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Cost-Effective Energy Conservation Techniques for Textile Spinning Mills

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ABSTRACT The growing Indian economy calls for the urgent need to review the ways and means to conserve energy consumed by the industrial sector. As a part of fulfilling the objective, the Government of India has made it mandatory to conduct periodic energy audits in the bulk industrial sector to be followed up with a practical implementation of energy conservation (ECON) measures as suggested by the energy audit team. This paper presents the energy audit conducted in a medium-size textile mill in western Tamil Nadu of India. The energy audit has been conducted, and an exhaustive study of the energy consumption pattern of the mill has been carried out using tools like power quality analyzer, thermal leak detectors, air leakage detectors, and luminance meter. The qualitative data measured has been studied, and suitable site-specific and problem-specific methods, suggestions, and recommendations have been examined to yield substantial energy savings. The implementation of energy efficiency technologies and energy saving (ES) methods like effective use of the existing machinery, installing application-specific machinery, reduction/ avoiding energy wastage was also carried out. The conducted energy audit on the chosen textile leads to the reduction of energy consumption by almost 21 % per day. It saved company utility energy by nearly 13.59 %. This paper examines the recommendations and the subsequent energy efficiency implementations about specifically (i) energy demand management, (ii) equipment healthiness, and (iii) identification of energy wasted. The energy-saving outcome is elaborated with cost-effective planning and execution.

INDEX TERMS Energy audit, energy conservation, textile mill, IE3 motors, VFDs, payback, return on investment.

I. INTRODUCTION

India is one of the fastest-growing major economies of the world. The sustenance of a high growth rate is critical for the growing economy of India. Energy, being a critical factor in India's economic growth and development, has witnessed a significant rise in its consumption in India. The energy, to the tune of 723.9 million tons of oil equivalent, was consumed by India during 2016, as shown in Fig.1, making it one of the most significant consumers of energy in the world [1]. Thus, the aim of the Indian Government concerning energy security is to reduce its dependency on the imported energy sources for economic growth [2]. On this count, some of the strategies adopted by the government to rationalize the energy usages are 1. Demand restraints, 2. Energy efficiency, and 3. Energy conservation. As a part of implementing them, the Government of India has enacted an act for Energy Conservation (ECON) in 2001 [3]. By the provision of the ECON act, it has notified the energy-intensive industries as a designated consumer. As per the act's schedule, the designated consumer

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has to carry out an energy audit conducted by an accredited energy auditor. An Effective energy management implementation guidelines [4], [5] and standard of procedures (SOP) [6], [7] in manufacturing and process industries [8], energy wastage identification and implementation of suitable energy waste reduction are essential [9]. Based on the directives of the energy conservation, the energy-intensive industries like chemical/petrochemical [10], [11], cement [12], paper [13], iron and steel [14], [15] industries, and textile plants in Germany [16], Colombia [17], Sri Lanka [18] and Pakistan [19] have initiated the energy conservation technologies.

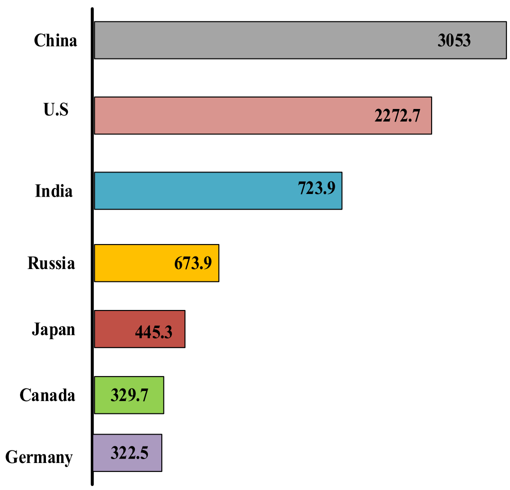

FIGURE 1. **Countrie's energy consumptions during the year 2016 [1].**

India's textile industry is one of the largest energy-consuming industries after engineering, cement, and chemical sectors, as shown in Fig.2. In general, the textile industry is considered energy-intensive as the energy cost (EC) constitutes 20-25% of the production cost. Out of the total EC, the cost due to electrical is 65%, the rest being fuel, etc. The energy audit guidelines and surveys [20], [21] and primary [22], [23] secondary [24] energy-efficient technologies have been carried out in textile mills [25], [26]. Energy Conservation studies by South India Textile Research Association (SITRA) have brought out the possibility of reducing energy consumption in the Indian textile industry by 20 to 25% and the norms for spinning mills has been published [20], and Confederation of Indian Industry (CII) has presented the energy-saving technologies in the textile sector [21]. The literature review [23] presented for energy utilization and 184 energy-efficiency technologies for textile plants, including subsectors such as spinning, processing, and weaving units with case studies. The emphasis on energy conservation and restructuring the Indian power sector is presented [24]. In [25], by adopting ECON techniques for proper utilization of transformer rating, power transmission cable sizing, operating temperature modifications in the air conditioning plant, and Energy-Efficient (EE-raring, which will provide high efficiency with less power consumptions) motors, an electrical energy saving (ES rating, which is capable to operate with less energy and saved the applied energy) of 18.23% and a total energy saving of 11.85% was achieved in a textile mill in Tamil Nadu. Similar methods are applied in the textile mill, reducing carbon dioxide (CO2) emissions [26]. In addition, the energy audit methodology, involving suitable energy-efficient technology, payback calculations, return on investments, and the environmental benefits are presented. In particular, the textile industry uses electric motors in the preprocess machines such as spinning frames, post spinning, humidification plants, and air compressors. Optimum loading of motors decides the economical use of energy in the plant machinery, humidification plants, and air compressors of textile mills. It is, therefore, essential to install EE motors and correspondingly load the motors optimally [27], [28]. EE motors' operating performance and technical specifications are presented [27], and the EE motors are more efficient than conventional motors, a considerable demand is reduced on the procurement [28]. In particular, the textile industry uses electric motors in the preprocess machines such as spinning frames, post spinning, humidification plants, and air compressors. Optimum loading of motors decides the economical use of energy in the plant machinery, humidification plants, and air compressors of textile mills. It is, therefore, essential to install EE motors and correspondingly load the motors optimally [29], [30]. EE motors' operating performance and technical specifications are presented [27], and the EE motors are more efficient than conventional motors, a considerable demand is reduced on the procurement [28].

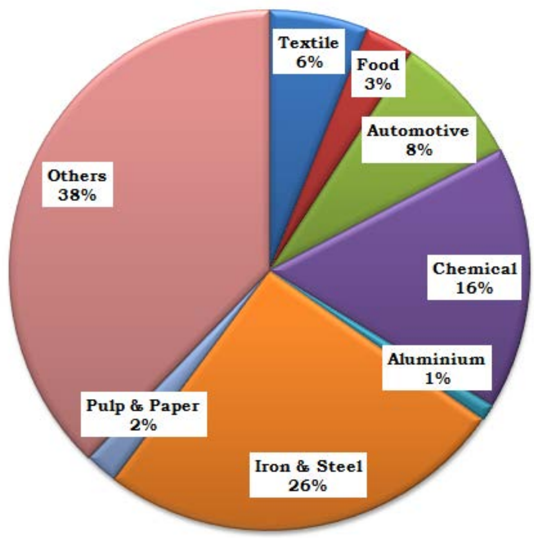

FIGURE 2. **Energy consumption of industry sectors in India.**

With methods to calculate load cycle and operating performance, it is possible to downsize the motor during rewinding suitable to the load cycle. Also, International Efficiency (IE) IE1 motors can be converted as IE2 motors with higher efficiency and power factor [29]. Industrial systems have a combination of many components such as power transmission by belts, gears, control valves, and so on. Installation of a premium efficient motor may improve system efficiency only when properly installed and operated in the desired load profile. Therefore, it is essential that the complete process system has to be addressed for accessing energy use and energy savings [30]. The most common and energy-intensive utilities in the textile spinning mill are compressed air systems [31], [32] and humidification plants [33], consuming about 10 to 20 % of energy in the plant. Therefore, they are one of the essential target systems for energy efficiency implementation and energy saving. The potential ES in the compressors plants is estimated to be around 20 to 30% of existing energy consumption. In [31], a benchmarking system is created for energy-intensive plants, which can set a value for a specific application. To optimize the overall system's efficiency, the parameters, such as power requirements, working pressure, air consumption, regulation method, air quality, energy recovery, and machinery maintenance, should be considered. Energy efficiency measures on the supply-side concerning the sub-part of the compressed air system improve the energy efficiency and non-energy benefits comparable production, maintenance, waste, emissions are achieved [32]. The ECON studies in humidification plants in textile mills are presented in research articles [33], and Ali Hasanbeigi recommended the energy efficiency technologies for humidification plants discussed in section IV. A considerable ES potential in industrial lighting can be achieved by optimizing plant lighting in production and non-production departments, a daylighting control strategy to achieve energy-efficient lighting [36], optimum use of natural sunlight, and non-conventional energy sources [34], [35]. Climate change due to CO2 emissions has increased during the last two decades, impacting human ecosystems [37], [38]. In [37] and [38], investigation on the impact of economic growth and CO2 emissions is directly related to energy consumption. Industry-specific studies and calculations of emission for textile plants [25] and steel-making plants [39] are presented. A comprehensive discussion is made to have low emissions through renewable energy, electric vehicles, and policies for reducing emissions [40], [41]. Henceforth, the way to reduce emissions is to implement energy efficiency technologies.

From the literature case studies, the potential ES opportunity in a textile spinning mill is mainly is to replace the conventional, IE1, IE2 motors in the process machinery with IE3 motors, downsizing of existing IE2 motor to IE3 motor, adapting variable frequency drive (VFD) in humidification plants and air compressors, pumps in cooling towers, maintaining power factor of varying loads, and so on. The energy audit has been conducted in a textile spinning mill in western Tamilnadu. In the preliminary audit, it is observed that the optimum utilization of electrical energy in terms of kWh (Units) per kilogram of yarn produced (Ukg) is 4.99 for 40s count of yarn [20]. The standard Ukg for a typical 40s count of a well-maintained mill will be around 4.5 Ukg. The management decides to bring down the Ukg from 4.99 to 4.5. Therefore, the energy efficiency measure and their implementation in the spinning mill have been carried.

The energy audit has been carried out and identified many potential areas of ES. A detailed study about energy purchase, energy consumption, equipment healthiness, and loading pattern has been carried out and suggested 22 techniques listed in section IV. The investigations on energy consumption and losses, operating performance of machinery, motors, and processes have been carried out. Then, the potential areas identified in which the energy conservation technique is to be implemented are energy procurement in terms of kVA, inefficient operation of electric motors, unoptimized operation of humidification plants, air leakage of air, and pressure settings for internal machinery in air compressor plants, and lighting. The implementation of ECON techniques in these machines and processes has been carried out to achieve the ES and reduce the Ukg. Foremost, The Ukg was brought down to a remarkable figure of 4.33, and a 13.59% reduction in the energy bill has been realized. Further, the demand is considerably reduced, which can be used for expansion. Since most of the implementation is common to the process industries, The ECON techniques recommended and implemented can be applied to any medium and large capacity textile spinning and processing plants and any process plants. Further, the power quality aspects, calibration of existing energy meters, pressure gauges, and cooling tower pumps are planned in the second phase.

This paper presents the energy audit conducted by our team in a medium-sized textile mill situated in the western part of Tamil Nadu and subsequent ECON implementation with payback periods. The paper is organized as follows: Section II presents the current functional status of the mill; The concept and audit methodology for energy-efficient measures is presented in section III; Section IV brought out the energy audit and the cost-effective implementation of energy-efficient technology in the mill. The energy-saving and energy cost-saving and the respective payback period are summarized in section V. Finally; section VI presents the conclusions of the energy audit.

II. THE EXISTING FUNCTIONAL STATUS OF THE SPINNING MILL

To have first-hand information about the energy consumption of the mill, the data on its utilities have been studied and recorded.

III. AUDIT METHODOLOGY FOR ENERGY-EFFICIENT MEASURES

The preliminary energy survey in the mill has been conducted concerning energy spending patterns and found that the mill is spending over 30% of its production cost on electricity. The power-consuming sections like preparatory, ring spinning, post spinning, humidification plant, and air compressors have been studied in detail. The data about power purchased from the local electricity distribution system was also analyzed.

TABLE 1. First hand information (FHI) sheet.

Sl. No.	First Hand Information (FHI) Sheet	Specification details
A	Nature of Production (Fabric Manufacturing)	a. Yarn in 40's count: 15 Tons per day (tpd) b. Units per kg of yarn production (Ukg):4.99
B	Energy supplier details and load demand and consumption tariffs	a. Supply source: State Electricity Board b. Applicable Tariff: I (Industrial Consumption). c. Maximum contracted demand: 4500 kVA d. Sanctioned demand: 3500 kVA e. Energy consumption: 74800 kWh/day f. MD Charges: $ 5.22/kVA g. Unit Charges: $ 0.094/kWh
C	Steam requirement for the manufacturing process	0.82tons/hr
D	Compressed air system requirement	a. Capacity : 1425 CFM b. Line Pressure : 7.4 kg/cm^2
E	Electrical load distribution sections are	Spinning, Preparatory, post spin, Humidification, compressor, and company lighting (Distribution percentage were shown in Fig.3)

TABLE 2. Distribution of electrical load in the mill.

Section	Connected Load , kW	% total load
Preparatory	565	10
Spinning	2890	50
Post spinning	380	7
Humidification plant	1405	25
Compressor	300	5
Lighting	190	3
Total load	5730	100%

Based on the analysis, the audit methodology was framed as follows:

i. Energy Demand Management [6], [23], [25]
ii. Equipment healthiness in terms of life and efficiency [29], [30]
iii. Identification of energy wasted [9]

A. ENERGY DEMAND MANAGEMENT

The tariffs levied by the Local Electricity Distribution Authority (LEDA) for an industrial consumer is of two parts, one being the actual energy utilization (in kWh) charges and the other is the maximum demand (MD) of supply (in kVA) required by the consumer on a monthly average basis. If MD exceeded the contracted value, a heavy penalty is imposed by LEDA. A detailed study is needed to monitor the MD reached, and a realistic value of MD has to be achieved by correlating with production.

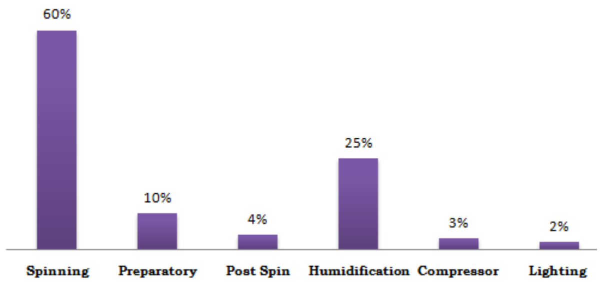

FIGURE 3. Electrical load distribution in the spinning mill.

B. EQUIPMENT HEALTHINES

A suitable predictive system to monitor and ensure the equipment's healthiness in terms of its efficiency and life has to be devised to avert the losses due to their failure. Condition monitoring of equipment will help to a great extent in ensuring their health and reliability [29], [30]. In general, the process machinery, drive motors, and associated parameters have to be monitored and analyzed by employing suitable data collection techniques. In the mill under study, the air compressors, motors were subjected to condition monitoring, and substantial ES were identified and recorded.

C. IDENTIFICATION OF ENERGY WASTED

In industries, the ES is achieved by avoiding energy wastage in the process and operations. Identification and prevention of energy wastage will enhance productivity [9], [32]. In the mill, the major power-consuming sections are electric motor drives, humidification plants, compressed air supply systems, and lighting. The wastage of energy in these sections is measured, and suitable ECON implementations are recommended. The possible means of energy wasted in the process and machinery include, Leakage in the compressed air distribution system, Improper setting in the humidification plants, and Distribution of the conditioned air inside the plants and its collection.

IV. ENERGY AUDIT AND COST-EFFECTIVE IMPLEMENTATION OF ENERGY EFFICIENT TECHNOLOGY

The Energy Audit (EA) team was formed, which comprised our certified energy manager, technicians, and the mill electrical engineer and academicians. A preliminary study has been conducted based on the three audit methodology framed in section III. The mill energy consumption data, production data have been monitored and analyzed. The monthly electricity consumption bills were analyzed, and the loading pattern of equipment concerning discrete and sustained loading has been analyzed and recorded.

It is observed that the potential ES process/ machinery in the plant, and the important energy-efficient technologies recommended in the first phase of implementations are: demand management, power factor correction, PF in individual loads having a variable duty, MV panel cable sizing, the proper size of cable to reduce losses, EE motors, operating performance of motors, the life of motors, maintenance of motors, the terminal connection of motors, using drives for motors, the optimum setting for pumps, humidification plants operation settings, air leakage, air pipe size, compressor pressure settings, design of air distribution system, design of optimum lighting in the shop floor, automatic light control, installing astronomical timer for street lights and using solar power for lighting and so on. Due to financial constraints, the management agreed to implement within a period of 6 months on the mill as per benefit of ECON

A. STUDY RELATED TO ENERGY PROCUREMENT

The energy audit has been conducted and is presented in observations, energy conservation technique employed, energy saving, energy cost savings, and payback period realized [23]–[26].

1) OBSERVATIONS

The mill purchases power from the State-owned Electricity Board with an incoming voltage of 11 kV. The tariff, sanctioned demand, and electricity consumption charges are as follows:

i. Contracted maximum demand (MD): 3500kVA
ii. Maximum demand (MD) charges: $5.22/kVA
iii. Energy (kWh) charges: $0.094 / kWh
iv. Energy consumption: 74800 kWh /day
v. Average yearly spending = $2549502

The MD pattern of the mill for one month along with production has been monitored and analyzed as in III. Fig. 4 shows the procedure of monitoring the MD using a Fluke power analyzer.

Along with the demand, the production targets for the day and the achieved target were also scrutinized. Interestingly the rated capacity was almost achieved every day without any break. The analysis of the maximum demand for the same period shows that the mill had never touched the maximum contracted demand. Fig.5 indicates the performance of the mill concerning yarn production and maximum demand.

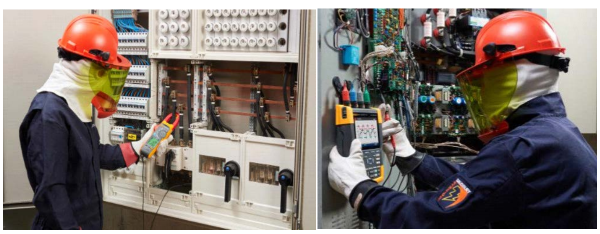

FIGURE 4. Monitoring of MD for a period of one month.

The MD attained is below the contracted demand by around 200 kVA. The MD registered for the previous 6 months has been monitored and observed that there is a surplus demand of 200 kVA existed.

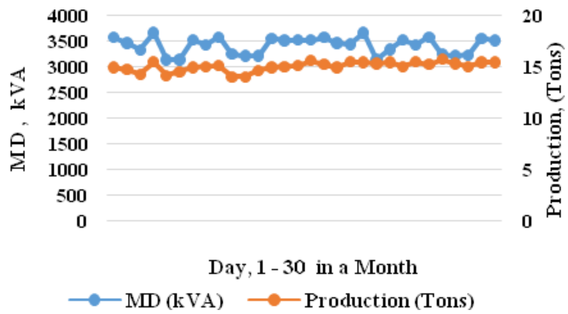

FIGURE 5. Yarn production and MD reached for a period of one month.

TABLE 3. Details of MD recorded with production for a month.

Day	MD, kVA	Production (Tons)	Day	MD,kVA	Production (Tons)
1	3562	14.9	17	3562	15.2
3	3323	14.2	19	3423	15.5
5	3131	14.1	21	3131	15.3
7	3510	14.9	23	3510	15.0
9	3567	15.1	25	3567	15.2
11	3211	14	27	3211	15.3
13	3544	14.9	29	3544	15.4
15	3509	15.1	31	3509	15.2

2) ENERGY CONSERVATION TECHNIQUE EMPLOYED

The unutilized portion of 200 kVA of the sanctioned demand was surrendered and 3300 kVA is sufficient to achieve its full capacity utilization and production.

3) ES AND CS REALIZED

By surrendering a minimum of 200kVA of contracted demand the CS is found to be 200kVA* $5.22/kVA = $1039 per month. The annual saving is $12468.

B. HEALTHINESS OF EQUIPMENT

The plant production norms can be achieved only if the reliability of plant equipment is high. Again the reliability of equipment depends on the healthiness of the equipment. Condition monitoring is one of the best tools for ascertaining the healthiness of equipment. The condition of plant machinery and equipment such as electric motors, humidification plants, and air compressor systems has been studied in detail. The corrective measures concerning their present condition have earned substantial ES and CS. The outcomes in the different processes and equipment such as air compressors, EE motors, and load concerning stator connection are elaborated.

1) AIR COMPRESSORS OBSERVATIONS

The air requirement for the internal process is studied and summarized in Table 3. Apart from using compressed air for production purposes, it is observed that the air is used to clean the floors and some machinery. The study conducted in the air compressor sections is shown in Fig.6 and Fig.7.

FIGURE 6. Condition monitoring of compressor units-measurement of energy consumed using Fluke power analyzer.

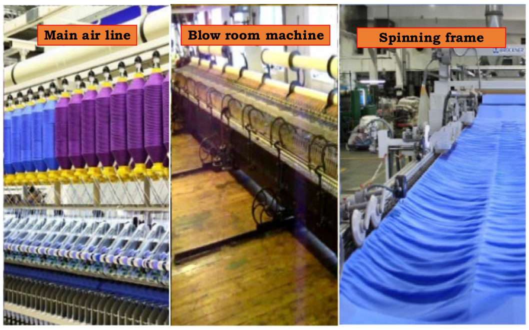

FIGURE 7. Compressed air pressure measurement in the (a) main line, (b) blow room and (c) spinning.

TABLE 4. Compressed air requirements in different processes.

Processes/Machines	Installed machines	Total Compressed air requirement, CFM
Blow Room	03	14.4
Carding	48	45.12
Lap former	08	12.8
Comber	45	12.6
Spinning	52	50.96
Link coner	44	563.2
Savioautoconer	06	120.00
Contamination machine	10	180.0
	Total	999.08

It is observed that there could be some energy losses in a compressed air system due to its ineffective conditions of equipment, operating parameters, and air leakage.

No. of compressors in the plant: 3

The capacity of each air compressor: 475CFM

Header pressure: 7.0 KG/cm2, Line pressure: 6.6 KG/cm^2

Motor rating: 90kW, Compressor air capacity: 1425CFM

The performance of the compressors has been for a period of 2 weeks. The following observations with regard to its performance were recorded.

- The energy consumed by the compressed air system is found to be 3564 kWh/day.
- The suction line of all the compressors was kept inside the utility room and the air temperature inside the room is found to be 38°C.
- The inlet air filter was found to be choked with oily dust and about 38% of the filter area was blocked.
- The header pressure has found to be 7.0 kg/cm2 and the line pressure was 6.6 kg/cm2.
- All three machines were found to be loaded fully and running round the clock.
- In some places of the plant, compressed air was used to clean the floor.
- Energy conservation technique employed.

As all the above factors lead to excess consumption of power, the following measure has been implemented.

- The suction lines of all the 3 compressors were extended and taken to the outside of the utility building and the suction face was kept facing south facilitating fresh air suction from the atmosphere. The inlet air temperature is measured is 32°C.
- Inlet air filter is removed and dilute acid cleaning has been carried out, and it ensures that 100% of filter area is clean to suck the air to its full capacity.
- The performance of the processes/equipment has been monitored for 30 days after reducing the line pressure to 6.05 kg/cm^2. It is observed that all the equipment is working satisfactorily with the reduced optimized air pressure.

After completion of the modifications recommended, the performance of compressors has been observed. Due to the reduction of air requirement, the loading factor of all the compressors came down to 0.6. The average power consumed by all the 3 compressors before the modification was recorded to be 3564 kWh.

2) ES AND CS REALIZED

Considering only the EC, the total CS is 535 * 0.094 = $ 50.29/day. Annual ES is 192600 kWh and the annual ECS is 192600 kWh*0.094 = $18104.40.

C. EFFICIENCY OF INDUCTION MOTORS

In the textile spinning mills, induction motors take about 60-70% of the load employed in productive and non-productive plants of the mill. The power rating of the motor employed varying from a few hp to 100 hp. The efficiency of the motors, as well as the optimum operating characteristics, yields a considerable ES [14], [23], [25], [28]–[30].

1) OBSERVATIONS

A study on the status of the induction motors of rating above 20 hp installed in the mill has been conducted and the details are given in Table 6.

The service history of the above motors has been analyzed, and it is observed that all the motors were 15 years old. Many of them have been rewound as many as three times. Therefore, it was decided to check the running performance of the motor to ascertain their efficiency. The fluke power quality meters were used for conducting the test on the motors shown in Fig. 8. The parameters like terminal voltage, load current,

TABLE 5. Observations on compressor through energy meter.

Before Modifications			After implementing ECON recommendations
Energy meter Readings		kWh Consumed	kWh Consumed
Day 1	Day 2		
25654	29220	3566	3028
29220	32797	3577	3018
32797	36355	3558	3024
36355	39897	3542	3034
39897	43547	3650	3051
43547	47036	3489	3049
Average Consumption		3564	3029.3

power, and load power factor were observed and recorded. These observations have been made when the mill is running to its total capacity. The performance of the existing induction motors is tabulated in Table 6.

TABLE 6. Rating of existing motors considered for study.

Motor rating, hp/kW	Quantity (Nos.)
75/55	24
60/45	6
30/22	5
20/15	20
No. of motors	55

FIGURE 8. Testing of existing electric motors through motor control centre panel and installing new IE 3 motors.

2) ENERGY CONSERVATION TECHNIQUE EMPLOYED

From the analysis of loading pattern and operating performance of existing conventional motors shown in Table 7, it is recommended to replace the IE3 motor with a reduced power rating [23], [25] as recommended in Table 8.

3) ES AND CS REALIZED

The theoretical ES calculations after to replacement of the existing standard motors with IE3 have been carried out. All the motors were operating round the clock for a period of 360 days in a year. The annual savings were calculated using

TABLE 7. Performance of the existing motors in the plant.

Rating, hp/kW	No. of motors	Average load, kW	Power factor	Motor loading	efficiency , %
75/55	26	40	0.78	78%	89
60/45	2	32	0.72	72%	90
30/22	2	14	0.76	76%	88
20/15	2	10	0.76	76%	79

TABLE 8. Specification of energy efficient (IE3) motors.

Existing motor,hp/kW	IE3 motor (hp/kW)	Efficiency, (%)
75/55	60/45	94.2
60/45	50/37	92.6
30/22	20/15	91.0
20/15	15/11	91.0

the following relations (1) [26].

$$\begin{aligned} ES = {} & \text{No. of motors} \times \text{yearly running hrs}^{*}\%\text{Loading} \\ & {}^{*}\text{motor kW}^{*}\left(\frac{1}{\eta^{Std}}\right) - \frac{1}{\eta^{eem}} \end{aligned} \quad (1)$$

$$\begin{aligned} CS = {} & \text{No. of motors}^{*}\text{yearly running hrs}^{*}\%\text{Loading} \\ & {}^{*}\text{motor kW}^{*}\text{EC/kWh}^{*}\left(\frac{1}{\eta^{eem}}\right) \end{aligned} \quad (2)$$

The total ES, ECS and payback period after replacement of motors are shown in Table 8. The total cost of IE3 motors of 32 numbers is \$ 52862.96, and the installation cost and cost of accessories are \$ 3967.79. The total motor replacement cost is \$ 56830.75

$$\text{Payback period} = \text{Expenditure/Total savings [15], [25]} \quad (3)$$

$$\begin{aligned} \text{Simple payback} &= 56830.76/54765.18 \\ &= 1.038 \text{ Years (12.5 months)} \end{aligned} \quad (4)$$

4) PRACTICAL OBSERVATIONS

The loading pattern of the recommended EE motors is observed and presented in Table 10. Based on the average percentage loading, the ES and ECS were worked out as in Table 9.

TABLE 9. Theoretical total ES, CS AND payback period after installing IE3 motors.

Existing motor hp/kW	IE3 motor ,kW	No. of motors	ES (kWh) (1)	ECS (\$) (2)	Total Cost of IE3 motors (\$)
75/55	45	26	451,434.	424342	
60/45	37	2	16,663	1566	
30/22	15	2	14,565	1369	56830.75
20/15	11	2	99,944	9394	
Total		32	582,608	54765	

D. WINDING CONNECTION OF SMALL MOTORS OBSERVATIONS

The operating performance of induction motors like efficiency, power factor, and loading percentage has been carried

TABLE 10. Loading pattern of the recommended IE3 motors.

Rating.kW	Actual loading (in %) Measured					Average loading
	Day 1	Day 2	Day 4	Day 5	Day 6	
45	72	73.2	74	71.8	71.4	72.50
37	69.3	70.3	70.1	70.2	69.8	70.15
15	50.3	50.6	49.9	49.7	50.1	50.00
11	77	76.1	77	76.3	77.1	77.00

TABLE 11. Practical total ES, CS and payback period after installing IE3 motors.

IE3 motor, kW	Annual ES (kWh) (1)	Annual ECS ($) (2)	Total Cost of IE3 motors ($)	Payback period
45	454,569	42729	56830	1.032 Years (12.4 months))
37	16,699	1569		
15	14,565	1369		
11	99,944	9394		
Total	585,778.9	55063.22		

out for power ratings from fractional horsepower (FHP) to 10 hp. In many sections of the mill, the small-capacity motors were running well below their rated capacity. As a trial measure, four nos. of motors of each 7.5 kW, 3.7 kW, 2.2 kW, and 1.5 kW capacities were taken for analysis. All of them were delta-connected, and their running load is 5.8 kW, 2.72 kW, 2.1 kW, and 1.0 kW, respectively.

1) ENERGY CONSERVATION TECHNIQUE EMPLOYED

The stator connections of the motors were changed to star and observed the load taken by them are found to be 5 kW, 2kW, 1.8 kW, and 0.8 kW respectively. The torque developed by them was found to be sufficient to drive the equipment and running satisfactorily [25].

2) ES AND CS REALIZED

The savings in terms of kW of the motors whose connections were changed are shown in 12. The corresponding ES is calculated in Table 13.

E. IDENTIFICATION OF ENERGY WASTED

The process industries require conditioned and pressurized air for the internal processes. In this context, the humidification plant and compressed air supply systems are identified as the processes in which the energy is wasted in the form of leakage and improper setting, and so on.

$$\text{ES realized} = 31.42 \text{ kWh}$$
$$\text{Annual ES} = 360^{*}24^{*}31.42 = 271468.8 \text{ kWh}$$
$$\text{Annual ECS} = 271468.8^{*}0.094 = \$25518.07.$$

1) HUMIDIFICATION PLANT

Many energy efficiency technologies for humidification plants reported are replacing the Electrical heating system with steam heating system for the yarn polishing machine, replacement of nozzles with energy-efficient mist nozzles in yarn conditioning room, installation of VFD for washer pump motor in Humidification, Humidification system fan motors for the flow control, Humidification system pumps, replacement of the existing Aluminum alloy fan impellers with high-efficiency F.R.P (Fiberglass Reinforced Plastic) impellers in humidification fans and cooling tower fans [23].

2) OBSERVATIONS

On average, the humidification plants in textile plants consume about 15% to 25% of the plant's total energy. In the mill, the percentage energy share of the humidification plant is estimated at 25%. While inspecting the humidification plant, special attention is given to the supply air (SA) fans and return air (RA) fans. They were found to be primary power-consuming machines.

Humidification Plant-1:

Total No. of SA fans installed with 30 kW drive motor is 10; Total power in kW=300 kW.

Total No. of RA fans installed with 37 kW drive motor is 16; Total power in kW=592 kW.

Humidification Plant-2:

Total No. of SA fans installed with 30 kW drive motor is 6: Total power in kW: 180 kW.

Total No. of RA fans installed with 37 kW drive motor is 9: Total power in kW: 333 kW.

An automatic control system is used to maintain the Relative Humidity (RH) which operates the motorized dampers SA fans of the humidification plant (Fig. 9) for all the sections of the mill were taken for auditing its energy consumption. At various percentages of damper openings, the current drawn by the motor is measured and recorded. It is concluded that all the fans are having a load cycle varying from 70% to 100% for dampers position varied from 20% to 100%. A typical record of a 30 kW SA and 37 kW RA fan is given in Table-14.

The full load current of the 30 kW SA fan motor is 54A and the 37 kW RA fan motor is 68 A. In the region between 60% and 100% of damper opening, significant ES could be achieved by VFD control for SA fan motors dispensing with the damper control.

3) ENERGY CONSERVATION TECHNIQUE EMPLOYED

The VFD is installed for one each of the SA and RA fan motors of both humidification plants [23], [34], the corresponding test results are presented in Table 23. A saving of 6 kW and 7 kW respectively for SA and RA fans is achieved in plant-1 and 6.15 kW and 7.5 kW respectively for SA and RA fans are found in Plant-2. The suggestion to provide VFDs to all the fan motors has been accepted by the Mill Management and VFDs are installed is shown in Fig. 9.

4) ES AND CS REALIZED

Humidification Plant-1:

ES realized = 10*6+16*7=172 kWh.

Total annual ES = 360 * 24 * 172 = 1486080 kWh

Total annual CS =1486080 * 0.094 = $ 139691.52

TABLE 12. ES achieved by the stator connection (Delta TO Star).

Before Modifications			After implementing EOCN recommendations		
Energy meter(EM) Readings		kW Consumed	Energy meter(EM) Readings		kW Consumed
Day1	Day 2		Day1	Day2	
7.5 kW motor			7.5 kW motor		
11347.2	11486.4	139.2	11764.3	11885.6	121.3
11486.4	11626.4	140	11486.4	11606.6	120.2
11626.4	11764.3	137.9	11626.4	11746.2	119.8
Average Power/day		139.03	Average Power/day		120.43
Average energy, kWh		5.79	Average energy,kWh		5.02
ES in kWh = 5.79 - 5.02 = 0.77 kWh.					
3.7 kW motor			3.7 kW motor		
15622.4	15688	65.6	15822.5	15870.4	47.9
15687.5	15753.3	65.8	15870.4	15919	48.6
15752.9	15817.7	64.8	15919	15967.2	48.2
Average Power/day		65.40	Average Power/day		48.23
Average energy in kWh		2.73	Average energy, kWh		2.01
ES in kWh = 2.73 - 2.01 = 2.72					
2.2 kW motor			2.2 kW motor		
13452.7	13503.8	51.1	13579.5	13622.9	43.4
13503.8	13553.6	49.8	13623.4	13665.5	42.1
13569.6	13620	50.4	13672	13716.2	44.2
Average Power/day		50.43	Average Power/day		43.23
Average energy, kWh		2.10	Average energy, kWh		1.80
ES IN kWh = 2.10 - 1.8 = 0.3 kWh.					
1.1 kW motor			1.1 kW motor		
12241.6	12265.5	23.9	14432.5	14452	19.5
12265.5	12290.1	24.6	14452	14471.1	19.1
12315.3	12339.4	24.1	14471.1	14490	18.9
Average Power/day		24.20	Average Power/day		19.17
Average energy, kWh		1.01	Average energy, kWh		0.80
ES in kWh = 1.01 - 0.8 = 0.21 kWh.					

TABLE 13. Total energy saved by changing stator connection.

Motor Rating	No. of motors	Change in kWh	ES (kWh)
7.5	36	0.8	14.4
3.7	32	0.72	11.52
2.2	28	0.3	3.9
1.5	21	0.2	1.6
		Total	31.42

TABLE 14. Damper opening and motor load current.

Damperopening (%)	40	50	60	80	90	100
30 kW motor , A	30	32	53.0	53.5	53.9	54
37 kW motor , A	23.8	62.8	67.0	67.3	68	68

Humidification Plant-2:

ES realized = 6*6.15+9*7.5 =104.4 kWh

Total annual ES = 360 * 24 * 104.4 = 902016kWh

Total annual CS=902016 * 0.094 = $ 84789.504

Total annual ES of humidification 1 & 2=2388096 kWh

Total annual CS of humidification 1 & 2 =$ 224481.02

FIGURE 9. Humidification plant (a) supply air (SA) fan (b)return air (RA) fan (c) the VFD installed.

TABLE 15. Test results after installation of VFD.

Humidification Plant-1						
Relative Humidity ,%	50	60	70	80	90	100
30 kW motor current, A	27	36.4	42	44	50	54
Power consumption ,kW	15	21	24	25	28	30
37 kW motor current , A	39.8	40	54.0	57.3	62	68
Power consumption, kW	19	22	26	32	34	37

5) PAYBACK CALCULATIONS

Total cost of 30 kW motors=16*$ 4217.05=$ 67472.80

Total cost of 37 kW motors =4667.47 * 25 = $ 116686.75

FIGURE 10. Illumination level in the working area.

Cost of Panel for 30kW VFD, main switch and standby starter, cables: \$ 455.17 * 16 = \$ 7282.72

Cost of Panel for 37kW VFD, main switch and standby starter, cables: 465.17 * 25 = \$ 11629.25

Installation cost = 41*44.52=\$ 1825.32

Total cost of installation of all VFDs=\$ 204896.84

Simple payback period = 204896.84/224481.024 ∗ 12 = 0.92 years (11 months)

F. ENERGY SAVINGS IN PLANT LIGHTING

Nowadays, light-emitting diodes (LED) lights are the preferred option in lieu of fluorescent or compact fluorescent lamp (CFL) lights as LED gives more brightness per watt of electricity consumed. Also, the lifespan of LED lamps is much more when compared with fluorescent lights. Its maintenance cost is also very low. The specification and performance of the lamps used are presented in Table -16.

TABLE 16. Specification and performance of lamps.

Specification of the lamp	Lumens output	Lifespan
32W,T8 twin lamps	2850 lumen	15000Hrs
100W, HPSV Lamps	9500 lumen	24000 Hrs
36W T8 LED lamps	4350 lumens	45000Hrs
60W LED street light lamps	7500 lumen	48000Hrs

1) ENERGY CONSERVATION TECHNIQUE EMPLOYED PLANT LIGHTING

On an experimental basis, two fluorescent fittings were replaced by a single 36W, T8 LED lamp in the working floor area. It is observed that the lumen output is very comfortable to work in the floor area, as shown in Fig. 10. It is recommended to replace all the fluorescent fittings with LED lamps. A total of 486 Nos. of fittings were replaced with LED lamps, and the ES estimated is shown in Table. 17. The payback period of 1.86 years is well within the lifespan of LED (7.7 years).

2) STREET LIGHTING

The suggestion by the audit team, to retrofit all the 87 Nos. of 100W, HPSV streetlight fittings by 60W LED and the ES worked out is shown in Table. 16. The payback period of 2.8 years is well within the lifespan of LED (7.7years).

TABLE 17. Energy saving and energy cost saving calculations in plant lighting.

Energy consumed by the existing 36W twin fluorescent lamps(A)	36*2*486 = 34992W
Total energy consumed by 486 Nos. of 36 watts LED lamps(B)	36W T8 LED lamps = 17.496 kW
Energy saved/annum(C)	17.496*16*365=102176.64 kWh
ECS / annum (D)	102176.64 kWh*\$0.094 = \$ 9604.60
Replacement cost of LED lamps(E)	486 × \$ 38.58 = \$18750.55
Replacement cost of fluorescent bulbs during 45,000 hours(F)	\$0.445 /lamp * 486 * 2 * 2 = \$ 865.41
Total retrofit cost (E) – (F)	\$ 17885.14
Payback Period	1.86 Years=22.3 months

TABLE 18. ES and CS calculations in street lighting.

Energy consumed by the existing 100 w, HPSV lamps(A)	87 Nos.*100W *12 hrs = 104.4 kW
Total energy consumed by 87 Nos. of 60W LED lamps(B)	87 Nos. * 60W * 12 hrs = 62.640 kW
Energy saved(C)	41.76 kWh
Annual energy saved	41.76*365=15242.4 kWh
ECS / annum (D)	41.76* 365 *\$ 0.094 = \$1432.79
The replacement cost of LED lamps(E)	87 *\$52 = \$4518.47
The replacement cost of HPSV bulbs during 48,000 hours(F)	\$2.13/lamp *87* 3 = \$ 555.93
Total retrofit cost (E) – (F)	\$ 3960.76
Payback Period	2.76 Years/33 months

V. OVERVIEW OF ENERGY AND ENERGY COST SAVINGS ACHIEVED

The energy audit team has supervised the implementation part of the ECON recommendations and the execution. The ECON recommendations were divided into two parts as (i). Modifications and rectification work without investment or very minimal investments (ii). Implementation works needed substantial investments. Initially, the first part has been executed, and while execution, the procurement part of the recommendations with investments is initiated. When monitoring the results of the no-cost recommendations, the installation works of the equipment procured were started. The installation, testing, and commissioning were carried out with close coordination with the production and engineering departments.

From the effective implementation of ECON recommendations, the electric energy consumption in terms of Ukg is reduced to 4.33 from 4.99. Before the ECON study, the average annual electricity bill was \$2549502. After completing

TABLE 19. Summary of ES practices implemented, ES, ECS and payback period.

Head	Implemented energy-efficiency measures and practices		ES,kWh	ECS ($)	Investment ,$	Payback Period	ROI (%)
	Experiment carried out	Recommendations and implementations					
MD management	MD was measured in plant full load condition	Reduction of 200 kVA MD		12468	-	Immediate	-
Healthiness of Equipment							
Compressor	Load cycle, efficiency, temperature of inlet air, air pressure	Reduction of air pressure, Relocation of inlet air pipe, maintenance of air filters	192600	18104	-	Immediate	-
IE3 motors	Performance evaluation of existing conventional and IE motors, loading of motors	Optimization of motor rating, installation of IE3 motors	585,779	55063	56830	1.038 yrs	8.7
Motor-stator connection	Load and toque with delta connection	Changed to Star connection	271469	25518	--	Immediate	-
Identification of energy wasted							
humidification plant-1 & 2	Load on the motor for different settings of damper	Recommended to install VFD	2388096	224481	204896	0.92 yrs	9.1
Plant lighting	Existing lighting with Twin 36 W fluorescent lamps are tested for illumination level	Recommended to install 36 WT T8 LED lamps	102177	9604	17885	1.86 yrs	4.5
Street lighting	100 W HPSV lamps are tested.	Recommended to install 60W LED lamps	15242	1432	3960	2.76 yrs	3.0
TOTAL			3555363	346670	283873	ROI=283873.49/ 29909=9.5%	

all energy conservation measures, a remarkable energy cost saving of (2549502-savings in MD charges of 12528 - ECS of 346670 = 2202770) 13.59% on annual mill electricity expenses has been being achieved, and the annual electricity bill is reduced to $2202770. It is observed that, after the implementation of ECON recommendations, a total annual energy savings of 3.555363 Million kWh (13.2%) has been achieved. Summary of energy-saving practices implemented ES, ECS, payback period, and the return on investment is presented in Table- 19 and Table- 20.

A. OVERALL ENERGY SAVING (ES) ACHIEVED

It is observed that 3555363 kWh (13.20 %) reduction or annual saving in total electricity consumption has been achieved. The annual energy consumption is reduced to 23372637 kWh from 26928000 kWh. The electrical energy consumption per kg of yarn produced (Ukg) is also reduced to 4.33 which meets the SITRA norms.

B. OVERALL ENERGY COST SAVING (ECS) ACHIEVED

The annual energy cost charges have been brought down to a value of 2.2202770 Million Dollars from 2. 549502 Million Dollars with a saving of 0.3555363 Million Dollars, and this CS is found to be 13.59% on the annual electricity charges.

TABLE 20. Overall energy consumption, electricity bill, ES and ECS.

	Before energy audit	After energy audit	Annual ES and ECS
MD in kVA	3500	3300	200 kVA
Annual energy consumption, kWh	26928000	23372637	3555363(13.20%)
Annual energy bill, $	2549502	2202770	346732(13.59%)

C. RETURN ON INVESTMENT (ROI)

The total investment for the execution of ECON recommendations is $283873. The implementation has been carried out for over 11/2 years in a phased manner as the investments to be made are substantial. Considering the significant investment made on ECON implementation, an average payback period is 1 year, and the average ROI on motors of 8.7%, and ROI on the lighting of 3.64% has been achieved. The overall ROI is 9.5%.

D. ENVIRONMENTAL BENEFITS

In India, the CO2, SO2, and NOx emission due to Fossil-fuel to generate kWh of electricity is 0.22 kg, 5.08 gm, and 2.63 gm, respectively [18]. The positive environmental impact attained in CO2, SO2, and NOx emission reduction

TABLE 21. Positive environmental impact.

Reduction of emission per annum		
CO_2	SO_2	NO_x
87.19 Tons	20.123 Tons	1.029 Tons

is also presented. The reduction of these pollutants indirectly helps conserve nature for future generations.

The value of emission reduction after ECON implementation in the mill is estimated and presented in Table 20. Apart from energy and cost-saving benefits and considerable emission reduces the environmental pollution.

VI. CONCLUSION

In this paper, the actual situation of a textile mill on energy usage before the energy audit and after is portrayed. The various energy-saving methods were identified and implemented. The essential and potential suggestions which would result in the immediate realization of energy ES have been discussed, and their implementation methodologies were explained. The audit methodology and execution of the ES solutions are narrated. The energy-efficient res and technologies have been implemented for sub-sections and processes of the plant. Foremost, the electric energy consumption, Ukg is reduced to 4.33 from 4.99. The significant part is the high lights of the savings in terms of electricity to the tune of 3.555363 Million kWh/annum (13.20%) and the energy cost of 0.346732 (13.59%) Million Dollars. Also, the investment in implementation has been paid back in an average of 1 year, proving that the whole exercise is cost-effective. Also, the overall return on the investment is 9.5%. By reducing electricity consumption, the indirect environmental benefit in reducing carbon emission is also accomplished. Further scope for energy conservation in the industry is also examined. The scope does exist in providing auto control for lighting, optimizing the operation of cooling tower pumps, improving the power quality, and exploring the use of adjustable speed control for drives.

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