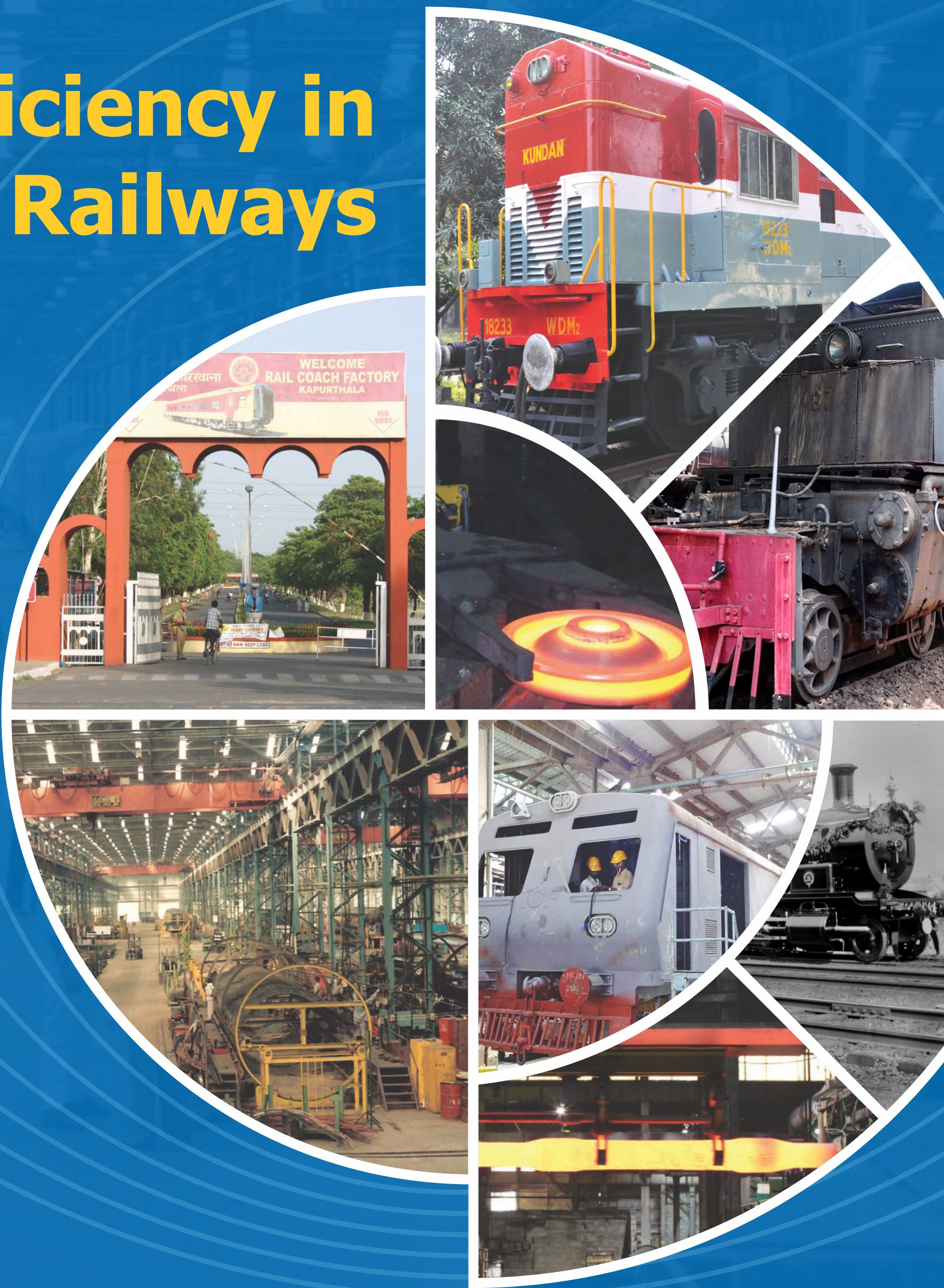
SHAKTI
SUSTAINABLE ENERGY FOUNDATION

Confederation of Indian Industry
Business and Beyond
125 Years: 1895-2020

Energy Efficiency in Indian Railways



Best Practices Manual

Version 2.0

About Us

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the development of India, partnering industry, Government, and civil society, through advisory and consultative processes.

CII is a non-government, not-for-profit, industry-led and industry-managed organization, playing a proactive role in India's development process. Founded in 1895, India's premier business association has over 9100 members, from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from around 291 national and regional sectoral industry bodies.

CII-Sohrabji Godrej Green Business Centre (CII-Godrej GBC) was established in the year 2004, as CII's Development Institute of Green Practices & Business, aimed at offering world class advisory services on conservation of natural resources. The Green Business Centre in Hyderabad is is housed in one of the greenest buildings in the world and through Indian Green Building Council (IGBC) is spreading the Green Building movement in the country. The Green Business centre was inaugurated by His Excellency Dr. A.P.J. Abdul Kalam, the then President of India on 14July 2004.

The Services of Green Business Centre Include - Energy management, Green Buildings, Green companies rating, Renewable Energy, GHG Inventorization, Green Product Certification, Waste Management and Cleaner Production Process. CII- Godrej GBC works closely with the stakeholders in facilitating India emerge as one of the leaders in Green Business by the year 2022.

About Shakti Sustainable Energy Foundation

Shakti Sustainable Energy Foundation works to strengthen the energy security of the country by aiding the design and implementation of policies that encourage energy efficiency as well as renewable energy. Based on both energy savings and carbon mitigation potential, it focuses on four broad sectors: Power, Transport, Energy Efficiency and Climate Policy. Shakti acts as a systems integrator, bringing together key stakeholders including government, civil society and business in strategic ways, to enable clean energy policies in these sectors. For more information, please visit: www.shaktifoundation.in

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Confederation of Indian Industry
Business and Beyond
125 Years: 1895-2020

BEST PRACTICES MANUAL

(Pilot study in Production units and Workshops)

Version 2.0

Indian Railways

Disclaimer

This manual is part of the Shakti Sustainable Energy Foundation(SSEF) and CII-Godrej GBC's effort to assist the Indian Railways achieve greater energy efficiency levels and also facilitate the designated consumers in Railways to meet their Perform, Achieve & Trade (PAT) targets set by Bureau of Energy Efficiency (BEE), Government of India.

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EXECUTIVE SUMMARY

Indian Railways (IR) is an Indian state-owned enterprise, operated by the Government of India through the Ministry of Railways. It is one of the world's largest railway networks, comprising 121,407 km of tracks, over a route of 68,400 km, covering 7,349 stations. The Indian Railways consumes over 20 billion kWh[1] of electricity annually, which is around 2% of the country's total power consumption, in addition to primary energy usage, mainly in the form of diesel. Indian Railways consumes approximately 2.5 Billion units of electricity for non-traction usage, spending about INR 1,700 crores per annum. This points to significant potential in saving energy in the Indian Railways. This has also been recognized by the Bureau of Energy Efficiency, and 16 traction units of the Indian Railways as well as six production units have been identified as designated consumers in the second cycle of the PAT scheme. The IR is also undertaking a series of environmental sustainability measures, across energy efficiency, renewable energy, waste management, etc.

Confederation of Indian Industry (CII) is a non-government, not-for-profit, industry-led and industry-managed organization, playing a proactive role in India's development process. Founded in 1895, India's premier business association has over 9100 members, from the private as well as public sectors, including SMEs and MNCs, and an indirect membership of over 300,000 enterprises from around 291 national and regional sectoral industry bodies. With 68 offices, including 9 Centre of Excellences, in India, and 11 overseas offices in Australia, China, Egypt, France, Singapore, UK, and USA, as well as institutional partnerships with 394 counterpart organizations in 106 countries, CII serves as a reference point for Indian Industry and the international business community.

CII- Sohrabji Godrej Green Business Centre (CII-Godrej GBC), one of the centers of excellence of CII was established in the year 2004, as CII's Developmental Institute on Green Practices & Businesses, aimed at offering world class advisory services on conservation of natural resources. The advisory Services of CII -Godrej GBC include - Energy Management, Green Buildings, Renewable Energy, GHG Inventorization, and GreenCo certification, Green Product Certification, Waste Management and Cleaner Production Process.

CII signed a Memorandum of Understanding (MoU) with the Indian Railways to facilitate various energy and environmental initiatives. The MoU dated 26 July, 2016, was signed in the presence of the Minister of Railways. The first project under this MoU was conceived to support implementation of energy efficiency measures in select Indian Railways units, six production units and four workshops, supported by Shakti Sustainable Energy Foundation (SSEF). The second phase of the project includes two additional production units and eight workshops, to further improve the energy performance as well as to ensure that Energy Efficiency (EE) is deep rooted in the Indian Railways.

Figure 1: MOU Signing Between Indian Railways & CII

In the second phase, in addition to the engagement with ten facilities, follow-up/handholding visits of the Phase-I units were also conductedto assess the nature of benefits achieved and identify additional information or provide necessary assistance required from CII to expedite the implementation activities. The feedback during the follow-up visitwas very encouraging, with the plants reporting the implementation of more than 150 energy efficiency and renewable energy projects, resulting in annual energy savings of 17.85 million units, which translated into monetary savings of INR 136.8 million, and a reduction of 15,914 tCO_2 emissions per year.

In Phase–II units, more than 252 energy efficiency opportunities were identified, with an anticipated annual energy saving potential of 10.10 million units, resulting in monetary savings of INR 67 million, and reduction potential of 8,998 tCO_2.

[1] As per IR Annual Environmental Sustainability Report 2018-19

Under this background, the Best Practice Manual is developed to help its readers understand various technologies and best practices in Energy Efficiency aspect. This manual is expected to assist Indian Railways production units to improve their energy efficiency levels and help them to achieve the reduction targets under PAT scheme.

However, implementation of these technologies calls for a sustained effort. Some of the technologies mentioned in this report are capital intensive and at times are time consuming to implement. However, implementation of these projects surely proves to be beneficial to the IR units.

INDIAN RAILWAYS INDUSTRY:

Indian Railways (IR) is one of the largest operating rail networks in the world. Being one of the most preferred mode of operation, IR operates 13,452 passenger trains every day as on 2017-18. As many as 8.286 billion passengers have travelled through the Indian Railways annually, which equates to almost 22.7 million passengers per day. IR also operates to transport freight and cargo, and as transported 1.16 billion tons of freight annually, as on 2017-18.

In terms of assets of the Indian Railways, itowns 71,825 passenger coaches, 2, 79,308freight wagons and 11,764 locomotives (Steam, Diesel and Electric) as on 2017-2018[2]. IR also owns various locomotive and coach production facilities, where a number of coaches, wagons, locomotives, rail wheels, etc. are manufactured.

Energy consumption in Indian Railways:

IR accounts for as much as 1.57%[3] of country's total electricity consumption, considering the conventional sources of energy. This estimates to 19.02 billion kWh of electricity consumption in 2017-18. IR, in its efforts towards sustainable development, has been taking various steps towards enhancing energy efficiency levels. This has led to reducing its specific electricity consumption by about 3.0% in traction on year-to-year basis.

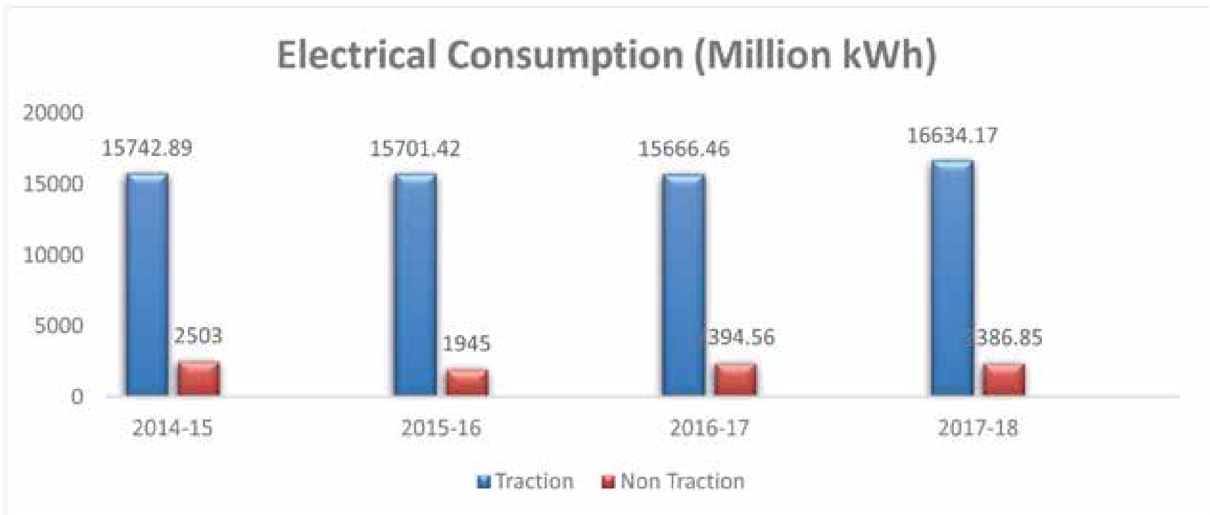


Figure 2: Electrical consumption of Indian Railways

Similarly, the diesel consumption of the Indian Railways for both the traction and non-traction is shown below:

[2] http://www.indianrailways.gov.in/railwayboard/uploads/directorate/stat_econ/pdf_annual_report/Railway%20Year%20Book_2017_18
[3] https://powermin.nic.in/en/content/power-sector-glance-all-india

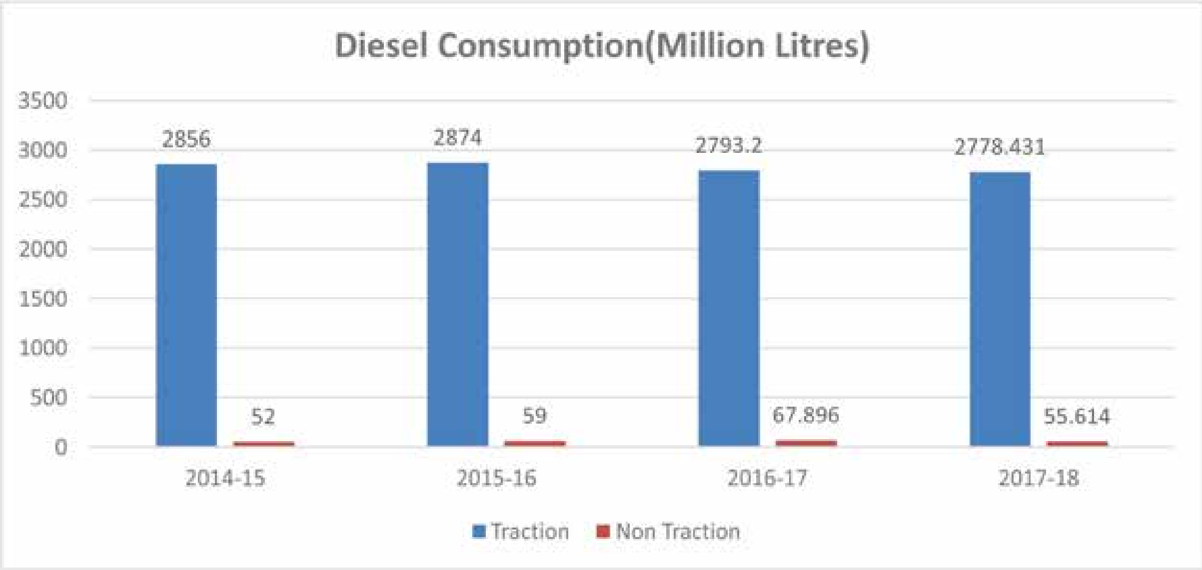


Fig 2a: Diesel consumption of Indian Railways[4]

It can be inferred from the above graph that the diesel consumption in non-traction category has witnessed 18.08% decrease over the FY 2016-17, which could be an indication of energy efficiency efforts taken by the Indian Railways.

CHALLENGES FACED BY INDIAN RAILWAYS

i. Turbulence of demand:

All the production units are designed for continuous operation. Batch operation of heavy machinery like arc furnaces not only consumes more energy but also reduces its life and efficiency. As the demand of the railway equipment like wheels, coaches, and locomotives is not continuous, it affects the effectiveness of plant machinery.

ii. Vintage of the Plants

Vintage of the plants has a key role in higher energy consumption of Indian Railways Production units. Many of the public sector units are old plants with vintage technologies. Introduction of new technologies in these plants proves to be very tedious thus hindering the progress of energy efficiency activities.

iii. Cost of energy efficiency

Any modification in the process for energy efficiency activities in Railway plantsis capital intensive. Therefore, several plants are apprehensive to go ahead with energy efficiency activities.The industriall ending rates of the bank sarevery high in India and thusthe Internal Rate of Return (IRR) is also low. This makes projects less attractive. In addition to this, there are no separate funds available for energy efficiency activities.

POLICIES FAVORING ENERGY ACTIVITIES:

Railways being the major consumer of energy, systematic programme was launched towards improving energy efficiency and energy conservation.

IR has been actively taking policy initiatives by issuing various Guidelines/ Circulars on General Power Supply Systems like use of LED lights, Star rated equipment etc. Listed below are some of the recent major Policy Guidelines/ Circulars and manual issued for Energy Conservation and energy management in Indian Railways:

- Energy audit guidelines, manuals and best operating procedures were developed for energy intensive railways

[4] Indian Railways Year Books

operations, including production units, traction substations, workshops, production units, maintenance depots and buildings. Energy audit was undertaken for 15 facilities including railway stations, workshops, hospitals and buildings across the Indian Railways.

- ❖ Gap analysis was carried out to identify opportunities for improving energy efficiency and to define areas for implementation of energy efficient technologies and measures.
- ❖ Development and issue of Energy Audit Manual & Standard Template for Contract Procedure for Energy Audits Services for Indian Railways Installations by RDSO.
- ❖ Use of star labeled products on Railways: to procure only star rated equipment (3-star or above) to which minimizes the use of energy.
- ❖ An online system, railsaver.gov.in, was developed by the Centre for Railway Information Systems (CRIS), it provides updated energy data across 16 zones of the Indian Railways. The analysis of data collected will facilitate in shaping the future strategies of the Indian Railways.
- ❖ CRIS has also designed & developed IRGREENERI website to disseminate the information regarding green initiatives taken by Indian Railways which was launched by Minister of Railways. The website is intended to act as a knowledge sharing platform on green initiatives and best practices.

ENVIRONMENTAL ISSUES FACED BY THE SECTOR

Indian Railways (IR) is the single largest carrier of freight and passengers in the country. It is a bulk carrier of several pollution intensive commodities like coal, iron ore, cement, fertilizers, petroleum etc. Being a major consumer of water and energy, policies adopted by the IR have a substantial impact on our environment and on the conservation of both water and energy in the country. Therefore, the approach of IR towards protection of the environment assumes great importance for tackling environment challenges.

Issues prevalent in the sector:

- ❖ Air pollution arises from the freight transportation

  Air pollution mainly arises due to handling of commodities like coal, iron ore, cement, fertilizer etc. at sidings/ goods sheds and transportation of these commodities in open wagons. These materials create substantial air pollution when carried by rail in open wagons and during loading/unloading operation.

- ❖ Water management

  There is no proper system for monitoring the quality and quantum of waste water generated at the stations. Effluents are frequently discharged from major stations to the nearby low-lying areas/water bodies and municipal discharge systems resulting in contamination of surrounding surface and ground water.Railway Board's instruction for installation of Effluent Treatment Plant at all major stations were also not adhered to.

- ❖ Waste

  Non-segregation of degradable and non-degradable wastes, inadequate storage facilities and improper disposal of garbage is common practice at railway stations.IR transports about 22 million passengers every day on average and generates about 3980 Metric Tonne of human wastes per day which is discharged directly on to the rail tracks. This pollutes the environment at both stations and alongside the tracks

- ❖ The sector is a major consumer of energy and as such is a major contributor to greenhouse gas emissions

Though many steps have been taken to reduce the pollutions like use of bio diesel and effluent treatments plants, bio toilets etc., compliance with the norms have not been followed in many places and the environmental concerns from Railways still persists.

PAT for Indian Railways

PAT is a regulatory instrument launched in 2012 to reduce specificenergy consumption (SEC) in energy intensive industries, using a market-based mechanism to enhance cost effectiveness. Energy Savings Certificate (ESCerts) are issued to those industries which reduce their SEC in excess to their specified target. For those companies who fail to achieve their target, ESCerts must be purchased as a compliance, or are liable tobe penalization. Trading of ESCerts are conducted onexisting power exchanging platforms. As per the schedule of the Energy Conservation (EC) Act, 2001, industries in 15 energy intensive sectors are being identified as a Designated Consumer (DC) and Railways are one of the identified energy intensive industries under the act notified them as a designated consumer.

Indian Railways is divided into two categories i.e. Traction and Non-Traction railways. All traction zonal railways having the annual energy consumption for traction of 70,000 metric tonne of oil equivalent (MTOE) and above are considered as DC and 30,000 MTOE and above for non-traction system are considered as Designated Consumer, which includes all production units. In PAT cycle 2, 16 Zonal Railways and 6 production units were included.

The PAT targets for 6 productions (Non Traction) are given below:

Table 1: PAT Targets of IR PUs

Sl. No.	Name of DC	Baseline energy consumption norms and standards in kilogram of oil equivalent (kgoe) per unit of product) for the baseline year 2014-2015			Target,%
		Category	Kgoe/Unit Produced	Unit Produced	
1	Chittaranjan Locomotive Works, Chittaranjan	Locomotive	17328.85	260	5.97
2	Diesel Locomotive Works, Varanasi	Locomotive	3421.05	266	5.97
3	Diesel Loco Modernisation Works, Patiala	Locomotive (rebuilding and manufacturing)	3399.8	306	5.97
4	Integral Coach Factory, Chennai	Coach	999.22	1704	5.97
5	Rail Wheel Factory, Bengaluru	Wheel	131.75	175175	5.97
6	Rail Coach Factory, Kapurthala	Coach (Equivalent)	1346.52	2042 (Equivalent)	5.97

HOW TO USE THIS MANUAL

- The objective of this manual is to act as a catalyst to facilitate Indian Railways towards continuously improving the performance of production units and workshops, thereby achieving world class levels (with thrust on energy & environmental management). To set goals for improving the performance and move towards accomplishing the best standards, best practices adopted in similar industries have been included in this manual.
- The suggested best practices may be considered for implementation only after defining the application of the technology and fine-tuning requirements of existing units.
- Suitable latest technologies may be considered for implementation in Indian Railways facilities to achieve world class energy efficiency standards. Assessment of feasibility of these technologies for individual plant conditions is also essential.
- The collated best operating parameters and the best practices identified from various plants need not necessarily be the ultimate solution. It is also possible to achieve better standards and establish benchmark standards in operation and maintenance practices.

The technologies proposed in the manual is outlined based on potential identified from the numerous visits conducted to selected facilities of Indian Railways, of Phase-I and Phase-II, as follow:

Table 2: IR units covered in the study

Phase -I	Phase -II
DLW, Varanasi	MCF, Raibareli
CLW, Chittaranjan	Rail Wheel Plant, Bela
ICF, Chennai	Carriage Repair Workshop, Matunga
RCF, Kapurthala	Coach Rehabilitation workshop, Bhopal
DLMW, Patiala	Coach & Wagon workshop, Liluah
RWF, Bengaluru	Coach Repair workshop, Hubli
Locomotive Workshop, Jamalpur	Carriage Repair Workshop, Alambagh
Wagon Repair Workshop, Jhansi	Carriage and Diesel Loco Repair Workshop, Ajmer
Golden Rock Railway Workshop, Trichy	Rail Spring Kharkhana, Sitholi
Carriage & Wagon Workshop, Jagadhri	Carriage, Wagon and Diesel Loco workshop, Kharagpur

The manual also illustrates sample calculations to assess the cost benefit of implementing a technology at an individual facility and the potential for replication across other Indian Railways facilities. Therefore, the Indian Railways team will find this manual resourceful to improve the performance and achieve world class energy efficiency standards.

INTRODUCTION TO ELECTRICAL SYSYTEM

It is well known that there is an all-round energy crisis all over the world and efforts are being made to conserve energy during the stages of conversion, transmission & distribution and at end use equipment.

Energy costs turned out to be a major operating expense due to an ever-increasing trend in energy prices and energy conservation techniques to reduce energy costs were seen as an immediate and handy tool to enhance competitiveness.

The first section of the manual deals with energy efficiency in electrical system viz electrical distribution and motors. It includes the latest development in technology, approach for energy conservation, design details, standards, definitions and formulae.

1. TRANSFORMERS

Transformers are classified as power transformers and distribution transformers. Power transformers are used in transmission network of higher voltages, used for step-up and step-down application (400 kV, 220 kV, 110 kV, 66 kV, 33kV). Distribution transformers are used for lower voltage distribution networks, which distributes the supply to the end users (11kV, 6.6 kV, 3.3 kV, 440V)

The transformers are inherently very efficient by design and the efficiency varies anywhere between 96 to 99.5 percent. However, the efficiency will depend on the effective load (% loading). Hence the efficiency of the transformers not only depends on the design, but also, on the effective operating load.

Selection of rating of transformer

Rating of the transformers: Calculate the connected load, apply the diversity factor applicable to the particular industry and arrive at the KVA rating of the transformer.

Diversity factor: Diversity factor is defined as the ratioof overall maximum demand of the plant to the sum of individual maximum demand of various equipment. With this definition, diversity factor will always less than one. Diversity factor various from industry and depends on various factors such as individual loads, load factor and future expansion needs of the plant.

Location of Transformer

Location of the transformer is very important as far as distribution loss is concerned; transformer receives HT voltage from the grid and steps it down to the required voltage. Transformers should be placed close to the load center, considering other features like optimization needs for centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

Transformers Losses

In transformers, the losses appear in the form of no-load losses (constant losses) and load losses (variable losses). The Variable losses depend on the effective operating load to the transformer. The energy consumed in meeting these losses are dissipated in the form of heat, which is not available for the consumers to use.

No-load loss (Core loss) is the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Load loss (Copper loss) is the power loss in the primary and secondary windings of a transformer due to the resistance of the windings. Copper loss varies with the square of the load current. (P=I2R).

The maximum efficiency of the transformer occurs at a condition when constant loss is equal to variable loss. For distribution transformers, the core loss is 15 to 20% of full load copper loss. Hence, **the maximum efficiency of the distribution transformers occurs at a loading between 40 - 60%**. For power transformers, the core loss is 25 to 30% of full load copper loss. Hence, **the maximum efficiency of the power transformers occurs at a loading**

between 60 - 80%.

The efficiency of the transformers not only depends on the design, but also, on the effective operating load.

Transformer Loss Estimation

1) Find the percentage loadingof the transformer

$$= \frac{\sqrt{3} \text{ x Voltage in kV x current x 100}}{\text{Rated kVA of transformer}}$$

2) Find out the no-load and full load copper loss of the transformer from the test certificate

3) Transformer loss = No-load loss + [(%loading/100)^2 x Full load copper loss]

The core loss and the full load copper loss for transformers are specified in the transformer test certificate. Typical values of no-load and full load losses are given below in the table.

Table 3: Transformer Losses

kVA Rating	No-load Loss (Watts)	Full Load Loss at 75oC (Watts)	Impedance (%)
160	425	3000	5
200	570	3300	5
250	620	3700	5
315	800	4600	5
500	1100	6500	5
630	1200	7500	5
1000	1800	11000	5
1600	2400	15500	5
2000	3000	20000	6

As per IS 2026, the maximum permissible tolerance on the total loss is 10%. The permissible limit for no-load and full load loss is +15%. There will be a little variation in actual no-load and load loss of transformers. The exact values can be obtained from the transformer test certificate.

Selection of transformers

The transformer user with a long term view should make the purchase decision based on the Total Owing Cost (TOC). There are three costs in the life cycle of the transformer. First is purchase price, second one is cost of energy lost from the transformer over its lifetime and the third one is the maintenance charges. The total cost of a transformer is the sum of purchase cost and net value of energy losses. The decision should be based on the lowest TOC.

2. POWER FACTOR

Most loads in modern electrical distribution systems are inductive in nature i.e. motors, transformers, gaseous tube lighting ballasts and induction furnaces. Inductive loads require a rotating magnetic field for operation.

Inductive loads require two kinds of current:

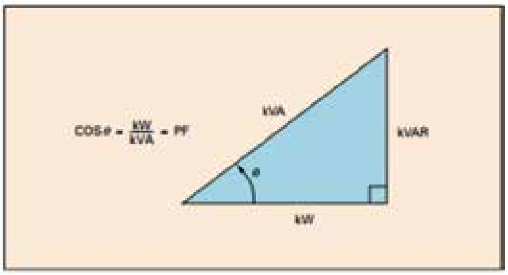
- Working power (kW) to perform the actual work of creating heat, light, motion, machine output, and so on.
- Reactive power (kVAR) to sustain the rotating magnetic field

Working power consumes watts and can be read on a wattmeter and is measured in kilowatts (kW). Reactive power doesn't perform useful "work," but circulates between the generator and the load. It places a heavier drain on the power source, as well as on the power source's distribution system and measured in kilovolt-amperes-reactive (kVAr).

Working power and reactive power together make up apparent power and is measured in kilovolt-amperes (kVA)

Fundamentals of power factor

Power factor is the ratio of working power to apparent power and it measures how effectively electrical power is being used. A high power factor signals efficient utilization of electrical power, while a low power factor indicates poor utilization of electrical power. In a linear or sinusoidal system, the result is also referred to as the cosine θ. The power triangle is given below:



Cos Φ = Power Factor
kW = Active Power
kVAr = Reactive Power
kVA = Apparent Power
$= \sqrt{kW^2 + kVAr^2}$

Figure 3: Power Triangle

The supply of reactive power from the system results in reduced installation efficiency due to

- Increased current for a given load
- Higher voltage drop in the system
- Increase in losses of transformers, switchgears and cables
- Higher kVA demand from the supply system

It is therefore necessary to reduce and manage the flow of reactive power to achieve higher efficiency of the electrical system. The easiest method of reducing and managing reactive power is by power factor improvement through power capacitors (Capacitor banks). As power factor tends to unity, the overall electrical system efficiency will improve.

Benefits of Power Factor Correction

The benefits of power factor correction are summarized as under:

- Reduction in demand charges
- Elimination of power factor penalties
- Reduction in current drawn
- Reduced transformer, switchgear and cable losses
- Improved voltage regulation
- Increased life of switchgear/cables due to reduced operating temperatures

Estimation of Capacitor Rating

The estimation of KVAr required for compensation to achieve desired power factor is generally done depending on the type of loads to be compensated. For ease of use, the tables and formulae given in this section may be used.

Capacitor KVAr for AC Induction Motors (Individual Compensation)

The following table gives the recommended rating of power capacitors, which are to be used directly with 3 phase AC induction motors.

Table 4: Capacitor Rating Required

Motor Rating (HP)	Capacitor rating (kVAr) for motor speed					
	3000	1500	1000	750	600	500
5	2	2	2	3	3	3
7.5	2	2	3	3	4	4
10	3	3	4	5	5	6
15	3	4	5	7	7	7
20	5	6	7	8	9	10
25	6	7	8	9	9	12
30	7	8	9	10	10	15
40	9	10	12	15	16	20
50	10	12	15	18	20	22
60	12	14	15	20	22	25
75	15	16	20	22	25	30
100	20	22	25	26	32	35
125	25	26	30	32	35	40
150	30	32	35	40	45	50
200	40	45	45	50	55	60
250	45	50	50	60	65	70

Note:

- It is considered less economical in industrial applications to improve power factor by individual compensation for motor ratings below 15 HP
- For motor ratings above 250 HP the capacitor kVAr rating would be about 25% of the motor rating in HP.
- In all cases it should be ensured that the capacitor current at rated voltage is always less than 90% of the no load current of the motor. This is due to the fact that when capacitor current exceeds the no load magnetizing current of the motor, excessive voltage surges can occur due to self-excitation in the event of an interruption in power supply, which will prove harmful to both the motor as well as the capacitor.
- The capacitor kVAr values indicated in the above table are after taking into consideration the condition specified in the item – 3 above and assuming motor loading of greater than 80%.
- If the motor is loaded to less than 80%, the capacitor kVAr required may be greater than the values indicated in the above table. In such a case the capacitor should be connected upstream in group of central compensation mode.

Selection of capacitor banks for Distribution / Industrial Networks

In electrical installations, the operating load kW and its average power factor (PF) can be ascertained from the electricity bill.

Alternatively, it can be easily evaluated by the formula

- Average PF = kWh/kVAh
- Operating load kW = kVA demand x Average PF.

The average PF is considered as the initial PF and the final PF can be suitably assumed as required. In such cases required Capacitor kVAr can be calculated as shown in example.

Example:

Calculate the required kVAr compensation for a 500kW installation to improve the PF from 0.75 to 0.96.

kVAr = kW x multiplying factor from Table:1

= 500 x 0.59 = 295 kVAr.

Present Power Factor in % | Desired Power Factor in %

⇩	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
50	0.982	1.008	1.034	1.060	1.086	1.112	1.139	1.165	1.192	1.220	1.248	1.276	1.306	1.337	1.369	1.403	1.442	1.481	1.529	1.590	1.732
51	.937	.962	.989	1.015	1.041	1.067	1.094	1.120	1.147	1.175	1.203	1.231	1.261	1.292	1.324	1.358	1.395	1.436	1.484	1.544	1.687
52	.893	.919	.945	.971	.997	1.023	1.050	1.076	1.103	1.131	1.159	1.187	1.217	1.248	1.280	1.314	1.351	1.392	1.440	1.500	1.643
53	.850	.876	.902	.928	.954	.980	1.007	1.033	1.060	1.088	1.116	1.144	1.174	1.205	1.237	1.271	1.308	1.349	1.397	1.457	1.600
54	.809	.835	.861	.887	.913	.939	.966	.992	1.019	1.047	1.075	1.103	1.133	1.164	1.196	1.230	1.267	1.308	1.356	1.416	1.559
55	.769	.795	.821	.847	.873	.899	.926	.952	.979	1.007	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
56	.730	.756	.782	.808	.834	.860	.887	.913	.940	.968	.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
57	.692	.718	.744	.770	.796	.822	.849	.875	.902	.930	.958	.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
58	.655	.681	.707	.733	.759	.785	.812	.838	.865	.893	.921	.949	.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
59	.618	.644	.670	.696	.722	.748	.775	.801	.828	.856	.884	.912	.939	.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
60	.584	.610	.636	.662	.688	.714	.741	.767	.794	.822	.850	.878	.905	.939	.971	1.005	1.043	1.083	1.131	1.192	1.334
61	.549	.575	.601	.627	.653	.679	.706	.732	.759	.787	.815	.843	.870	.904	.936	.970	1.008	1.048	1.096	1.157	1.299
62	.515	.541	.567	.593	.619	.645	.672	.698	.725	.753	.781	.809	.836	.870	.902	.936	.974	1.014	1.062	1.123	1.265
63	.483	.509	.535	.561	.587	.613	.640	.666	.693	.721	.749	.777	.804	.838	.870	.904	.942	.982	1.030	1.091	1.233
64	.450	.476	.502	.528	.554	.580	.607	.633	.660	.688	.716	.744	.771	.805	.837	.871	.909	.949	.997	1.058	1.200
65	.419	.445	.471	.497	.523	.549	.576	.602	.629	.657	.685	.713	.740	.774	.806	.840	.878	.918	.966	1.027	1.169
66	.388	.414	.440	.466	.492	.518	.545	.571	.598	.626	.554	.682	.709	.743	.775	.809	.847	.887	.935	.996	1.138
67	.358	.384	.410	.436	.462	.488	.515	.541	.568	.596	.624	.652	.679	.713	.745	.779	.817	.857	.905	.966	1.108
68	.329	.355	.381	.407	.433	.459	.486	.512	.539	.567	.595	.623	.650	.684	.716	.750	.788	.828	.876	.937	1.079
69	.299	.325	.351	.377	.403	.429	.456	.482	.509	.537	.565	.593	.620	.654	.866	.720	.758	.798	.840	.907	1.049
70	.270	.296	.322	.348	.374	.400	.427	.453	.480	.508	.536	.564	.591	.625	.657	.691	.729	.769	.811	.878	1.020
71	.242	.268	.294	.320	.346	.372	.399	.425	.452	.480	.508	.536	.563	.597	.629	.663	.701	.741	.783	.850	.992
72	.213	.239	.265	.291	.317	.343	.370	.396	.423	.451	.479	.507	.534	.568	.600	.634	.672	.712	.754	.821	.963
73	.186	.212	.238	.264	.290	.316	.343	.369	.396	.424	.452	.480	.507	.541	.573	.607	.645	.685	.727	.794	.936
74	.159	.185	.211	.237	.263	.289	.316	.342	.369	.397	.425	.453	.480	.514	.546	.580	.618	.658	.700	.767	.909
75	.132	.158	.184	.210	.236	.262	.289	.315	.342	.370	.398	.426	.453	.487	.519	.553	.591	.631	.673	.740	.882
76	.105	.131	.157	.183	.209	.235	.262	.288	.315	.343	.371	.399	.426	.460	.492	.526	.564	.604	.652	.713	.855
77	.079	.105	.131	.157	.183	.209	.236	.262	.289	.317	.345	.373	.400	.434	.466	.500	.538	.578	.620	.687	.829
78	.053	.079	.105	.131	.157	.183	.210	.236	.263	.291	.319	.347	.374	.408	.440	.474	.512	.552	.594	.661	.803
79	.026	.052	.078	.104	.130	.156	.183	.209	.236	.264	.292	.320	.347	.381	.413	.447	.485	.525	.567	.634	.776
80	.000	.026	.052	.078	.104	.130	.157	.183	.210	.238	.266	.294	.321	.355	.387	.421	.459	.499	.541	.608	.750
81	----	.000	.026	.052	.078	.104	.131	.157	.184	.212	.240	.268	.295	.329	.361	.395	.433	.473	.515	.582	.724
82	----	----	.000	.026	.052	.078	.105	.131	.158	.186	.214	.242	.269	.303	.335	.369	.407	.447	.489	.556	.698
83	----	----	----	.000	.026	.052	.079	.105	.132	.160	.188	.216	.243	.277	.309	.343	.381	.421	.463	.530	.672
84	----	----	----	----	.000	.026	.053	.079	.106	.134	.162	.190	.217	.251	.283	.317	.355	.395	.437	.504	.645
85	----	----	----	----	----	.000	.027	.053	.080	.108	.136	.164	.191	.225	.257	.291	.329	.369	.417	.478	.620
86	----	----	----	----	----	----	.026	.026	.053	.081	.109	.137	.167	.198	.230	.265	.301	.343	.390	.451	.593
87	----	----	----	----	----	----	----	----	.027	.055	.082	.111	.141	.172	.204	.238	.275	.317	.364	.425	.567
88	----	----	----	----	----	----	----	----	----	.028	.056	.084	.114	.145	.177	.211	.248	.290	.337	.398	.540
89	----	----	----	----	----	----	----	----	----	----	.028	.056	.086	.117	.149	.183	.220	.262	.309	.370	.512
90	----	----	----	----	----	----	----	----	----	----	----	.028	.058	.089	.121	.155	.192	.234	.281	.342	.484
91	----	----	----	----	----	----	----	----	----	----	----	----	.030	.061	.093	.127	.164	.206	.253	.314	.456
92	----	----	----	----	----	----	----	----	----	----	----	----	----	.031	.063	.097	.134	.176	.223	.284	.426
93	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.032	.066	.103	.145	.192	.253	.395
94	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.034	.071	.113	.160	.221	.363
95	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.037	.079	.126	.187	.328
96	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.042	.089	.150	.292
97	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.047	.108	.251
98	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.061	.203
99	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	.142

Note:-

The above table is based on the following formula:

kVAr required = kW(tan θ_1 – tan θ_2)

Where,

$\theta_1 = \cos^{-1}$ (PF1) and $\theta_2 = \cos^{-1}$ (PF2)

PF1 and PF2 are present and desired power factors respectively.

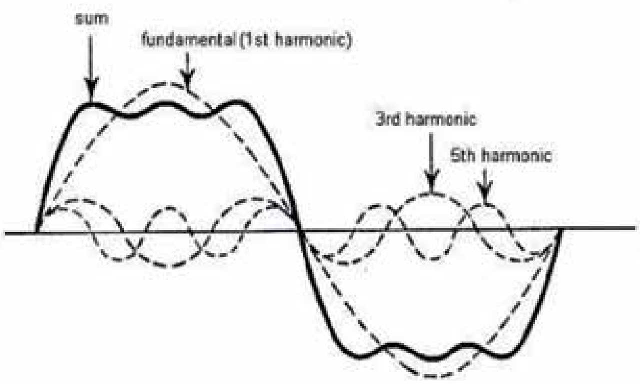
3. POWER QUALITY

Power quality is of prime importance in deciding the efficiency of any motor and one of the critical parameters of the power quality is Harmonics.

Harmonics

Electrical loads can be classified as linear and non-linear loads; a linear load is one which draws a sinusoidal current when subjected to sinusoidal voltage as shown in figure. The current wave may or may not have a phase difference with respect to the voltage. A pure resistance, inductance or capacitance or any combination of these forms a linear load.

The non-linear load is one which draws non-sinusoidal or pulsating current when subjected to sinusoidal voltage. Any non-sinusoidal current can be mathematically resolved into a series of sinusoidal components (Fourier series). The first component is called as fundamental and the remaining components whose frequencies are integral multiples of the fundamental frequency are known as harmonics. If the fundamental frequency is 50 Hz, then 2nd harmonic will have a frequency of 100Hz and the 3rd will have 150Hz and so on.



Sources of harmonics

Following are some of the non-linear loads which generate harmonics:

- Static Power Converters and rectifiers, which are used in UPS, Battery charges, etc.
- Arc Furnaces
- Power Electronics for motor controls (AC /DC Drives.)
- Computers.
- Television receivers.
- Saturated Transformers.
- Fluorescent Lighting.
- Telecommunication equipment.

Locating the Harmonics

On radial utility distribution feeders and industrial plant power systems, the main tendency is for the harmonic currents to flow from the harmonic-producing load to the power system source. The impedance of the power system is normally the lowest impedance seen by the harmonic currents

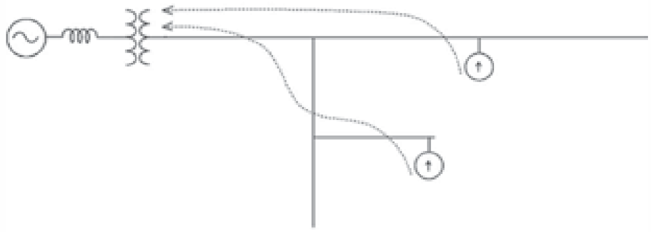
General flow of harmonic currents in a radial power system

This general tendency of harmonic current flows can be used to locate sources of harmonics. Using a power quality monitor, simply measure the harmonic currents in each branch starting at the beginning of the circuit and trace the harmonics to the source.

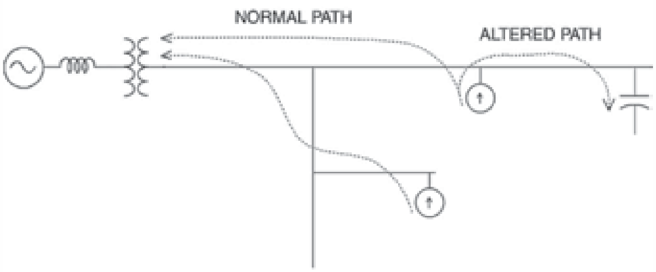
Power factor correction capacitors can alter this flow pattern for at least one of the harmonics. For example, adding a capacitor may draw a large amount of harmonic current into that portion of the circuit. In such a situation, following the path of the harmonic current will lead to a capacitor bank instead of the actual harmonic source.

Power factor capacitors can alter the direction of flow of one of the harmonic components of the current. Thus, it is generally necessary to temporarily disconnect all capacitors to reliably locate the sources of harmonics.

It is usually straightforward to differentiate harmonic currents due to actual sources from harmonic currents that are strictly due to resonance involving a capacitor bank. A resonance current typically has only one dominant harmonic riding on top of the fundamental sine wave. Note that harmonic sources produce more than one single harmonic frequency.



Waveforms of these harmonic sources have somewhat arbitrary wave shapes depending on the distorting phenomena, but they contain several harmonics in significant quantities. A single, large, significant harmonic nearly always signifies resonance. This fact can be exploited to determine if harmonic resonance problems are likely to exist in a system with capacitors. Simply measure the current in the capacitors. If it contains a very large amount of one harmonic other than the fundamental, it is likely that the capacitor is participating in a resonant circuit within the power system. Always check the capacitor currents first in any installations where harmonic problems are suspected.



Another method to locate harmonic sources is by correlating the time variations of the voltage distortion with specific customer and load characteristics. Patterns from the harmonic distortion measurements can be compared to particular types of loads, such as arc furnaces, mill drives, and mass transits which appear intermittently.

Correlating the time from the measurements and the actual operation time can identify the harmonic source.

Effects of Harmonics

Harmonics have varied effects on equipment and devices, causing malfunctioning or even total failure depending on the extent of harmonic pollution. The effects of harmonics can be broadly classified as instantaneous effects and long term effects.

Instantaneous effects

- Vibrations and noise in transformers, reactors, and induction motor etc.
- Series / parallel Resonance resulting in damage to equipment connected to the network
- Malfunctioning of Sensitive electronic Devices and interferences in communication and control circuits (telephone, control and monitoring circuits)
- Total energy required to perform the desired function increases, imposing a higher demand on the electrical supply system thereby increasing energy cost.

Long-term effects

- Failure of rotating machines: Harmonic rotating fields creates pulsating mechanical torques resulting in vibrations and increased mechanical fatigue in rotating machines. This leads to premature mechanical failure.
- Reduction in capacitor life: Capacitors draw abnormally high currents in the presence of Harmonics leading to reduction in the rated life of the Capacitor.
- Premature failure in machines, transformers, cables etc- harmonics cause additional iron losses and copper losses (due to skin effect). These additional losses increase the operating temperature of the equipment to abnormal levels, thereby causing its premature failure.

Remedial Measures

In environments polluted with Harmonics, proper remedial measures must be taken to mitigate the harmonic levels. The recommended method to arrive at appropriate solutions is listed below:

- Measurement of harmonic levels and analysis of the behavior of electrical network
- Deciding of type of remedial action to be taken and design of harmonic filters to achieve desired harmonic levels.
- Harmonic filters are to be built using the appropriate components and devices
- Installation of harmonic filters to be carried out as per design requirements.

IEEE Standards

IEEE Standard 519 (2014) has been already existing which specifies limits of the harmonics in power systems. The acceptable limit for harmonic distortion as per IEEE standard is as under:

Voltage Harmonics

Table 5: Voltage Harmonics Limit

Bus Voltage V at PCC	Individual harmonics (%)	Total harmonic distortion THD(%)
V ≤ 1.0 kV	5.0	8.0
1kV < V ≤ 69 kV	3.0	5.0
69 kV < V ≤ 161 kV	1.5	2.5
161 kV < V	1.0	1.5

Current Distortion limits for systems rated 120 V through 69 kV

Table 6: Current Harmonics Limit

Maximum harmonics current distortion in percent of IL						
Individual harmonic order (odd harmonics)						
ISC/IL	3≤h<11	11≤h<17	17≤h<23	23≤h<35	35≤h<50	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Even harmonics are limited to 25% of the odd current harmonic limits above

Current distortion that results in a dc offset, e.g., half wave converters, are not allowed

Where, I_{SC} = Maximum short circuit current at PCC

I_L = Maximum demand load current at PCC (Fundamental frequency component) at the PCC under normal load operating condition.

INTRODUCTION TO UTILITIES

Utilities are one of the most vital sections of the plant which ensures smooth functioning of overall process activities. Utilities basically includes air compressors, pumps, cooling towers, HVAC, blowers, etc. The functionalities of the utility equipment include maintaining sufficient air pressure at end-user, ensuring continuous flow of cooling water, maintaining comfortable working environment, proper cooling of the cooling water, etc.

1. AIR COMPRESSORS

Compressors are the most common energy consuming utility in any industry and compressed air finds applications in sectors ranging from small machine shop to larger industries such as cement, power, automobile, aluminum, iron & steel, etc. There are instances when the industry might cease to operate without compressed air, such is its importance. They play critical roles across various sectors in the form of instrumentation equipment (control valves/ actuators), powering tools, conveying, automations, spraying, bag filter purging and much more.

With the percentage of energy consumption of compressed air utilities ranging between 5-30%, there exists significant potential to reduce energy consumption by at least 20-40%, by improving the energy efficiency of compressed air systems.

The end-use efficiency of compressed air systems is as low as 15-20%, and the potential areas where energy is lost are due to compression heat loss, compressed air leakages, inefficient design of layout, and also through usage of auxiliary such as filters, coolers, valves, nozzles, etc. Therefore, major significance must be given to compressed air systems during the design stage itself, starting from the selection of compressors to the kind of pneumatic equipment used by the consumer.

There are, of course, various factors which must be taken into consideration while designing a compressed air system. Some of the key factors include compressor size and numbers, type of control, layout design, air receiver size and numbers, and type of air dryer, etc. This not only helps to ensures high performance of compressed air systems, but also efficient operation during peak and part demand.

Compressed Air System – Fundamental

A compressor is a mechanical device that can pressurize compressible fluids/gas from a lower pressure to a higher pressure. An industrial compressed air system comprises of various components, including air filters, compressors, prime movers, air quality systems, end-user accessories, distribution network, control systems, etc. A prime mover such as an electrical motor drives the compressor by converting the electrical energy into mechanical energy of the compressor.

The air quality equipment like air dryer and filter removes moisture and dust from the compressed air so as to allow clean and dry air to enter the compressed air distribution network, thereby ensuring effective operation of end-user equipment. In addition, the control system of the compressor regulates the pressure and the flow rate of the generated compressed air. Finally, the distribution network connects the generation and the end-user equipment and transports the compressed air wherever needed.

Assessing the Life Cycle Cost of a Compressor

Air compressor is one of the major utilities in a plant. The energy consumption of air compressor varies from 10-30% of the entire plant consumption depending on the usage and the type of product manufactured in the facility.

Life Cycle Cost assessment of the compressor gives an important insight on various expenditures incurred in investment, operating and maintenance over the lifecycle of the equipment, which can be helpful in making a complex decision.

Evaluating the operating cost of air compressor:

$$\text{Operating cost/annum} = \frac{kW_R \times T \times (\%\ t) \times \text{Unit cost}}{\eta m}$$

kW_R = Rated Compressor Power

T = total operating hours per annum

%t = percentage time for loading /unloading

ηm = efficiency of motor drive

The total operating cost can be estimated for the total life cycle of the air compressor, when compared with the initial cost of the compressor and the maintenance costs incurred, the operating costs constitutes 80% of the life cycle cost of the compressor.

Establishing compressed air baseline

Establishing a compressed air baseline is as important as selecting a compressor and the various selection criteria that go into analyzing the compressed air requirements are the air quality, quantity, pressure requirements, artificial demand and demand/loading pattern of the process. Analyzing these five parameters enables the user to select the size and type of the compressor, select the type and capacity of air dryer, and decide on a possible combination of compressors to operate during non-peak demands and control systems to operate the compressors.

Baselining compressed air is required to effectively manage the processes for peak performance and reliability. This can be done through various measurement and monitoring systems and collect data related to the peak and average compressed air consumption of the plant. This helps to create a baseline, which acts as a point of reference for existing operating conditions, performance levels and costs of the compressed air at a given specific level of production.

- Measure and record various performance parameters such as power, flow and pressure.
- Analyze the compressed air consumption trend on hourly and daily basis.
- Correlate with corresponding production levels and estimate specific energy consumption.
- Regularly conduct leak surveys and repair all leaks.
- Analyze readings weekly.
- Ensure that the air leakages are as minimum as possible and unnecessary consumption of compressed air is avoided.

Performance assessment of Air Compressors

The performance of compressors and compressed air systems tends to deteriorate over a period of time. This can be attributed to various reasons, such as poor maintenance, wear & tear, use of poor-quality lubricants, etc.

Performance degradation of air compressors results in increase of overall power consumption, and increase in cost of compressed air. Therefore, a periodic performance assessment of compressors is required to ensure rated compressed air delivery, operating efficiency and specific power consumption.

Another key component of performance assessment is the compressed air leakage level. The increase in leakage level leads to increased energy loss. The leakage level in the plant must be monitored periodically by carrying out a leakage test. This section explains various concepts related to the performance assessment of air compressors.

a. Performance test

The following parameters are determined by carrying out the performance test on the compressors:

Free air delivery (FAD)

Free air delivery is the quantity of compressed air delivered by the compressor at ambient pressure.

Volumetric efficiency

Volumetric efficiency is the ratio of the actual free air delivered to the compressor swept volume or design capacity.

Specific power consumption

Specific power consumption of the compressor is the ratio of actual power consumption to the quantity of free air delivered.

After carrying out the performance test, the actual performance of the compressor has to be compared with the design values. Suitable measures should be taken to improve the operating efficiency.

b. Measurement of free air delivered by the compressor

The quantity of free air delivered by the compressor can be measured by using the pump-up method.

The pump-up test method is the simplest method of estimating the capacity of the compressor. This method does not require any sophisticated measuring instruments and can be measured by the plant team themselves.

The procedure to conduct the Free Air Delivery (FAD) is explained below:

- The compressor to be tested and a known volume of receiver have to be isolated separately from the main line.
- Empty the compressed air receiver and close the outlet valve of the receiver.
- Ensure that there is no condensate water inside the receiver and the drain valve should also fully closed after emptying the reciever.
- Start the compressor and note down the time taken for raise in pressure in the receiver to the normal operating pressure (P_2) from the initial pressure (P_1). The same exercise can be repeated three times for concurrency.

The free air delivered by the compressed air can be calculated using the following formula:

$$\text{Free air delivered by the compressor} = \frac{(P_2 - P_1)}{P_{atm}} \times \frac{V}{T} \text{ Nm}^3\text{/min}$$

Where,

P_2 - Final pressure in the receiver, kg/cm^2

P_1 - Initial pressure in the receiver, kg/cm^2

P_{atm} - Atmospheric Pressure, kg/cm^2

V - Volume of the receiver, m^3

T - Time taken for pressure to increase from P_1 to P_2, seconds

While estimating the volume of compressed air storage, the volume of after-cooler and the volume of pipeline from the after-cooler to the receiver should be included along with receiver volume.

In most cases, the discharge temperature of the compressed air is higher than the ambient temperature. Therefore, the free air delivered has to be multiplied by the following correction factor.

$$\text{Correction factor} = \frac{T_{atm}+273}{T_1 + 273}$$

Where,

T_1 - Temperature of compressor at discharge, °C

T_{atm} - Ambient Temperature, °C

c. Compressed Air Leakage test

The leakage test has to be periodically carried out to estimate the compressed air leakage in the plant. The leakage test has to be carried out when there are no compressed air users in operation. Hence, plant shut down time is the ideal time for conducting a leakage test.

For conducting leakage test run the compressor and pressurize the system to the normal pressure. Once the system reaches the normal operating pressure, the compressor will begin to unload.If there are no leakages inside the plant, the compressor should remain in the unload condition for longer duration of time and should not get loaded again. But, in actual practice, due to compressed air leakages, the system pressure will come down and the compressor will go to load mode once the pressure falls below loading pressure.

The loading and unloading of the compressor indicate the compressed air leakage inside the plant. Note down the load/unload time (take at least three readings).

The compressed air leakage can be estimated using the formula given below:

$$\text{System leakages} = \frac{\text{Loadtime}}{(\text{Load time} + \text{Unloadtime})} \times \text{Compressor FAD}$$

$$\%\text{leakage} = \frac{\text{Airleakage}}{\text{Compressorcapacity}} \times 100$$

d. Cost of compressed air leakages

For efficient operation, air compressors have an on-load and an off-load pressure setting. The differential between these two settings should not be allowed to exceed 10% of the maximum pressure setting. Hence, the pressure drop due to air leakage play is a key factor for energy savings.

The cost of compressed air leakage at 7.0 bar pressure is given below:

Table 7: Compressed air leakage and its impacts

Orifice size (mm)	Energy loss (kW)	*Cost of air leakage (Rs / year)
0.8	0.2	8,000
1.6	0.8	32,000
3.1	3.0	120,000
6.4	12.0	480,000

*Based on Rs 5/kWh; 8000 operating hours;at 7.0 bar pressure

e. Leak Management System

The most common and effective method of arresting leakages is through a "Red Tag System". This is the simplest and most effective means, wherein the operator/site official is responsible for identifying the location of compressed air leakage, ties the red tag on the identified leakage area and notifies the concerned department to arrest/repair the leak. The maintenance team arrests the leakage at the next available opportunity. However, the red tag system is only a part of the complete leak management system.

There are various steps to be followed to implement a successful leak management system.

Step 1 **Know your baseline**	The first step of the leak management system is to establish the current operating demand of compressed air, i.e., knowing the baseline. With the corresponding FAD of the compressor already measure, the overall compressed air consumption can be estimated based on the loading pattern of the compressors. This essentially forms the basis for leak management.
Step 2 **Carry out leakage test**	The next step is to quantify the amount of compressed air leakage, which can be used as a baseline to compare and assess the effectiveness of the leakage management.
Step 3 **Estimate monetary value of air leakage**	This includes two components. First is the monetary loss of energy and cost due to air leakages. Second is the amount of resources required to be allocated for effectively arresting all the identified leakages. This includes costs incurred in replacement of pipeline, damaged regulators, filters, valves, etc.
Step 4 **Physical identification & documentation**	Physical inspection must be carried out to assess the damages of the identified leakage areas in the compressed air line. While conducting the survey, the red tags can be used to highlight the leakage area. It is also important to document/log the specification of the leakage and the necessary resources required for arresting them.
Step 5 **Arresting/Repairing leakage**	Bigger leaks are easier to identify and arresting them should be the maintenance team's first priority. The maintenance team must cross-verify with the list of leakages logged by the operation team, just to ensure all leakages are tracked and necessary action has been taken.
Step 6 **Compare with baseline**	The final step of the leak management system is to compare the results of implementing the leak-arresting exercises. This can help the industry measure the effectiveness of the leak management system. Repeat the leakage test and compare the percentage of leakage now. An effective system illustrates lower leakage percentage than the baseline.

Air leakage is a common issue faced by every industry. It is continuous and recurring, and industries must take immediate actions towards arresting the leakages. The leakage test must be conducted periodically (recommended quarterly/semi-annual) and the leak management system must be implemented effectively.

Industries with a very successful leak management system have achieved leakage percentage of less than 5%, which can be considered as an industry which is efficient in operation. It is important to remember that an effective leak management system induces efficiency, reliability, and cost effectiveness to any compressed air system, irrespective of the type of industry.

Figure 5: Red Tags

Best Practices for Compressor Management System

It is not uncommon that plants don't pay much attention to low-cost best practices to improve energy efficiency and only invest more in operating and maintaining the compressed air systems. So, the following are some of the best practices which can be adopted for an efficient compressor management system.

Periodic daily and weekly maintenance

Air compressors are often forgotten about until a problem appears. It is recommended to visit the compressor daily and check all basic maintenance points. Some of the daily, weekly, monthly and quarterly maintenance checklist can be seen in the figure.

It is to be noted that, although, many plants follow routine or preventive maintenance, the end result is cleaning of machines. This should be avoided, instead thorough check up is required.

A checklist as illustrated in the figure must be made and the utility or maintenance team must ensure that timely maintenance follow-ups are conducted to ensure proper maintenance of the compressed air systems.

Figure 6: Maintenance Check List

Maintain proper records/daily log sheets

A history of your compressor is very useful while troubleshooting problems. Noting down some of the key performance related parameters every day can prove to be crucial, keep records of each and every maintenance done on the compressor: what was changed, where there any problems, what oil was used, etc.

Some of the main things to keep records of are mentioned below:

- Running hours (loaded/unloaded).
- Outlet pressure.
- Ambient temperature & element outlet temperature.
- Dew point temperature of air dryer.
- Was condensate drained from all drains? How much water came out?
- Is compressed air clean and free from water, oil, rust, dirt?
- RPM or speed/capacity percentage (if VFD installed).

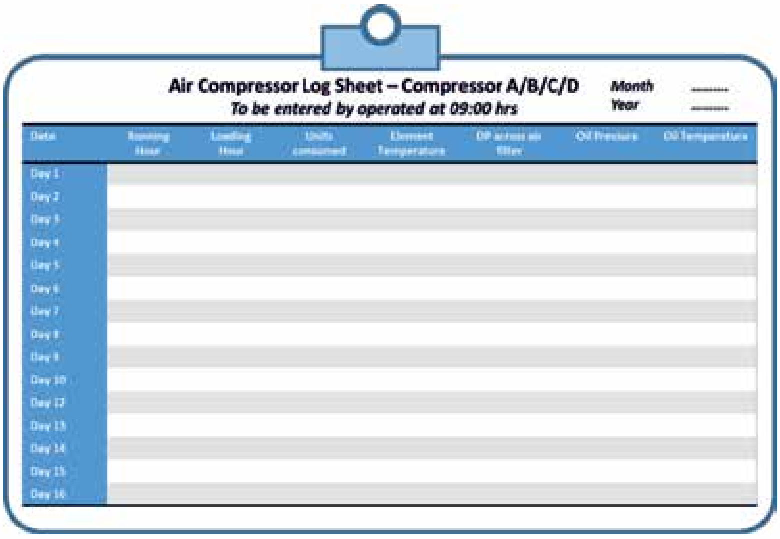


Figure 7: Compressor Log Sheet

Checklist for Energy Efficient Compressed Air System

- Temperature of air in compressor room should be at par with ambient temperature.
- Avoid choking of inlet filter. Differential pressure across the inlet filter should be < 10 mmWc.
- In intercooler of a reciprocating compressors, air temperature after intercooler should be not more than "10 ^{0}C above ambient temperature".
- In water cooled compressor, the cooling water temperature ΔT = 5 to 8 ^{0}C.
- FAD test to be conducted quarterly, to understand actual free air delivered by the compressor.

- % Unload power should be with prescribed limits of OEM specification.
- Dryer dew point temperature should be monitored on periodic basis.
- Pressure drop across dryers should not be more than 0.3 kg/cm^2
- Pressure drop from generation to distribution end should be less than 0.4 kg/cm^2 for a 1 km long pipeline.
- Install VFD in the existing compressor if % Unloading is greater than 20%
- Percentage leakage should be maintained between 8 to 10%.

2. PUMPS

Energy Efficiency in pumps & umping systems provide one of the excellent opportunities for efficiency improvements in any industry. The total energy consumed by the pumps, in a majority of cases, is less compared to the other energy consumers of the plant. In most industries, it is difficult to optimize the pumping systems at the design stage itself. This is because, in general, design efforts are focused majorly towards minimizing capital expenditure, which leads to system inefficiencies.

In cases where the pumping systems have been operating for a long time, the efficiency of the pumping systems deteriorate and move away from their design conditions. Therefore, efficiency improvements in pumping systems can be in the form of improving the design efficiency of the pump, matching the design & operating specifications of the pumping system, avoiding throttling of the pump, installation of VFD, utilizing gravitational head, etc.

Some of the common issues related to pumps and pumping systems and potential measures to improve energy efficiency are tabulated below:

Issues related to Pumps and Pumping Systems	Measures to improve energy efficiency
Excess demand on pumping system	Identify the processes in which excess demand is created on the pumping system. Take measures to reduce the demand to the actual amounts required
Oversized pumps	Choose the pump which can sufficiently cater to the actual requirements of the processes. Ensure that the pumps are operating as close to the Best Efficiency Point (BEP). Other measures which can be used are impeller trimming, VFD installation, pump replacement, etc.
Mismatch in head and flow	Make sure that the actual head delivered by the pump matches with the design head of the pump.
Less Efficiency Impeller	Impeller replacement suggested to improve the pump efficiency
Less efficiency Motor	Motor replacement suggested; preferred class of motors are IE3/IE4
Inefficiency due to throttling	Recommended to install a VFD or replace the pump to the actual required specifications
Lack of measurement and monitoring	Install online flow meters, preferably with data loggers to continuous record and analyse real time data

Analyzing pump performance – Best Efficiency Point (BEP)

Practically, pumps tend to operate 15-30% away from its Best Efficiency Point (BEP). BEP gains a lot of significance because it is the points where the pump operates most cost effectively in terms of both energy efficiency and maintenance. There are, of course, various reasons why pumps operate away from its BEP. It could be because of the variability of flow and/or head demanded by the process, mismatch in design and operating parameters, throttling operation, etc. This can be visualized in the pump characteristic curve illustrated in the figure below:

Estimating the efficiency of a pump

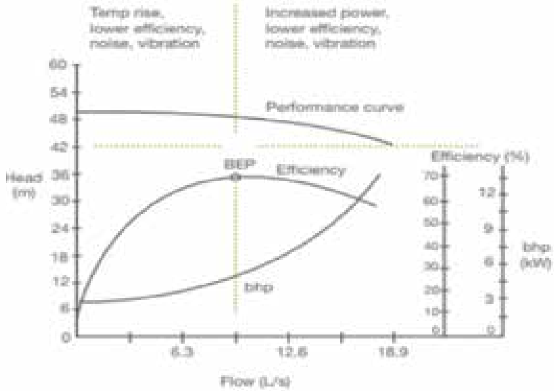


Figure 8: Pump Efficiency Curve

Pump efficiency (η) is the ratio of the total power output (ηhydraulic) of the pump to the total power input (ηshaft) to the pump. The hydraulic power (ηhydraulic) is the energy delivered to the operating fluid in the pump, which is dependent on density of the fluid, pressure developed and the quantity of fluid delivered. The shaft power (ηshaft) is the power delivered by the shaft from the prime mover. In case of a motor, it is the product of total input electrical power (kW) and the efficiency of the motor (ηmotor). In mathematical terms, it is represented as,

$$\text{Pump Efficiency (\%)} = \frac{\text{Hydraulic Power}}{\text{Shaft Power}} \times 100$$

$$\text{Hydraulic Power (kW)} = \frac{\text{Flow (m}^3\text{/sec) x Head (m) x Density (kg/m}^3\text{)}}{102}$$

$$\text{Shaft Power (kW)} = \text{Motor Efficiency (\%) x Motor Input Power (kW)}$$

Energy conservation opportunities in pumping systems

The following are some of the energy conservation opportunities which can be looked into for improving the energy efficiency of pumps and pumping systems.

- Ensure availability of measuring and monitoring instruments such as pressure gauges, flow meters, etc.
- Operate pumps as close to Best Efficiency Point (BEP).
- Avoid throttling operation of pumps as much as possible by modifying pumping system as per required specifications.
- In case of any fluctuations in load, utilize Variable Speed Drives (VSD), and automate with interlocks.
- For small loads requiring higher pressures, recommend usage of booster pumps.
- Optimize the operating of the process to minimize flows of process fluids, which in turn can reduce pump power consumption.
- Utilize gravitational head (if available) and avoid pumping systems; in case of temperature differentials,use siphon effect to take advantage of density differences
- Avoid cooling water re-circulation in non-operational/standby equipment such as DG sets, air compressors, refrigeration systems, cooling towers, etc.
- Replace old pumps/motors by energy efficient pumps/motors.
- Avoid operation of over-designed pumps, and install variable speed drive, or downsize/replace impeller or replace with correct sized pump.
- Optimize number of stages in multi-stage pump considering that there are sufficient margins available to reduce the head.
- Reduce system resistance by pressure drop assessment and pipe size optimization.

3. COOLING TOWER

Cooling towers forms an integral part of the process in various industries, performing the important task of rejecting the heat of the process/cooling fluid to the atmosphere. In a majority of cases, the cooling water is used from which the low-grade heat is extracted. The cooling water picks up the heat from the process and is transferred to the cooling tower and is temperature is reduced using forced draft, induced draft or natural draft (usually found in power plants).

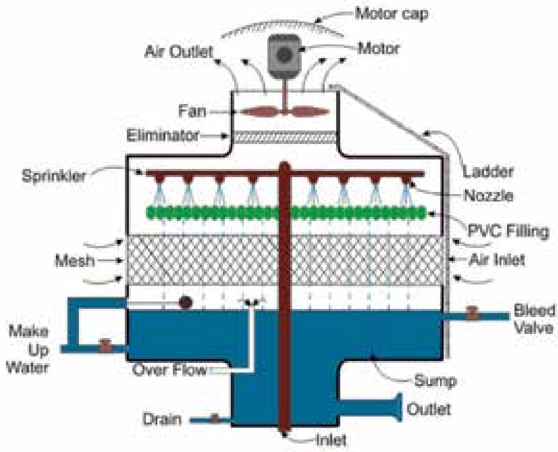


Figure 9: Cooling Tower Schematic

Basic Terminologies

Range – Difference between the cooling water inlet temperature and cooling water outlet temperature

Approach – Difference between cooling water outlet temperature and the Wet Bulb Temperature (WBT) of ambient surrounding.

Effectiveness – Ratio of Range of the cooling tower to the sum of range & approach of the cooling tower. It is mathematically represented as,

$$\text{CT Effectiveness} = \frac{\text{Range}}{\text{Range + Approach}}$$

A higher ratio of effectiveness is an indicative that the performance of cooling tower is high.

Cooling capacity – It is the amount of heat (load) rejected in terms of kCal/hr or TR, which is dependent on the flow rate of cooling water, specific heat and temperature difference across cooling tower.

Evaporation Loss – During the process of heat exchange, water tends to evaporate for the cooling duty and requires timely replenishment. Theoretically, the evaporation quantity works out to 1.8 m^3 for every 1 MkCal of heat rejected. The evaporation loss can be calculated using the formula,

Evaporation loss (m^3/hr) = 0.00085 x 1.8 x circulation rate (m^3/hr) x Range

Cycle of Concentration (COC) - Ratio of dissolved solids in circulating water to dissolved solids in makeup water

Blow-down Ratio – It is dependent on COC and the evaporation ratio, and is mathematically represented as,

$$\text{Blow down} = \frac{\text{Evaporation Loss}}{\text{COC} - 1}$$

L (Liquid)/G (Gas) Ratio – It is the ratio of water and the air massflow rates. In comparison to the design specifications, seasonal variations require adjustment water and air flow rates to get the best cooling tower effectiveness. Therefore, L/G ratio gains significance to ensure maximum possible effectiveness.

$$L = h_2 - h_1$$

$$G = T_1 - T_2$$

The variation of L/G Ratio with respect to type of fills is tabulated below:

Table 8: L/G Ratio For Cooling Towers

	Splash Fill	Film Fill	Low Clog Film Fill
Possible L/G Ratio	1.1 – 1.5	1.5 – 2.0	1.4 – 1.8
Effective Heat Exchange Area	30 – 45 m^2	150 m^2	85 – 100 m^2
Fill Height Required	5 – 10 m	1.2 – 1.5 m	1.5 – 1.8 m
Pumping Head Requirement	9 – 12 m	5 – 8 m	6 – 9 m
Quantity of air required	High	Relatively Low	Low

Checklist for improving Energy Efficiency in Cooling Towers

- Continuously monitor L/G ratio and Cooling Water flow rates w.r.t. design as well as seasonal variations.
- Increase water load during summer and times when approach is high and increase air flow during monsoon times and when approach isnarrow for maximizing the cooling tower performance.
- Continuously monitor approach, effectiveness and cooling capacity for possible optimization and also as per seasonal variations and heat load variations.
- Close loop control of cooling tower fans based on cooling water outlet temperatures by using a thermocouple. The cooling towers can be switched ON/OFF or controlled by using VFD.
- Optimize cooling tower fan blade angle based on the seasonal and/or load variations.
- Clogging can sometimes become a nuisance in cooling towers and can reduce affect the flow through spray nozzles. Therefore, it is recommended to continuously monitor nozzles and replace them if required.
- Excessive and/or uneven fan blade tip clearance and poor fan balance need to be corrected if necessary.
- Ensure that the spray nozzles functions with a more uniform water pattern
- Balance flow to cooling tower in case of multiple cooling tower operation. Maximize the effectiveness of cooling tower operation.
- Minimize the formation of fouling on the water basins; carryout frequent maintenance to clean any formation of algae, as it can lead to clogging in the water circuit.
- Optimize the blow down flow rate, taking into account the cycles of concentration (COC) limit.
- Segregate high heat loads like furnaces, air compressors, DG sets, and isolate cooling towers for sensitive applications like A/C plants, condensers of captive power
- Plant etc.
    - o As a thumb rule, rise of cooling water temperature by 1°C may result in increase of Air-Conditioning compressor power consumption by 2.7%.
    - o In a thermal power plant, 1°C drop in cooling water temperature can give a heat rate saving of 5 kCal/kWh.
- Nowadays, adoption of FRP blade instead of conventional metal blade provides significant scope for energy saving.

INTRODUCTION TO RENEWABLE ENERGY

Renewable energies are undoubted sources of clean and inexhaustible energy. As much as they differ from the conventional sources based on their diversity, availability and potential to use anywhere, they neither produce greenhouse gases, which causes climate change, nor polluting emissions, which affects basic life forms. With popularity and awareness on the rise, the technologies are becoming easily available than ever, at a sustainable rate. On the other hand, the cost for fossil fuels is the opposite, owing to its scarcity and difficulties to match demand and supply.

In terms of the technology, there have been various advancements in terms of the overall improvements in system efficiencies, hybrid technologies and other waste-to-energy technologies, to substitute to a part of the total energy demand, if not all. This section illustrates some of the latest technologies that have been adopted in the space of renewable energy.

SOLAR - Bifacial PV Model:

Solar PV is not new to the renewable domain; however, these bifacial PV modules have taken new emphasis due to their high efficiency solar cell, which provides higher low-light performance and best thermal properties. Integration of continuous monitoring, safety and optimization ensure that the bifacial PV modules give the best performance.

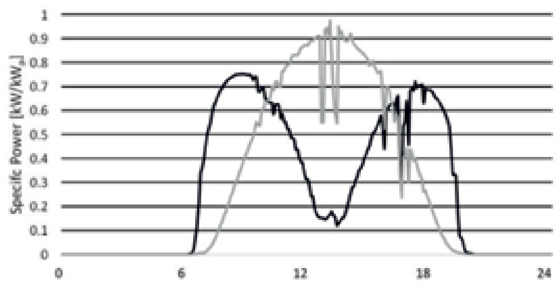


Figure 10: Solar Bifacial Panel

Bifacial modules produce solar power from both sides of the panel, whereas traditional opaque-back sheeted panels are monofacial, bifacial modules expose both the front and backside of the solar cells, when bifacial modules are installed on a highly reflective surface.

As illustrated in the figurethe generation potential of these bifacial solar modules and the trend of power generation can be inferred. As in the conventional case, the peak performance occurs at the zenith, i.e., when the face of the solar panels is directly facing the sun. But, as the figure indicates, the bifacial panels generates two peaks throughout the day. The generation is lower during the zenith and higher during sunrise and sunset.

Some of theother unique features of bifacial PV are:

- Backside has a power rating of at least 90% of front side
- Energy yield enhanced with higher reflectivity: PV module with all-round & undisturbed reflection will have potential of higher energy yield
- Energy yield enhanced as the elevation of the modules from the roof surface increases - 20-30% with an elevation of 1.5 m.

Bifacial solar modules offer some unique advantages over traditional solar panels:

❖ **Better performance** at similar project size, more production at a barely higher installation cost, so LCOE reduces.

Figure 11: Solar Bifacial Examples

- ❖ **More Durable** because both sides are UV resistant and potential-induced degradation (PID) is less
- ❖ **Optimization** for projects on sites with high albedo (white roofs, gravel)
- ❖ **Synergy** between rear-facing exposure and improved ventilation
- ❖ **Aesthetic interest**

Waste-to-Energy: Biogas

Biogas is produced from various raw materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste or food waste. Biogas is a form of renewable energy and in many cases exerts lesser carbon footprint.

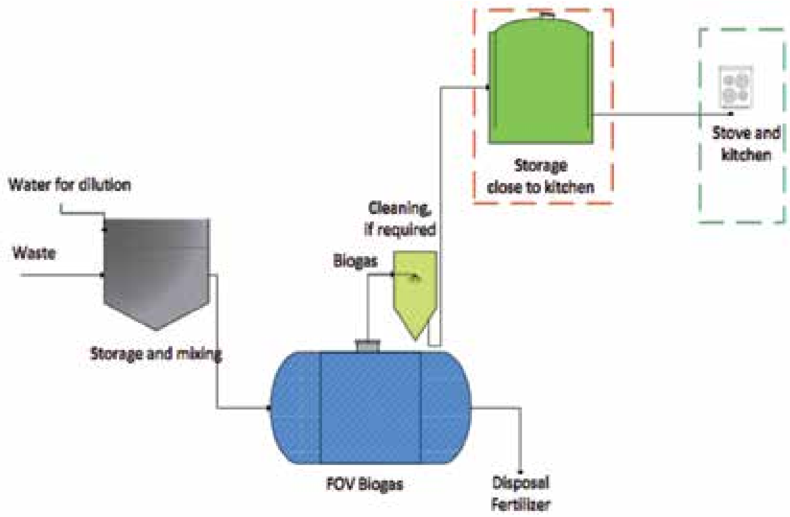


Figure 12: Block diagram of Bio gas plant

Biogas is primarily composed of methane (CH_4) and carbon dioxide (CO_2) with minor constituents of hydrogen sulfide (H_2S), moisture and siloxanes. The combustible gases in the form of methane, hydrogen and carbon monoxide (CO) can be burnt or oxidized with oxygen to generate heat, which can be used for any heating applications such as cooking, space heating, etc. In many cases, it is also used as fuel for gas engines to convert the energy in the gas into electricity and heat.

Process of Bio gas production from Waste:

Firstly, the size of the organic waste needs to be reduced, using pretreatment processes, before the waste can be converted into biogas. This can be done manually or by using an industrial crusher, mixer or screw pump. Water is then added in order to achieve the particle concentration most suitable for the biological process. The resulting substrate, known as the slurry, is fed into the reactor manually, by machines or by pump-driven piping.

The slurry enters the reactor and takes part in the ongoing anaerobic digestion, i.e. breaking down of organic material by bacteria and enzymes in an oxygen-free environment. Biogas is the end product of this process.

The biogas is piped directly into houses, other buildings or a gas tank. It can also be converted into electricity by a generator or upgraded into biofuel and used for transportation.

The digestate contains a high amount of nitrogen, phosphates and other nutrients. Some of the digestate is fed back into the reactor, thus saving water. The rest can be used as a high-quality organic fertilizer or can be sold.

Bio gas pants of different capacities can be setup based on the waste input capacity

LATEST TECHNOLOGIES & CASE STUDIES

1. Improving power factor close to unity

Project Background:

During the site visit to various production units/workshops of Indian Railways, it was observed that average power factor maintained by the units was 0.92, thereby drawing high current for the equivalent apparent power consumed by the utilities. Therefore, it is essential to improve the power factor to 0.99 to minimize the distribution losses and reduce the overall electricity bill.

The various losses due to maintaining poor power factor is as follows:

- The current drawn by the equipment is higher for the equivalent apparent power of the equipment, thereby increasing the copper losses in the conductors and switch gear machinery
- High voltage drop across transformers, distribution network, etc., therefore requiring additional equipment to compensate for the loss in voltage at end user and maintain the desired power quality which increases the cost of the power systems
- At low power factor, transmission or distribution of power at a constant voltage draws more current, hence, increasing the size of distribution lines or reduces the capacity of network.

Project Description:

Power factor can be improved by installing automatic power factor correction (APFC) system and the best method to improve the overall power factor of the facility is by using distributed reactive power compensation method.

The figure shown below illustrates the distributed power factor compensation method in which capacitor banks are installed at PCC level as well as at the MCC level which improves the power factor on the load side as well as on the distribution side.

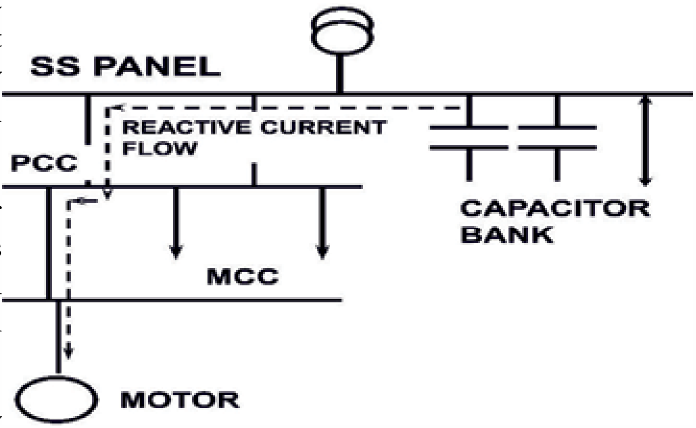


Figure 13: Power Factor Compensation Method

Installation of APFC increases the power factor, thereby resulting in the following benefits:

- Minimum voltage drop at distribution side and thus less distribution losses
- Copper loss in the transformer reduces
- Maximum demand decreases for the same load which helps in addition of extra loads in the transformer in case of expansion
- Reduction in overall electricity bill and avoiding the penalties from electricity department for maintaining low power factor in case of kWh billing system

Cost Benefit Analysis:

The unit was maintaining an average power factor of 0.92 and had average monthly energy consumption of 1, 20,000 kVAh (units). The sample calculation of cost benefit analysis for one Indian Railway facility, by improving power factor is shown below:

Table 9: Cost Benefit Analysis of Power Factor Improvement

Description	Value	Unit
Total no of Substations	10	
Losses per substation, when both the TF in loading	3.73	kW

Losses per, when one TF in loading	3.1	kW
Conservative Energy Saving per substation	0.63	kW
Unit Cost	6.5	INR/kWh
Annual Savings per substation	0.34	INR Lakh
Total Annual Savings in all substations	3.40	INR Lakh
Investment	Nil	

Benefits

By improving the power factor to 0.99, the conservative cost savings potential of INR 6.80 Lakh can be achieved and the investment incurred by implementation of this proposal is INR 14.00 Lakh, with a payback of 24 months. It has a high replication potential in Indian Railways facilities and can be implemented where overall power factor is low.

2. Optimizing the loading of distribution transformers

Project Background:

During the site visit to various production units/workshops of Indian Railways, it was observed that the loading of distribution transformers in substations was typically less than 40%. The efficiency of distribution transformer is optimum at 40-60 % loading that is when copper losses will be almost equal to iron losses.

Project Description:

The efficiency of the transformers not only depends on the design, but also, on the effective operating load. Typically transformer losses consist of two parts: No-load loss and Load loss

- No-load loss (also called core loss) is the power consumed to sustain the magnetic field in the transformer's steel core and core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are caused by two factors: hysteresis and eddy current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the core.
- Load loss (also called copper loss) is associated with full-load current flow in the transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the load current. ($P = I^2R$).

For a given transformer, the manufacturer can supply values for no-load loss, $P_{NO\text{-}LOAD}$, and load loss, P_{LOAD}. The total transformer loss, P_{TOTAL}, at any load level can then be calculated from:

$$\mathbf{P_{TOTAL} = P_{NO\text{-}LOAD} + (\%\ Load/100)^2 \times P_{LOAD}}$$

Since the two distribution transformers were operating at low load there is a possibility of shifting the load of one transformer to another and keeping the other on standby.

Cost Benefit Analysis:

The plant was having 10 nos. of substations having two distribution transformers each substation and typical peak load on the transformers during morning hours were 16% and 26% respectively. Since the two distribution transformers in each substation were operating at low load there was a possibility of shifting the load of one transformer to another and keeping the other on standby in each substation.

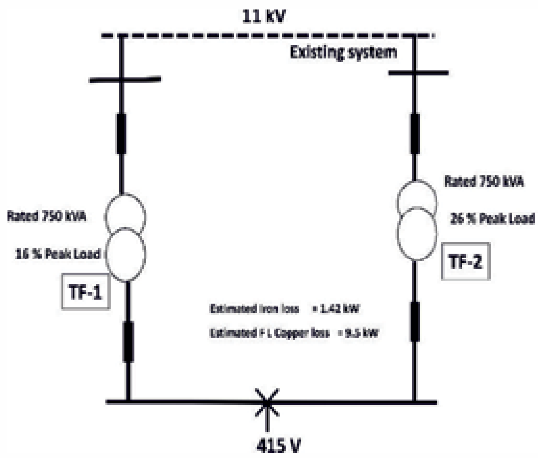


Figure 14: Transformer loading profile

The sample calculation of cost benefit analysis for one Indian Railway facility, by improving the loading profile on transformers is as shown below:

Table 10: Cost Benefit Analysis for Optimization of Transformer Loading

Description	Value	Unit
Total no of Substations	10	
Losses per substation, when both the TF in loading	3.73	kW
Losses per, when one TF in loading	3.1	kW
Conservative Energy Saving per substation	0.63	kW
Unit Cost	6.5	INR/kWh
Annual Savings per substation	0.34	INR Lakh
Total Annual Savings in all substations	3.40	INR Lakh
Investment	Nil	

Benefits

By improving the loading profile of transformers, the conservative cost savings potential of INR 3.40 Lakh can be achieved without any investment. It has a high replication potential in all Indian Railways facilities and can be implemented after proper analysis of the loading pattern of transformers.

3. Isolating primary of idle running distribution transformer

Project Background:

Distribution transformers are used to step down the voltage form the main receiving station to various utilities. As a general practice, the primary of the distribution transformer is charged to have backup power supply, although no load is connected to the transformer.

The loss arises due to the inherent magnetization of the transformer, thereby consuming power. This loss is referred to as no-load loss of the transformer. The no-load losses is a factor which is proportional to the rating of the transformer.

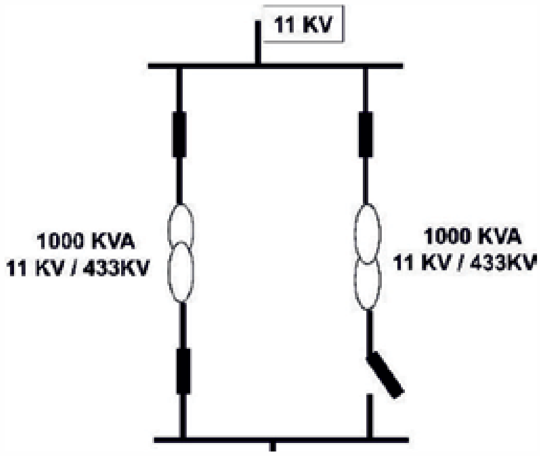


Figure 15: Idle TF primary charged

Project Description:

It is advised to isolate the primary of idle transformer in order to avoid the no-load losses, thereby saving energy consumed during idle condition of the transformer.

Cost Benefit Analysis:

In one Indian Railways facility, there were 12 substations, having 3 nos. of transformers of 1000kVA in each; normally two of the transformers were in loading condition and the third one was kept as standby transformer with primary always in charging mode.

The sample calculation of cost benefit analysis the IR facility, by avoiding the idle losses of transformers is as shown below:

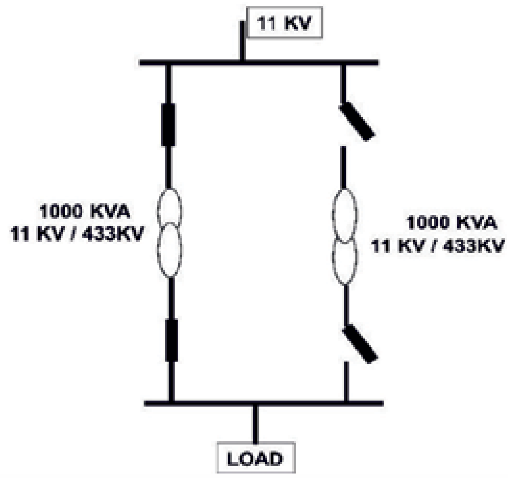


Figure 16: Idle TF disconnected from primary

Table 11: Cost Benefit Analysis for Idle Running Transformer

Description	Value	Unit
Total no of Substations	12	
No of idle TF with primary charged per substation	1	
Rated Capacity of TF	1000	kVA
No-load losses of TF (1000 kVA)	1.77	kW
Total Losses in all substations	21.24	kW
Unit Cost	6.5	INR/kWh
Annual Savings	11.6	INR Lakh

Benefits:

By isolating the primary of idle distribution transformers, savings potential of

INR 11.60 Lakh can be achieved without any investment. This replication potential of this nil-investment proposal is there in majority of the Indian Railways facilities.

4. Installation of Light pipe to harness day light

Project Background:

Lighting system finds application in office spaces and shop floors of the workshops and contributes to a significant amount of energy and cost for electricity for lighting load. For instance, one of the production unit of Indian Railways utilizes artificial lighting at various locations of the plant, which can be substituted with day lighting.

Latest advancements in technology allows us to tap the incident solar light which can be considered as a viable alternative to conventional lighting methods.

Project Description:

Light pipes are primarily used for illuminating deep interior spaces where windows do not have provision for illuminating indoor environment. Light pipe consists of mainly three parts (collector, transmission pipe, and diffuser).

- Collector comprises of a Dome which functions to collect sunlight from all angles and transmitting maximum possible sunlight into the tube. Generally, Polycarbonate or Acrylic materials are used for the Domes.
- Light is then refracted through the collector and transmitted into the tube. Reflective material such as anodized aluminum with silver coating are used on the inner surface of the tube.
- Diffuser plate is placed at the other end of the tube, which functions to evenly distribute light inside the room.

Both direct and diffuse radiation falling on receiving end of the pipe can be channeled, after multiple reflections off the inner walls and used at the exit. The inner surface of the light pipes are made with a material having high spectral reflectivity for all angle of incidences and all wavelengths of considered spectrum width. Any variation in spectral reflectivity of pipe surface leads to change in spectral distribution of transmitted radiation. In the areas where roof mounting is not feasible due to practical considerations, wall mounting of light pipes can also be done.

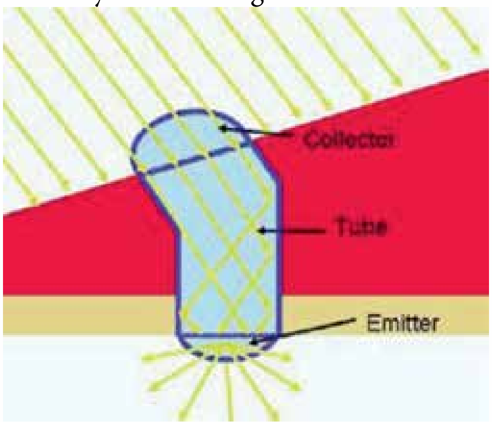


Figure 17: Components of Light Pipe

Despite the advantages of the technology, there exists barriers in implementation of light pipe, namely:

For mass replacement, disposal of conventional lights is difficult

While installing the light pipes in dusty areas care should be taken care to clean the dome in a timely manner

The following are the Lighting load and Lux levels in various locations of the railway unit.

Table 12: Lighting Load and Lux Levels Requirements at Different Locations

Description	STL(40W)	T5(28W)	LUX	Total load (W)
Generator office	2	2	124	136
Stores	12	1	106	508
Computer room	4	0	134	160
Inverter section	16	8	217	864
Pump section	16	8	124	864
Total	50	19	705	2532

Cost Benefit Analysis:

In one of the IR facility, during day time artificial lights were glowing to meet the lux level requirement. After discussion with the technology supplier, it was suggested to install 15 light pipes in the identified area and switch off the discharge lamps during the day time. This will help in maintaining good level of illumination during the day time without electrical energy.

Table 13: Cost Benefit Analysis for Light pipe

Description	Value	Unit
No of light pipes to be installed	25	
Total lighting load	9.0	kW
Unit Cost	7.2	INR/kWh
Annual lighting energy saved	31500	kWh
Monetary savings	2.27	INR Lakh
Investment	5	INR Lakh
Simple Payback Period	26	Months

Benefits:

Implementation of Light pipes (at least 25 nos.) can result in annual cost savings potential of INR 2.27 Lakh with an investment of INR 5.00 Lakh, and an average payback period of 26 months. This proposal can be replicated in all the facilities and corresponding savings can be achieved.

5. Supply/Demand Side Management with Industry 4.0 for Air Compressors

Artificial demand is a common problem faced by every industry using compressed air. It is the additional volume of compressed air required by the system, as a result of unregulated use by the compressed air user. The performance of compressor is affected due to the intermittent use of multiple pneumatic equipment which is causing the air pressure to fluctuate. Under the high demand condition, it causes the pressure to drop at the point of use. This drop in the pressure is detected by the air compressors only when it travels upstream through the distribution network. This results in the compressor to load more or increase in speed (in case of VSD) and open the IGV in case of volumetric displacement Compressors, to meet the demand.

This actually gives rise to a time lag for the compressed air network to attain the desired pressure. Therefore, the usual practice to overcome this lag in response time is to maintain air compressors at higher level of pressure to meet the sudden demand, leading to Artificial Demand.

The following figure illustrates the typical demand pattern of a compressed air network:

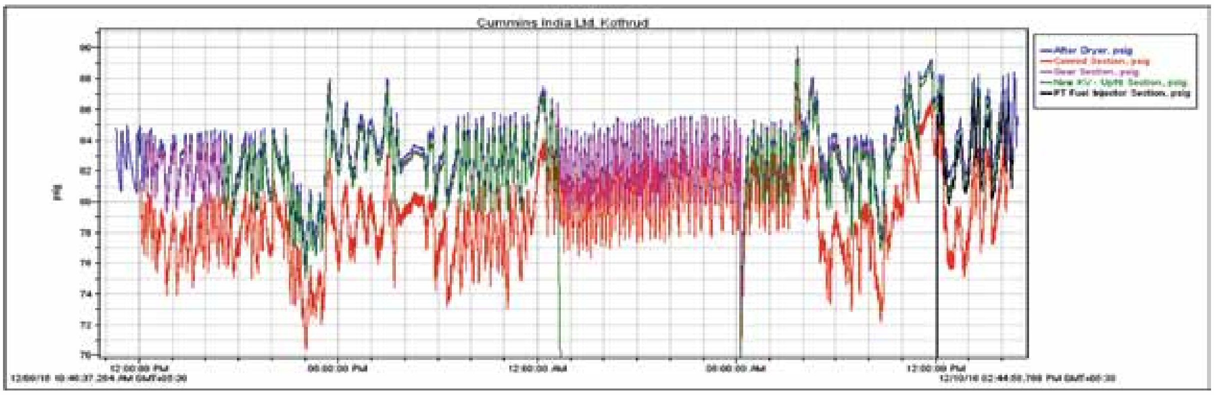


Figure 18: Typical Demand Pattern of a Compressed Air network

Say that the pressure in the compressed air system was varying from 5 bar to 6.3 bar. This has resulted in high artificial demand leading to increased energy consumption of Air Compressors. So, this can be reduced by installing demand side management systems in the compressed air network.

Demand Side Management Systems –In simple terms, it reduces the artificial demand by controlling the air flow & pressure being delivered to the plant. It is specifically designed to operate at an intermediate point of the compressed air system i.e. on the downstream side of the air treatment equipment and upstream side of the main piping distribution system. It creates useful storage by introducing a controlled differential pressure across an upstream receiver and itself. This storage isolates the compressors from demand side fluctuations. Peaks are dealt with releasing the stored reserve energy instead of additional horsepower, facilitating the compressors to run on reduced load. It also provides air at a controlled differential and optimum pressure to the plant, which reduces the mass of air consumed by pneumatic equipment, tools & amount of leakages, which ultimately result in the reduction in energy consumed by air compressors.

The following illustrates the on-screen dash board display, indicating the performance parameters of the compressed air system:

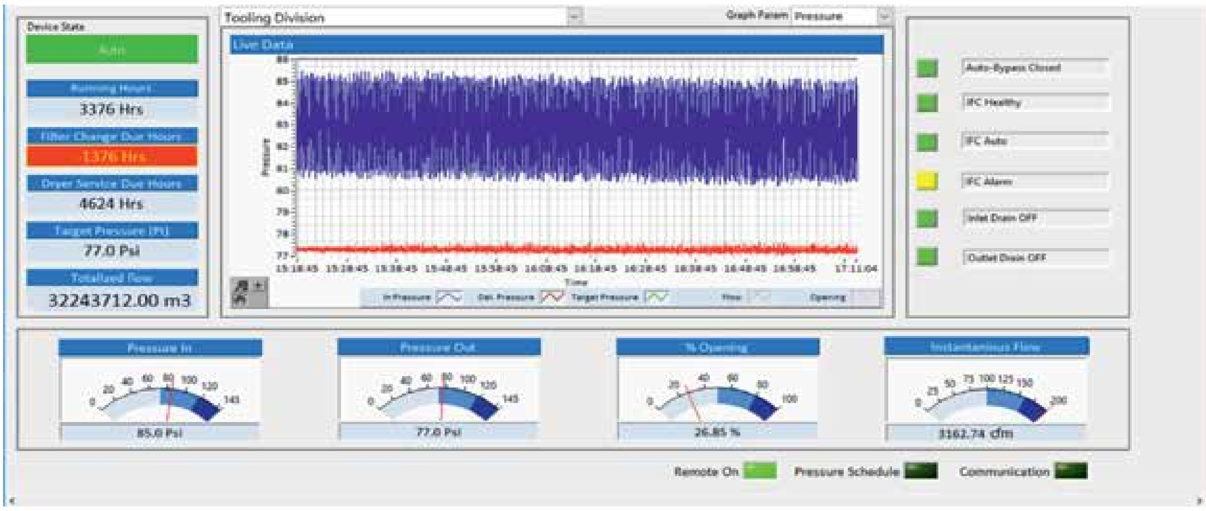


Figure 19: Dash Board for monitoring Compressed Air system

Supply Side Management Systems - Conventionally, in a multiple air compressor system, the capacity control is achieved through individual band of cascaded pressure setting. Load & Unload pressure bands are individually set through Pressure Switch or Microprocessor Controller on each Air Compressor in case of fixed speed Compressors. And, in case of variable speed compressor, the RPM modulation pressure is set for capacity control.

Therefore, the different combination of is compressors are run on day-to-day basis and this results in multiple pressure bands, depending on which compressors is set to meet the base load demand and which to meet the variable load demand.

The Supply Side Control System manages up to 12-24 numbers of compressors (Screw/Reciprocating), irrespective of the size or brand or capacity control, operating on a common compressed air network. Supply Side Management manages the fixed speed compressors with Load/Unload capacity control and the VFD compressors with RPM control. It is programmed for flow capacity and type of control of each air compressor at site during its commissioning.

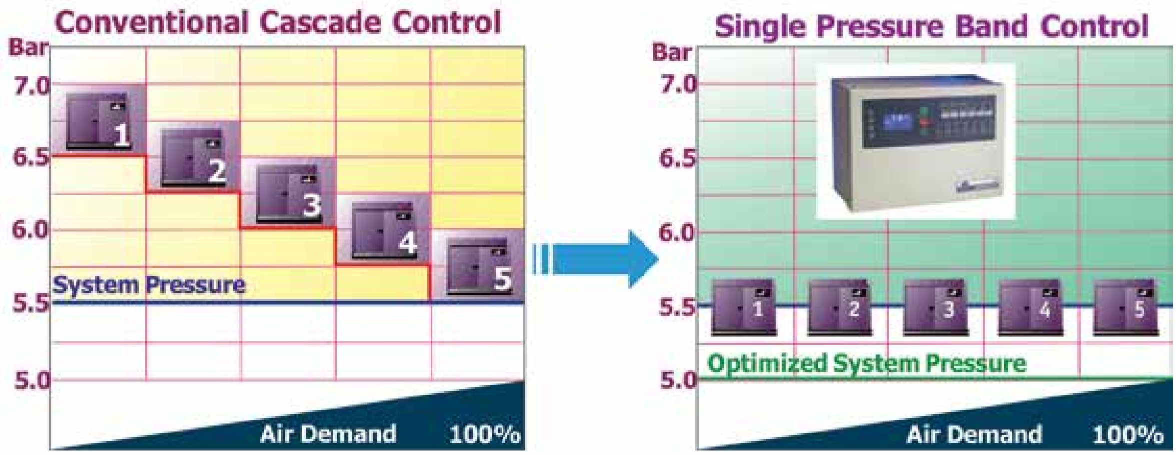
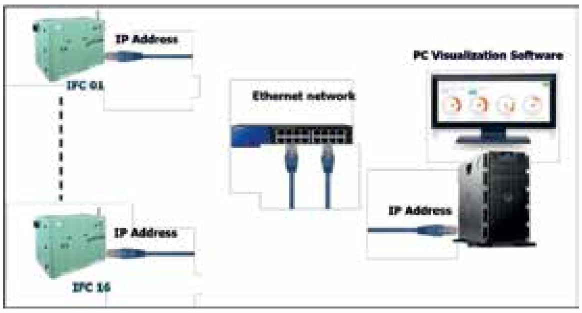


Figure 20: Capacity Control System for Compressor

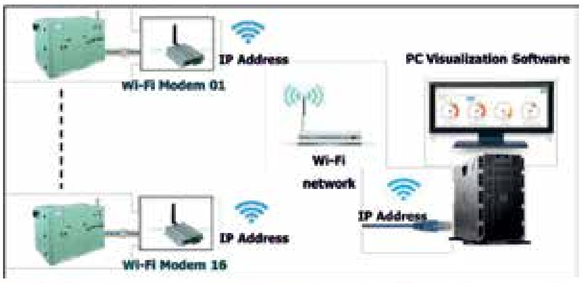
With accurate detection of demand variation, a continuous feedback is given to the internal control logic to select the best suited combination of air compressors to meet the air demand in a single target pressure control philosophy without human intervention. This results in efficient compressor usage & optimization by using the most efficient combination to cater to the demand.

Industry 4.0 - The Demand and Supply Side Controller is Industry 4.0 ready with RS-485, Ethernet, GPRS Modem, Wi-fi Modem for remote monitoring & control through PC.

- System Architecture for Wired Communication through Ethernet connection



- System Architecture for Wireless Communication through Wi-Fi



The demand side and supply side controller are applicable in all manufacturing or process industry using compressed air; such as Automobiles, Cement, Electronics / Semiconductor, Engineering, Food & Beverages, Forging, Pharmaceuticals, Steel, Textile, Tyres and others.

Remote PC Visualization & Monitoring of Air Compressors with Supply Side Management:

Remote PC visualization & monitoring of air compressors displays information such as online pressure trend, status of individual air compressor, percentage loading, overall system efficiency, etc.

Benefits:

- The installation of demand side management has various benefits:
- Reduces energy consumption by reducing the additional loading caused due to artificial demand.
- Separates the demands fluctuations between the peaks and lows.
- Reduces the overall leakages in the plant.
- Maximizes the usefulness of air storage.
- Ensures consistency in delivery to downstream end-users.
- Is compatible with any compressor manufacturer.

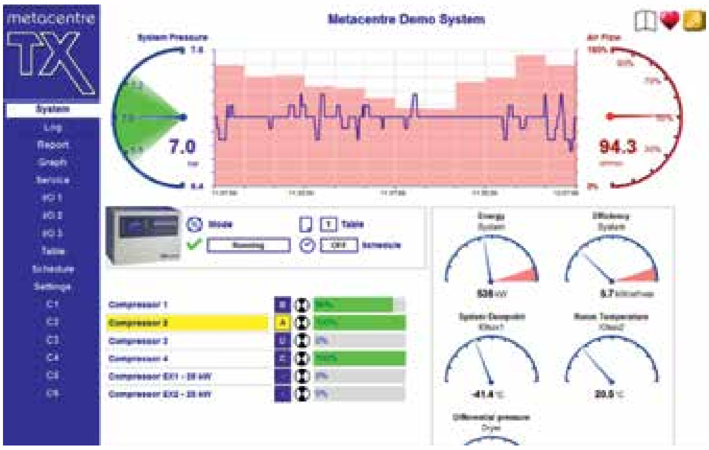


Figure 21: Supply Side Management system for compressors

This combination of Supply & Demand Side Management Control Systems was estimated to provide energy saving of 14% and constant pressure to the Shops within +/- 1 psig (0.07 bar).

6. Smart Monitoring System for measuring compressed air network

Specific Energy Consumption (kW/CFM) is a commonly used parameter to compare the performance of the air compressor. The comparison could be with respect to the design specifications or other compressors installed in the plant. While most of the end-users measure the compressor's power consumption, the compressors' output flow remains unmeasured leading to factual errors while estimating SEC.

The ambient conditions along with inefficiency and other tolerance factors that are built into a compressor affects its energy consumption and may even increase the SEC even up to 30% of the compressor's claimed efficiency.

Hence, there is a need formeasurement and monitoring of a compressor's power consumption and discharge flow to continuously monitor the compressor performance. Further a well-designed system should define various key performance indicators such as flow, power, pressure, dew point and should be measured at the right locations to understand the overall system dynamics as shown below.

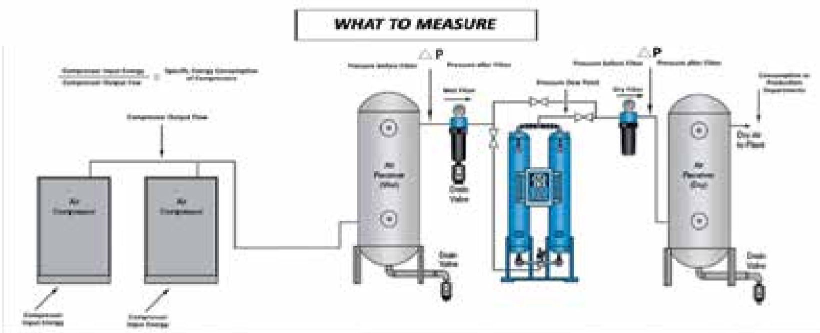


Figure 22: Smart Monitoring System for Compressed Air Network

The supply side of the system when improperly aligned with the demand side will result in over compensation of system pressures and will increase artificial demand and related problems like,

- Higher air demand
- Higher leak rate
- Higher repair intervals and costs
- Higher energy bills
- Higher cost per product produced
- Less profits

An automotive component manufacturing plant was consuming almost 1300 CFM from 2 of their rotary screw compressors of capacity 850 CFM (132 kW) and 450 CFM (75 kW) respectively. On papers, these compressors were showcasing a specific energy consumption of 0.16 kW/CFM. The factory, in their efforts of reducing their consumption to 600 CFM, installed a smart monitoring system to measure the total volume of compressed air generated and consumed at different production departments. The smart monitoring system, when installed revealed that both the compressors put together were generating only 1120 CFM as against their rated capacity of 1300 CFM but were consuming close to 220 kW. Hence, the actual specific energy consumption of these compressors was at 0.196 kW/CFM, an increase of over 18 % from the manufacturer's claims.

Extensive service and maintenance were carried out at these compressors and the result, the specific energy consumption was reduced to 0.17 kW/CFM and the factory was able to realise a power savings of over 537 kWh per day.

On the demand side: The measurements also revealed that the assembly and curing departments were consuming close to 800 CFM as against their actual demand of nearly 300 CFM. The painting booth was also consuming close to 320 CFM as against the actual demand of only 50 CFM. With these data in hand, the factory optimised the operating pressures of the machines thereby eliminating artificial demand and saved close to 150 CFM and further reduced a volume of 350 CFM by repairing leakages.

The smart monitoring system was installed at this factory in 2015 and even after 4 years the factory continues to maintain the savings achieved and even has lowered their consumption to 560 cfm as against the post project consumption of 620 CFM. The factory also saved close to 60% in their spares costs since it avoided the purchase of huge spares which are usually listed out by external leak survey agencies during their surveys.

The return of investment for this project for implementing the smart monitoring system is around 6 months.

7. Heat Recovery System for Air Compressors

The end-user efficiency of compressor is only 10-15% of the total energy consumed. Some of these losses are avoidable by arresting leakages, reducing loss of pressure across the network and operation and maintenance practices. The heat dissipated through the lubrication oil during compression a major contributor to the energy loss, which is lost in the form of heat. The overall energy consumption, utilisation and losses are illustrated in the figure below:

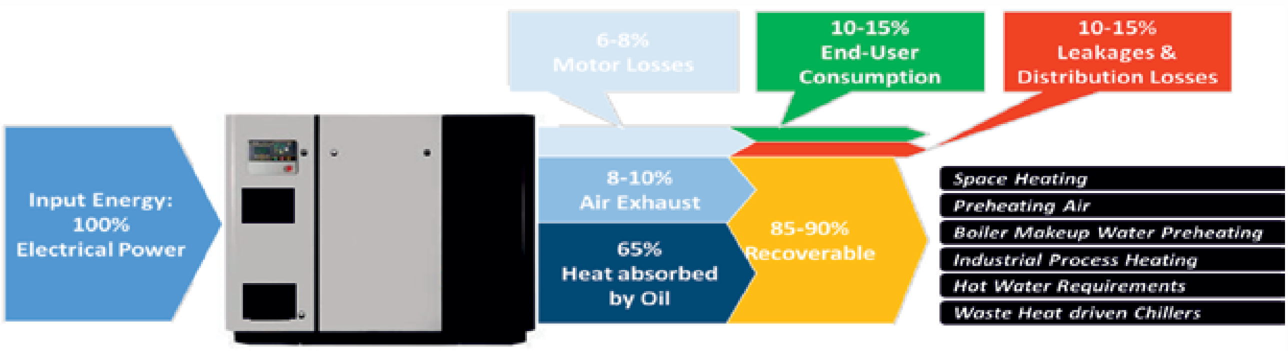


Figure 23: Schematic Diagram of Compressed Air System Losses

During the compression process, the increase in the pressure of air increases the temperature, wherein the heat is extracted by the lubrication oil. This is necessary to ensure proper lubrication of the compression element, while also contributing to cool the compressed air. Additional benefit is the improvement in air compressor equipment life and machine reliability.

The heat generated by the compression process is absorbed by the lubrication oil. Heat exchangers (e.g. plate type or shell & tube) are used for transferring the heat to the process fluid. As illustrated in the figure below, the water is pumped through the plate type heat exchanger and heat from the lubricating oil is transferred to the water. The effectiveness of the heat exchanger is dependent on the area available for heat exchange, availability of heat, heat transfer coefficient of the heat exchanger and the properties (mass flow rate, density, specific heat, etc.) of the fluid to which heat is exchanged.

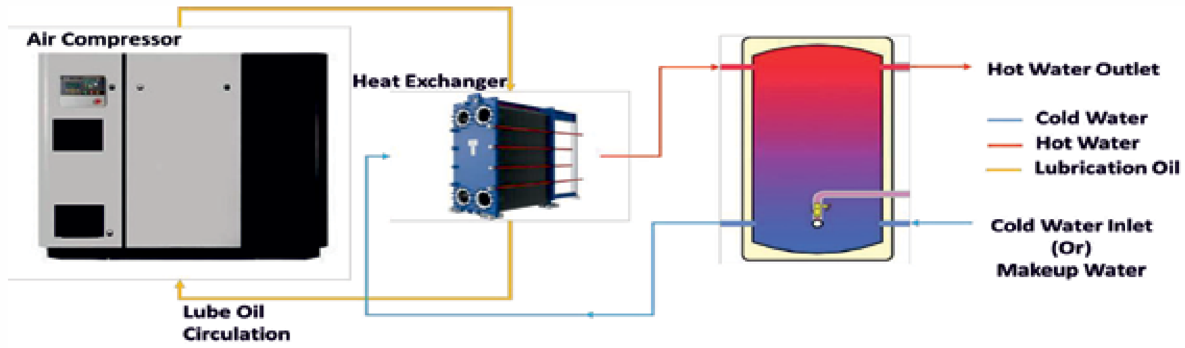


Figure 24: Schematic Diagram of Heat Exchangers in Compressed Air System

As much as 85-90% of this heat can be recovered and made useful for various applications such as space heating, water/air preheating, process heating, etc. The remaining heat is unrecoverable in the form of heat carried away by compressed air or as heat radiated to the surrounding ambient environment.

Heat recovery technologies helps to lower industry's energy costs incurred on heating systems which uses various energy sources such as natural gas, coal, or even electrical heating. This not only reduces the operating costs of the process, but also improves the energy efficiency levels of the industry.

On a commercial standpoint, heat recovery systems have an attractive payback, considering the purview of various dependent factors such as amount of heat rejected, loading on the compressor, demand for heat recovery applications, cost of alternative energy source, age and efficiency of existing technologies, etc.

8. Replacement of old reciprocating compressors with screw compressors

Project Background:

Generally, the compressor performance is constant over a period of 4 to 5 years of its operation. Also, with regular maintenance and overhauling, the compressor performance deteriorates, especially in the case of reciprocating compressor, where components such as cylinder bore, piston, valves and other accessories are rigorously maintained.

Performance assessment of a compressor is carried out to evaluate the free air delivered by the compressor.And, the specific energy consumption (SEC), in kW/CFM, can be estimated of the compressor and compared with other operating compressors or also with the design specifications of the compressor.

Although the design SEC of the reciprocating compressor are at par with the reciprocating compressors, over a period of time, the average operating SEC of the reciprocating compressor increases, which is around 0.18 kW/CFM (@ average operating pressure of 6.0 bar). The performance deteriorates due to various factors such as aging, maintenance and other operating conditions with which the compressor is operating.

Project Description:

Screw compressors operate at an average SEC of 0.15 kW/CFM (@ average operating pressure of 5.5 bar), therefore reducing the power consumption of the screw compressor for the same capacity as a reciprocating compressor. The screw compressor offers reliability at the required loads and can also be integrated with a VFD to cater variable loads requirements.

In addition, the screw compressor offers the advantage of lesser maintenance costs than the reciprocating compressors.

Cost Benefit Analysis:

In one of the Indian Railways facility, the plant was operating 5 nos. of old reciprocating compressors and average operating specific power consumption of the compressors were on higher. The sample cost benefit analysis of replacement of existing reciprocating compressor with screw compressor is shown below:

Table 14: Cost Benefit Analysis for Replacement of old reciprocating compressors

Description	Value	Unit
Number of reciprocating compressors	5	
Average operating SEC of reciprocating compressors	0.21	kW//CFM
Average operating SEC of screw compressors	0.16	kW//CFM
Compressed air requirement	500	CFM
Energy Saving potential per compressor	25	kW
Annual Operating hours	3500	Hrs
Unit Cost	6.8	INR/kWh
Cost Savings per compressor	5.95	INR Lakh
Total Cost Savings	29.75	INR Lakh
Investment	65	INR Lakh
Simple Payback Period	26	Months

Benefits:

Replacement of old inefficient reciprocating compressors can result in annual cost savings potential of INR 29.75 Lakh with an investment of INR 65.00 Lakh, and an average payback period of 26 months. This proposal can be replicated in all the facilities where plants are still operating the old reciprocating compressors.

9. Installation of VFD for existing screw compressors

Project Background:

The traditional capacity control of a compressor is by operating the motor at full speed till the compressed air attains the required pressure (loading period) and then operating the motor at idle mode (unloading period). The compressed air is stored in a receiving tank at a pressure higher than the required pressure to allow a hysteresis in the pressure.

Also, in cases where the installed capacity is more than the compressed air requirement, the compressors usually tends to operate in load-unload mode. During unloading, there is no useful work done, the power consumption is used to overcome only the internal frictional losses.

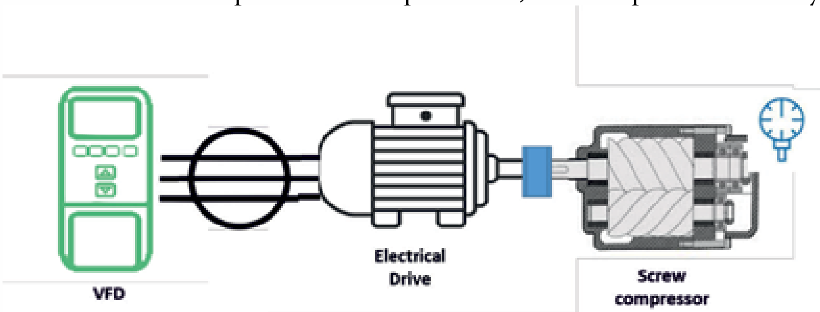


Figure 25: Vector Diagram of compressor with VFD

This “load-unload” method is common but not a recommended practice, since the motor runs continuously at its nominal speed regardless of the work done by the compressor. However, when the set pressure is attained, the slide valve is activated and the compressor is disconnected from the prime mover (in this case, motor). This uncovers part of the rotor and reduces the capacity of the machine down to typically 25-40% of the compressor's capability, thereby unloading the compressor.

Project Description:

Energy consumption can be reduced by using a VFD where the motor draws power considering a set point lower than the previously set average pressure. VFD is power electronics based device which converts the base fixed frequency, fixed voltage to a variable frequency, variable output voltage thereby providing precise control on the speed of the induction motor.

For instance, in case of a screw compressor, at Loading & Unloading pressure of 6 bar and 7 bar respectively, the average pressure at which the compressor operates is 6.5 bar, can be considered as a reference value.

By installing a VFD, the average operating pressure can be reduced to 6.1 bar. Hence, there is a significant savings in the compressor energy consumption due to reduction in the operating pressure.

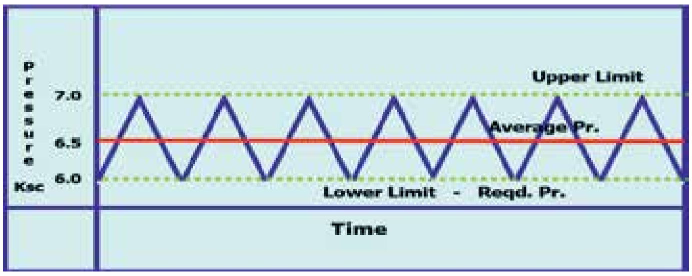


Figure 26: Compressor pressure graph before VFD

Cost Benefit Analysis:

In one of the Indian Railways facility, the plant was operating a screw compressor and based on the counter values of the compressor, it was found that the compressor was running on unloading mode with average unloading of 47%. The sample cost benefit analysis of optimizing the operation of screw compressor by installingvariable frequency drive is shown below:

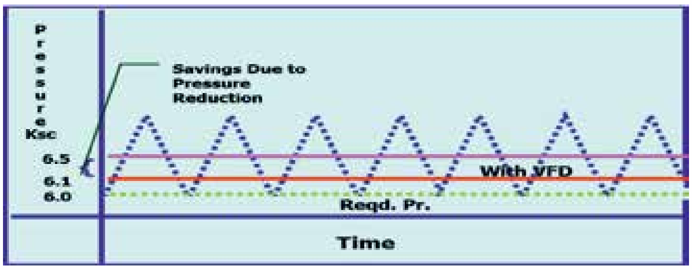


Figure 27: Compressor pressure graph after VFD

Table 15: Cost Benefit Analysis for Installing VFD in Compressor

Description	Value	Unit
Rated CFM of Compressor	950	CFM
Total average power consumption	87.23	kW
Unloading Power Consumption	39	kW
Total Running hrs of compressor	18213	Hrs
Total Loading hrs of compressor	9655	Hrs
Total Unloading hrs of compressor	8558	Hrs
Unloading percentage of compressor	47	%
Annual Operating hours	3500	Hrs
Unit Cost	6.8	INR/kWh
Energy saving	18	kW
Total Cost Savings	4.40	INR Lakh
Investment	6.00	INR Lakh
Simple Payback Period	17	Months

Benefits:

Implementation of VFD in compressors results in the following benefits:

- As the operating pressure is reduced, compressor power consumption is reduced which is proportional to the operating pressure.

➢ Increased reliability of the compressors, ensuring consistency of operation.

Optimizing the operation of compressors can result in annual cost savings potential of INR 4.49 Lakh with an investment of INR 6.00 Lakh, and an average payback period of 17 months.This proposal can be replicated in most of the screw compressors, which are not optimally loaded.

10. Transvector nozzle for compressed air cleaning application

Project Background:

Utilization of compressed air for servicing application such as cleaning and drying is not uncommon and is also not a recommended practice for such applications. The service air points are being used at a pressure of 5.5 kg/cm^2, resulting in wastage of energy.

For instance, using cleaning air from a hose of ½" dia., at 5.5 kg/cm^2, the amount of air consumed is approximately 336 CFM. Considering that the compressor operates at a specific energy consumption of 0.18 kW/CFM, the total energy consumed is 60 kW/hr.

For cleaning applications, the volume of airflow is the governing factor and not the operating pressure of the compressed air. Therefore, cleaning can be effectively achieved with a low pressure compressed air as well, thereby saving significant amount of energy.

As per the standards, reduction in the delivery pressure by 1 bar in a compressor would reduce the power consumption by 6 – 10 %. As the compressor is operated a higher pressure than is required, there is a scope of saving energy.

Project Description:

Utilize a dedicated compressor at low pressure or a blower (if pressure from blower is sufficient) for service air applications would result. In order to further optimize the compressed air intake, transvector nozzles can be utilized for cleaning applications.

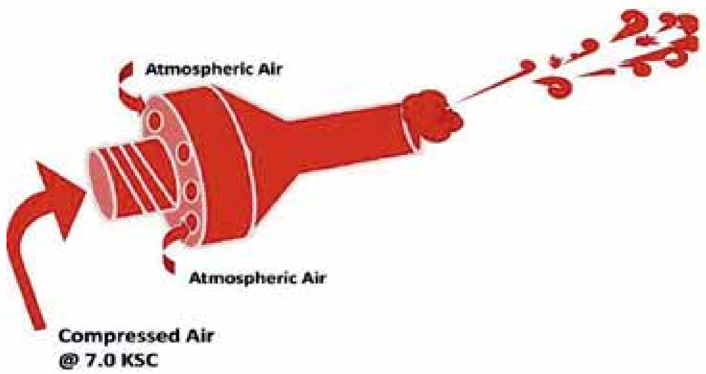


Figure 28: Transvector Nozzle

When compressed air enters the nozzle or jet, it fills a chamber with only one exit path - a thin annular orifice. As air passes through this orifice, the venturi effect of the orifice entrains the free surrounding air as it exits. This results inincreased airflow volume more than supplied by the compressed air.

Hence the required volume and pressure required for cleaning application is met by consuming minimum amount of compressed air. Results show that as much as 30 to 40% of the atmospheric air is utilized, thereby reducing the compressed air consumption, which indirectly saves load on the compressor and saves the energy consumed by the compressor.

Cost Benefit Analysis:

In one IR facility, 30 nos. of compressed air cleaning points were used for dust cleaning and man cleaning. The sample cost benefit calculation of the energy savings by implementing transvector nozzle is shown below:

Table 16: Cost Benefit Analysis for Transvector Nozzle

Description	Value	Unit
Number of cleaning points considered	30	
Flow through 0.5" hose at 5.5 bar pressure (as per standard)	336	CFM
Savings in cfm consumption with per transvector nozzle	168	CFM
Present SEC (Average)	0.18	kW/CFM
Total savings per transvector nozzle	30.2	kW
Average Annual Operating hours	180	Hours
Unit cost	6.35	INR/kVAh
Annual savings	1.63	INR Lakh
Investment required	1.50	INR Lakh
Simple Payback period	11	Months

Benefits:

Application of service air is common in all theIndian Railways facilities and implementation of transvector nozzle can be replicated in all the production units and workshops.

- Implementing transvector nozzle indirectly saves load on the compressor and saves the energy consumed by the compressor.
- By using transvector nozzle, around 40% of the compressed air usage can be reduced.

By replacing 30 nozzles, cost saving potential of INR 1.63 lakh can be achieved with an investment of INR1.50 Lakh with a payback period of 11 months.

11. Installation of Level Sensor based auto drain valves

Present Background:

In general, most of the plants installtimer-based drain valves for draining the condensate accumulated in the air receiver. In a timer-based drain valve, the condensate drain has to be changed based on atmospheric conditions. For example, during rainy seasons, the humidity is usually higher and hence the accumulation of condensate is also higher, and vice versa during summer. Another disadvantage is compressed air loss of some quantity cannot be avoided as the timer setting has to be set a higher value to ensure complete removal of condensate. If the timer is set at a lower time setting, the compressed air drain is manually opened to allow water collected. Some amount of compressed air loss cannot be avoided by using timer-based drain valves.

An alternate to timer-based drain valves is sensor-based drain valves, which senses the level of condensate collected and drains only the condensate avoiding compressed air loss. There is a good potential to replace timer-based drain valves with level-based drain valves, which avoids compressed air leakage.

Project Description:

Level based drain valves work by sensing the level of condensate accumulated in the drain. The condensate flows through the inlet valve and is collected in the housing. The capacitive sensor senses the quantity of condensate in the drain and gives a feedback to the electronic sensor based on the filling level. When the level of condensate is full in the housing the pilot valve is activated and the membrane opens the outlet causing the condensate to be removed. Once the condensate level drops the pilot valve closes the membrane, thus avoiding loss of any compressed air in the system.

The drain valve at the receiver is currently leaking compressed air and this can be avoided by installing a level-based drain valve.

1 - Inlet	2 - collection chamber
3 - Level sensor	4 - Pilot valve
5 - Membrane	6 - Balance line
7- Valve seat	8 - Discharge line

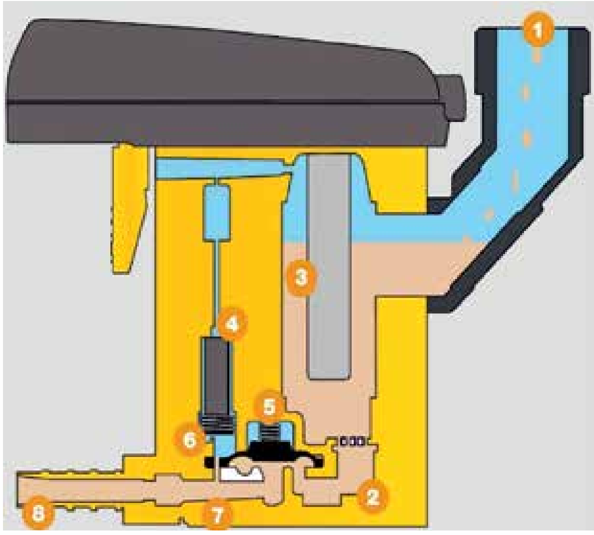


Figure 29: Level Sensor Based Moisture Drain Valves

Cost Benefit Analysis:

The sample calculation of cost benefit analysis of modifying the drain valve is shown below:

Table 17: Cost Benefit Analysis for Moisture Drain Valves

Description	Value	Unit
Capacity of compressors operating (4 nos.)	4000	CFM
CFM saved by auto drain valves	80	CFM
Power saved by auto drain valves	12	kW
Annual Operating hours	800	Hrs
Annual savings	0.60	INR Lakh
Investment for 4 nos. of valves	0.80	INR Lakh
Simple Payback Period	16	Months

Benefits:

- 2% reduction in compressed air leakage
- Automatic draining of condensate which reduces leakge and cleaning involved

By installing 4 nos. of auto drain valves in one of Indian Railways, cost savings potential of INR0.60 Lakh can be achieved with an investment of INR 0.80 Lakh and a payback period of 16 months

12. Opportunity to reduce compressed air leakage

Project Background:

Leakages is considered to be one of the significant sources of wasted energy in an industrial compressed air system, which contributes up to wasting 20-30% of a compressor's output.

In addition to the wasted energy, leaks can also contribute to other operating losses. Leaks causes a drop in system pressure, which can make air tools function less efficiently, adversely affecting production. Leakages also forces the equipment to run a greater number of cycles, which is detrimental to the life of compressors.

Project Description:

The first step of the arresting the leakage is to quantify the percentage of compressed air which is leaked to the surroundings. It is essential to ensure that there is no demand for compressed air in the system while conducting the leakage test and all user points remain closed. The following are the steps to be followed for conducting a leakage test:

- Start the compressor and allow it to run

❖ If there are no leakages, the compressor once unloaded should not load again as there is no consumption at the user point

❖ If there are leakages, it will operate in load and unload mode

❖ Note down the loading and unloading time of the compressor. The percentage loading indicates the percentage leakage.

Figure 30: Compressed air Leakage Identification

Total leakage percentage can be calculated as

Leakage (%) = {UL/(UL+L)}*100

(UL= Unload time; L= Load time)

The percentage leakage should be less than 10% of the total capacity of the compressor.

Red tag system - A leak prevention program:

In order to prevent leakages in the system, a red tag system is adopted and the following steps are carried out:

- Form a team among the employees with an objective to arrest leakages and handover red tags to each one of them
- Ensure that all the compressed line is distributed among employees
- Using an ultrasonic detector, identify the leaks in the compressed pipe line and at the user points, or notice for a hissing sound, and place a red tag at the identified leak
- Rank the leak based on its severity (on a scale of 10)
- Instruct the maintenance team to arrest the leaks and remove the red tag once the leak is arrested. When there is no red tag in the system, it can be concluded that the leaks are at minimum in the system.

Cost Benefit Analysis:

The plant was operating 3 nos. of air compressors and leakage was identified 40%. The cost benefit analysis by arresting compressed air leakage is shown below:

Table 18: Cost Benefit Analysis for Arresting Compressed air Leakage

Description	Value	Unit
Operating Capacity of compressors (3 Nos x 500 CFM)	1500	CFM
Present leakages	40	%
Desirable leakages at least	10	%
Specific power consumption of compressor	0.16	kW/CFM
Reduction in leakages (from 40% to 10%)	450	CFM
Power saved by arresting leakages	72	kW
Annual operating hours	2400	Hrs.
Unit cost	6.5	INR/kWh
Annual cost saving	11.23	INR Lakh
Simple Payback period	Immediate	Months

Benefits:

Arresting the compressed air leakages and maintaining it to less than 10% by adopting red tag system, can have a conservative cost saving potential of INR 11.23 Lakh with negligible investment and almost immediate payback period.The red tag system must be adopted in all the Indian Railways facilitiessince compressor is one of the significant energy consuming utility and leakages must be arrested to less than 10%.

13. Aluminum piping for compressed air network

Project Background:

Air pipeline forms an integral part of the compressed air system, as it connects the generation and the distribution to the end-users of compressed air. Therefore, the selection that goes into consideration of pipeline material plays an important role.

More than 60-70% of all compressed air systems installed today use black iron or galvanized pipe, due to a variety of factors:

- Contractors are familiar with these materials.
- Material costs are low.
- The pipe and compressed air system fittings are readily available.
- Steel pipe is rated for high pressure

Figure 31: Al Pipe for Compressed air network -1

As mentioned earlier, MS piping is the most commonly used compressed air pipeline material in almost every industry. One of the major drawbacks is the corrosion resistance of MS pipe, which is lesser when compared to aluminum piping. In circumstances when there are contaminants carried over into the MS pipeline, there is possible build-up over time. In technical terms, MS piping oxidizes faster than aluminum due to presence of particles such as oil, water, etc. This results in turbulent flow of compressed air in the pipeline, thereby increases the pressure drop across the distribution network. Therefore, in order to compensate pressure lost due to friction, the compressor is forced to operate at higher pressure, thereby consuming more amount of energy.

In production units and workshops of Indian Railways, compressed air network is as long as 10-15 kms. At such magnitude, various contaminants, turbulent flow, and the material used impact the air quality and the energy consumed by the compressor.

Project Description:

Aluminum piping is superior metal compared to the conventional steel piping for the following reasons:

1. Lower installation costs.
2. Easier to install and to modify.
3. Much lighter in weight.
4. Better resistance to corrosion
5. Secure fitting and less leakages.

A contrast between the MS piping, stainless steel piping and aluminium piping is illustrated below:

Figure 32: Al Pipe for Compressed air network -2

Table 19: Features of MS piping, stainless steel piping and aluminum piping

Parameters	Carbon/MS Piping	Stainless Steel Piping	Aluminium Piping
Installation Time	Slow	Slow	Quick
Modifications	Hard	Hard	Easy
Modification Time	Long	Long	Short
Inner Roughness	1.9μm	1μm	0.2-0.4 μm
Pressure Loss	Relatively large	Relatively less	Less
Leakage	10-30%	5-10%	Negligible
Long Term Corrosion	High	Normal	Very Low
Impact on air quality	Big	Small	No
Initial Investment	Low	High	High
Operating cost	High	Relatively Low	Low
Weight	Relatively Heavy	Relatively Light	Light

The following table briefs about the features of Aluminium Piping:

Feature	Description
Zero Leakages	The pipe and fittings are made of Aluminium, and the system ensures that no leakages from the piping and the components translating into a 10 years zero leak guarantee by various technology suppliers.
Corrosion resistant	The Pipe material has been engineered so as to counter corrosion issues which results in scaling and porosity, leading to high pressure drop and leakages.
Minimum Pressure Drop	Minimal pressures drop by the virtue of long lasting internal smooth surface of the pipe. Smooth surfaces translate to laminar flow. This results in huge energy savings (6% per Bar of Δp).
Modular System	Aluminium Piping system is modular & scalable to keep up with industry's expansion plans and layout changes. Reusable fittings ensure flexibility of piping layout and higher return on investment.

Cost Benefit Analysis:

The sample calculation of cost benefit analysis of implementing aluminum piping is shown below:

Table 20: Cost Benefit Analysis of Aluminum piping

Description	Value	Unit
Operating Capacity of compressors(4 Nos x 1000 CFM)	4000	CFM
Average Power Consumption	600	kW
Average Power saving on conservative basis	30	kW
Annual operating hours	2400	Hrs.
Annual cost savings	4.5	INR Lakh
Investment	18	INR Lakh
Simple Payback Period	48	Months

Benefits:

Replacing the steel pipes with Aluminum piping yields the following benefits:

- 5% energy savings can be achieved
- Zero leakage
- Less friction
- Improved air quality
- Lighter weight & ease of installation

By implementing the proposal, 5% energy savings can be obtained in compressed air network.

14. Energy Saver for packed Air Conditioning units

Project Background:

In Administrative building of production units & workshops Split/ Window AC units and packaged AC units are installed to cater the HVAC load of office rooms. Indian Railways facilities have installed old and new AC units although most of the new AC units are 3 star rated. Production units consists of 80 nos. and workshops have 40 nos. AC units on average operating during summer period (March to August).

Figure 33: AC Energy Saver

AC compressor unit is normally controlled by relay and timer to achieve the set temperature based on predefined algorithms for hottest region.

Conventional packed AC units have following problems:

- AC manufacturers cannot customize each unit to the different climates, therefore, designing a common control setting for the hottest conditions. This leads to huge wastage. When the set temperature is achieved, the compressor continues to run for an additional fixed period (6-8 minutes – known as the "Overcooling period") which is required only for few hours in a day in peak summer but is over-utilized because of the balance of time. Also, in hotter climates, by reducing the prefixed "off-time", the overcooling can be reduced substantially.
- Many AC's typically do not achieve the set temperature especially if it is set at 18oC or 19oC. As a result, the compressor runs continuously resulting in wastage of huge amount of electricity giving rise to issues such as:
  - Ice formation on the coil- reduced heat transfer and cooling.
  - Motor and Compressor run at higher temperatures, increasing the specific energy consumption by 30-40%.
  - Refrigerant liquefies leading to the risk of compressor seizing.
  - Frequent maintenance issues

Project Description:

AC energy saver is a latest generation intelligent controller having external sensors which can be retrofitted in the existing packaged AC units to provide Artificial Intelligence with a set of powerful Algorithms to the AC to save energy & life of the compressor. It has additional digital room temperature sensor similar to a precision AC to maintain the precise set temperature along with an additional programmable sensor to read, display "The Coil Temperature" and control "The Differential Temperature" after the set temperature is achieved which further enhances energy savings.

Energy saver lets you to program your Off-Time and Over-Cooling period based on your climate and day/night usage. The Coil sensor in energy saver will cut off the compressor at a Coil temperature programmed by the user and not only saves on energy consumption but also increases the life of the compressor and reducing breakdowns.

Cost Benefit Analysis:

The sample calculation of cost benefit analysis for Packed AC energy saver is shown below for one IR facility.

Table 21: Cost Benefit Analysis of AC Energy Saver

Description	Value	Unit
Average energy consumption of 1.5TR, 3 star Rated AC unit	1.566	kW
Total nos. of AC units in the facility	80	
Total Load	125.3	kW
Average Energy Savings of AC units with Energy Saver	25.1	kW
Annual energy savings of AC units with energy saver	37584	kWh
Annual Saving	2.5	INR Lakh
Total Investment	3.6	INR Lakh
Simple Payback period	17	Months

Benefits:

By installing the 80nos. of intelligent energy saver, on a conservative basis, cost savings potential of INR 2.50 Lakh can be achieved in one the Indian Railways facilities. The investment incurred by implementation of this proposal is INR 3.60 Lakh, with a payback of 17 months.This proposal has a replication potential in all the facilities.

15. Replacement of old welding sets with new Inverter-based welding technology

Project Background:

Welding is a critical operation in the Indian Railways in locomotive manufacturing units, coach manufacturing facilities and workshops. During welding operation, an electric arc is formed between the consumable wire electrode and the work piece where the heat generated causing the work piece to melt and join together.

Specific application requires specific welding technique such as Metal Inert Gas (MIG), Gas Metal Arc Welding (GMAW), etc. This technique uses a spool of wire to feed towards the workpiece and also consists of inert gas that flows from the machine to the welding handle to isolate the weld from the surrounding air.

The process of the thyristor based welding technology is shown below:

In thyristor based welding machine, significant part of the power consumption goes into heating the transformer and the surrounding air, resulting in significant losses.

Project Description:

The present scenario of thyristor based welding technology consumes significantly high energy compared to energy efficient inverter based welding equipment.

In inverter based technology, the 50 Hz incoming power is fed directly into a transformer, which is rectified to 50 Hz DC. Then it is fed into the inverter section of the power supply where it is switched on and off by solid state switches at frequencies as high as 20 kHz. This pulsed, high voltage, high frequency DC is then fed to the main power transformer, where it is stepped down to low voltage 20 Hz DC suitable for welding and is processed through a filtering and rectifying circuit. Output control is performed by solid state controls which modulate the switching rate of the switching transistors.

The operation of the inverter based welding technology is illustrated below:

Cost Benefit Analysis:

Rated capacity of the welding equipment	:	400A/30V
Output parameters	:	30 A - 250 A, 4.3 KW
Length of rod considered	:	2.5 mm
Number of thyristor based welding sets	:	100
Daily Operating hours	:	2 hrs
Idle time	:	30 mins
Shifts	:	2 hrs

Table 22: Cost Benefit Analysis of Inverter Wielding Sets

Description	Inverter	Thyristor	Unit
Power factor	0.7	0.9	
Input power taken during operation	10.56	8.33	kW
Input power taken during no load	0.5	0.13	kW
Power consumption per day	42.74	33.45	kWh
Annual Savings	14.50		INR Lakh
Investment required	40.0		INR Lakh
Simple payback period	34		Months

Benefits:

Considering replacement of 100 nos. of thyristor based welding sets in a phased manner, can result in annual cost savings potential of INR 14.50 Lakh (conservatively) with an investment of INR 40.00 Lakh, and an average payback period of 34 months.This proposal can be replicated in all the units and corresponding savings can be achieved.

16. Regenerative drives for EOT Cranes application

Project Background:

Cranes find much application in Production units and workshops for material handling. The selection of cranes is a dependent factor on the application of load, capacity and time of operation.

Cranes consume a significant amount of energy to transfer loads from one place to another pertaining to three axes of motion, namely, Hoist, Travel and Cross Travel.

During lifting operation, the motor draws current from the main incomer, thereby generating the required torque to lift the component. While lowering, the self-weight of the component, accompanied with dynamic braking is used to provide precise control of operation to lower the component at the required destination. During this operation, the shaft of the motor rotates in the opposite direction, wherein the energy is dissipated in the form of heat through the resistors in the braking unit.

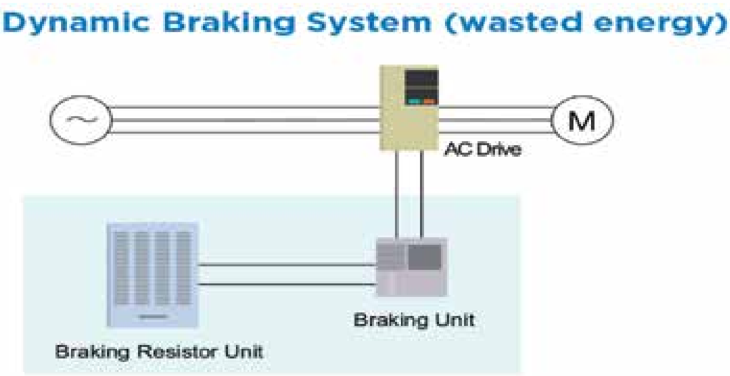


Figure 34: Block diagram of dynamic braking in OH cranes

The figure illustrates the dynamic braking operation of the cranes utilized in the workshops of Indian Railways, which indicates a significant potential for Energy Efficiency Measures.

Project Description:

As illustrated in the figure, the heat dissipated during the lowering operation of the crane, can be converted into useful energy by installation of a Regenerative Drive.

During lowering operation, the weight of the load automatically rotates the motor, thereby, acting as generator and produces electrical energy. This electrical energy which initially dissipated as heat energy, can be converted into useful electrical energy and fed back to the supply unit, using regenerative drives.

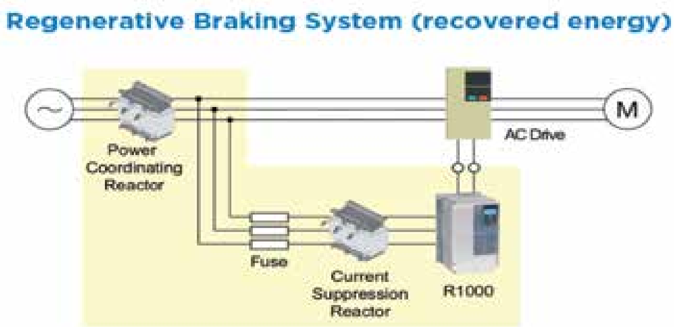


Figure 35: Block diagram of regenerative braking in OH cranes

There exists various barriers in implementing of regenerative drives:

- The energy saving is dependent on the operation time (running hours) of the crane. This method is most suitable for continuous crane use applications.
- Initial cost may be high.

Cost Benefit Analysis:

The sample calculation of cost benefit analysis of implementation of Regenerative drive for one crane is shown below:

- Working Load : 20 Ton
- Main hoist motor rating : 45 kW
- Present dynamic braking resistor values : 2 x 17.5 kW

Under regenerative braking we can save regenerative energy which is been currently wasted as heat at dynamic braking resistors.

- Regenerative unit capacity selected : 37 kW

This analysis considers 4 hrs. ofcontinuous hoist operation per day and the sample calculation is shown below:

Table 23: Cost Benefit Analysis of Regenerative Drive

Description	Value	Unit
Total No of 20 T cranes operating in plant	3	
Input power of the hoist motor	45	kW
% of regeneration (conservative)	25	%
Hoist operating hours per day	4	Hrs.
Operating hours during motoring mode	2	Hrs.
Operating hours during regenerative mode	2	Hrs.
No. of working days	350	Days
Annual Operating hours for regeneration	700	Hrs.
Energy saved per crane	7875	kWh
Annual monetary savings per crane	0.51	INR Lakh
Total monetary saving	1.54	INR Lakh
Investment required	7.5	INR Lakh
Simple Payback Period	59	Months

Benefits:

Although the investment of regenerative drives is relatively high, the proposal can be replicated in all the IR facilities, which utilizes continuous operation of cranes.

By installing regenerative drives, the following benefits can be achieved:

- Conservatively at least 25% of hoist energy supplied to main feeder, thereby reducing the power consumed from the grid.
- Energy savings can be monitored with a digital HMI panel.

Implementation of regenerative drives for hoist motors in 20 Ton cranes, in one facility considering 3Nos. cranes, results in a cost saving potential of INR 1.54 Lakh, incurring an investment of INR 7.50 Lakh, with a payback of 59 months.

17. Replacement of Ceiling Fans with Energy Efficient BLDC ones

Project Background:

Conventional ceiling fans operates using an induction motor which comprises of a stator and a rotor that are responsible for rotating motion.An induction fan consists of coils (also known as windings) on Stator and Rotor, which induces an electric flux when current passes through the stator winding. This current flows through the coil depending on the stator arrangement. The conduction of current through the coils in rotor causes the motor to rotate.

Regulation of speed in an induction fan is either through resistance based or voltage chopping mechanisms, resulting in significant amount of energy lost as heat, albeit the average consumption of conventional ceiling fan being 75 W.

Project Description:

A BLDC fan works with BLDC motor instead of a conventional induction motor consumes as low as 28W on an average, which is significantly less when compared to the conventional ceiling fan.

The primary difference between BLDC and ordinary DC fans is the commutation method which is the technique of changing the direction of current in the motor for the rotational movement. In a BLDC motor, in the absence of brushes, the commutation is done by the driving algorithm in the electronics. The main advantage is that over a period of time, due to mechanical contact in a brushed motor the commutators tend to wear and tear, which is eliminated in BLDC Motor thereby improving the durability of the motor. The key challenge of the technology is the higher investment incurred compared to the conventional ceiling fans, resulting in longer payback periods.

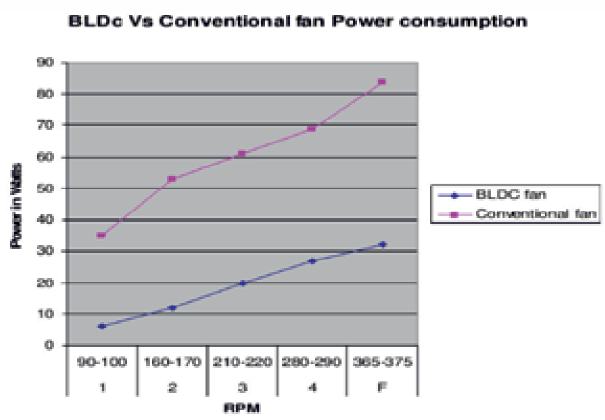


Figure 36: Power consumption comparison

The same BLDC technology now available for air circulators/ man cooling fans and IR facilities have a huge no of air circulators having old type of induction motors. These circulators can be replaced with latest BLDC technology ones.

Speed	Power Consumption in Watts	
	Ordinary fan	BLDC fan
Low	12	4
Medium	39	12
High	75	28

Energy saving calculations:

The sample calculation for BLDC ceiling fans and the cost benefit analysis of implementation of BLDC fans is shown below:

Table 24: Cost Benefit Analysis of BLDC Ceiling Fans

Description	Value	Unit
Total no of fans	2500	
Total Power consumption@75W/fan	187.5	
After replacement @28W/fan	70	kW
Energy saving	117.5	kW
Unit cost	6.5	INR/kWh
Annual Monetary Savings	23	INR Lakh
Investment	62.5	INR Lakh
Simple payback period	33	Months

Benefits:

Replacing conventional ceiling fans with Energy Efficient BLDC fans can reap the following benefits:

Nearly 50% of the energy savings can be obtained.

Due to negligible heating of the motor, the life of a BLDC fan is also expected to be much higher than ordinary fans.

Considering replacement of 2,500 fans in one of the IR facility on average, the cost savings potential of INR 23.00 Lakh can be achieved with an investment of INR 62.50 Lakh, at a payback period of 33 months.

18. Installation of Energy management system (EMS) to optimize energy consumption

Project Background:

The energy meters are installed in the plant at the substation and main incoming feeder of the facility. This is essential to analyze the trend of operation, so as to draw conclusions on the performance assessment of the equipment.

In most of the production units and workshop of the Indian Railways, unavailability of monitoring equipment to assess energy performance results in wastage of energy at the end-user.

Project Description:

Energy management system provides the means to controlling and reducing the energy consumption. It involves metering, data collection, data analysis and interpretation of energy consumption.

EMS communicates with multiple energy meters installed at site location of the utility. Energy monitoring system can detect overloading from a section and enable control measures to act against it.

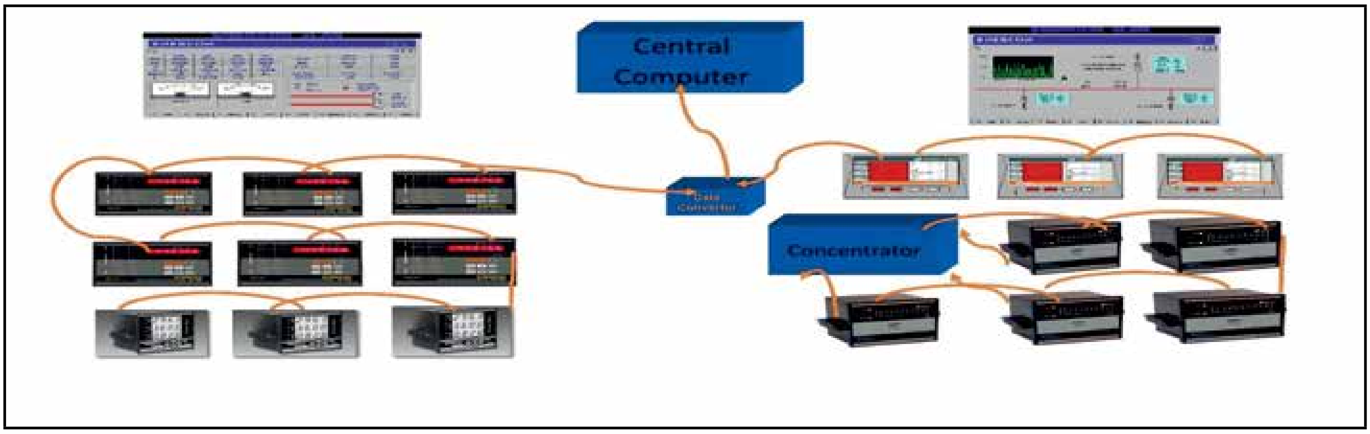


Figure 37 EMS network

Implementation of Energy Management System provides the following benefits:

- Identification and assessment of application and consumption and prioritizing in those areas identified as high consumers.
- Identification and prioritization of savings opportunities by comparison of economic variables such as initial investment required and the payback period.
- Defining the baseline energy consumption by comparing the energy performance of the industry before and after initiating the energy management system.
- Analyzing the trend of energy consumption using the system data and, analyze the performance of the organization in achieving the energy objectives and also establish future energy goals and programs.

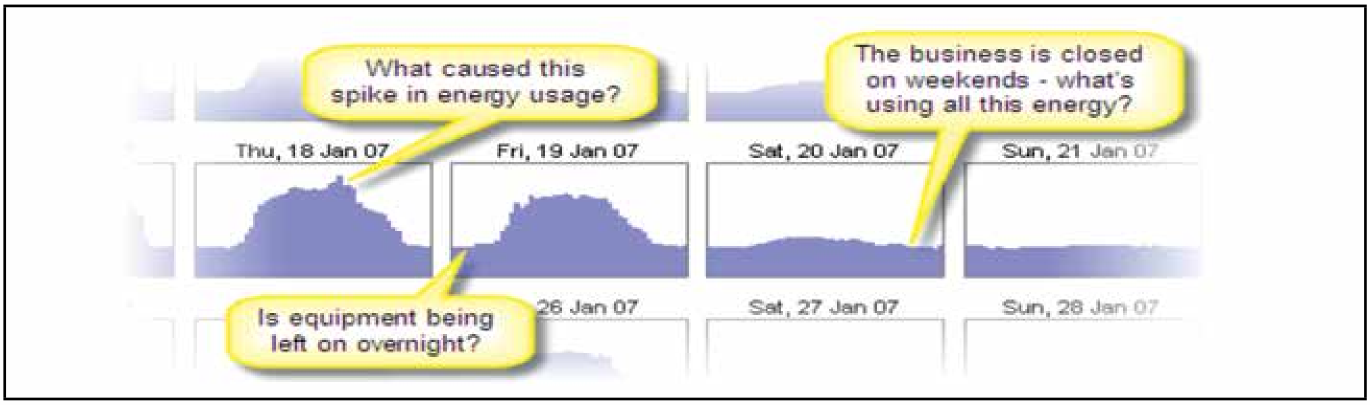


Figure 38: Possible References from EMS Data

Benefits:

Most of the Indian Railways Production units/Workshops are not having energy management or energy monitoring system and it one first step to implement for understanding the energy consumption pattern section wise as well as equipment wise to optimize the overall energy consumption. And on a conservative basis, 1% of the energy consumed by the plant can be saved by installing Energy Management system.

19. Installation of Efficient direct driven motors for AHUs

Project Background:

Air handling units (AHUs) are used to cater the HVAC load of the administrative building. These AHUS are operated with belt-pulley driven systems which accounts for belt slippage losses, resulting in 90% efficiency in transmission of the system. Normally induction motors are used for AHUs, operated at a loading of around 40-60%. As the motors are operated at loading below the rated value it is likely to give low efficiency and operate at a lower power factor. There is a potential of increasing the efficiency of the motor by replacing the existing ones with the new energy efficient motors.

The latest technology for AHUs is to replace existing motors with direct driven energy efficient permeant magnet motors. This system comes with a speed control.

Project Description:

Replacing the old Belt -Pulley system with driven EC motors, 25 -30% savings can be achieved. Permanent magnet motors have better efficiency and power factor due to less stator and rotor losses.

Following are the advantages of using EC motors:

- Smooth rotation at low speeds: Brush motors are available which are specially designed for low speed smoothness with a large number of commutator segments. Brushed motors are the smoothest of the available motor technologies.
- Low cost drive: A DC brush drive can be made very economically since only a single bridge circuit is required.
- No power used at standstill: with no static loads on the motor, any current is required to hold position.
- High peak torque available: In intermittent duty applications, particularly when positioning mainly-inertial loads, the motor can be overdriven beyond its continuous rating.
- Flat speed-torque curve: Gives optimum performance with easily generated linear acceleration ramps.
- Wide variety of types available: Brush motors are produced in many styles including very low inertia types for high dynamic applications.

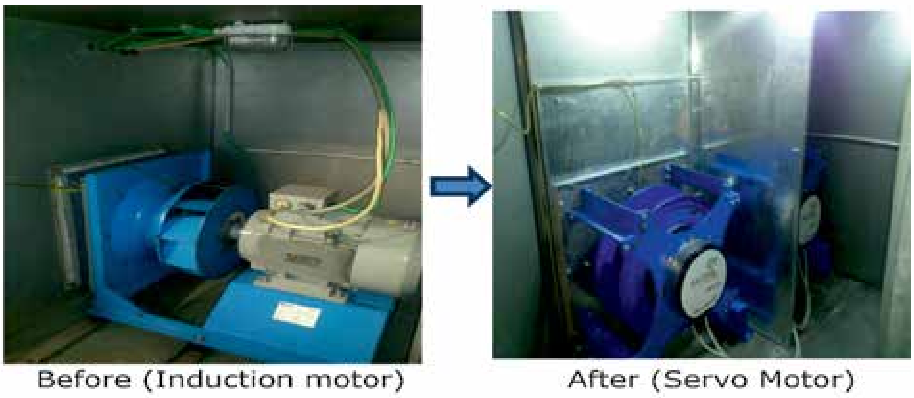


Figure 39: EC Motor for AHUs

Benefits:

By installing the direct driven EC motors, on a conservative basis, 25% energy savings can be achieved when compared to the conventional belt pulley system.The proposed system has a replication potential in all the IR facilities where old AHU with belt-pulley system is installed and new AHUs are to be installed.

20. Alternate fuel and combustion catalyst for Diesel

Project Background:

In various Indian Railways production units and workshops, diesel is consumed in furnaces for heat treatment of machined components. For furnaces using diesel as a fuel for combustion, the combustion efficiency of the fuel is a governing factor for the heat rate, which forms the measure to assess the performance of the furnace.

Poor combustion factor of the fuel leads to detrimental effects, namely:

- Poor Fuel Economy
- Incomplete & toxic exhaust emissions
- High maintenance cost
- High carbon scaling

For instance, one of the production units of Indian Railways utilizes approximately 11,000 kL of diesel annually for heat treatment furnaces, excluding the quantity of fuel used for transport and engine test facility.

With combustion efficiency playing a key role in assessing the performance during operation, there exists potential to improve the combustion efficiency using diesel additives.

Project Description:

Latest advancements in fuels combustion enables the combusting fuel to enhance the oxygenating capacity, providing more oxygen exposure to the molecules of the fuel. This conditions the fuel to instigate more clean combustion, reducing particulate emissions such as CO_2, S_{OX}, N_{OX} and CO, whilst maintaining the combustion quality.

Also, as a green initiative towards substituting diesel as a combustion fuel, bio-fuels are considered to be the next alternatives synthesized from plastic waste and converted to useful combustible fuel. These "Net Zero CO_2 Emission" fuels can be used as a direct substitute or blended with diesel at any ratio. Bio-Fuels are best applicable for combustion in kilns, boilers, hot air generators, etc. but not recommended for internal combustion machinery. The fuel can be a direct substitute without downgrading the calorific value of combustion, while keeping the particulate emissions minimum.

This proposal can be implemented in those units or workshops which utilizes external combustion techniques for heat treatment.

Benefits:

The benefits of using diesel additives are:

- Enhanced fuel efficiency
- Reduced toxic pollutants
- Less soot deposition
- Reduced maintenance cost

Blending/direct substitution of diesel with Bio-Fuels offers the following benefits:

- Replacement of diesel without infrastructural modifications
- Does not compromise on the Calorific value when compared with diesel
- Recycled from waste, therefore a substitute to incineration technology which emits toxic gases.

21. Battery Operated Electric Fork lifts

Project Background:

Indian Railway facilities have diesel operated fork lifts for material handling and each unit is having an average no of 10 forklifts of mostly 3Ton and 5Ton. Diesel operated fork lift have noise and fume emissions also the diesel forklifts are bigger and bulkier than the compact-sized electric-powered lift and thus requires more room for overall storage inside a warehouse or plant. The operating cost of diesel one is much higher than the electric battery operated one.

Proposed technology:

Battery operated fork lift are more environmentally friendly than a diesel-powered forklift, an electric-powered lift truck is not only quieter than its alternative, it doesn't generate or release any harmful emissions into the air. These are particularly important aspects to consider if the lift truck is going to be primarily used indoors where workers would be directly and regularly exposed to the loud noise and fumes of a diesel-powered forklift. In addition, electric forklifts are more compact, easier to maneuver around small, tight spaces, and don't require their drivers to use a clutch. Further, an electric-powered forklift is less expensive to maintain than a diesel-powered forklift since it has less moving parts and a rechargeable battery (vs. regularly refilling a tank). The electric fork lifts are available in different lifting capacities starting from 1.5T to 5.5T.

Figure 40: Electric Fork Lifts

This proposal can be implemented in those units or workshops which utilizes diesel operated forks for material handling.

Benefits:

The benefits of using diesel operated forklifts are as follows:

- Operating cost lower than Diesel operated forklifts
- No requirement of fuel storage
- Zero Emission
- Noiseless operation
- Reduction of wear and fatigue for the operator due to Automatic Braking
- Elimination of usage of engine oil and coolant
- Longer maintenance intervals

22. Solar mill to Harness solar and Wind Energy

Renewable energy is deemed to be the best substitute for conventional fossil fuel. Implementation of renewable energy posts various challenges such as capital cost and consistency of power output, the latter can be solved by the installation of Solar Mill (Figure shown below). Solar mill can be installed on Rooftop to tap the energy from wind and solar.

The Solar Mill generates:

- Solar Energy during daytime
- Day & Night energy from the wind Energy
- Energy during overcast conditions

- ➢ More energy on hot sunny days due to cooling effect on solar panels by wind.

The solar mill consists of 3 vertical axis wind turbines coupled to three permanent magnet generators. Automatic mechanical braking is provided once the wind speed goes beyond the cut-off speed. On-board smart electronics include dynamic Maximum Power Point Tracking (MPPT). It uses wind and solar resources on a 24/7 basis, allowing access to energy with minimal interruption of services. The design life of solar mill is 25 years.

Figure 41: Solar wind hybrid system at IR station

Specifications:

The increase of renewable power per square foot of roof is obtained by combining two power sources.

For a roof top installation, combining solar and wind power is a complementary combination. For example, many locations are less windy in the middle of the day when the sun is at its peak and the wind picks up after dusk.

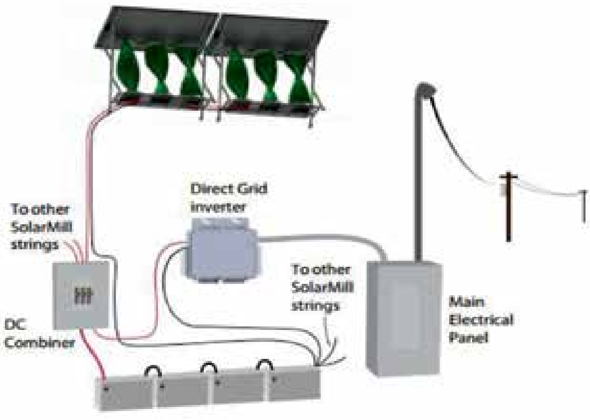


Figure 42: Hybrid mill connected to supply

Other advantages are solar module providing protection for the wind portions of the mechanism from direct rain and hail, and assisting with the direction of air into the turbines.

Since this compact installation is designed for rooftops and urban atmosphere, savonious type of wind turbine is chosen for its low running speed and relative insensitivity to turbulence.

Power generation begins at a cut-in speed of 2 m/s and mechanical braking at high-speed winds beyond 18.5 m/s.

Independent MPPT for both wind and solar is calibrated. Maximum power point tracking (MPPT) is algorithm that included in charge controllers used for extracting maximum available power.

The power from both wind and solar generation is routed into a common 48V DC bus which has built-in charge control for a lead acid battery bank.

Also, in a grid tied system, the bank of batteries is connected to one or more Direct Grid micro-inverters which connect to the user's electrical panel. The inverters push power back to the grid efficiently when the batteries become fully charged.

In off-grid storage, the batteries can be used to supply power to electrical devices in off-grid settings. This electrical energy can power DC powered devices through a voltage converter, or can power AC devices through an inverter.

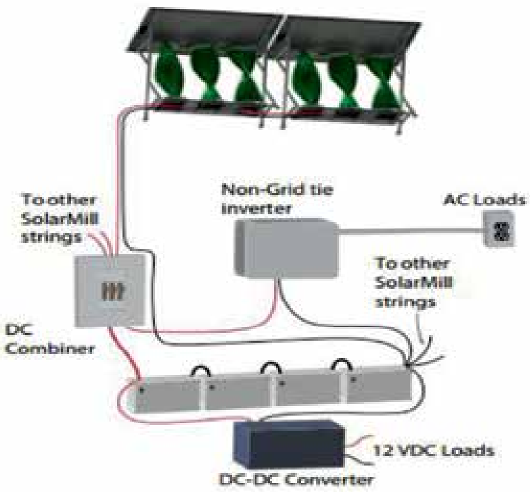


Figure 43: Hybrid mill connected to loads

Cost Benefit Analysis:

The sample calculation of cost benefit analysis for a 50kWp solarmill is shown below for one IR facility is shown below:

Table 25: Cost Benefit Analysis of Solar Hybrid mill

Description	Value	Unit
Installed Capacity of Solar wind Mill	50	kWp
Average generation per day per kWp	8	kWh
Area Required	60	M2
Average Annual Energy Saving on conservative basis	132000	kWh
Annual cost savings	8.6	INR Lakh
Investment	45	INR Lakh
Simple Payback Period	63	Months

On grid solarmill can be installed in all the IR facilitates to cater the lighting and other general load of the shop floor.

Benefits:

By installing the solarmill On Grid system in one of IR facility, on a conservative basis, cost savings potential of INR 8.60 Lakh can be achieved. The investment incurred by implementation of this proposal is INR 45.00 Lakh, with a payback of 63 Months

ACTION PLAN AND CONCLUSION

Over the years, Indian Railways, has taken significant measures towards promoting energy efficiency in both traction and non-traction areas. Though there are many initiatives taken by Indian Railways to reduce energy consumption through stringent guidelines/policies on General Power Supply Systems such as the use of LED lights, Star rated equipment and websites dedicated to energy savings, challenges in various aspects such as technological, administrative, financial, etc., progress has been difficult and to adhere to these compliances.

Action Plan:

- The individual facilities have to assess the baseline performance and develop their own individual target for improving all the parameters.
- Set and achieve voluntary target of at least 2 to 5% reduction in specific energy consumption every year within defined timelines
- The best practices and the performance improvement projects compiled in this manual may be considered for implementation after suitably fine tuning to match the individual plant requirements.
- Formation of a cross functional energy team with an Energy Manager to implement study and implement various technologies.
- Identify specific person to facilitate implementation of the technology.
- The team must prioritize the projects based on short/medium/long term energy efficiency opportunity and implement in a phased manner
- If required, CII-Godrej GBC will help the individual units to improve the performance by providing energy audit services and identifying performance improvement projects specific to individual units to achieve the targets.
- The present level of performance and the improvements made by the individual units have to be monitored.

Conclusion:

The objective of the project will be fulfilled only if the performance of all the Indian Railways units improves and achieves world class standards. We are sure that the Indian Railways will make use of this manual to improve their performance, set benchmarks and become world class in Energy Efficiency.

ANNEXURE 1

METHODOLOGY ADOPTED FOR PILOT EE STUDIES

The following methodology was adopted to enhance energy efficiency in Indian railways:

1. Project Inception workshop was organized
2. Awareness workshops and training programs on the technological aspectof energy efficiency and best practices adopted in the Indian industry were organized
3. Missions for officials of IR to the best performing automobile and engineering industries to help understand and absorb cutting edge technologies and practices
4. Identified potential technology suppliers who have energy saving offerings for the IR and organize workshop/ meetings with them and other key stakeholders to ensure swift development of EE projects in the railway units
5. Felicitate the best performing IR units with Energy Efficiency Award as a part of CII's National Award for Excellence in Energy Management
6. Best Practices Manual for Energy efficiency in Indian Railways

1. Project Inception Workshop

Inception workshop meeting for phase - II was held on10 September 2018 CII-Sohrabji Godrej Green Business Centre, Hyderabad and all the coordinators of the respective production units and workshop have participated and agenda of the Inception meeting is following:

- To understand various facilities participating in this engagement and their expectations
- Agree on action plan at various facilities
- Discuss timelines and deliverables at each engagement level
- Finalize the plan of visits for each of the 10 locations and other industries to be visited as part of the missions
- Tentative agenda for the technology workshops

The Outcome of the Inception workshop was following:

Dates of plant visits, Missions and technology workshops will be finalized by Individual plant after formal communication letter from Central Indian Railways office

Understanding basic details of IR facilities, operations, major energy consumers, typical energy bills and key energy efficiency initiatives taken in last two years

2. Training programs and Identification of Energy saving opportunities

CII delivered tailored training programme to the Indian Railways professional and the objective of these training programs was to disseminate knowledge on energy efficiency aspects on various equipment like Pumps, Fans, Compressors and compressed air systems, HVAC and air conditioning etc. and also share the best practices on the fronts of energy efficiency. The training programme also aimed to provide in-depth knowledge about various regulations and financing mechanisms for Energy Efficiency Projects.

A Site Visit of 3 days was done at different facilities of Indian Railways to identify key energy saving opportunities and training program

The details of the activities carried out for three days were following:

1. Day-1 :
    a. Introduction with plant team.
    b. Detailed discussion with the plant team on the process and equipment
    c. Walk through visit of the plant
2. Day 2:
    a. Training program and sharing of best practices by CII
    b. Doubt Clarification and Gemba Walk
    c. Discussion on the findings identified during plant visit and Gemba Walk
    d. Technology suppliers visit
3. Day 3 :
    a. Presentation by CII team on the findings
    b. Interactive session and close

3. Mission to be best performing Engineering Unit of similar Nature

We have Facilitated focused missions of Indian railways professionals to best performing plants like Tata Motors, Pune; Mahindra and Mahindra, Zaheerabad; Ashok Leyland, Bhandara; Toyota Kirloskar, Bidadi; J K Tyre, Chennai and Hero MotoCorp, Gurgaon. The objective of the mission was to showcase Indian Railways various energy efficiency initiatives taken by the similar units in India and understand the drivers, approach, involvement of all stakeholders, etc. that made energy efficiency improvements possible.

4. Technology supplier Workshop

Technology supplier workshops was conducted to make identification of technology options quicker and implementation of EE projects at Indian Railways faster. IR officials participated from different Indian Railway facilities and technology suppliers presented their technologies on following energy intensive areas:

- Compressors and compressed air system energy optimization
- Electrical system & lighting,
- Power Quality and Reactive power compensation
- Regenerative drive solution for EOT cranes
- Energy efficient BLDC ceiling fans and Air circulators
- Packed and split AC unit energy saver
- Inverter based wielding sets and other shop floor utilities and Renewable energy
- Solar wind hybrid system
- Soar thermal and heat Pump

5. Energy Efficiency Awards

We have conducted Energy efficiency award programs for Indian Railways alongside CII's energy awards since 2017, to showcase their initiatives to other industrial sectors present in the event. In 2019, 19 Indian Railway facilities applied for the awards and finally only 9 facilities participated in the energy efficiency award program and out which 4 facilities got shortlisted. These four facilities namely Carriage Repair Workshop, Jagadhri; Central Workshop, Trichy; DLMW, Patiala and MCF, Rare Bareli received energy efficient unit award.

6. Best Practice compilation

CII team visited all the 20 Indian railways units involved in phase-I & II, for the identification of various energy saving opportunities with replicable potential across the production units/workshops and documented all the replicable energy saving potential.

ANNEXURE 2

LIST OF TECHNOLOGY SUPPLIERS

S.No	Technology Supplier	Contact Name	Phone number	Email ID
AC Energy Saver for Spilt and Packaged AC units				
1	Magnetron International	Mr. Kishore Mansata	9748727966	indiaenergysaver@gmail.com
2	Ecopower Pvt. Ltd.	-	022-25185916/17	
3	Gloabtel Convergence Ltd	Mr Chirag Morakhia	9324176440	chirag@gloabtel.com
4	Om Energy Savers	-	022-24158800 9323153504	sales@omenergysavers.in
Aluminium pipe lines for compressed air system				
5	Legris Parker	Mr. Joy Deewan	124 4590617	joy.dewan@parker.com
6	Godrej & Boyce Mfg Co. Ltd.	Mr. Kiron Pande	9820348824	kcp@godrej.com
Automatic Power Factor control unit-APFC				
7	Crompton Greaves Limited.	Mr. Ashok Kulkarni	9713063377	ashok.kulkarni@cgglobal.com
8	P2Power Solutions Pvt Ltd	Mr.Venkatesh	8368378480	grandhi.venkatesh@p2power.com
Battery operated tools for riveting and grinding				
9	Bosh Limited	MN. Nabi Khan	9963022188	nabikhan.mn@in.bosch.com
Bio gas - Colony area/Plant area				
10	FOV Bio gas	Fredrik Johansson		fredrik.johansson@fov.se
Battery operated fork lifts				
11	Toyota	Suresh kasula	9100878731	kasula.s@tmhin.toyota-industries.com
12	Godrej	Mr. Ranganath	9885286984	rangnath@godrej.com
13	Voltas	Mr. Vivek	7875260914	vivek.thakur@voltas-mh.com
Blending Oil in HSD to reduce its consumption				
14	MS Solutions	Mr. Nitin Bidi	7730011144	nitin@mssolutionsg1.in
Compressors -Energy Efficient screw compressors				
15	Kaeser Compressors I Pvt Ltd.	Mr. Mohan Raaj	9840844438	mohan.raj@kaeser.com
16	Atlas Copco	Mr. Hemant Patil	9822911530	atul.bhargava@in.atlascopco.com
17	ELGI Equipments	Mr. Balamurugan K	422 2589116	bala.kalaimani@elgi.com
18	Ingersoll Rand Climate Solutions Pvt. Ltd	Mr. Gopi Krishna	9535611688	Gopi.Javvaji@irco.com

Cooling Towers				
19	Inductokool Systems (P) Ltd	Mr. Dilip Govande	9440608322	inductokool@gmail.com
Compressed air Solutions: Intelligent Flow Controller- IFC				
20	Godrej air Solutions	Mr. Prasad R. Shrirame	9833033648	shrirame@godrej.com kcp@godrej.com
Dust Control Systems				
21	DCL Bulk Technologies Pvt.Ltd.	Mr. Venkatesh Ravula	9848031376	ceo@dclbulktech.com dclbulktech@hotmail.com
22	Flex Clean Systems Pvt Ltd	Mr. K G Kuruvatti	9619149610	kuruvatti@flexcleanindia.com
Energy efficient BLDC Ceiling fans and Wall fans				
23	Gorilla fans	Mr. Arindam	9051503838	arindam@atomberg.com
24	superfans	Ms. Susila	9488594506	susila@versadrives.com
Energy management system				
25	Elmeasure	Mr. Sagar	9963471135	venkatasagar@elmeasure.com
26	E-cube energy	Mr. Umesh	9831012510	umesh@eetpl.in
27	Atandra	Mr. Sreenivas	9884038730	ks@atandra.in
Electronically commuted Direct coupled motors for AHUs				
28	Ebmpapst	Mr. Gopinath	9551070554	gopinath.murugesan@in.ebmpapst.com
29	Add tech	Mr. Ravi Pandey	9594627773	ravi@aadtech.in
ESP - Electrostatic precipitator				
30	Kraft Powercon	Mr. Anish Murthy	9886868333	anish.murthy@kraftpowercon.com
Flat Belts				
31	Elgi Ultra Industries Ltd.		0422-2304141	info@elgiultra.com
32	Habasit-Iakoka Pvt. Ltd		0422-2627879	habasit.iakoka@habasit.com
Hydroxy fuel generator to reduce fuel consumption				
33	Vaigunth EnerTek (P) Ltd.	Mr. E Manoharan	044-45575551	info@v-enertek.com
34	AL Shorooq Green Energy		9003009738	manoharan.e@shrooqal-shams.com
Inverter Based welding machines				
35	Ador Finotech	Mr. Kiran	9396515582	krishnakumar@adorfon.com
Level-sensor based Auto drain Valves				
36	Orchid Industrial Equiments & Energy Utility Services	Mr. S Baskaran	94440 10371	orchidie@eth.net
Light Pipe				
37	Sky shade	Mr. Sekhar Nori	9399952777	sekhar@skyshadedaylights.com

38	Eview Global Pvt Ltd	Mr. Rajiv Gupta	9757158328 9769421112	rajiv@eviewglobal.com
kVAr compensator				
39	Athena Cleantech Pvt Ltd	Mr. Rishi Shroff	9820104126	rishi@cleantech.com.sg
Neutral Ramming Mass- Neutral Refractory				
40	Saint Gobain	Mr. Sunil Jain	9811309092	
41	Carborundum Universal Limited	Mr. N Thiagarajan	98404 30332	ThiagarajanN@cumi.murugappa.com
42	HASLE Refractories India Pvt Ltd.,	Mr. S Mukhopadhyay	9949013987	sm@hasle-refractories.com
Recuperative burners for furnaces				
43	Bloom Combustion India Pvt., Ltd.	Mr. Rahul Pathak	9881001342	rpathak@bloomeng.com
Solar Wind Hybrid system				
44	WindStream Energy Technologies	Mr. T.Venugopal	9959918782	vtimmaraju@windstream-inc.com
Transvector nozzles				
45	General Imsubs	Mr. kushalraj	9327030174	air@giplindia.com
Variable Frequency Drive -VFD				
46	Yaskawa	Mr. Sree Kumar	9573770123	sreekumar_n@yaskawa.in
47	Siemens	Mr. Kiran	7702282525	k.kiran@siemens.com
48	Danfoss	Mr. Nagahari Krishna L	9500065867	Nagahari@danfoss.com
49	Siemens	Mr. Shanti Swaroop	9000988322	santhiswaroop.m@siemens.com
Solar Thermal systems				
50	Aspiration Energy	Mr. Aditya Birewar	8308844243	aditya.b@aspirationenergy.com
Ceramic Coatings to reduce surface heat loss				
51	Innovative Surface Coating	Pankaj C. Patil	7887860660 9326605194	patilpankaj08@yahoo.com
Biogas plant				
52	Sri Jagathees Product	Mr. R. Rajendran	9443132628	
53	Thermax Ltd.	Mr Akhil Javagal	020-25511010	akhiljavagal@thermaxindia.com
54	AGR Technology – Ahuja Engineering	Dr A G Rao	9949010736	
55	Sintex Industries Limited	Mr Alok Varma	9898047133	plastic@sintex.co.in
STP/ETP				
56	K K Nag Pvt Ltd	Mr Naresh Kewalramani	9579562255	ngkewalramani@kknag.com
Solid waste management				
57	Ramky Enviro Engineers	Mr Balasubramanian	040-2301 5000	waste@ramky.com

58	Aruna Green Ventures Pvt Ltd	Mr S R Kumar	8861921167	greeneria@arunagreen.com
59	Excel Industries Ltd.	Mr Harshad Gandhi	9773144455	harshad.gandhi@excelind.com
Waste Heat Recovery from compressors				
60	Opel Energy Systems Pvt. Ltd.	Mr. Y. D.Chavan	020 – 24377646	sales@opelenergysystems.com
61	Promethean Energy Pvt. Ltd.	Mr Ashwin KP	9167516848	ashwinkp@prometheanenergy.com
Heater less vaporizer for LPG plant				
62	Super gas	Mr. Ganesh Thangraj	9010455540	gkthangaraj@supergas.com