hoisting and holding drum drive is suggesting that the hydraulic based system would reduce the power usage if more bridges with more trolleys are used. After both the drive to move the sugar cane to the processing system the cane feeder is utilized with the 15HP motor to feed the cane to the processing stages. The automation that carries on the logging and analysis of the data regarding power usage takes help of the IOT technology using the Raspberry Pi along with the voltage and current sensors.

a. IOT based automated Energy Audit

The IOT implementation on the energy audit of the sugar industry is carried out using the above data that is gathered from the sensors connected at nodes that matters in the sugar plant. The energy audit process involves the following steps,

- The first step is the identification of the higher energy consuming equipment in the sugar industry.
- Grouping the energy consuming equipment according to its usability
- IOT sensors decided on the basis of different nodes to be chosen
- Data Collection from different nodes through cloud environment
- Energy Usage variation due to seasonal variation, cost saving suggestions and payback period.
- Identifying higher power consuming section in the plant
- Calculating Energy for per unit production in the plant

The rating of the different sections after grouping the equipment by means of its process in the sugar industry is given in Table 3.

Table III : Segregated Energy Consumption after Grouping

Type or Group	Energy Consumption	Hours Used
Cane Handling	70.87KW	22hrs
Milling	3690KW	22hrs
Bagasse Processing	186.5KW	22hrs
Cane Juice to Sugar processing	1093.195KW	22hrs

Among all the process in the sugar industry the Milling process takes maximum power of around 3690KW. Among them Fibrizer takes the maximum power of 3MW. It can be observed that the total amount of the power used by the complete sugar industry is coming to around 5041KW for a 7500 tonnes of sugar cane per day. If the Variable Frequency Drives (VFD) is applied there is directly a 28% reduction in the overall power used from the machines used for the process. As discussed by [11].The output sugar is coming to around 9%-10% of the total tonnage of the sugar cane reaching to around 750 tonnes in a day. The Bagasse with 50-52% moisture reaches the air preheater and then superheated to generate the power of about 8000KW.

b. IOT based automation in Energy Auditing

The sensors involved in the whole process of the sugar industry are observed using the IOT boards at the sensing nodes and the Raspberry Pi at the central node. Each of the sensing nodes comprises of the sensor and the node MCU. The node MCU comprises of the ESP8266 along with required sensors. The sensors include voltage and current sensors for each phase of the supply to the drives. As this is meant for the energy audit purpose only the sensors that are meant for the energy audit is considered and the instrumentation sensors that are meant for different process control in the sugar industry is not considered.

- **Current Sensor**

Since the Energy Auditing need real time measurements of the current and voltage, a current sensor is used. The current sensor consists of a shunt resistor that has a very low resistance so it would affect the actual usable current as little as possible.

Furthermore, the voltage drops over the shunt resistor would be measured and by ohms law the current would be obtained. However, because of the small resistance the voltage drop would be very low. The Node MCU controller could not detect such low values; thus, a sensing circuit is used. As seen in Figure 1, the current sensing circuit amplifies the voltage drop which the Node MCU receives through the ADC. The calibration equations for this sensor circuit is defined by the voltage divider equation defined below,

$$V_{out} = I_{in} \cdot R_{shunt} \cdot \frac{R_{out}}{R_{in}}$$

where $R_{shunt} = 0.008\Omega$. Since the Node MCU analog read input only can have a maximum 5 V input, the equation becomes:

$$5\,V = I_{in} \cdot 0.008\Omega \cdot \frac{R_{out}}{R_{in}}$$

Furthermore, Rin and Rout was chosen as 800Ω and 250kΩ respectively. This makes a 5 V input voltage to the Node MCU correspond to 2.5 A and 0.05 V corresponds to 0.025 A, which suits the design in terms of maximum current and resolution.

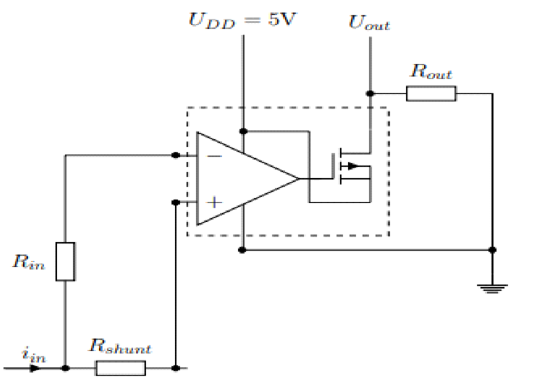

Fig. 1.Current sensor circuit

- **Voltage Sensor**

In order to measure the input voltage a simple voltage divider is constructed, as seen in Figure 2. Voltage divider circuit scales down the voltage such that it can be measured by the ADC, since the Node MCU only can measure a maximum of 3.3 V the voltage divider circuit is capable of calibrating the variation of the voltage in the circuit. Voltage sensor circuit is shown in Figure 2.

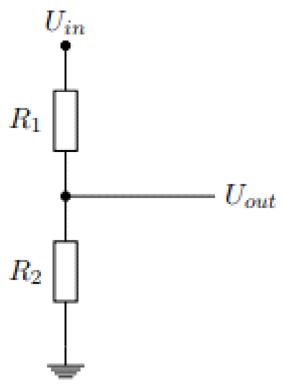

Fig. 2.Voltage sensor circuit

From Ohm's law the expression for the output voltage to the Node MCU will be:

$$U_{out} = U_{in}\frac{R_2}{R_1 + R2}$$

The values of R1 and R2 was chosen large and so that the above equation would yield a corresponding scale, since the Node MCU can read until 3.3 V.

- **Clip and Clamp Circuit**

While sensors senses the AC waveform from both the voltage and the current sensor in order to apply the control algorithm the compatibility of the Node MCU processor is that it can only receive positive voltage and that too in the range of 0-3.3/5V. Thus clipping and clamping are used to feedback the AC waveform in to the controllers. The circuit guarantees the voltage and current measured at the grid, not exceed the limit of 0-3V with clipping the voltage is limited and by clamping the offset to the AC voltage is given.

The detailing of the clipping and the clamping circuit is given in the Figure 3 .

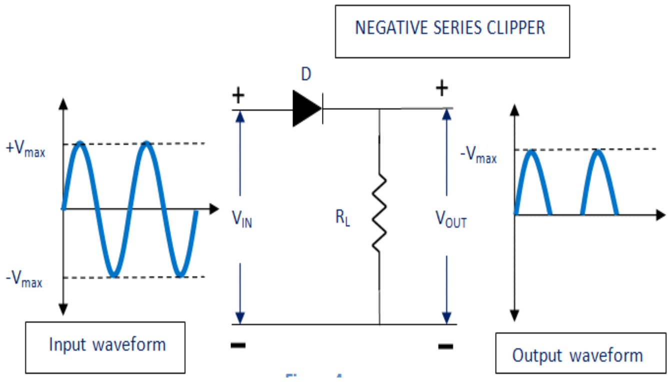

Fig. 3. Clipping Circuit diagram

The clipping is done with simple diode circuit and the clamping is done with the amplifier circuit. This clipping and clamping circuit is one of the important protection circuit in the system. Fig.4 shows the clamping circuit.

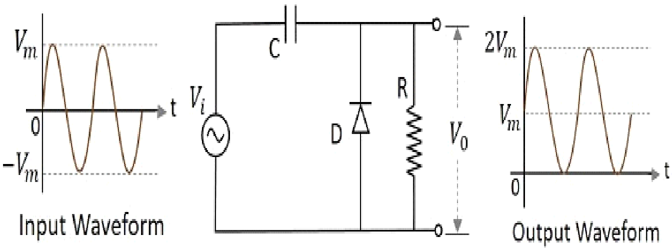

Fig. 4. Clamping Circuit diagram

The clamping circuit depicted in the Figure 4 pushes the negative half cycle to the positive portion of the waveform, facilitating sensed signals to be connected to the ADC directly. The unidirectional current will occur across R in the circuit which can be connected to Node MCU. Here the level of voltage 2Vm is maximum of 5V for Node MCU. The sensed voltage and current are taken from the sensors and are passed to the cloud called as Adafruit io and are reaching the central Raspberry processor. The central processor can observe the voltage and current at every instant of the sugar making process.

c. Iot Energy Audit Case Study

A research study has been conducted based on energy audit in a sugar mill for a week. That sugar mill was separated into each section according to their processes. There are four main section which are all consuming more power and also working for more time period compared to the other section per day.
So In each section electrical devices will be there. In those motors are the things which is consuming more power. So an current sensor and voltage sensor are placed in each and every motor to find the amount of current and voltage has been consumed by them. The major sections block diagram is shown in Figure5 .The four sections are:

1. Cane Milling Plant.
2. Cane Preparation
3. Mills Drive
4. BagasseConveying System

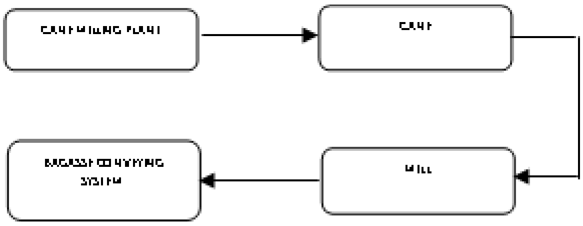

Fig. 5. Monitoring sections

These four sections are monitored daily for a whole week continuously. Their voltage and current values will b measured and stored in an cloud using an WIFI module (ES -node cu).Those values will be measured for every minute and average will be calculated for one hour and graph were plotted. Weekly current and voltage graph for major sections is shown in Figure 6 and Figure 7

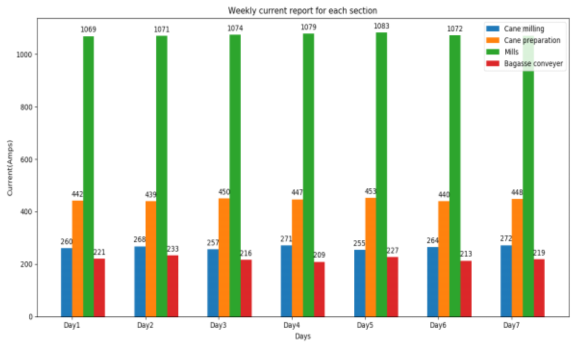

Fig. 6. weekly current graph for major sections

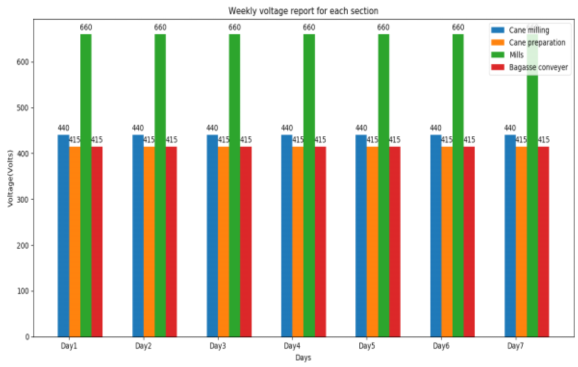

Fig. 7. weekly Voltage graph for major sections

The current value of each and every section has been measured and average value has been calculated as per day and compared with every section and plotted in a graph.

The voltage value of each and every section has been measured and average value has been calculated as per day and compared with every section and plotted in a graph.

Cane Milling Plant

This section is used to carry the process of bringing sugarcane inside the mill. To bring the sugarcane inside the milling plant it requires four machine which will do four different process to carry the sugarcane inside the mill. The four machines are Cane handling, Feedertable, Rake carrier and Cane carrier. The cane handling is used to lift sugarcane from the stock and to place inf the feeder table. The cane handling is done by the combination of three motors operation. Two squirrel cage and one slipring motor are used in cane handling. Cane milling plant block diagram is shown below in Figure 8.

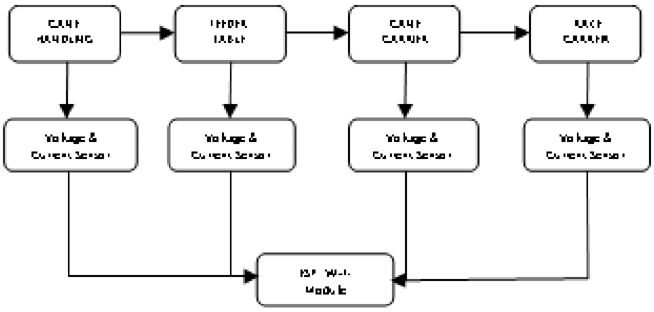

Fig. 8. Cane milling plant block diagram

Followed by cane handling the canes will be shifted to the feeder table. The feeder table is used to feed(insert) the canes inside the mills. A squirrel cage motor is used to operate this feeder table. After the feeding the cane inside the mill the canes will be carried by cane carrier. The cane carrier is operated by an induction motor. Then rake carrier is a slope type carrier is used to move the received canes to the top. These are the process are handled by cane milling plant and the power consumed by each machine in a cane milling plant has been monitored and measured. Each machines current and voltage values have been measured for every minute in aworking hour of a day. The average of those values has been calculated for every one hour and a graph has been plotted as per the time of one hour.

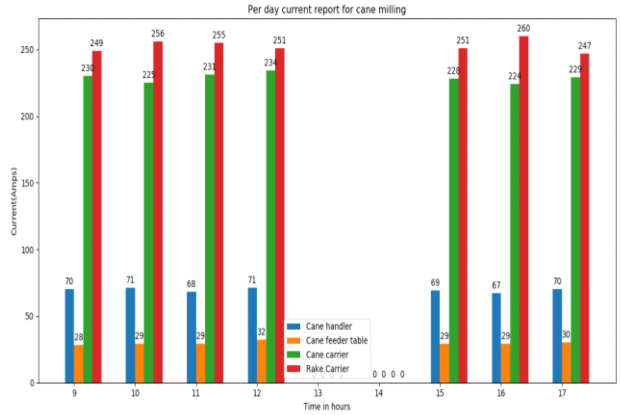

Fig. 9. per day current report for cane milling plant

The current value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

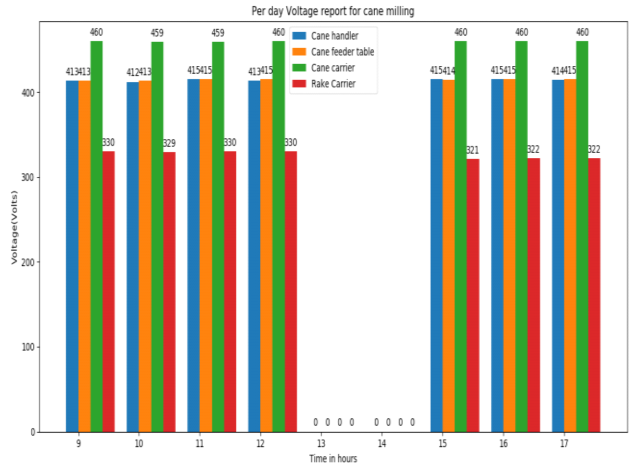

Fig. 10. per day voltage report for cane milling plant

per day voltage and current report for cane milling plant is shown above in Figure 9 and Figure 10. The voltage value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

B. Cane Preparation:

These sections used to carry out the process chopping, slicing and crushing the sugar cane. Cane preparation section consists of three different machines for these processes. Those machines are Cane chopper, Cane leveler and swing hammer. In these we avoided the swing hammer because of its minimal power consumption when compared to other two. But this machine is doing some important process of crushing sugarcane. Before crushing the cane, the leaf and root of a sugarcane should be separatedand should be cut in an equal size. cane preparation block diagram is shown below in Figure 11.

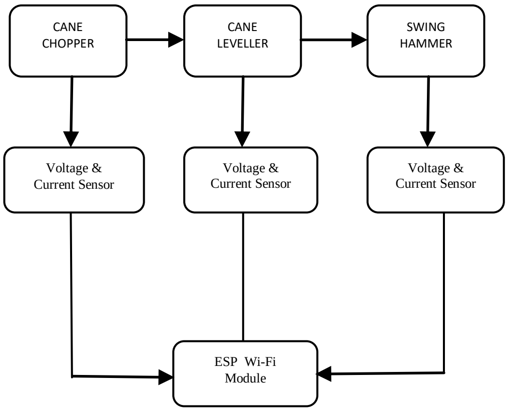

Fig. 11. cane preparation block diagram

These separation and levelling process are carried out by cane chopper and cane levelers per the earlier process voltage and current sensor has been placed for the cane chopper and leveler except swing hammer because of his power consumption. These are the process are handled by cane preparation plant and the power consumed by eachmachine in a cane preparation plant has been monitored and measured. Each machines current and voltage values have been measured for every minute in an working hours of a day. The average of those values has been calculated for every one hour and a graph has been plotted as per the time of one hour. Per day current and voltage report for cane preparation is shown below in Figure 12 and Figure 13

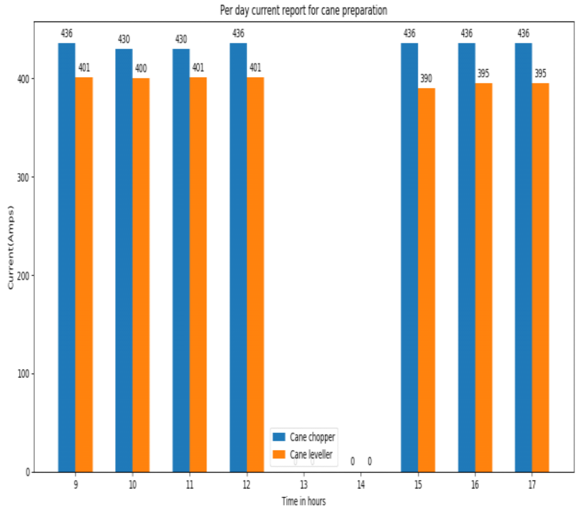

Fig. 12. per day current report for cane preparation

The current value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

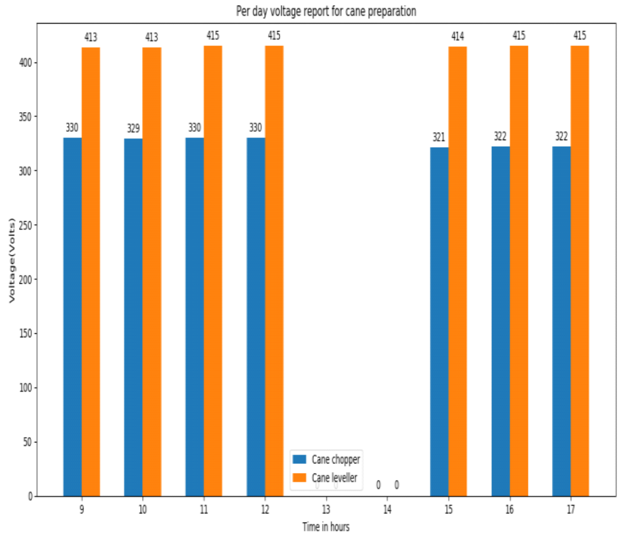

Fig. 13. . per day voltage report for cane preparation

The voltage value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

3. Mills Drive:

It'sa section about two motor drivers. Andmoreover, this is the section which is consuming lots of power when compared to all other section in the whole sugar mill. In simple words based on this sections power rating only this whole sugar mill supply wasdecided. Andit's the section which is controlling the whole machines in mills (another section in that sugar mill) section.

That mills section consists of roller mill, underfeedroller, Donnelly type chute and rake type intermediate carrier. These are the machines which are used to transport those chopped sugar cane and filtered sugar inside the whole mill. But these four machines are controlled by two drivers Variable speed D.C drivers and Convertor station drivers.

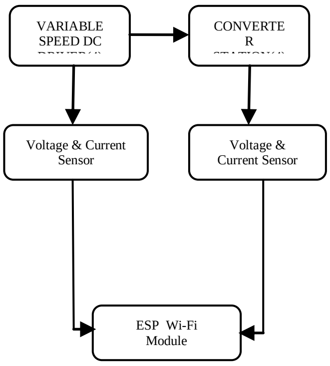

Fig. 14. mills section block diagram

The above Figure 14 shows the block diagram for mills sectionEach driver control two machines in mills section. So instead of monitoring mills section we decided to monitor mills drive section because of its control over on mills section. Therefore, according to the process a voltage and current sensor has been placed on each driver. Each drivers current and voltage values have been measured for every minute in aworking hour of a day. The average of those values has been calculated for every one hour and a graph has been plotted as per the time of one hour.

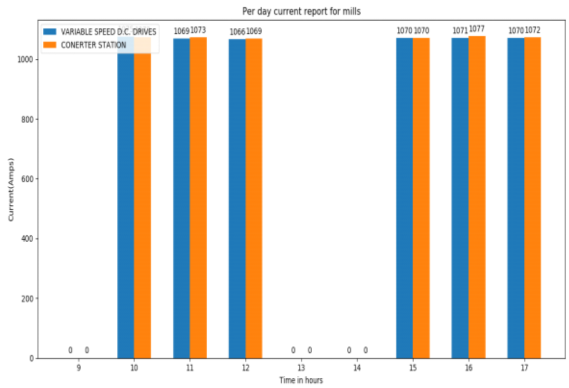

Fig. 15. per day current report for mills section

The current value of each drivers has been measured and the average of those values has been plotted in a graph for every one hour of time period.

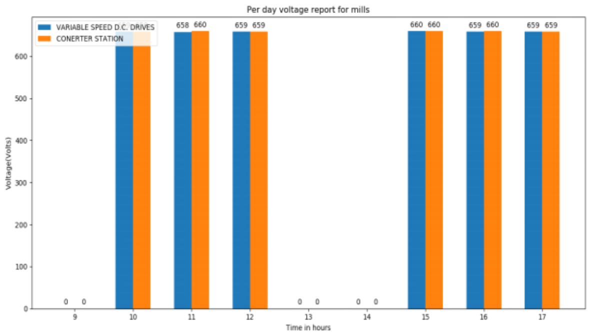

Fig. 16. per day voltage report for Mills section

Per day voltage and current report for Mills sections show above in Figure 15 and Figure 16.The voltage value of each drivers has been measured and the average of those values has been plotted in a graph for every one hour of time period.

4. Bagasse conveyer system:

Bagasse conveyer system is similar to mills section but one difference instead of carrying out the transport process inside the sugar mill it will conduct outside. These sectionsconsist of four carriers named as return bagasse conveyor, bagassecarrier, bagasse elevator and rubber belt conveyor. These machines are used to transport the used sugar canes outside the mills. Andit's also an major power consuming section in sugar mill. Bagasse conveyer system block diagram is shown below in Figure 17.

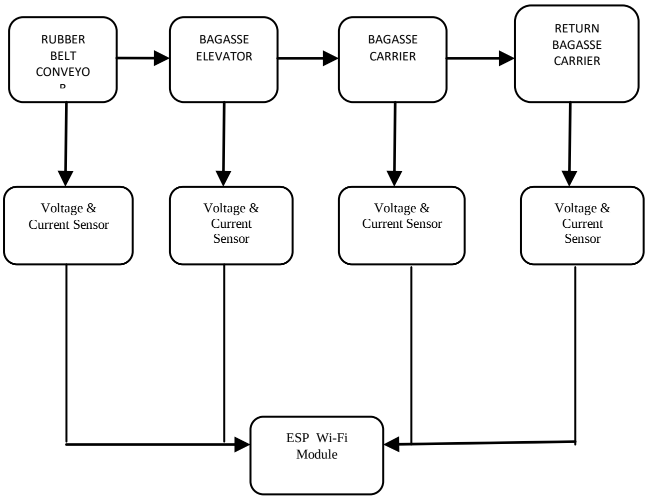

Fig. 17. bagasse conveyer system block diagram

According to our every other procedure here also we placed voltage and current sensors in each machine for monitoring purpose. But these used to start working after two hours when every machine will start to work. We didn't get any continues voltage and current value in the first two hours of every morning and that has been clearly plotted on graph also. Each machines current and voltage values have been measured for every minute in a working hour of a day. The average of those values has been calculated for every one hour and a graph has been plotted as per the time of one hour. Per day current and Voltage report for bagasse conveyer system Figure 18 and Figure 19.

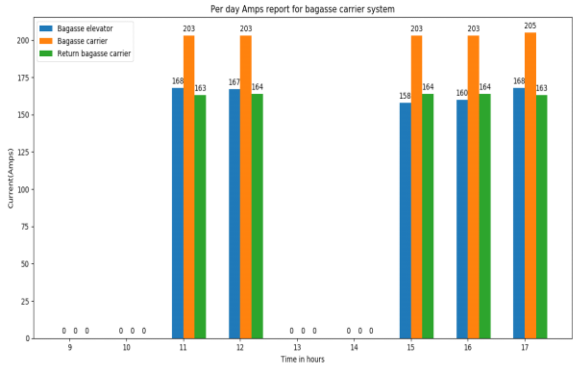

Fig. 18. per day current report for bagasse conveyer system

The current value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

The voltage value of each machines has been measured and the average of those values has been plotted in a graph for every one hour of time period.

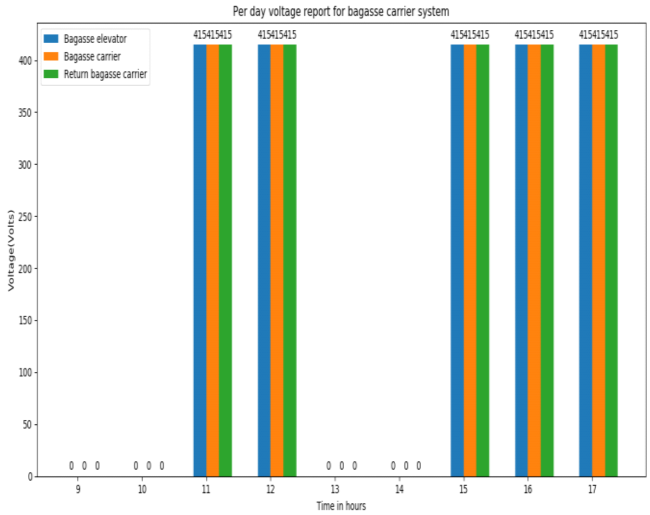

Fig. 19. per day voltage report for bagasse conveyer system

III. FINAL REPORT PER DAY:

At the end of the total current and voltage has been consumed by the whole sugar mills has been measures for every minute. The measures value has been calculated for every hour and those values has been stored and plotted in an graph as an day report for an whole week.

Day-1:

We used to start monitoring at 8.30 AM and mills used to start running at 8.55 or 9.00AM.Then it will continuously run till 1. 00PM.From 1.00 PM to 2.00PM lunch break. Then it will continuously run till 5.00PM. Minimal value for every hour has be neglected. Plotted graph for day 1 is shown below in Figure 20

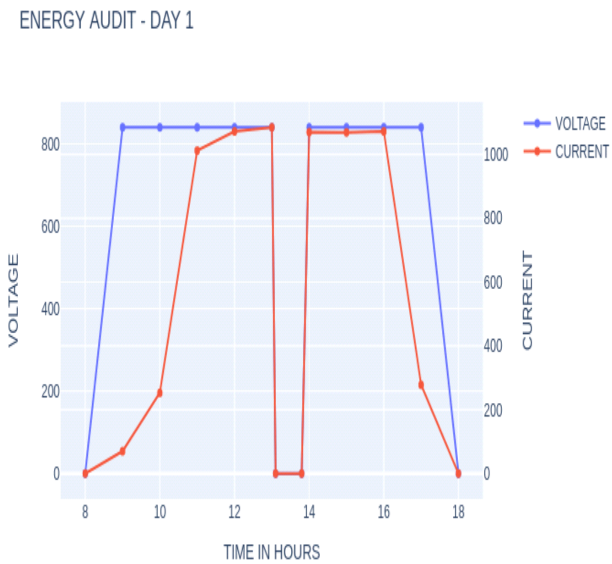

Fig. 20. Energy Audit-Day1

Day-2:

We didn't get the same value we got for the previous day some values were little bit high when compared to previous day. Plotted graph for day 2 is shown below in Figure 21

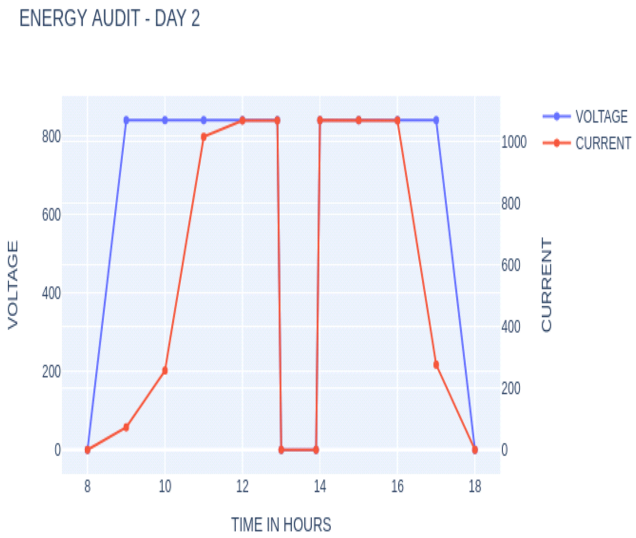

Fig. 21. Energy Audit-Day2

Day-3:

In the third day also, we faced the same problem that we faced on second day the current values were higher previous two days. Plotted graph for day 3 is shown below in Figure 22

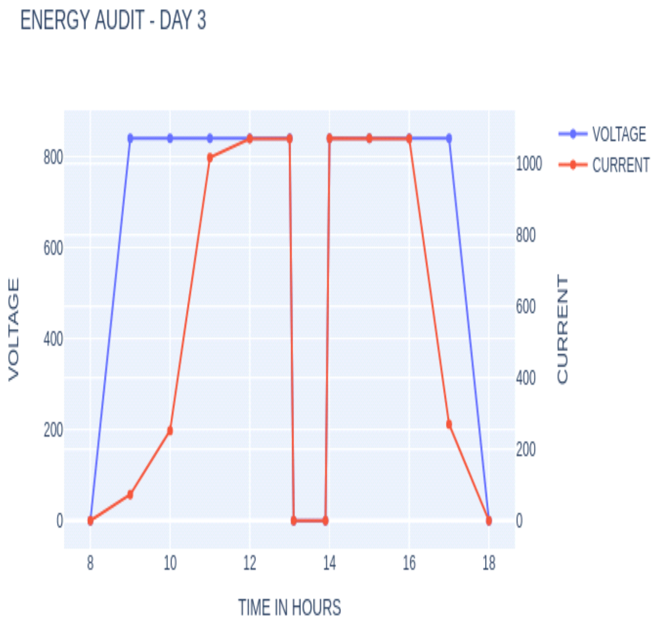

Fig. 22. Energy Audit-Day3

Day-4:

In day four also same problem but little bit different. I the whole week of monitoring in day 4 only we got those least range of values when compared to all other days in that week. Plotted graph for day 4 is shown below in Figure 23

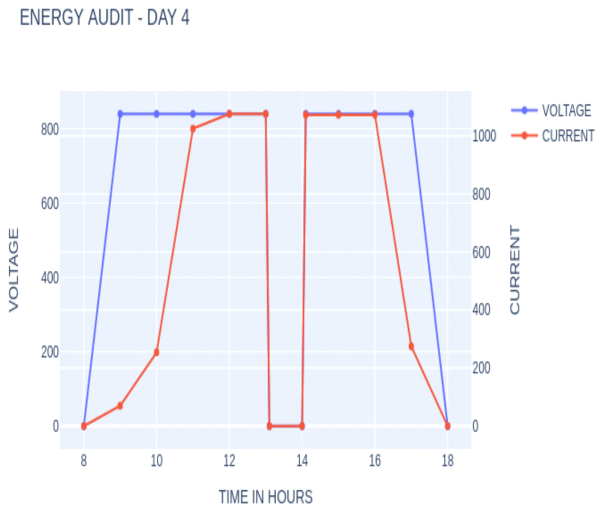

Fig. 23. Energy Audit-Day4

Day-5:

in day 5 the values are somewhat similar to the day two but we didn't get similar values. Plotted graph for day 5 is shown below in Figure 24

Fig. 24. Energy Audit-Day5

Day-6:

Again, the same problem but those values are not too high nor too low but not similar values.Plotted graph for day 6 is shown below in Figure 25

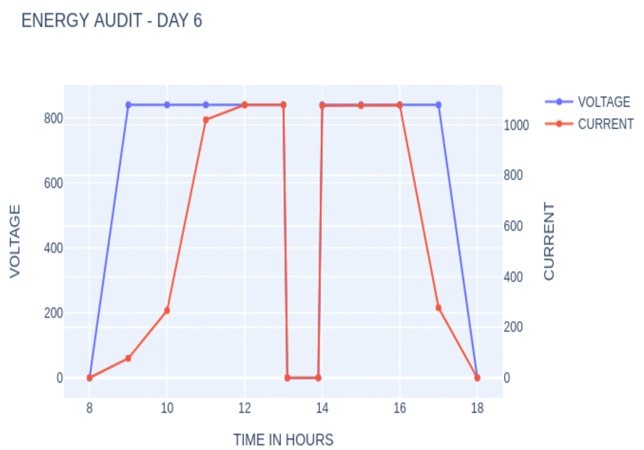

Fig. 25. Energy Audit-Day6

Day-7:

Same like all other days in this day also those values were not same. Plotted graph for day 7 is shown below in Figure 26

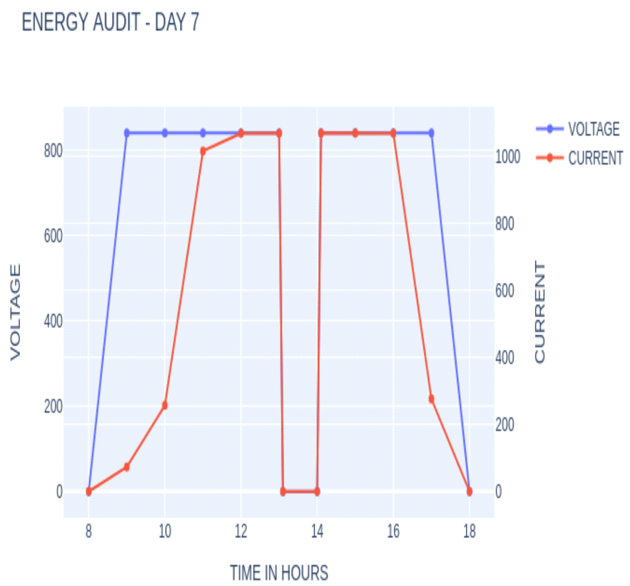

Fig. 26. Energy Audit-Day7

So we came to conclusion that even though those working time, power rating and yield are same power consumption is somewhat not similar.

IV. RESULTS AND DISCUSSION

The 28% improvement in the power delivery because of the replacement of the ordinary drive system to VFD is a necessary change that needs to be taken in to account.

The usage of the IOT in the process of the energy audit implementation would increase the efficiency of observation along with the reduction in the human intervention that decreases the cost of human effort.

The payback period of the equipment is to be calculated to realize the overall cost reduction in the sugar industry automation. The current and the voltage sensor and clipping and clamping circuit hardware images are as given in the following.

One among of the different current and voltage sensor for the energy auditing is as shown in the Figure 5.

The Figure consists of the relays connected to the three phase supply of the VFD input and they are followed by the voltage and the current sensors.

The clipping and clamping circuit that follows the sensor before connecting to the node MCUs are shown in Figure 6.

The central controller is the Raspberry Pi controller that receives all the voltage and current waveform from the different sensors in the nodes through node MCUs.

These node MCUs update the current and the voltage values instantaneously on the cloud Adafruit IO.

These cloud data is received from the cloud to the raspberry Pi and analysed for the complete data received.

Retrieval Number: F3340049620/2020©BEIESP
DOI: 10.35940/ijitee.F3340.049620
Journal Website: www.ijitee.org

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

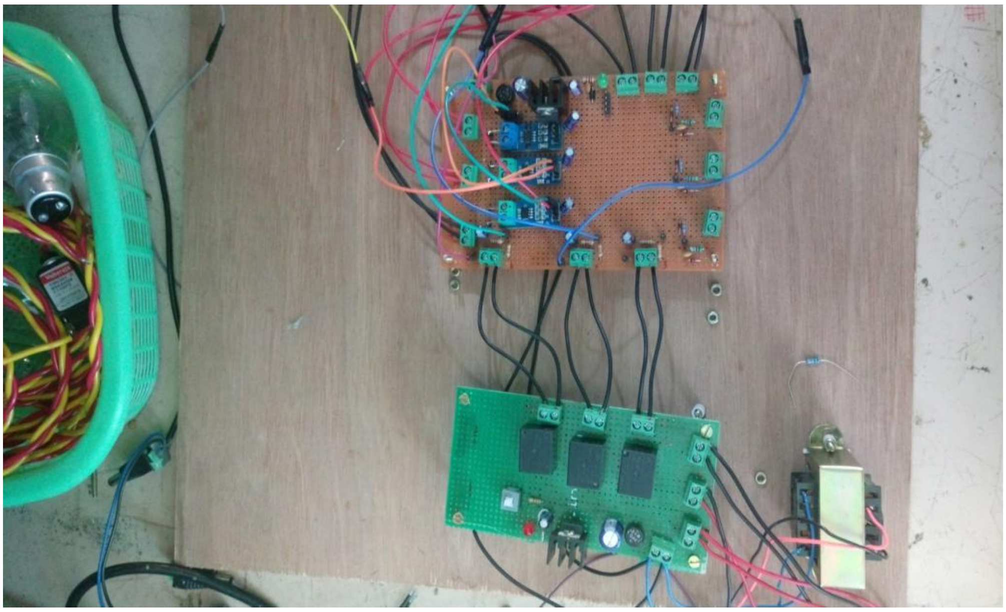

Fig. 27. Current and Voltage Sensor

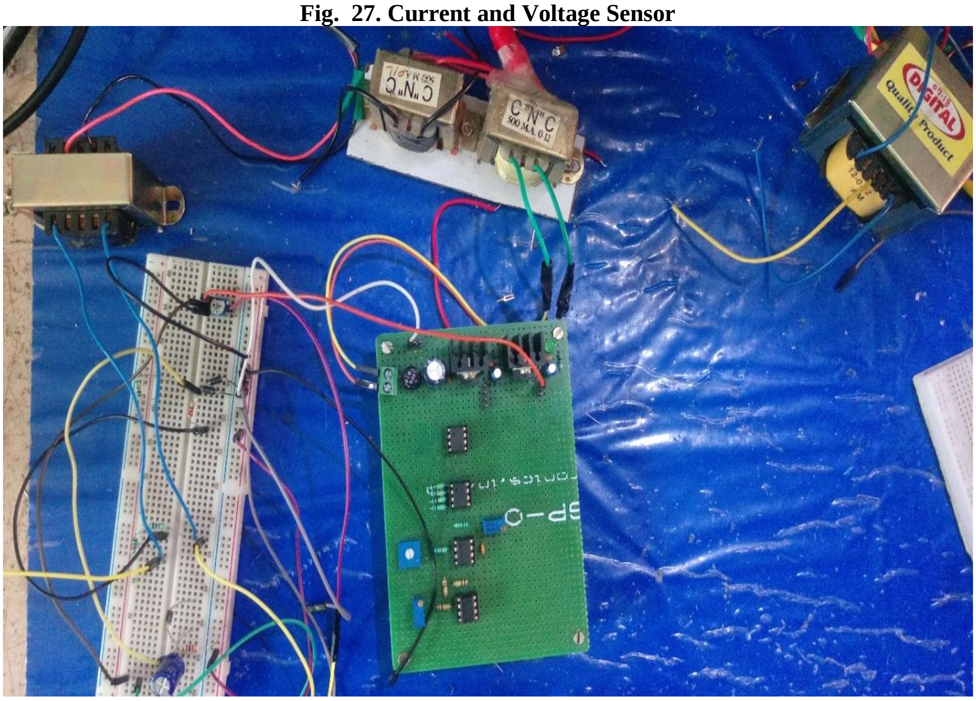

Fig. 28. Clipping and Clamping Circuit

The observation from the data received from the sensors has proved that the introduction of the VFD drive would improve the power delivery by 28% of the total power delivered to the sugar industry.

V. CONCLUSIONS

An IOT based energy audit is developed on the sugar industry and the possibility of the automation is realised by means of the IOT implementation. A Raspberry Pi based implementation realizes that there is a need for introduction of VFD in the sugar industry in order to get a better payback from the sugar industry. The reduction of human effort in the industry also aides in the reduction of the overall cost in the industry spending by introducing the IOT based automation.

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AUTHORS PROFILE

Yamanappa.N .Doddamani currently working as the Principal in Governtment Polytechnic , Belagavi, has 26 years of teaching experience at different levels completed his M.Tech in National Institute of Technology in the year 2004 and currently pursuing his PhD in Electrical Engineering in VTU Belagavi. His research interests are energy audit and mechanical engineering, Internet of Things(IOT).

Dr. U. C. Kapale, has pursued B.E. (Mech.; 1988), M.E. (Thermal Power Engg.; 1994) from PDA College of Engg., Kalburgi, and Ph. D. (Heat Power; 2007) from MNNIT, Allahabad. He has 30 years of teaching and 01 year industrial experience. He has contributed 12 research papers in International journal and 04 research papers in National journal. At present 08 candidates are pursuing Ph. D. under his guidance and presently working as Professor, Head, Mech. Engg. and Dean (Acad.) at SSET'S. S. G. Balekundri Institute of Technology, Belagavi, Karnataka.