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Energy Management through Energy Auditing for a Sustainable Development - A Judicious Approach

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Abstract

The imperatives of the prevailing energy crisis situation calls for energy conservation measures, which essentially mean using less energy for the same level of activity. Energy audit helps in energy cost optimization. Pollution control and safety aspects suggest the methods to improve the operating and maintenance practices of the system. It is instrumental in coping up with the decision on using energy efficient equipments, practices and technologies. An attempt is made in this paper, to analyze the existing energy consumption pattern, through energy auditing, at an educational institution (Saranathan College of Engineering campus) with a major focus on lighting. Detailed implementable real time energy efficient solutions were brought out.

Index Terms—energy, conservation, auditing, breakeven period, ILER, , room index, retrofit, waste heat, power saving

Introduction

Lighting is one of the primary and the most visible requirements of progress. Almost 19% of world's electricity is consumed by lighting. If the world were to switch to energy efficient lamps, the results would include "555" million fewer tones of CO_2 emission, more than 1560 million fewer barrels of oil consumed each year.; this is equivalent to switching off 53, 01, 000 MW power plants. In India, nearly 70%

of total power generation is done from coal-based thermal power plants. Global warming is threatening the very existence of our planet. Lighting, a key in gradient for development, can do a lot to keep the earth habitable for future generation. We are amidst severe power crisis that is making life of people from all quarters worse. Because of the current deficit of power, our industries are struggling and this results in downfall of our national GDP. The total installed generation capacity in Tamil Nadu including state-owned capacity, centrally owned capacity, and private sector capacity is 17686.37 MW (as on 31.08.2012), comprising 7617.8 MW of thermal (coal, gas and diesel), 524 MW of nuclear, 2, 122 MW of hydro, and 7, 422.84 MW from renewable resources.

Tamil Nadu is one among the states that is currently facing severe power crisis. To overcome this deficit many new generating stations are being installed. About 9, 460 MW of new coal-based thermal power projects (expected to be commissioned by 2015–16) are still at very preliminary stages (majority of them at the pre environmental impact assessment stage). Of this, about 2, 400 MW capacity is not expected to have any domestic coal linkage and the state is assessing plans to use 100% imported coal for these new capacities. But with the issues related to the availability of domestic coal, import dependence, and price volatility of imported coal, it is imperative for the state to factor-in the long-term risks of coal dependent power planning. On the one hand, large sums of government investment will be locked in capital costs and debt repayments for projects that may not deliver low-cost power, while on the other hand, rising power costs would have an inflationary effect on prices, affecting business growth and economic development. Taking in to considerations of the above facts, energy conservation measures and energy efficient practices could be the judicious and economic solutions for the rational utilization of the electrical energy and it is the need of the hour too.

Load Assessment

The following load/source details were collected during energy auditing at Saranathan College of Engineering Campus and were furnished in Table 1 to 3 below:

Data Capturing

EB Contracted Demand	: 112 kW (LT Consumer)
Total connected load	: 1450 kVA
Lighting load	: 225kVA
UPS	: 230 kVA
Air conditioning load	: 326 kVA
Power load(machines)	: 560 kVA
Water pump	: 47 kVA

TABLE 1 Outdoor Light Details

Appliances	Power Consumption (W)	Number of Working Hours /Day	Quantity
TL-D Tube light	54	12	70
FLOOD LIGHT (Metal Halide)	400	12	6
FLOOD LIGHT (Metal Halide)	250	12	1
FLOOD LIGHT (Metal Halide)	150	12	3

TABLE 2 Load Details of Hostel

Type of Load	Quantity	Total Power(kW)	Hours of Working/Day
Tube light	235	9.4	8
Ceiling Fan	238	14.6	14
Corridor Lighting	77	0.988	12
Outdoor	3	0.815	12
Motor	2	4.47	3
Fridge	1	0.725	24
Grinder	3	2.424	4
Ups	1	4.75	5
Freezer	1	0.6	24
Mixer	1	0.746	1
Aqua Guard	1	0.25	24
Pesto Flash	3	0.12	4
Total		40(Approx.)	

TABLE 3 Details of Diesel Generator Set

Location	Quantity	Capacity	No. of Working Hours/Day
Generator Room	1	140 kVA	4
Generator Room	1	125 kVA	2
Hostel	1	40kVA	Standby source

Energy Performance Assessment in Lighting

Lighting sector holds quite an appreciable share of the total connected load. Hence it is important to conserve energy in the lighting sector. The primary objective from energy conservation point of view is to provide the required lighting effect with lowest power consumption.

There are two methods discussed here to reduce the power consumption with the availability of required lighting effect.

- Installation of energy saver in lighting circuit.
- Usage of newer generation of lamps.

Case Study:

The performance of the existing lighting system in the machines lab has been investigated using the performance test.

Measured floor area of the interior:

Length = 40.23 m

Breadth = 9.144 m

Thus floor area =367.86 m^2

Estimated Room Index (RI) value = 3.76 (Since RI >3, lux measurement was taken in number of vulnerable locations as per the lighting standards requirements.)

Measured Average Lux = 102.6

TABLE 4 Power measurements

Phase	Voltage (V)	Current (A)	Power (W)	Power factor
RN	240	4.46	590	0.55
YN	235	1.48	184	0.511
BN	232	1.59	269	0.725

The total circuit Watts from Table 4	=1043 W
Watts per square meter	=2.83
Measured lux/watt/m^2	=36.25
Target lux/watt/m^2	=48 (obtained from standards based on RI and applications)
Estimated Installed Load Efficacy Ratio (ILER)	= 0.75

TABLE 5 Assessment of system based on ILER

ILER	Assessment
0.75 or over	Satisfactory to good
0.51 to 0.74	Review suggested
0.5 or less	Urgent action required

The ILER value shows that the system is just satisfactory and it is at the boundary with reference to Table 5. Hence review is suggested to further improve upon the performance.

Energy Saver

Energy saver is one of the potential options for achieving the energy conservation in the lighting sector. Lighting at the industries is mainly provided by discharge lamps like sodium vapour lamps, blended mercury vapour and fluorescent lamps. In these the light output is roughly proportional to the input voltage; a reduction in voltage of about 5% does not cause a proportional decrease in light output. The light output is reduced marginally 2%, but there is a substantial reduction of 10 % in power consumption. Hence in places where separate lighting feeders are available a step down transformer can be incorporated and a considerable amount of power can be saved. Thus energy savers are step down transformers that can be used in lighting circuit to save energy. For the same machines laboratory, the performance tests were done with the energy saver option and furnished below:

Floor area	=367.86m^2
Room Index (RI) value	= 3.76
Measured average lux	= 76.5
Measured locations	= 45 nos as per lighting standard Since RI > 3

TABLE 6 Power Measurements with Energy Saver

Phase	Voltage (V)	Current (A)	Power (W)	Power factor
RN	200	2.98	384	0.645
YN	198.5	1.02	135	0.655
BN	197.7	1.18	195	0.832

The total circuit Watts from Table 6	= 714 W
Watts per square metre	=1.94
Measured lux/watt/m^2	=39.43
Target lux/watt/m^2	=48 (obtained from Standards based on RI and applications)
Estimated Installed Load Efficacy Ratio (ILER)	= 0.82

The ILER value suggests that the systems energy consumption is satisfactory to good. Thus with the introduction of energy saver in the circuit, the amount of energy going as waste is reduced and the system condition is improved.

Units saved with the introduction of energy saver in the lighting circuit of machines lab

The amount of energy consumed is reduced when energy saver is introduced in the circuit. The units saved per year for the machines lab is calculated below

Total Power consumption with 240 V	= 1043 kW
Total Power consumption with 200 V	= 714 W
Total power saving	= 329 W

Total No. of lamps in the room	= 20
Power Saving / lamp	=16.45 W
Operating hours	= 8 hours
No of working days/year	= 300
Total energy saved/year	= 789.6 kWh

Cost Economics

Maximum expected Power consumption by a single lamp	=54W
No of lamps	=20
Total power consumption measured	=1043W
Power factor of the lamps	= 0.5
KVA rating of the lamps required	= 2.086
Cost of standard 2.2kVA transformer	= Rs 10, 000.
Units saved per year with energy saver	= 789.6 units
Therefore cost saved per year	=Rs. 5922
Break even Period	=1.69 years

Newer Generation Lamps

In the olden days incandescent lamps were generally used for lighting purpose which is now being replaced by fluorescent lamps and compact fluorescent lamps. These lamps, in turn, save appreciable amount of energy with reduced greenhouse effect. Fluorescent lamps with copper choke or electronic choke consuming 54W and 36W respectively under standard conditions are now used in most of the places. They can be retrofitted with number of newer generations of lamps such as LED tubes, CFL and some improved types of fluorescent lamps so that the power consumption can be further reduced with enhanced light output. Similarly some of the outdoor lights presently in use can be replaced with their counterparts consuming lower power. The Table 7 and 8 below represents the different lights presently in use and their retrofits for indoor and outdoor applications.

TABLE 7 Indoor lamps and their newer generation retrofits

Type	Circuit Power(W)	Lumens	Life (Hours)	Power factor	CRI
Incandescent lamp	60	584	1000	1	100
CFL(R)	11	570	6000	0.85	80
TL-40/54W (copper choke)	54	2450	13000*	0.5	72
TLD-36/54W (Electronic choke)(R)	36	2450	13000*	0.98	72
CFL(R)	36	2900	15000*	0.98	80
T5(R)	32	2480	15000	0.98	80
LED(R)	19	1650	40000**	0.9	83

(R) retrofit for the incandescent lamp
(R) retrofit for the second row (TL-40)

TABLE 8 Outdoor lamps and their newer generation retrofits

Type	Power (watts)	Lumens	Life (hours)	Power factor	CRI
Metal Halide Focus	400	32000	20000*	0.85(W.S.C)	65
LED focus(R)	150	13000	50000	>0.9	75
Metal Halide Focus	250	20500	20000*	0.85(W.S.C)	65
LED focus(R)	108	10200	50000	>0.9	75
Metal Halide focus	150	12700	12000	0.85	96
LED focus(R)	56	5300	50000	>0.9	75
LED Street light	25	1650	50000	>0.9	75
Mercury vapour	125	6200	16000*	0.5	46
Sodium Vapour(R)	70	5600	28000*	0.85	25

*life after which the lumen output falls below 50%
** life after which the lumen output falls below 70%
W.S.C-With Specified Capacitor
CRI- Colour rendering Index
(R) Indicates retrofit for the preceding row

Estimation of payback for its retrofit

After the comparison of different types of lamps, it has been found that LED tube of 19W and T5 of 32W consumes lesser energy and could be the apt retrofits for the TL 40(Fluorescent tube)

Scrap cost/tube light(including copper coil, iron core and sheet metal part = Rs 36

Replacement with 19W LED tube

Cost of one LED tube with fitting	=Rs 2, 100
Capital cost	=Rs 42, 000
Total scrap cost	= Rs 720
Net Capital cost	=Rs 41, 280
Units saved/year	=1680
Therefore total cost saved/year	=Rs 12, 600
Pay back period	=3.276 years

Replacement with 32W T5

Cost of one T5 lamp with fitting	=Rs 525
Capital cost	=Rs 10, 500
Total scrap cost	= Rs 720
Net Capital cost	=Rs 9780
Units saved/year	=1056
Therefore total cost saved/year	=Rs 7, 920
Pay back Period	= 1.23 years

Similarly the retrofit and the payback period were evaluated for the other lamps located in different parts of the campus after duly carrying out the energy auditing. The results are consolidated in Table 9.

TABLE 9 Comparison of break even periods for Machines Lab Lighting system

Lamp/method of energy saving	Energy saver	LED tube 19W	T5 32W
Cost saving/annum(Rs)	5, 922	12, 600	7, 920
Capital cost to be invested(Rs)	10, 000	41, 280	9, 780
Payback period(year)	1.69	3.276	1.23

Capacitor Bank

As with any equipment, an electrical system handles its job to some degree of efficiency ranging from poor to excellent. The measure of electrical efficiency is known as Power Factor. The motors and other inductive equipment in a plant require two kinds of electric power. One type is working power, measured by the kilowatt (kW). This is what actually powers the equipment and performs useful work. Secondly, inductive equipment needs magnetizing power to produce the flux necessary for the operation of inductive devices. The unit of measurement of magnetizing or reactive power is the kilo Volt Ampere reactive (kVAr). The working power (kW) and reactive power (kVAr) together make up apparent power which is measured in kilovolt ampere (kVA).Most AC power systems require both kW (kilowatts) and kVAr (kilo Volt Ampere reactive). Capacitor installed near the loads in a plant is an efficient way of supplying the required kilo Volt Ampere reactive. This means that kilo Volt Ampere reactive need not have to be sent all the way from the utility generator to the customer. This relieves both the customer and the utility from the cost of carrying this extra kilo Volt Ampere reactive power. This makes the customer free from the charges imposed by the utility directly or indirectly in the form of power factor penalty charge. In addition, this improves the system capacity, voltage, power factor with loss reduction.

Energy Auditing in Capacitor Bank

Energy Auditing carried out in a capacitor banks revealed that majority of the banks were not providing adequate reactive power compensation due to either of the following reasons:

- Defects in the delta connected capacitor banks in the form of open/short circuits in the individual capacitors.
- Reduction in the terminal voltage of the capacitor bank.

Measurements

Overall measurements on different capacitor banks are brought out in Table 10.

TABLE 10 Measurements on Capacitor Banks

Location	Rated Kvar	Rated Voltage (V)	Avg Voltage (V) Measured	Rated Current (A)	Avg Current (A) Measured	Actual kVAr Delivered
Well1	2	440	404	2.62	2.19	1.5
ME Block	5	440	416	6.56	6.2	4.46
ME Block	3	440	416	3.94	2.5	1.8
ME Block Genera-tor room	2 10	440 440	416 414.43	2.62 13.12	2.56 12.8	1.85 9.188
Genera-tor room	5	415	414.43	6.96	3.57	2.56
Work shop	10	440	413.86	13.12	11.2	8.028
Well 2	1	440	-	1.31	0	0

Location:	Bore well submersible pump (Well 1)
Rated kVAr	= 2kVAr
Rated voltage	= 440V
Rated Current	= 2.62A
Average measured current	= 2.19A
Average Measured voltage	= 404V
Expected kVAr due to terminal voltage reduction	=1.68kVar
Actual kVAr supplied	= 1.5kVAr

In this capacitor bank, it was observed that the present capacitor was not capable of producing rated kVAr due to the terminal voltage drop, current reduction (owing to its ageing) and capacitor defect.

Cable Loss

Almost in all the industries and the organizations the power transfer and distribution inside the campus is carried out with the help of underground cables. All the cables have some amount of resistance(R) and hence power loss (I^2R) due to joule's heating effect occurs. This loss increases with the increase in length of the cable. One of the remedial measures for reducing the cable loss is discussed below based on our field data:

Cable 1: From main transformer to generator room

Present case: No of cables/phase =2
Length of the cable =0.2 km
Total Area of cross section of the cable/phase = 240 mm^2

Practical Measurements through power Quality analyzer:

The cable loss is measured with the power quality analyzer in the energy loss calculator mode and the readings taken are shown in Fig. 1.

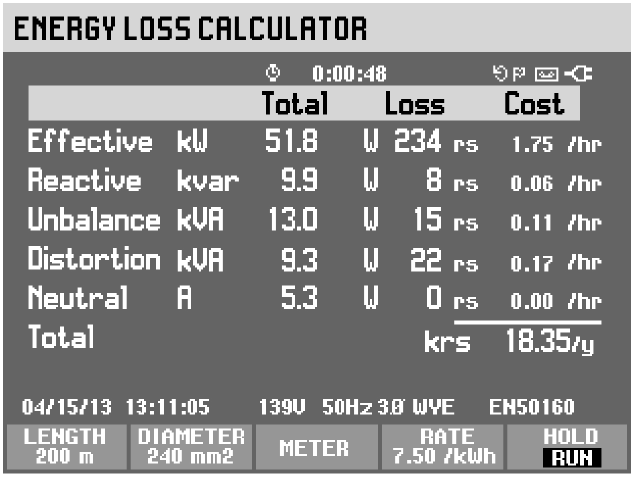

Fig. 1 Measurements of cable1 from main transformer to generator room

Cable 2: From generator room to RV block computer lab

Present case: No of cables =1
Length of the cable =0.2km
Area of cross section of the cable = 185 mm^2
Practically Measured loss
Theoretically calculated loss with measured value of current:
Average current flowing
through the cable =71.86 A(measured)
Resistance of $3\frac{1}{2}$ core Aluminium
conductor of 185mm^2 =0.197 Ω/km
I^2R loss =203.45 W
Total power loss for all the three phases =610.36W
Total units lost/year =5346.8 units
Money lost due to loss/year = Rs. 40, 100.65 /year

For loss minimisation

Addition of one more parallel cable/phase with the existing cable
Effective resistance is =0.0985 Ω/m
loss per phase =101.72 W

Total power loss for all the three phases	=305.18W
Total units lost	=2673.4 units
Money lost due to loss	= Rs. 20, 050.30/year
Total cost that can be saved by	= Rs 20, 050.35/year

Thus the amount of money that can be saved by increasing the number of cables is found and this could give a reasonable payback, based on the loading conditions.

Waste Heat Recovery System

Waste heat is heat generated in a process by way of fuel combustion or chemical reaction, which is then "dumped" into the environment and not reused for useful and economic purposes. The essential fact is not the amount of heat, but rather its "value". The mechanism to recover the unused heat depends on the temperature of the waste heat gases and the economics involved. Large quantities of hot flue gases are generated from boilers, kilns, ovens and furnaces. Details of typical waste heat temperatures for different equipments are tabulated in Table 11. If some of the waste heat could be recovered then a considerable amount of primary fuel could be saved. The energy lost in waste gases cannot be fully recovered. However, much of the heat could be recovered and adopting the following measures as outlined in this chapter can minimize losses.

Table 11 Typical waste heat temperature at medium temperature range from various sources

Types of Devices	Temperature (ºC)
Steam boiler exhaust	230 —480
DG Set exhaust	350—550
Gas turbine exhaust	370 —540
Reciprocating engine exhaust	315 —600
Reciprocating engine exhaust (turbo charged)	230 —370
Heat treatment furnace	425 —650
Drying & baking ovens	230 —600
Catalytic crackers	425 —650
Annealing furnace cooling systems	425 —650

Today the usages of Diesel Generators are quiet common due to the energy crisis problems. There is a way to recover the waste heat from the exhaust flue gas of DG sets. So we took an initiative to find the potential of waste heat recovery from the DG Sets. A typical energy balance in a DG set indicates the following break up:

Input:	100%	Thermal Energy
Outputs:	35%	Electrical Output
	4%	Alternator Losses

33% Stack Loss through Flue Gases
24% Coolant Losses
4% Radiation Losses

Among these, stack losses through flue gases or the exhaust flue gas losses on account of existing flue gas temperature of 350°C to 550°C, constitute the major area of concern towards operational economy. We have practically evaluated the waste heat recovery on a 140kVA DG set.

Principle:
The principle of operation is nothing but an heat exchanger. The heat from the exhaust flue gas is transferred to the colder fluid via copper tube.

Experimental setup:
¼" Copper tube is wound over the exhaust pipe as shown in the Fig. 2. The cold water was flown through the copper coil and the hot water was collected at the outlet of the copper tube at a specific discharge rate under the prevailing load conditions.

Without thermal insulation:

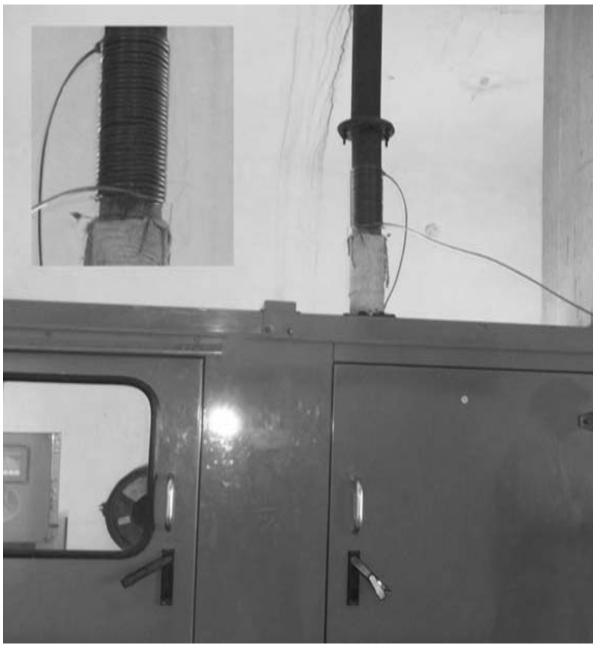

Fig.2 Waste Heat recovery from 140kVA DG set without thermal insulation

At 50% loading of the DG set	
Inlet water temperature	=30°C
Outlet water temperature	=45°C
No. of operating hours	= 6
No. of operating days /year	=300

Flow rate of water = 1.33 litre/minute
Heat value recovered =m*c_p*Δt
m - mass of the water(kg)
c_p - specific heat (kCal/kg-K)
Δt - Change in temperature (K)
Heat value we recovered = 21, 54, 600kCal/year
Calorific value of LPG =1, 68, 980 kCal/cylinder
Equivalent numbers of LPG
cylinders that we have recovered =13cylinders/year(approx.)

With thermal insulation:

Fig.3 Waste Heat recovery from 140kVA DG set with thermal insulation

Thermal insulation is wound over the heat exchanger as shown in Fig. 3.
Inlet water temperature =30°C
Outlet water temperature =58°C
No. of operating hours = 6
Flow rate of water =1.33 litre/minute
Heat value recovered/year =m*c_p*Δt
= 40, 21, 920kCal/year
Calorific value of LPG =1, 68, 980 kCal/cylinder
Equivalent no. of LPG cylinders = 24 cylinders / year

There is further scope in this investigation to recover more heat by varying the flow rate and by varying the loading of the DG set

Energy Conservation in Motors

Motors form about 70% of the total load connected in the world or in any country. Hence if their efficiency can be improved then a considerable amount of energy can be saved.

Ways to improve energy efficiency

- Changing the under loaded motor winding connection from delta to star.
- To replace the standard efficiency motors by higher efficiency motors.

Changing the under loaded motor winding connection from delta to star

The under loaded motors have very low efficiency, power factor due to increased magnetic losses. In order to reduce these losses the motor winding connection should be converted into star, by converting into star the voltage applied to the motor will get reduced by $\frac{1}{\sqrt{3}}$. Due to reduction in the supply voltage the following things happen:

- The magnetizing current and hence overall current drawn by the motor is less
- Copper loss and core loss are reduced

The power factor and hence the overall efficiency of the motor gets improved as shown in the Fig.4.

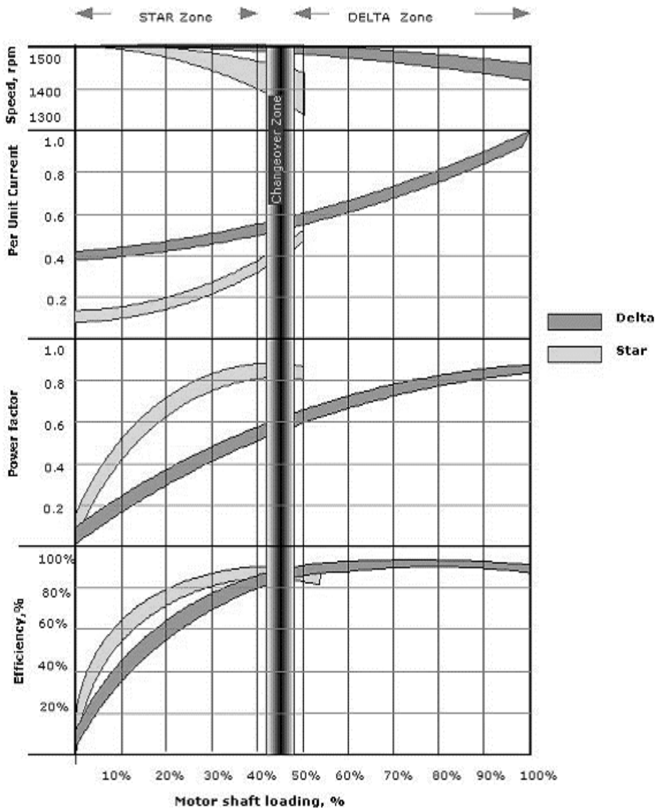

Fig.4 Comparison between the star and Delta connection performance of the same motor

It was observed that it is quite an efficient method to change the motor connections from delta to star for motors operating consistently at 40% of the rated load and below.

Conversion of standard motors into higher efficiency motors

As the efficiency of standard motors at lesser loading is low, its operating performance get reduced considerably .If the delta to star change over option is not suitable for improving the efficiency, replacement of existing standard motors with energy efficient motors with efficient motor would be quite appropriate. The conditions, which increase viability of installing energy efficient motors, are as follows:

- Standard motors operating at low load
- Operating hours are high (nearly continuous).
- Standard motors are older and more number of times they were rewound

Load Vs Efficiency curve:

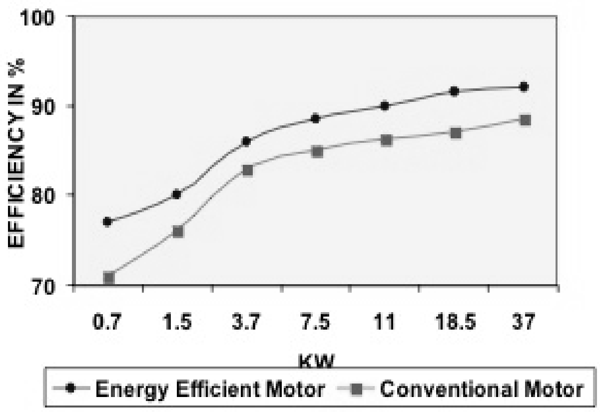

Fig. 5 Efficiency of Standard and Higher Efficiency motor for various loads

The efficiency of the energy efficient motor is almost constant at all percentage loadings as shown in Fig. 5. Due to its flat efficiency characteristic, it maintains efficiency almost constant at all loads. Normally, this option is suitable for the motors with rated capacity below 50HP. The efficiencies of standard motors above 50 HP ratings are almost similar to that of energy efficient motors. In many cases, though the initial cost of energy efficient motor is 15 to 20% higher than the standard motors, the payback period is less due to savings.

Results And Discussion

- In order to save energy in the lighting system

  - Energy saver could be used to optimize energy consumption in a circuit having 40W fluorescent lamps
  - Newer generation of Lamps likeT5 and LED could be opted in Tube Light circuits

- The performance of capacitor banks should be tested periodically to ensure that the capacitor supplies it's rated kVAr.
  - If the capacitors don't supply the rated current for the particular kVAr, then some internal fault in the capacitor is suspected and it needs replacement
  - If the capacitors don't supply rated kVAr due to the reduced terminal voltage at the point of installation, then additional capacitors should be included at the point, to supply the required kVAr.

- The power factor should be maintained near UPF with the help of capacitor bank to reduce the kVA demand and to avoid penalty due to low power factor.
- In order to improve the efficiency of motors, automatic star-delta-star controllers could be used for motors loaded below 40% or else they can be replaced by higher efficiency motors.
- The waste heat from the DG sets could be recovered and utilized for various useful productive purposes.

Conclusion

Energy can neither be created nor be destroyed based on the principle of Energy conversion. However, the Energy can be converted from one form to another form. Does this conversion take place efficiently? This, of course, needs a great focus. Energy efficiency and Energy auditing are related concepts. Successful Energy management requires the establishment of a system to collect analyze and report on the Energy costs and consumption. This will enable an overview of energy use and its related costs, as well as facilitating the identification of savings that might otherwise not be detected. Energy auditing is a typical tool to achieve this and to explore the potential of anticipated Energy savings in a particular process. The strategic approaches made by the State and Central Governments have resulted in the Energy Efficient products. One such example is Energy Labeling and identification of the star rated Energy Efficient products. The awareness of Energy Efficiency and Energy conservation are gradually gaining popularity among the consumers. There are more strategies to explore and new heights to conquer in Energy Audit. We are the proud owners of the oldest and noblest culture in the whole world. But people refuse to change and accept new realities, equations and dimensions. Everyone wants to follow the easy path. Our firm belief is that by just changing the culture of the organization and its employees, 10% saving is possible in any industry. The conventional Energy resources will run out in the future. Deployment of green Energy and identification of the potential avenues for Energy conservation is the need of hour for a greener environment and a sustainable growth.

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Author's Profile

The author, Dr.D.Kalyanakumar, has thirty four years of experience in various industries and academia both in India and abroad. He obtained his Ph.D in the area of Power Quality. He has several publications (both national and international level) at his credit. He is also a certified Energy auditor by the Bureau of Energy Efficiency(under Ministry of Power).Currently he is working as professor in the department of Electrical&Electronics Engineering, Saranathan College of Engineering, Trichy, Tamilnadu