A Survey Report on the Electrical Installations Adopted by the Traditional Tea Factories in North Bengal

Arkabrata Dattaroy, Ankit Chakraborty, Swarnendu Mandal and Santanu Das

Abstract Tea industry, the Queen of North Bengal has accelerated downhill lately, owing to inefficient machineries. This survey pivots over Chronological Conditional Load Monitoring of the electrical machineries under CTC (Cutting, Tearing & Curling) texture, considering widely varying conditions, namely three types of tea leaves: Hard, Medium and Soft, as well as seasonal variation between Summer (July) and Monsoon (September). The entire load distribution of surveyed factory has been monitored, noted and analyzed. Developed Power Layout Diagram and associated survey data with extensive analyses have also been reported here. Based on the conducted survey reports and analyses, possible scopes of improvement of energy consumption and subsequent implementation schemes have been proposed in this report.

Keywords Energy efficiency · Loading percentage · Power factor Reactive power

1 Introduction

Tea has been "The Beverage of the Masses" in India since time immemorial. Tea industry is the backbone of earning FOR-EX (Foreign Exchange) on behalf of North Bengal, especially in the Darjeeling Hills and the Dooars [1]. However, the major

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technical issues (electrical) that lie beyond the unfortunate rapid shutdowns lately and deteriorations in the profitability of these tea factories, mainly the load monitoring and efficiency issues, are addressed in this project.

The major technical reasons leading to the downfall of late can be initially ascertained to be the inefficient and poor power factor operation of the electrical machineries, and their relative effects are quantified and referenced in this project.

2 Objectives of the Survey

- Detailed survey and Load monitoring of the tea factory:
  (a) Graphical approach with respect to time.
  (b) Comparison of calculated and measured values.
  (c) Determining optimal size and capability of the machines.
- Power Flow analysis
  (a) Traditional installations.
  (b) Active and reactive power calculations.
- Loading percentage calculations
  (a) Present loading percentage for the CTC Motors.
  (b) Attempts at improvement of loading percentage and their effects on power flow, without hampering productivity and employment.

3 Survey Details

The survey details as obtained on cumulative data collection have been depicted below with the help of a sample tea factory reference.

3.1 Sample Tea Factory Courtesy

Name and Address of the factory: Bikram Tea Factory,
CTC Units,
Assam More,
Jalpaiguri,
West Bengal, India.

3.2 Machineries and Outline of Operation

The electrical supply of the tea factory is catered to with the help of an incoming WBSEDCL (West Bengal State Electricity Distribution Corporation Ltd.) 11 kV feeder via HT (High Tension) valley, switchgear, a 500 KVA step down 11 kV/440 V, Star-Delta transformer and a charging Diesel Generator set of capacity 250 KVA. The connections to the panel room are via underground cables. The panel room consists of three panels-CTC *(Cutting, Tearing & Curling)* Main Panel, Change-Over Panel and Auxiliary Panels. The Main Panel has capacitor banks installed in delta to have Power Factor Correction (PFC).

Induction motors play the pivotal role in the CTC section of the industry. There are 3 sections of CTC Rows in the factory, out of which only 2 rows can be active at a time. The raw tea leaves start their journey via the path-Trough (where they are collected and dried via fans), Monorails and thereafter into the Rotor vane of each of the 3 rows of CTC, with the help of which they are dried and cut preliminarily. Thereafter, they continue their journey via the CTC rows for CTC Operation, with each row having 4 *Cuts*-1st Cut, 2nd Cut, 3rd Cut and the 4th Cut motors, all ending at revolving drums named Googies. There is an extra set of Googie and 1st Cut motor, in case there are bits and pieces of tea leaves yet to curl and fine tune. Thereafter, they traverse through the CFM (Continuous Fermenting Machine) section via Conveyors, where they are fermented and cooled via CFM fans and they ultimately derive their texture. Next they are dried and roasted well in the Groover and Vibrator section. The heat for the combustion is derived from burning of coal, which is oxidized via air intake with the help of Hot Blower and Cold Blower motors. Heating is done with the help of Hot Heater and Cold Heater. The fumes are released through a chimney and ash is collected and disposed off. Next comes the Sorting and Grading Section, where the tea leaves are separated with respect to their quality with the help of a Sieving Technique and then packed for sale. The total lighting load is of the LED (Light Emitting Diode) type, estimated at 2 kW.

The panels have the following functions:

The CTC Main Panel accounts for the voltage and current absorbed by the CTC sections combined. It also possesses the capacitor banks, which indicate the corrected power factor at any instant of time. The Change-Over Panel accounts for the voltages and currents absorbed by the CFM, Groover, Vibrator, Grading and Sorting sections. The Auxiliary panel takes care of the transformer charging power, the lighting loads and other unaccounted power supplied.

For the purpose of this project, the meter readings are focused only on the part consuming variable reactive power with variation in loading, that is, the CTC section. The loading percentage of the CTC Cut motors is observed and the corresponding CTC panel readings help to find out energy efficiency estimates and the power factor, both in the operating and improved case, with the help of capacitor bank estimates.

3.3 Load Distribution

The load distribution along with the rated load is enlisted as follows:

A. HT Valley & Gear.
B. Transformer: 500 KVA, 11 kV/440 Volts, Star-Delta.
C. Diesel Generator Set: 250 KVA.
D. Trough Fans: 11 Troughs $\times$ 2 Fans $\times$ 3 HP = 66 HP.
E. Monorails: 2 HP.
F. Rotor vane: 3 $\times$ 20 HP = 60 HP.
G. CTC Cutting: (Cut 1–25 HP, Cut 2–20 HP, Cut 3–20 HP, Cut 4–20 HP, Blower-2 HP, 3 HP) $\times$ 3 sets + extra 1st cut-25 HP, all 415 Volts, all rated at 0.75 power factor lagging = 295 HP.
H. Googie: 4 $\times$ 3 HP = 12 HP.
I. CTC Conveyors: 6 $\times$ 1.5 HP = 9 HP.
J. CFM (Continuous Fermenting Machine) Conveyor: 1.5 HP.
K. CFM Motors: 1 $\times$ 5 HP, 1 $\times$ 3 HP, Brush Motors: 2 HP = 10 HP.
L. CFM Fans: 7.5 HP, Small fans: 4 $\times$ 1 HP, Water Sprayer: 0.5 HP = 12 HP.
M. Groover Motors: 1 $\times$ 7.5 HP, 1 $\times$ 5 HP, 1 $\times$ 2 HP = 14.5 HP.
N. Groover Conveyor: 1 $\times$ 2 HP = 2 HP.
O. Vibrator: 1 $\times$ 5 HP = 5 HP.
P. Cold Blower: 1 $\times$ 3 HP = 3 HP.
Q. Hot Blower: 1 $\times$ 2.5 HP = 2.5 HP.
R. Cold Heater DC Motor: 1 $\times$ 1 HP = 1 HP.
S. Hot Heater: 1 $\times$ 2 HP = 2 HP.
T. Chimney: 1 $\times$ 5 HP = 5 HP.
U. Sorting: 2 $\times$ 3 HP = 6 HP.
V. Sorting Conveyor: 4 $\times$ 2 HP = 8 HP.
W. LED (Light Emitting Diode) Lighting Load: 2 KW.
X. CTC Main Panel with capacitor bank connected in delta.
Y. Change-Over Panel.
Z. Auxiliary Panel.

3.4 Power Layout Diagram of the Factory

The power layout diagram of the factory has been depicted here (Fig. 1).

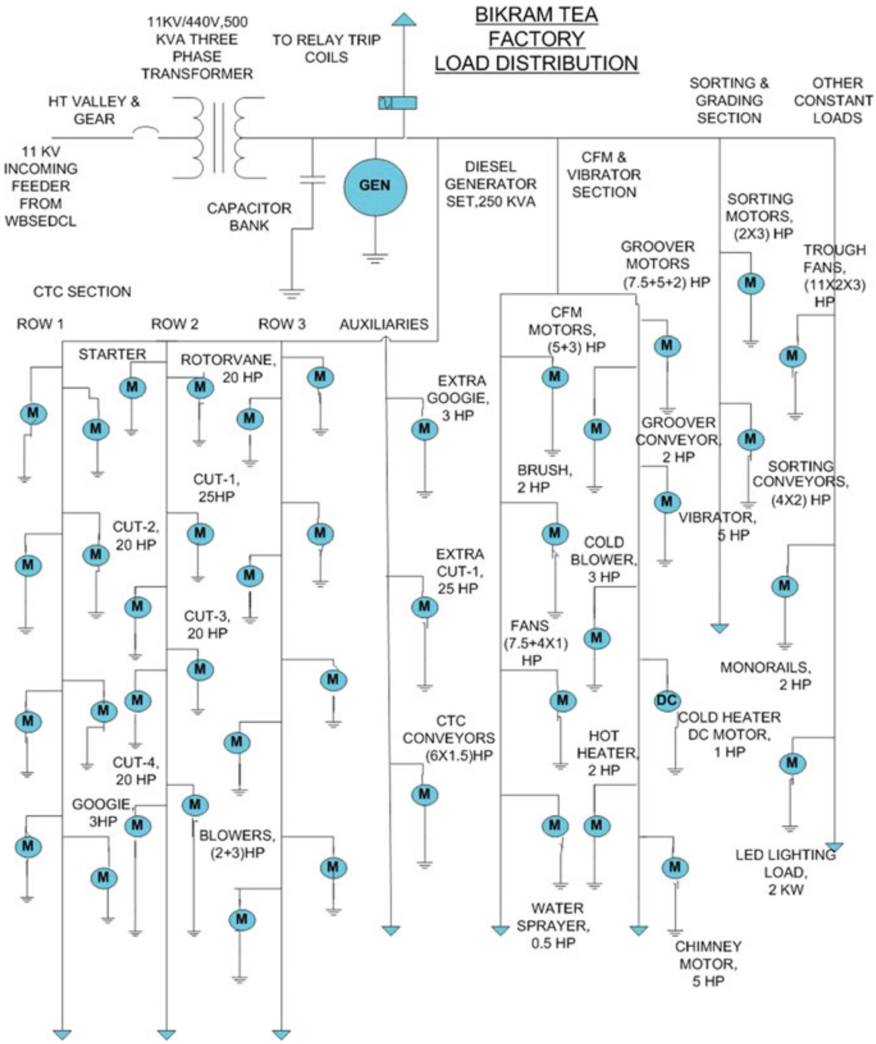

Fig. 1 This figure depicts the extensive power layout diagram of the factory under survey. It also categorizes the distribution into various sections and reveals the associated *ratings* of the machineries therewith

4 Survey Data Collection and Analysis

4.1 Rated Loading Calculations

For Cut 1 Motor: 25 HP, 415 V, 0.75 lag power factor

$$I(\text{full load}) = (25 \times 746)/(1.732 \times 415 \times 0.75) = 34.6 \text{ Amperes} \quad (1)$$

For Cut 2, 3 & 4 Motors: 20 HP, 415 V, 0.75 lag power factor

$$I(\text{full load}) = (20 \times 746)/(1.732 \times 415 \times 0.75) = 27.68 \text{ Amperes} \quad (2)$$

4.2 Loading Observed Under Varying Conditions

Analysis of the loading observed

For the 4 Cut motors under variable conditions, the loading as observed under Tables 1, 2 and 3 are quite as expected. The Cut motors are rated at 0.75 lagging power factor and this data is used for determining the loading percentages of the individual motors (Fig. 2, 3 and 4).

As the raw tea leaf changes from Soft to Hard via Medium under different weather conditions, seasons and days, the average loading percentage of each individual motor

Table 1 Data collected on 24. 07. 2017, Type of leaf: Soft

Time (pm)	Cut 1 Current (A)	Cut 2 current (A)	Cut 3 current (A)	Cut 4 Current (A)
12.30	20	13	10	11
12.40	19	12	8	9
12.50	18	14	10	11
1.00	20	15	13	12
1.10	20	13	9	10
1.20	18	15	12	13
1.30	23	19	15	15

Table 2 Data collected on 07. 09. 2017, Type of leaf: Medium

Time (pm)	Cut 1 current (A)	Cut 2 current (A)	Cut 3 current (A)	Cut 4 current (A)
3.00	20	13	10	11
3.15	19	12	8	9
3.30	18	14	10	11
3.45	20	15	13	12
4.00	20	13	9	10

Table 3 Data collected on 29. 07. 2017, Type of leaf: Hard

Time (pm)	Cut 1 current (A)	Cut 2 current (A)	Cut 3 current (A)	Cut 4 current (A)
12.45	28	17	14	15
12.55	22	15	12	13
1.05	40	24	17	16
1.15	26	15	13	11
1.25	22	15	11	12
1.35	26	16	13	11
1.45	28	18	15	13

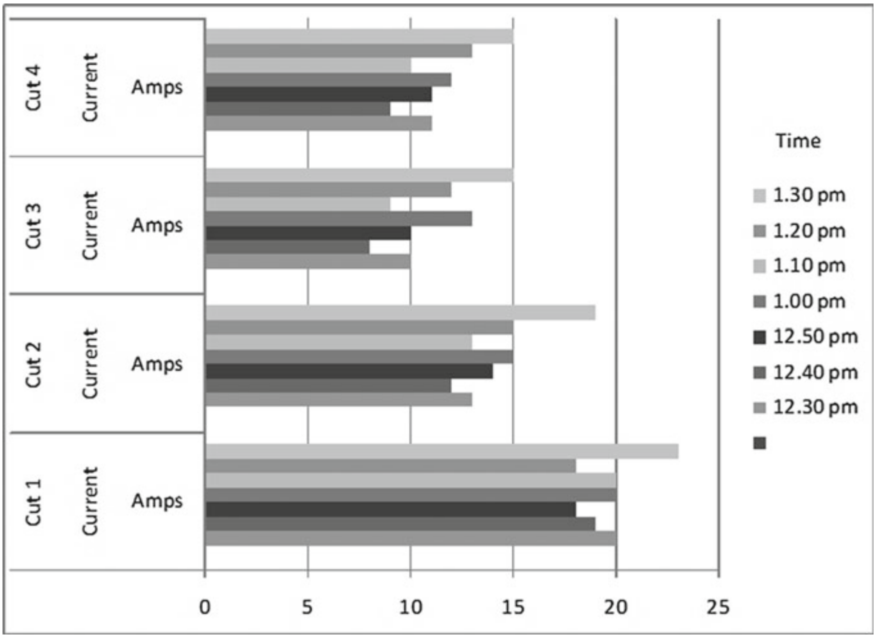

Fig. 2 Bar graph representation of loading on 24.07.17 (*Soft leaf)*

also increases, since amount of current drawn is *directly proportional* to the hardness of the raw leaf, as it requires more power for crushing it. It is found that the loading percentage gradually decreases from 1st to 4th Cut, which is obvious since the 1st Cut gets the hardest raw leaf.

The loading observed reveals the following information:

(i) *Soft Leaf*: The Cut 1 motor loading percentage varies from 52.04 to 66.49%; the Cut 2 motor loading percentage varies from 43.35 to 68.64%; the Cut 3 motor loading percentage varies from 28.9 to 54.19% and the Cut 4 motor loading percentage varies from 32.51 to 54.19%.

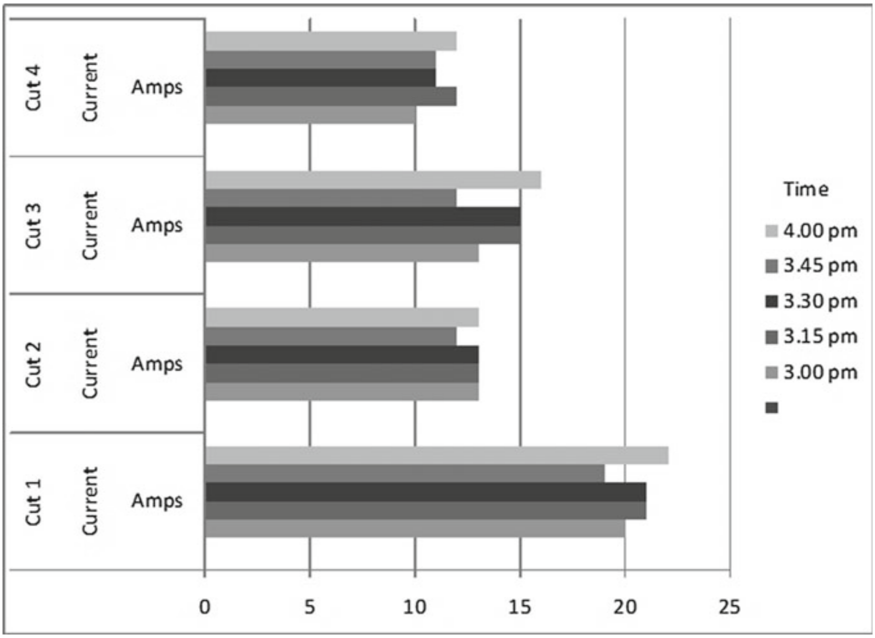

Fig. 3 Bar graph representation of loading on 07.09.2017 (*Medium leaf)*

(ii) *Medium Leaf:* The Cut 1 motor loading percentage varies from 57.82 to 63.6%; the Cut 2 motor loading percentage varies from 43.37 to 46.98%; the Cut 3 motor loading percentage varies from 43.37 to 57.82% and the Cut 4 motor loading percentage varies from 36.14 to 43.37%.

(iii) *Hard Leaf:* The Cut 1 motor loading percentage varies from 63.6% to an occasional 115.64%; the Cut 2 motor loading percentage varies from 54.19to 86.71%; the Cut 3 motor loading percentage varies from 39.74 to 61.42% and the Cut 4 motor loading percentage varies from 39.74 to 57.8%.

It is observed that there is no appreciable change in the loading of the 3rd and 4th cut motors under any condition, they are always poor. More the loading percentage, less is the reactive power consumed by the motor, and higher is the efficiency and power factor of the plant. If power factor improves by itself, there would be a lower tariff slab for the owners, ensuring profitability and providing further impetus to the industry. So, the loading percentage of 3rd & 4th cut motors are hypothetically assumed next to be 75% each and having an improved power factor of 0.75 and then analyzed.

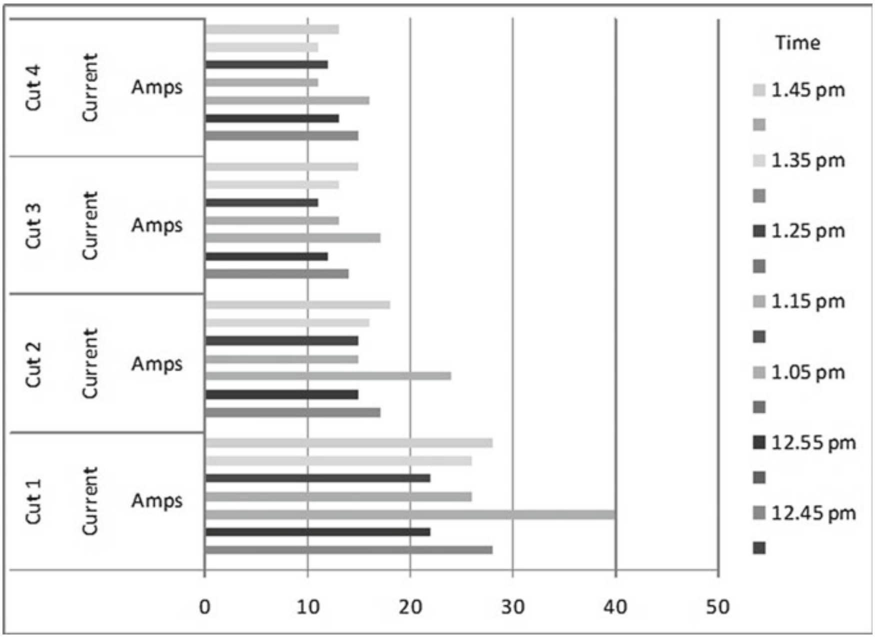

Fig. 4 Bar graph representation of loading on 29.07.2017 *(Hard leaf)*

5 Reactive Power Calculations and Comparative Analysis of Normal Loading with Theoretically Improved Loading Percentage and Improved Power Factor of the 3rd and 4th Cut Motors with Same Rating

For the comparative analysis, we take the case of 29.07.2017 with Hard Loading.

5.1 Normal Loading

Here, we take the power factor of the motors as 0.7 lagging instead of rated 0.75 lagging, owing to ageing and de-rating of the age-old motors (Table 4, 5).

Table 4 Reactive power calculation with normal loading and power factor of all motors at 0.7 lagging

Time (pm)	CTC Panel Voltage (V)	CTC Panel Current (A)	Total reactive power drawn by 4 motors (KVAR)	Primary panel voltage (V)	Primary panel current (A)	Power factor (lag)	Reactive power supplied from Source (KVAR)	Reactive power drawn by the 2 CTC rows (KVAR)	Reactive Power supplied by the capacitor Banks (KVAR)
12.45	385	100	35.23	365	225	0.98	28.3	70.46	42.16
12.55	390	85	29.88	360	238	0.98	29.53	59.76	30.23
1.05	390	120	46.78	365	237	0.96	41.95	93.56	51.61
1.15	390	85	31.35	360	275	0.98	34.12	62.7	28.58
1.25	385	75	28.56	360	281	0.98	34.87	57.12	22.25
1.35	380	85	31.04	360	245	0.98	30.4	62.08	31.68
1.45	380	100	34.78	360	229	0.98	28.42	69.56	41.14

Table 5 Reactive power calculations with Cut 3 & 4 motors at 75% loading, all at 0.7 lag power factor

Time (pm)	CTC Panel Voltage (V)	CTC Panel Current (A)	Total reactive power drawn by 4 motors (KVAR)	Primary Panel Voltage (V)	Primary Panel Current (A)	Power factor (lag)	Reactive power supplied from Source (KVAR)	Reactive power drawn by the 2 CTC rows (KVAR)	Reactive Power supplied by the capacitor Banks (KVAR)
12.45	385	100	41.21	365	225	0.98	28.3	82.42	54.12
12.55	390	85	37.88	360	238	0.98	29.53	75.76	46.23
1.05	390	120	50.89	365	237	0.96	41.95	101.78	59.83
1.15	390	85	39.8	360	275	0.98	34.12	79.6	45.48
1.25	385	75	37.4	360	281	0.98	34.87	74.8	39.93
1.35	380	85	39.27	360	245	0.98	30.4	78.54	48.14
1.45	380	100	41.13	360	229	0.98	28.42	82.26	53.84

5.2 Theoretically Improved Loading of 3rd and 4th Cut Motors Fixed at 75%, All Operating at 0.7 Power Factor Lag

Here, hypothetically 3rd and 4th cut motors are considered to have a high 75% fixed loading, and all motors operating at 0.7 power factor lagging, reactive power calculations are performed (Table 5).

5.3 Theoretically Improved Loading Percentage of 3rd and 4th Cut Motors Fixed at 75% with Higher Power Factor of 0.75 Lagging

Here, the loading percentage of 3rd and 4th Cut motors is fixed at 75% and higher power factor of 0.75 lagging (for the 3rd & 4th Cut motors) and reactive power calculations are performed (Table 6).

5.4 Analysis of Reactive Power Calculations

Reactive power calculations are performed under three conditions taking hard leaf as a sample:

(i) *Normal loading, all 0.7 lag power factor*:

First of all, we consider the normal loading percentages with power factor taken as 0.7 lag power factor instead of rated 0.75 for the motors, owing to the ageing and depreciated quality of the long-used motors and the reactive power consumed by each CTC row is calculated, and thereby for 2 CTC rows in total, working in tandem. The Primary Main Panel readings and improved power factor after rectification by the capacitor bank are calculated. The reactive power supplied from the source after Power Factor Correction (PFC) is calculated. The difference between the reactive power consumed by the 2 CTC rows and that supplied from source results in the reactive power supplied by the capacitor bank. So, the capacity of the capacitor bank installed can be estimated.

(ii) *3*rd *& 4*th *Cut Motors at 75%, all operate at 0.7 lag power factor:*

Next the hypothetical case where the 3rd & 4th Cut motors are operating at higher loading of 75% and operating at the same 0.7 lag power factor is considered. Here, an increased reactive power consumption by the motors due to increase in the currents drawn is observed, since reactive power drawn = (1.732*Line Voltage*Line Current*power factor). Also, the reactive power supplied by the capacitor bank increases, thus indicating the need for a higher rated capacitor bank.

Table 6 Reactive power calculations with Cut 3 & 4 Motors at 75% loading and 3rd & 4th Cut Motors operating at 0.75 lag power factor

Time (pm)	CTC panel voltage (V)	CTC panel current (A)	Total reactive power drawn by 4 motors (KVAR)	Primary panel voltage (V)	Primary panel current (A)	Power factor (lag)	Reactive power supplied from Source (KVAR)	Reactive power drawn by the 2 CTC rows (KVAR)	Reactive power supplied by the capacitor banks (kvar)
12.45	385	100	39.71	365	225	0.98	28.3	79.42	51.12
12.55	390	85	36.38	360	238	0.98	29.53	72.76	43.23
1.05	390	120	49.39	365	237	0.96	41.95	98.78	56.83
1.15	390	85	38.3	360	275	0.98	34.12	76.6	42.48
1.25	385	75	35.9	360	281	0.98	34.87	71.8	36.93
1.35	380	85	37.79	360	245	0.98	30.4	75.58	45.18
1.45	380	100	39.65	360	229	0.98	28.42	79.3	50.88

(iii) *3*rd *& 4*th *Cut Motors at 75% and 0.75 lag power factor, other 2 Cut Motors at 0.7 lag power factor:*

Next, the hypothetical case where the 3rd & 4th Cut motors operate at 75% loading and at an improved power factor of 0.75 lag is considered, the 1st and 2nd Cut still essentially operating at the same 0.7 lag power factor. It is found by calculations, the reactive power drawn by the motors and the reactive power supplied by the capacitor bank has decreased from its value as in case (ii). This ensures the fact that, with an increase of power factor of the motors and loading percentage towards full load, lower capacity capacitor bank suffices, which is lower in cost and volume if installed in place of the present one. Also, an increase in loading ensures higher efficiency, due to increase in utilization factor of the machines. Also, a lower capacity motor can be substituted in place of the present one, to ensure higher loading near full load. Also, problems on loss can be addressed with a lower size motor.

6 Results

Chronological data monitoring has been performed under wide variety of raw leaf and weather conditions. Loading percentage and reactive power calculations are performed and ultimately, it is observed that an increase in loading percentage and power factor lead to better performance of the factory, ensuring profitability.

With an estimated increase in power factor of the motors and loading percentage towards full load, lower capacity capacitor bank can serve the purpose and be installed. Also, an increase in loading of 3rd and 4th Cut CTC motors along with improved power factor ensures higher efficiency, and lower reactive power consumption, as is calculated and observed graphically. Entire load distribution of surveyed factory, power layout diagram and associated survey data with extensive analyses is presented in this survey. The graphical comparison of reactive power consumed under the three different cases is depicted below.

There are two major scopes of improvement of the situation which are discussed below (Fig. 5 and 6).

(i) *Usage of energy efficient motors of smaller adequate rating.*

Energy efficiency is the prime concern while installing any machinery in an industry. However, if the running cost for such a machine exceeds the installation cost in the long run, with efficiency having decreased, it might well be non-profitable to the industry. So, it is important to re-install newer energy efficient motors with lower operation costs, after detailed cost-benefit analysis. Also, due to smaller air gap in the IE classes of motors, reactive power requirement is lesser, hence more efficient.

There are energy efficient classes of motor, which can substitute the age-old induction motors hereby in operation. The energy efficiency classes of these motors are classified as follows in terms of IE (International Efficiency):

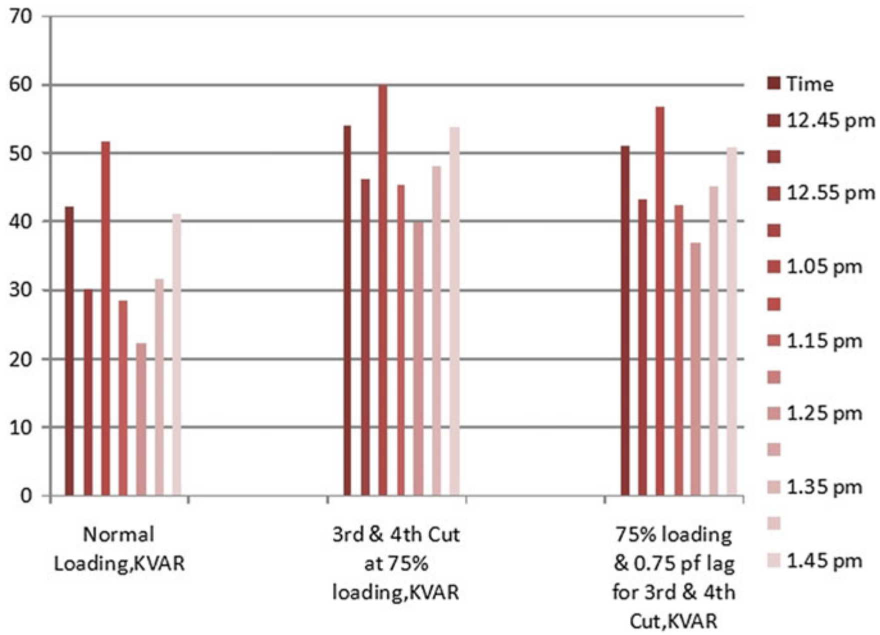

Fig. 5 Comparison of Reactive Power supplied by the Capacitor Bank during normal loading, increased loading percentage and both increased loading percentage and power factor (Left to Right respectively)

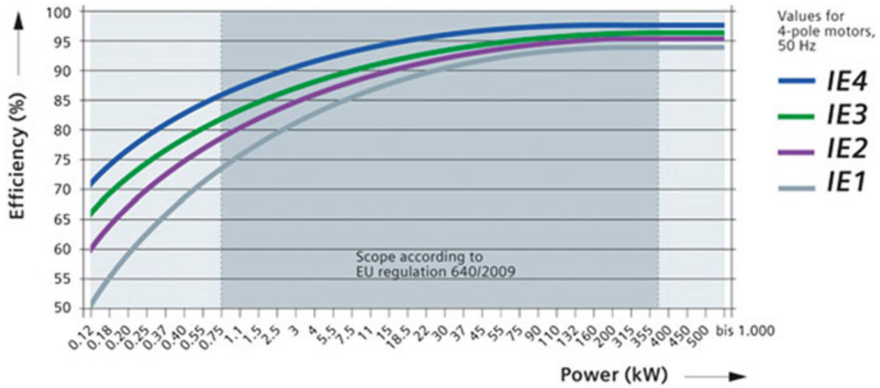

Fig. 6 Energy Efficiency Classes of motors and their range of percentage efficiency [2]

(a) IE1 (Standard Efficiency).
(b) IE2 (High Efficiency).
(c) IE3 (Premium Efficiency).
(d) IE4 (Super Premium Efficiency).

From these energy efficient motors, IE2 or IE3 motor with rating near 20 HP or 15KW (approximately) can be appropriately installed in place of the 3rd and 4th Cut motors in the CTC rows for healthier operation.

(ii) *Installing Power Factor Correction equipments, specifically FACTS (Flexible AC Transmission System) devices.*

FACTS devices are connected in series or parallel with an electrical catering, consists of power electronic switching devices in order to regulate reactive power flow and improve power factor of operation.

"APFC (Automatic Power Factor Correction) devices are the ideal choice. APFC essentially employs a current control loop, which is fed by input sinusoidal supply. A bridge rectifier is used to convert it into DC (Direct Current). There is a second outer voltage control loop, which employs appropriate scaling factor by analog multiplier. APFC is a sine magnitude controlled loop employing current control [3]".

These devices can be operated along with the tea factory machineries in operation to improve the power factor of the industry.

7 Conclusion

It is observed that an increase in loading percentage and power factor leads to better performance of the factory, ensuring profitability. A highly efficient alternate solution to this problem lies in installing energy efficient IE2/IE3 Class motors with smaller ratings. Also, Specific Energy Consumption (SEC) decreases with IE Class Motors.

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