Confederation of Indian Industry
CII-Sohrabji Godrej Green Business Centre

Energy Efficiency Guidebook For ELECTRICAL ENGINEERS

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Energy Efficiency Guidebook For Electrical Engineers

CII
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This guidebook has been prepared by CII- Godrej GBC by way of review of literature available from various sources and reports. The guidebook is a store of information to the plant personnel involved in energy conservation.

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FOREWORD

Industries play an important role in the economic development of the country. Thus energy the important input to the industry plays a crucial role in terms of the economic growth. Indian power sector has an installed capacity of 1,73,626 MW as on March 2011 against 30,000 MW in 1981. Despite of the increase in the supply we are facing severe power shortages and poor power quality. India's energy consumption is in an increasing trend due to the population growth and economic development.

CII- Sohrabji Godrej Green Business Centre, as part of making the Indian industries world class in energy efficiency has been releasing several publications, case study booklets to make the latest information available to the entire stake holders in the industrial sector.

Indian industrial sector has been focusing on energy conservation for quite a long period of time. But still the scope for improvement exists with the latest equipments and technologies. The guide book stresses the fundamental theory of basic electrical equipments and provides the up-to-date information on electrical systems such as motors and its control, transformers, lighting systems etc. It also throws light on the possible energy saving opportunities and newest trends in electrical and lighting systems.

I am confident that the energy efficiency guide book for electrical engineers will serve as a valuable reference guide in practicing energy efficient design and operation in Indian industrial sector.

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Vice President (Electrical & Electronics Services), Godrej & Boyce Mfg Co Limited

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1.0 Introduction

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 turn out to be a major operating expense due to an ever-increasing trend in energy prices. Energy conservation techniques to reduce energy costs are therefore seen as an immediate and handy tool to enhance competitiveness. This guidebook deals with energy efficiency in electrical system viz electrical distribution, motors and lighting. It includes the latest development in technology, approach for energy conservation, design details, standards, definitions and formulae.

2.0 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. The efficiency varies between 96 and 99.5 %. 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 ratio of overall maximum demand of the plant to the sum of individual maximum demand of various equipment. With this definition, diversity factor will always be less than one.

Diversity factor varies with the 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 centre, considering other features like optimisation needs for centralised 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 of the transformer. The energy consumed in meeting these losses are dissipated in the form of heat, and 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 and 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. ($P=I^2R$). The efficiency of the transformers not only depends on the design, but also, on the effective operating load and occurs at a condition when constant loss equals variable loss.

Transformer Loss Estimation

1) Find the percentage loading of the transformer =

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

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 in the following table:

kVA Rating	No-load Loss (Watts)	Full Load Loss at 75 deg C (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

Transformer type	Core loss as a % of full load	Loading at which maximum efficiency is achieved (%)
Distribution transformer	15 - 20 %	40 - 60 %
Power transformer	25 - 30 %	60 - 80 %

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.

Energy efficient amorphous transformers

The iron loss of any transformer depends on the type of core used in the transformers.The conventional transformer is made up of silicon alloyed iron (Grain oriented) core. The latest technology is to use amorphous material for the core. The expected reduction in energy loss over conventional (Si Fe core) transformers is roughly around 70%, which is quite significant.

Electrical distribution transformers made with amorphous metal cores provide on excellent opportunity to conserve energy right from the installation. Though these transformers are costlier than conventional iron core transformers, the overall benefit towards energy savings will compensate for the higher initial investment. At present amorphous metal core transformers are available up to 1000 kVA.

The following table shows the no load and full load loss of conventional (Cold Rolled Grain Oriented) and amorphous metal core transformers with the present available technology.

Rating (kVA)	No Load Loss (W)		Load Loss (W)		Efficiency (%)	
	Amorphous	CRGO	Amorphous	CRGO	Amorphous	CRGO
250	180	570	3200	4000	98.7	98.2
500	250	900	4800	6550	99	98.53
630	200	1000	5200	8000	99.1	98.54
730	365	1250	6050	9000	99.2	98.65
1000	450	1500	7650	11800	99.2	98.68

Use of best quality core material like Amorphous Magnetic alloy offers great advantage not only at fundamental frequency but, the advantage increase manifold as the distortion in both load current and supply voltage increases. There is increase in total loss and decrease in efficiency with higher distortions, but this phenomenon is affecting this core material much less as compared to Transformer with poor quality core.

For a 3 phase, 250 kVA Transformer under non-harmonic and harmonic conditions the losses calculation is as follows[1]

Without Harmonic Distortion		
Lossess	Amorphous	CRGO
Hysterisis (A)	99	155
Eddy Current (B)	33	311
Total Core Loss (C) = (A+B)	132	466
Coil Loss (D)	966	1084
Loading	55%	58%
Total Loss (C+D)	1098	1550

With Total Harmonic Distortion of 26%		
Lossess	Amorphous	CRGO
Hysterisis (A)	99	155
Eddy Current (B)	74	698
Total Core Loss (C) = (A+B)	173	583
Coil Loss (D)	1553	1671
Loading	55%	58%
Total Loss (C+D)	1726	2524

Selection of transformers

The transformer user with a long term view should make the purchase decision based on the Total Owning Cost (TOC). There are two costs in the life cycle of the transformer. One is purchase price and other one is cost of energy lost from the transformer over its lifetime. The total cost of a transformer is the sum of purchase cost and the net value of energy losses. The decision should be based on the lowest TOC.

The formula for calculating TOC is as follows.

TOC = Initial cost + Capitalized cost of annual Iron losses + Capitalized cost of annual copper losses + Capitalized cost of annual auxiliary losses

1 IEEMA Journal

Capitalized cost of Iron losses per kW $= 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n} = A$

Capitalized cost of Copper losses per kW $= 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n} \times LS = B$

Capitalized cost of Auxiliary losses per kW $= 0.4 \times 8400 \times EC \times \frac{(1+r)^n - 1}{r(1+r)^n} \times LS = C$

Where,

r	=	Rate of interest
EC	=	Cost of Energy (Rs per kWh)
n	=	Life of the transformer (Normally taken as 20 years)
LS	=	Annual loss factor
	=	$0.3\ LF + 0.7\ (LF)^2$
LF	=	Annual load factor

The total number of hours of operation is taken as 8400 hours/ year.

The cooling fans (auxiliary) operation is taken as 40% of the time of the transformer operation. Substituting the values,

The Total Owning Cost or the Capitalized cost of transformer $= IC + (A \times Wi) + (B \times Wc) + (C \times Wp)$

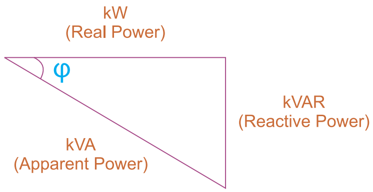
Where,

IC	=	Initial cost in Rs
Wi	=	Iron loss in kW
Wc	=	Copper losses in kW
Wp	=	Auxiliary losses in kW

The above method of calculating Capitalized cost of transformer is based on Central Board of Irrigation and Power (CBIP) manual on transformers.

3.0 POWER FACTOR AND REACTIVE POWER MANAGEMENT

Majority of electrical loads in industrial installations are inductive in nature. Typical examples are induction motors, transformers and fluorescent lighting. These inductive loads consume both active and reactive power. The active power is used by the load to meet its real output requirements, whereas reactive power is used by the load to meet its magnetic field requirement. The reactive power is always 90^0 lagging with respect to active power. The power triangle is given below:



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

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. As power factor tends to unity, the electrical system efficiency increases.

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.

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

Motor Rating (HP)	Capacitor rating (kVAR) for Motor Speed					
	3000	1500	1000	750	600	500
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 :

1) **It is considered uneconomical in industrial applications to improve power factor by individual compensation for motor ratings below 15 HP**

2) **For motor ratings above 30 HP the capacitor kVAR rating would be about 20 - 25% of the motor rating in HP**

3) **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**

4) **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 loaing of greater then 80%**

5) **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**

TABLE 1: MULTIPLIERS TO DETERMINE CAPACITOR KVAR REQUIRED FOR POWER FACTOR CORRECTION

Original Power Factor	Desired Power Factor																				
	0.80	0.81	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1.00
0.50	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	1.440	1.481	1.529	1.589	1.732
0.51	0.937	0.962	0.989	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
0.52	0.893	0.919	0.945	0.971	0.997	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
0.53	0.850	0.876	0.902	0.928	0.954	0.980	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
0.54	0.809	0.835	0.861	0.887	0.913	0.939	0.966	0.992	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
0.55	0.769	0.795	0.821	0.847	0.873	0.899	0.926	0.952	0.979	1.007	1.035	1.063	1.093	1.124	1.156	1.190	1.227	1.268	1.316	1.376	1.519
0.56	0.730	0.756	0.782	0.808	0.834	0.860	0.887	0.913	0.940	0.968	0.996	1.024	1.054	1.085	1.117	1.151	1.188	1.229	1.277	1.337	1.480
0.57	0.692	0.718	0.744	0.770	0.796	0.822	0.849	0.875	0.902	0.930	0.958	0.986	1.016	1.047	1.079	1.113	1.150	1.191	1.239	1.299	1.442
0.58	0.655	0.681	0.707	0.733	0.759	0.785	0.812	0.838	0.865	0.893	0.921	0.949	0.979	1.010	1.042	1.076	1.113	1.154	1.202	1.262	1.405
0.59	0.619	0.645	0.671	0.697	0.723	0.749	0.776	0.802	0.829	0.857	0.885	0.913	0.943	0.974	1.006	1.040	1.077	1.118	1.166	1.226	1.369
0.60	0.583	0.609	0.635	0.661	0.687	0.713	0.740	0.766	0.793	0.821	0.849	0.877	0.907	0.938	0.970	1.004	1.041	1.082	1.130	1.190	1.333
0.61	0.549	0.575	0.601	0.627	0.653	0.679	0.706	0.732	0.759	0.787	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.156	1.299
0.62	0.516	0.542	0.568	0.594	0.620	0.646	0.673	0.699	0.726	0.754	0.782	0.810	0.840	0.871	0.903	0.937	0.974	1.015	1.063	1.123	1.266
0.63	0.483	0.509	0.535	0.561	0.587	0.613	0.640	0.666	0.693	0.721	0.749	0.777	0.807	0.838	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.474	0.503	0.529	0.555	0.581	0.608	0.634	0.661	0.689	0.717	0.745	0.775	0.806	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.445	0.471	0.497	0.523	0.549	0.576	0.602	0.629	0.657	0.685	0.713	0.743	0.774	0.806	0.840	0.877	0.918	0.966	1.026	1.169
0.66	0.388	0.414	0.440	0.466	0.492	0.518	0.545	0.571	0.598	0.626	0.654	0.682	0.712	0.743	0.775	0.809	0.846	0.887	0.935	0.995	1.138
0.67	0.358	0.384	0.410	0.436	0.462	0.488	0.515	0.541	0.568	0.596	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.965	1.108
0.68	0.328	0.354	0.380	0.406	0.432	0.458	0.485	0.511	0.538	0.566	0.594	0.622	0.652	0.683	0.715	0.749	0.786	0.827	0.875	0.935	1.078
0.69	0.299	0.325	0.351	0.377	0.403	0.429	0.456	0.482	0.509	0.537	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.906	1.049
0.70	0.270	0.296	0.322	0.348	0.374	0.400	0.427	0.453	0.480	0.508	0.536	0.564	0.594	0.625	0.657	0.691	0.728	0.769	0.817	0.877	1.020
0.71	0.242	0.268	0.294	0.320	0.346	0.372	0.399	0.425	0.452	0.480	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.240	0.266	0.292	0.318	0.344	0.371	0.397	0.424	0.452	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.212	0.238	0.264	0.290	0.316	0.343	0.369	0.396	0.424	0.452	0.480	0.510	0.541	0.573	0.607	0.644	0.685	0.733	0.793	0.936
0.74	0.159	0.185	0.211	0.237	0.263	0.289	0.316	0.342	0.369	0.397	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.158	0.184	0.210	0.236	0.262	0.289	0.315	0.342	0.370	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.131	0.157	0.183	0.209	0.235	0.262	0.288	0.315	0.343	0.371	0.399	0.429	0.460	0.492	0.526	0.563	0.604	0.652	0.712	0.855
0.77	0.079	0.105	0.131	0.157	0.183	0.209	0.236	0.262	0.289	0.317	0.345	0.373	0.403	0.434	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.078	0.104	0.130	0.156	0.182	0.209	0.235	0.262	0.290	0.318	0.346	0.376	0.407	0.439	0.473	0.510	0.551	0.599	0.659	0.802
0.79	0.026	0.052	0.078	0.104	0.130	0.156	0.183	0.209	0.236	0.264	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.633	0.776
0.80	0.000	0.026	0.052	0.078	0.104	0.130	0.157	0.183	0.210	0.238	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.000	0.026	0.052	0.078	0.104	0.131	0.157	0.184	0.212	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82			0.000	0.026	0.052	0.078	0.105	0.131	0.158	0.186	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.555	0.698
0.83				0.000	0.026	0.052	0.079	0.105	0.132	0.160	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.529	0.672
0.84					0.000	0.026	0.053	0.079	0.106	0.134	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85						0.000	0.027	0.053	0.080	0.108	0.136	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86							0.000	0.026	0.053	0.081	0.109	0.137	0.167	0.198	0.230	0.264	0.301	0.342	0.390	0.450	0.593
0.87								0.000	0.027	0.055	0.083	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88									0.000	0.028	0.056	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89										0.000	0.028	0.056	0.086	0.117	0.149	0.183	0.220	0.261	0.309	0.369	0.512
0.90											0.000	0.028	0.058	0.089	0.121	0.155	0.192	0.233	0.281	0.341	0.484
0.91												0.000	0.030	0.061	0.093	0.127	0.164	0.205	0.253	0.313	0.456
0.92													0.000	0.031	0.063	0.097	0.134	0.175	0.223	0.283	0.426
0.93														0.000	0.032	0.066	0.103	0.144	0.192	0.252	0.395
0.94															0.000	0.034	0.071	0.112	0.160	0.220	0.363
0.95																0.000	0.037	0.078	0.126	0.186	0.329
0.96																	0.000	0.041	0.089	0.149	0.292
0.97																		0.000	0.048	0.108	0.251
0.98																			0.000	0.060	0.203
0.99																				0.000	0.143
																					0.000

Note:-

The above table is based on the following formula :

kVAR required = kW(tan φ_1 – tan φ_2)

Where,

φ_1 = Cos^{-1} (PF1) and

φ_2 = Cos^{-1} (PF2)

PF1 and PF2 are the initial and final power factors respectively.

Capacitor kVAR for Transformers

Power and distribution transformers, which work on the principle of electro-magnetic induction, consume reactive power for their own needs even when its secondary is not connected to any load. The power factor will be very low under such a situation. To improve the power factor, it is required to connect a fixed capacitor bank at the LT side of the transformer. The table gives the approximate kVAR of capacitor required.

kVA Rating of the Transformer	kVAr Required for compensation
Upto and including 315 kVA	5% of kVA rating
315 – 1000 kVA	6% of kVA rating
Above 1000 kVA	8% of kVA rating

(Reference: L&T Switchgear Division)

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 the following example.

Example :-

Calculate the required kVAR compensation for a 500 kW 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

4.0 POWER QUALITY

Power quality is of prime importance in deciding the efficiency of any motor. Some of the critical parameters of the power quality are

- Harmonics
- Voltage Unbalance
- Voltage Fluctuations

In an alternating current (AC) system, the voltage potential and the current through load circuit is described in terms of frequency and amplitude. The frequency of the current will be identical to the frequency of the voltage as long as the load resistance/impedance does not change. In a linear load, like a resistor, capacitor or inductor, current and voltage will have the same frequency. As long as the characteristics of the load components do not change, the frequency component of the current will not change. When we deal with non-linear loads such as switching power supplies, transformers which saturate, capacitors which charge to the peak of the supply voltage, and converters used in drives, the characteristics of the load are dynamic. As the amplitude of the voltage changes and the load impedance changes, the frequency of the current will change. That changing current and resulting complex waveform is a result of these load changes.

Harmonics are voltage and current frequencies riding on top of the normal sinusoidal voltage and current waveforms. Usually these harmonic frequencies are in multiples of the fundamental frequency, which is 50 hertz (Hz). Harmonics are created by these “switching loads” (also called “nonlinear loads,” because current does not vary smoothly with voltage as it does with simple resistive and reactive loads). Each time the current is switched on and off, a current pulse is created. The resulting pulsed waveform is made up of a spectrum of harmonic frequencies, including the 50Hz fundamental and multiples of it. The higher-frequency waveforms collectively referred to as total harmonic distortion (THD), perform no useful work and can be a significant nuisance.

The operation of nonlinear loads causes the distorted current, which is path dependent; the effect of current distortion on loads within a facility is minimal. Therefore, harmonic currents can’t flow into equipment other than the nonlinear loads that caused them. However, the effect of current distortion on distribution systems can be serious, primarily because of the increased current flowing in the system. Therefore current harmonics causes increased losses in the customer and utility power system components.

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 chargers, etc.
- Arc Furnaces
- Power Electronics for motor controls (AC /DC Drives)
- Computers
- Television receivers
- Saturated Transformers
- Fluorescent Lighting
- Telecommunication equipment

Effects of harmonics

The harmonics have a multifold effect on various network elements present in a system. Whenever a harmonic current flows through an equipment,

- It causes additional losses due to its higher frequency, devices such as motors, transformers, etc. which has a laminated core have higher losses due to higher frequency of the harmonic current.
- In cables, the harmonic current trend to flow through the outer skin of the conductor due to skin effect and results in heating of these conductors.
- Harmonics can cause nuisance tripping of the relays and failure of capacitors installed in distribution system for power factor improvement
- Certain harmonic currents (for e.g. 5th harmonic) has the reverse phase sequence which means any electro mechanical device used for metering will not register true values. Similarly, in a polluted network a normal induction motor may not develop necessary torque because of harmonic current generating a torque in the reverse direction
- Higher order harmonics interfere with telecommunication system also. Whenever a telephone line runs parallel to a power line having harmonics, a noise is introduced in the telephone line. This phenomenon is known as telephonic interference
- A highly polluted voltage may lead to mal operation of devices such as thyristors, operation of which depend on the zero crossing of the voltage wave form. This may result in commutation failure in thyristors
- A high harmonic content also results in a low power factor. The angle between the fundamental component of current and voltage gives the Displacement Power Factor, whereas, the same between the voltage and rms current (fundamental and harmonic) gives the total Power Factor. In a linear load, the P.F. and D.P.F. are same, whereas for the loads which generate lot of harmonics, the P.F. is much lower than the D.P.F.
- Some of the harmonic current which are zero sequence current (3rd harmonic current) tend to flow in the neutral in a 3 phase, 4 wire system. In most of the domestic and commercial load, which are non – linear in nature generate substantial amount of 3rd harmonic current, the neutral conductor gets overheated and may lead into melting of the same. It has been observed that in extreme cases, the neutral current can exceed 1.5 times the normal line current
- The harmonic current affect the generator also, as most of the big generators operate at maximum capacity and they do not have excessive margin to accommodate heating losses resulting due to flow of harmonic current into it. All such heating losses result in deterioration of insulation used in electrical equipment.

Mitigation of Harmonics

The best way to deal with harmonics problems is through prevention: choosing equipment and installation practices that minimize the level of harmonics in any one circuit or portion of a facility. Many power quality problems, including those resulting from harmonics, occur when new equipment is haphazardly added to older systems. However, even within existing facilities, the problems can often be solved with simple solutions such as fixing poor or nonexistent grounding on individual equipment or the facility as a whole, moving a few loads between branch circuits, or adding additional circuits to help isolate the sensitive equipment from what is causing the harmonic distortion. If the problems cannot be solved by these simple measures, there are two basic choices: to reinforce the distribution system to withstand the harmonics or to install devices to attenuate or remove the harmonics[2]. Reinforcing the distribution system can be done by installing double-size neutral wires or installing separate neutral wires for each phase, and/or installing oversized or K-rated transformers, which allow for more heat dissipation. There are also harmonic-rated circuit breakers and panels, which are designed to prevent overheating due to harmonics. This option is generally more suited to new facilities, because the costs of retrofitting an existing facility in this way could be significant.

Strategies for attenuating harmonics, from cheap to more expensive, include passive harmonic filters, isolation transformers and active filters.

2 Platts

Functions of Harmonic Filter

1. Reduces neutral current
2. Reduces transformer loading
3. Protects electrical systems
4. Reduces fire hazard
5. Protects the neutral conductor
6. Enhance system protection
7. Minimizes impact on distribution transformers
8. Reduces local neutral local to ground voltage
9. Increases system capacity
10. Decreases system losses
11. Reduces Total Harmonic Distortion (THD)

Passive filters include devices that provide low-impedance paths to divert harmonics to ground and devices that create a higher-impedance path to discourage the flow of harmonics. Both of these devices, by necessity, change the impedance characteristics of the circuits into which they are inserted. Another weakness of passive harmonic technologies is that, as their name implies, they cannot adapt to changes in the electrical systems in which they operate. This means that changes to the electrical system (for example, the addition or removal of power factor–correction capacitors or the addition of more nonlinear loads) could cause them to be overloaded or to create "resonances" that could actually amplify, rather than diminish, harmonics.

Isolation transformers are filtering devices that segregate harmonics in the circuit in which they are created, protecting upstream equipment from the effects of harmonics. These transformers do not remove the problem in the circuit generating the harmonics, but they can prevent the harmonics from affecting more sensitive equipment elsewhere within the facility.

Active harmonic filters, in contrast, continuously adjust their behavior in response to the harmonic current content of the monitored circuit, and they will not cause resonance. Active filters are designed to accommodate a full range of expected operating conditions upon installation, without requiring further adjustments by the operator.

Selection of Harmonic Filter

The selection of harmonic filter must be based on the following criteria

1. kVA requirements of the load
2. Harmonic profile of the load current
3. Harmonic factor of the neutral current
4. Configuration of existing or proposed system

Calculation of Distortions

Current Distortion

Total current distortion, in general defines the relationship between the total harmonic current & fundamental current.

Total Harmonic Distortion, THD(I) = IH/IL

Where, IH = $(I_2^2 + I_3^2 + \ldots + I^2_{25})^{1/2} \times 100$
IL = The maximum Load current (Fundamental frequency component)

The upper summation limit of H = 25 is chosen for practical purpose.

Voltage Distortion

Total voltage distortion in general defines the relationship between the total harmonic voltage and fundamental voltage.

Total Harmonic Distortion THD(V) = VH/VL
Where, VH = $(V_2^2 + V_3^2 + \ldots + V^2_{25})^{1/2} \times 100$ (Total line to neutral harmonic voltage)
VL = Fundamental AC line to neutral voltage

Voltage distortion is created by current distortion or inherent due to the type of voltage source

IEEE Standards

IEEE Standard 519 (1992) 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

Supply System Voltage (kV) at point of common coupling	Total Harmonic Voltage Distortion V_T (%)	Individual HarmonicVoltage Distortion (%)	
		Odd	Even
0.415	5	4	2
6.6 and 11	4	3	1.75
33 and 66	3	2	1
132	1.5	1	0.5

Current Distortion

Maximum Harmonic Current in % of I_L

I_{SC}/I_L	<11	11 < h <17	17 < h <23	23 < h <35	THD
<20	4.0	2.0	1.5	0.6	5.0
20 < 50	7.0	3.5	2.5	1.0	8.0
50 < 100	10.0	4.0	4.0	1.5	12.0
100 < 1000	12.0	5.5	5.0	2.0	15.0
> 1000	15.0	7.0	6.0	2.5	20.0

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

Where, I_{SC} = Maximum short circuit current at PCC
I_L = Maximum demand load current at PCC (Fundamental frequency component)

The allowable % current harmonics is based on the I_{sc}/I_L ratio at that customer's point of common coupling with the utility. The following example shows how to arrive at the I_{sc} / I_L of the transformer.

Consider a transformer of 2000kVA with rated full load current of 2666A. The transformer impedance is 6.42%.

Short Circuit Current I_{sc} = I_L/Z_i
= 2666/.0642
= 41,526A

Therefore I_{sc}/I_L = 41256/2666
I_{sc}/I_L = 15.47

Apart from G5/3, IEEE 519 (1992), other guidelines such as IEC 1000 - 2 -2 define acceptable limits of harmonics in power system. In India, till now no guideline has been published. However, the Central Board of Irrigation & Power (CBIP) is working in this direction and has published a finding on presence of harmonics at various voltage levels for industrial load as well as for utility supply system.

VOLTAGE UNBALANCE[3]

Voltage unbalance degrades the performance and shortens the life of a three-phase motor. Voltage unbalance at the motor stator terminals causes phase current unbalance far out of proportion to the voltage unbalance. Unbalanced currents lead to torque pulsations, increased vibrations and mechanical stresses, increased losses, and motor overheating, which results in a shorter winding insulation life.

Voltage unbalance is defined by the National Electrical Manufacturers Association (NEMA) as 100 times the absolute value of the maximum deviation of the line voltage from the average voltage on a three-phase system, divided by the average voltage. Voltage unbalance is defined as

$$\text{Voltage Unbalance} = \frac{V_{max} - V_{min}}{V_{avg}} \times 100$$

Where $V_{avg} = (V_{RY} + V_{YB} + V_{BR})/3$

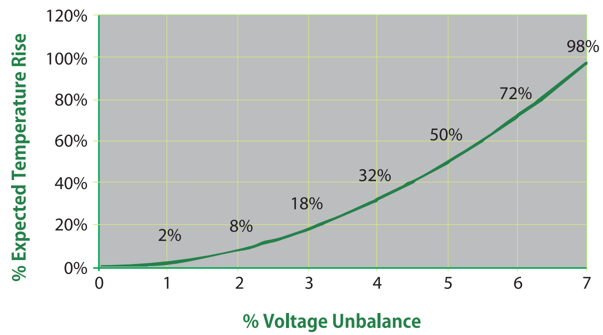
For example, if the measured line voltages are 420, 411, and 405 volts, the average is 412 volts. The voltage unbalance is:

$$\frac{(420-405)}{412} \times 100 = 3.60\%$$

Unbalanced currents and reverse rotation from voltage unbalance produce energy wastage and reduces motor efficiency. The reduction in motor efficiency is proportional to the unbalance and more pronounced at reduced motor load.

3 US Department of Energy

Temperature Rise Caused by Unbalanced Voltages



Voltage unbalance causes extremely high current unbalance. The magnitude of current unbalance may be 6 to 10 times as large as the voltage unbalance. A motor will run hotter when operating on a power supply with voltage unbalance. Winding insulation life is reduced by one-half for each 10°C increase in operating temperature.

Common causes of voltage unbalance include:

- Faulty operation of power factor correction equipment
- Unbalanced or unstable utility supply
- Unbalanced transformer bank supplying a three-phase load that is too large for the bank
- Unevenly distributed single-phase loads on the same power system
- Unidentified single-phase to ground faults
- An open circuit on the distribution system primary

Suggested Actions

- Regularly monitor voltages at the motor terminals to verify that voltage unbalance is maintained below 1%
- Check the electrical system single-line diagrams to verify that single - phase loads are uniformly distributed
- Install ground fault indicators as required and perform annual thermographic inspections

5.0 MOTORS

AC induction motors account for a major share of the total use of electricity in the industrial sector. In the agricultural and commercial sectors also, power consumption by AC motors is quite substantial. About 70% of the electrical energy consumed in India is used for driving electric motors. The energy consumed by a motor in one year is 10 to 20 times the initial purchase cost of the motor. Therefore the efficiency of the motor is of paramount importance right from stage of selection.

Majority of equipment use squirrel cage induction motor as the driving element in industry. The motor loading survey indicates that the most of the motors used in industry are oversized.

This results in poor efficiency, which leads to more energy consumption and energy cost. Therefore, motor loading survey and its improvement must be a part of any comprehensive energy conservation effort.

Oversized / under loaded motors

The efficiency of the induction motors vary with respect to percentage loading of the motors. The maximum efficiency of the motor happens at the full load of the motor. The operating efficiency drops down drastically, if the loading of the motor is less than 60%. In under loaded motors, the iron loss portion is more dominant than the copper loss. Hence the motor power factor is also poor at the lower loading.

The following methods are employed to improve the efficiency of the under loaded motors:

1) Down sizing the motor capacity
2) Converting delta to star connection at the motor terminal
3) Installing automatic star-delta-star converters

Down sizing motor capacity - If the motor is continuously under loaded, one of the options is to down size the motor capacity. This will improve the percentage loading of the new motor and the operating efficiency of the motor is improved. **The expected improvement in efficiency in**

this method is about 4 to 5% of the actual power consumed by the motor.

Delta to star conversion - Converting delta to star connection at the motor terminal is the best option for improving the efficiency of the under loaded motors, if the percentage loading is always less than 40%. When converting delta to star connection in lightly loaded motors, the applied voltage is reduced by 58% of the rated voltage. This reduces the capacity and torque of the motor to 33% of the full load capacity. This results in improvement in efficiency due to the following reason:

- Voltage related iron losses are drastically reduced due to lower operating voltage
- There is an improvement in percentage loading due to which the power factor and operating efficiency of the motor improves

If there is a permanent reduction in loading of the motor below 40%, this method gives an energy saving of 10 to 20%. The overload relay (OLR) of the motor has to be re-set at 58% of the rated current to prevent the motor from 'burn-out' due to overloading condition.

Automatic star-delta-star converters – This can be incorporated in motors, where loading of motors is varying between lightly loaded conditions to higher loading. Auto star-delta-star converter does the function of sensing the load on a continuous basis and operating the motor, either in delta or star mode. If the loading is below 40 %, the motor is automatically put in star mode, thereby achieving energy saving.

If the loading exceeds 40 %, the motor is automatically put in delta mode, thereby protecting the motor from overloading and burning the windings. This is suitable for loads which are operating at lightly loaded condition for longer time and occasionally operating at loading more than 40%.

Replacing old-rewound motors with energy efficient motors

The efficiency of the motor is reduced whenever the motor is rewound. The reduction in efficiency depends on the type of burn-out in the motor and the quality of rewinder. Generally the drop in efficiency varies from 0.5% to 1% for every rewind. When the old motors are rewound more than

5 times, it can be replaced with new energy efficient motor. The overall efficiency improvement considering reduced efficiency of old rewound motor and improvement in energy efficient motor can be up to 10-12%.

Energy Efficient Motors

The efficiency of conventional motors range from 70% to 90% depending on the size of the motors.

Energy Efficient Motors are designed with low operating losses. The efficiency of Energy Efficient motors is high when compared to conventional AC induction motors, as they are manufactured with high quality and low loss materials. The efficiency of Energy Efficient motors available in the market range from 75% to 96%, depending on the size.

The efficiency of Energy Efficient motors is always higher than conventional motors for all ranges of motors. The design improvements in Energy Efficient Motors are :

Stator and Rotor copper loss

Stator and rotor copper losses constitute for 55-60% of the total losses. Copper losses are reduced by using more copper conductors in stator and by using large rotor conductor bars.

Iron loss

Iron loss accounts for 20-25% of the total losses. Using a thinner gauge, low loss core steel and materials with minimum flux density reduces iron losses. Longer rotor and stator core length, precise air gap between stator and rotor also reduce iron losses.

Friction and windage losses

Friction and Windage losses constitute for about 8-10% of the total losses. Friction loss is reduced by using improved lubricating system and high quality bearings. Windage loss is reduced by using energy efficient fans.

Stray load loss

Stray load loss accounts for 4-5% of the total losses. Use of optimum slot geometry and minimum overhang of stator conductors reduces stray load loss.

Loading vs. Efficiency

In industry, the loading of the motors generally vary between 40 – 80% of the rated capacity.

This is because, normally motors are selected one size higher to accommodate higher starting load and varying process requirements. Efficiency of a motor is proportional to the loading of the motor. Conventional Motors operate in a lower efficiency zone when they are under loaded. The Energy Efficient motors operate at a flat efficiency curve above 50% loading.

Advantages of Energy Efficient Motors

- **Maximum efficiency -** Energy Efficient Motors operate at maximum efficiency even when they are lightly loaded because of their better design.
- **Longer life -** Energy Efficient motors dissipate less heat compared to standard motors, as they are more efficient. Use of energy efficient fans keeps the motor at a lower temperature. This increases the life of insulation and windings, besides increasing the overall life of motor.
- **Lower operating costs -** The total energy cost of Energy Efficient motors during its life cycle is much lower when compared to conventional motors.
- **Other benefits**
  - Better tolerance to thermal and electrical stresses
  - Ability to operate at higher ambient temperature
  - Ability to withstand abnormal operating conditions such as low voltage, high voltage or phase imbalance

When to Install Energy Efficient Motors

- When motors are under loaded (50-70% loading) / downsized in an operating plant
- When old motors are rewound more than 5 times.
- When new projects are being considered

Impact of Slip

Rewound motors have higher slip than Energy Efficient motors. While replacing Rewound motors with Energy Efficient motors, one has to consider the impact of a relatively higher speed. In centrifugal equipments, there would be increase in capacity due to high speed, which will result in marginal increase in power consumption. While replacing the old motors with energy efficient motors in centrifugal equipment, increase in capacity also needs to be considered while comparing power consumption.

National Standard for Energy Efficient Motors

The efficiency of the motor is of paramount importance both during selection and operation. Even a small increase in efficiency improvement can make a big difference in energy savings. The need for energy efficiency was felt in late 1970s and manufactures all over the world have started manufacturing energy efficient motors with the aim to increase the efficiency. Over a period, many standards were developed on energy efficient motors by various organizations. As on today we have different standards such as National Electrical Manufacturers Association (NEMA) , Bureau of Indian Standard (BIS) etc.

IS 12615: 2004 (First Revision) is the first national standard for Energy Efficient Induction Motors (Three Phase Squirrel Cage induction motors). IS 12615 covers Energy Efficient motors from 0.37 kW to 160 kW (up to Frame size 315L). IS 12615 specifies two efficiency levels, which are Eff-1 and Eff-2. The efficiency levels of Eff-1 motors are superior to Eff-2 motors.

The energy efficient motors manufactured in India must conform to one of the following efficiency levels specified in IS 12615:

- Improved Efficiency (Eff-2)
- High Efficiency (Eff-1)

The efficiency levels of both Eff1 & Eff2 are higher than the nominal values specified in IS 8789: 1996.

The various standards make it difficult to understand the similarities of different standards. In order to make a harmonization among them the International Electrotechnical Commission (IEC) has introduced a new standard relating to energy efficient motors. IEC 60034-30 defines new efficiency classes for motors and harmonizes various standards around the world. It will hopefully put an end to the difficulties encountered by manufacturers producing motors for the global market. Motor users will benefit through the availability of more transparent and common efficiency standard. The proposed new International motor Efficiency standard IEC 60034-30 classify motors into four different groups such as IE1, IE2, IE3 & IE4. The new standard defines three IE (International Efficiency: IE1, IE2 & IE3) efficiency classes for single-speed, three phase, cage induction motors. IE4 motors are not commercially available as on today.

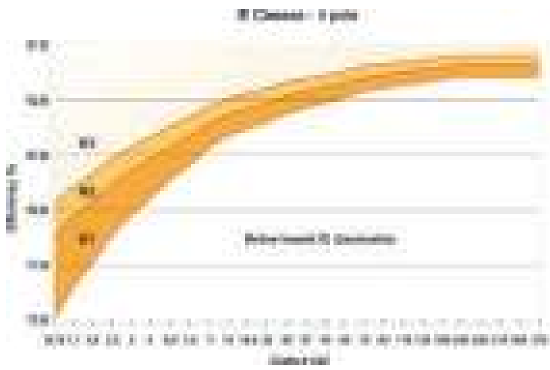
IE Standard in India

Bureau of Indian Standards has taken an immediate step in harmonizing the existing Indian Standard IS 12615 with IEC to the extent possible. The new standard efficiency will be classified as below and is expected to be effective in India from 2012 onwards.

Standard Efficiency	IE1	Comparable to EFF2
High Efficiency	IE2	Comparable to EFF1
Premium Efficiency	IE3	Premium
	IE4	Super Premium

IE Efficiency classes for 4-pole motors at 50Hz is as follows[4]

4 ABB



EFFICIENCY COMPARISON OF IE CLASSIFICATION[5]

Table 1 : Values of Performance Characteristics of 2 Pole Energy Efficient Induction Motors (3000 rpm)

Sl No.	Rated Output	Frame Size	Full Load Speed (Min.)	Full Load Current (Max.)	Breakaway Torque in terms of full load torque (Min.)	Breakaway Current in terms of full load current (equal or below)			Nominal Efficiency (percent)		
						For IE1	For IE2	For IE3	IE1	IE2	IE3
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

5 BIS

Table: 2 Values of Performance characteristic of 4 pole energy efficient induction motors (1500 rpm)

Sr No	Rated Output	Frame Size	Full Load Speed (Min.)	Full Load Current (Max.)	Breakaway Torque in terms of full load torque (Min)	Breakaway Current in terms of full load current (equal or below)			Nominal efficiency (%)		
						For IE1	For IE2	For IE3	IE1	IE2	IE3
	KW		RPM	Amps	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1	0.37	71	1330	1.4	170.0	550	600	650	65.1	70.1	73.0
2	0.55	80	1340	1.7	170.0	550	600	650	69.1	75.1	78.0
1	0.75	80	1380	2.2	170.0	550	600	650	72.1	79.6	82.5
2	1.1	90S	1370	2.9	170.0	550	600	650	75.0	81.4	84.1
3	1.5	90L	1380	3.8	170.0	550	600	650	77.2	82.8	85.3
4	2.2	100L	1390	5.1	170.0	650	700	750	79.7	84.3	86.7
5	3.7	112M	1410	8.1	160.0	650	700	750	82.7	86.3	88.4
6	5.5	132S	1420	11.4	160.0	650	700	750	84.7	87.7	89.6
7	7.5	132M	1430	15.4	160.0	650	700	750	86.0	88.7	90.4
8	9.3	160M	1430	18.5	160.0	650	700	750	86.9	89.3	91
9	11.0	160M	1440	22.0	160.0	650	700	750	87.6	89.8	91.4
10	15.0	160M	1440	30.0	160.0	650	700	750	88.7	90.6	92.1
11	18.5	180M	1440	36.0	160.0	650	700	750	89.3	91.2	92.6
12	22.0	180L	1440	43.0	160.0	650	700	750	89.9	91.6	93.0
13	30.0	200L	1450	58.0	160.0	650	700	750	90.7	92.3	93.6
14	37.0	225S	1450	68.0	160.0	650	700	750	91.2	92.7	93.9
15	45.0	225M	1460	84.0	160.0	650	700	750	91.7	93.1	94.2
16	55.0	250M	1460	100.0	160.0	650	700	750	92.1	93.5	94.6
17	75.0	280S	1470	134.0	160.0	650	700	770	92.7	94.0	95.0
18	90.0	280M	1470	166.0	160.0	650	700	770	93.0	94.2	95.2
19	110.0	315S	1480	204.0	160.0	650	700	770	93.3	94.5	95.4
20	125.0	315M	1480	234.0	160.0	650	700	770	93.4	94.6	95.5
21	132.0	315M*	1480	247.0	160.0	650	700	770	93.5	94.7	95.6
22	160.0	315L**	1480	288.0	160.0	650	700	770	93.8	94.9	95.8
23	200.0	As per manufacturer catalogue	1480	348.0	160.0	650	700	770	94.0	95.1	96.0
24	250.0		1480	435.0	160.0	650	700	770	94.0	95.1	96.0
25	315.0		1480	540.0	160.0	650	700	770	94.0	95.1	96.0
26	355.0		1480	618.0	160.0	650	700	770	94.0	95.1	96.0
27	375.0		1480	653.0	160.0	650	700	770	94.0	95.1	96.0

Note: Output to frame size relation is maintained in accordance with IS 1231 for all motors except those marked as *, wherein the frame size indicated is "preferred size"

Table: 3 Values of Performance characteristic of 6 pole energy efficient induction motors (1000 rpm)

Sr No	Rated Output	Frame Size	Full Load Speed (Min.)	Full Load Current (Max.)	Breakaway Torque in terms of full load torque (Min)	Breakaway Current in terms of full load current (equal or below)			Nominal efficiency (%)		
						For IE1	For IE2	For IE3	IE1	IE2	IE3
	KW		RPM	Amps	Percent	Percent	Percent	Percent	Percent	Percent	Percent
1	0.37	80	870	1.4	160	550	650	650	63.0	69.0	71.9
2	0.55	80	870	1.8	160	550	650	650	67.0	72.9	75.9
1	0.75	90S	890	2.3	160	550	650	650	70.0	75.9	78.9
2	1.1	90L	900	3.2	160	550	650	650	72.9	78.1	81.0
3	1.5	100L	900	4.0	160	550	650	650	75.2	79.8	82.5
4	2.2	112M	910	5.5	150	650	700	750	77.7	81.8	84.3
5	3.7	132S	920	8.8	150	650	700	750	80.9	84.3	86.5
6	5.5	132M	920	12.7	150	650	700	750	82.1	86.0	88.0
7	7.5	160M	930	16.7	150	650	700	750	84.7	87.2	89.1
8	9.3	160L	930	20.3	140	650	700	750	85.6	88.0	89.7
9	11.0	160L	935	23.0	140	650	700	750	86.4	88.7	90.3
10	15.0	180L	940	30.5	140	650	700	750	87.7	89.7	91.2
11	18.5	200L	940	37.5	140	650	700	750	88.6	90.4	91.7
12	22.0	200L	945	44.0	140	650	700	750	89.2	90.9	92.2
13	30.0	225M	945	59.0	140	650	700	750	90.2	91.7	92.9
14	37.0	250M	950	72.0	140	650	700	750	90.8	92.2	93.3
15	45.0	280S	960	87.0	140	650	700	750	91.4	92.7	93.7
16	55.0	280M	960	107.0	140	650	700	750	91.9	93.1	94.1
17	75.0	315S	970	145.0	140	650	700	770	92.6	93.7	94.6
18	90.0	315M	970	173.0	140	650	700	770	92.9	94.0	94.9
19	110.0	315M**	970	214.0	140	650	700	770	93.3	94.3	95.1
20	125.0	315M**	970	245.0	140	650	700	770	93.4	94.6	95.2
21	132.0	315L**	980	257.0	140	650	700	770	93.5	94.6	95.4
22	160.0	as per motor mfr catalogue	980	315.0	140	650	700	770	93.8	94.8	95.6
23	200.0		980	370.0	140	650	700	770	94.0	95.0	95.8
24	250.0		980	461.0	140	650	700	770	94.0	95.0	95.8
25	315.0		980	583.0	140	650	700	770	94.0	95.0	95.8
26	355.0		980	657.0	140	650	700	770	94.0	95.0	95.8
27	375.0		980	694.0	140	650	700	770	94.0	95.0	95.8

* Efficiency values are subject to tolerance as per IS325

* The value of required efficiency should be met up to 45 deg C ambient temperature and 1000 meter altitude

COVERAGE OF THE STANDARDS

As part of the harmonization of different standards the International Efficiency (IE) covers the following area.

Inclusions:

- Single-speed, three-phase, 50 and 60 Hz
- 2, 4 or 6-pole
- Rated output from 0.75 to 375 kW
- Rated voltage up to 1000 V
- Duty type S1 (continuous duty) or S3 (intermittent periodic duty) with a rated cyclic duration factor of 80% or higher
- Capable of operating direct online 50 and 60 Hz

Exclusions :

Motors made solely for converter duty application in accordance with IEC 60034-25, motors completely integrated into the machine (e.g pumps, compressors, special machines etc) that cannot be tested separately from the machine and the motors rated for duty cycles S4 (Intermittent periodic duty with starting) and above are excluded for the scope of this standard.

Energy Saving Calculation

The formula for calculating the savings on account of replacing old motors with energy efficient motor is given below:

Where,	Let E_{old}	=	Efficiency of standard motor, in %.
	E_{new}	=	Efficiency of energy efficient motor, in %
	P	=	Power output of motor, in kW
	H	=	Number of hours of operation of motor per year

Energy saved per annum in kWh = $P\,[(1 / E_{old}) - (1 / E_{new})] \times 100 \times H$

Motor Selection

The energy saving techniques (Energy Efficient motors) employed in motor design adds to its cost. The value of these savings is seen in reduced energy costs. Even though, no standard method is available for comparing the efficiency evaluation of motors at site, the following method can be followed for evaluating the cost economics.

$$\text{Capitalized cost of motor} = \left\{ \begin{array}{l} \text{Initial Cost} + [(1-\eta_{at\ running\ load}) \times \\ \text{Load Factor} \times \text{Annuity factor} \times \text{EC} \times \\ \text{Operating hrs / annum} \times \text{Motor rating} \end{array} \right.$$

Where,

$\eta_{at\ running\ load}$	=	% efficiency from manufacturer catalogue at the likely percentage Loading
Load Factor	=	Ratio of average load in kW supplied during a designated period to the peak or maximum load in kW occuring in that period
Annuity factor	=	$\dfrac{(1 + r)^n - 1}{r(1 + r)^n}$
r	=	Rate of interest
n	=	No. of years of operation
EC	=	Energy cost (Rs / kWh)

The efficiency of the motors depends on the percentage loading. The details of efficiency at different loading should be known for calculating capitalized cost of motors.

The following example shows cost economics calculation for two different efficiency motors at 75% loading.

Consider two 90 kW, 4 pole motors with the efficiency of 94.5% and 93.5% at 75% loading. The cost of the motors is Rs.1.45 lakhs and Rs.1.30 lakhs respectively.

Capitalized cost of Motor.1

Capitalized cost of Motor = Initial cost +[(1 - $\eta_{at\ running\ load}$) x Load Factor x Annuity factor x EC x operating hrs/annum x Motor rating]

Initial cost	=	Rs.1, 45,000/-
Load factor	=	0.75
η @ 75% loading	=	94.5%
Annuity factor	=	$\frac{(1+r)^n - 1}{r(1+r)^n}$
Where, r	=	18%
n	=	10 years
Annuity factor	=	4.49
EC	=	Rs.3.00 / kWh
Annual operating hours	=	8000 hrs
Motor rating	=	90 kW
Capitalized cost of motor-1	=	Rs.5,45,000/-

Capitalized cost of Motor.2

Capitalized cost of Motor = Initial cost +[(1 - $\eta_{\text{at running load}}$) x Load Factor x Annuity factor x EC x operating hrs/annum x Motor rating]

Initial cost	=	Rs.1, 30,000/-
Load factor	=	0.75
η @ 75% loading	=	93.5%
Annuity factor	=	$\frac{(1+r)^n - 1}{r(1+r)^n}$
Where, r	=	18%
n	=	10 years
Annuity factor	=	4.49
EC	=	Rs.3.00 / kWh
Annual operating hours	=	8000 hrs
Motor rating	=	90 kW
Capitalized cost of motor-1	=	Rs.6, 02,800/-

The annual cost of energy saved by selecting high efficiency motor is Rs.57, 800/-

The above method can be followed for selecting the energy Efficient Motor at Design Stage

Energy Efficient motors therefore have tremendous potential for energy saving. Energy Efficient Motors are 15-20% more expensive than conventional motors. However, as above, the additional investment on Energy Efficient motors can be recovered in 1 to 3 years time, depending on the working hours and cost of energy. Energy Efficient motors have been successfully implemented in several plants both at the design stage and as retrofits in existing plants, resulting in substantial energy saving.

Speed Control Of Motor

i) Variable Frequency Drives (VFDs)

Variable frequency drives have become more popular in industry due to very high energy saving potential in various applications like centrifugal equipment. The operating speed of a motor connected to a VFD is varied by changing the frequency of the motor supply voltage. LT VFDs are used as a speed control technology for majority of the low voltage drive applications that results in enormous energy saving.

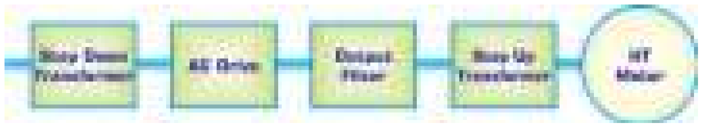
VFDs convert the fixed-frequency supply voltage to a variable frequency, thereby allowing motor to operate at desired speed. If speed control is to be achieved by changing the frequency, the supply voltage also has to be changed simultaneously. If supply frequency is reduced keeping the applied voltage constant, the flux increases, which causes increasing excitation current and core losses. This will reduce the efficiency of the motor. On the other hand, if the frequency is increased, flux will decrease, thereby reducing the torque developed. Therefore it is important that the frequency and voltage should be changed proportionately so that V/f is kept constant.

The motor should be located as close to the VFD as possible. For applications where the motor is to be located more than specific distance away from the VFD, a load reactor or dV/dt filter should be installed. As motor lead length increases, voltage spikes generated by the VFD's output transistors become amplified. In extreme cases, these spikes can result in premature insulation breakdown in the motor. Adding an output reactor or dV/dt filter reduces the spikes. The suggested maximum length of the cable from VFD to motor for different capacities of motor that can be used without any chokes/filter is given below.

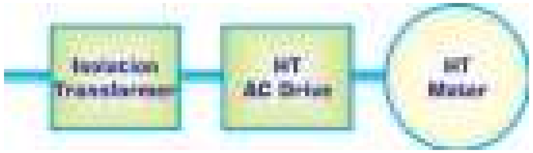
Motor Rating	Maximum Length of cable
0.75kW	25 m
1.1 kW	30 m
1.5 kW	40 m
2.2 kW	50 m
4.0 kW	60 m
5.5-11 kW	100 m
15-37 kW	150 m
45-110 kW	200 m
120 kW	300 m

ii) HT Variable Frequency Drives

Apart from the commonly used low voltage VFDs, the application of HT VFD's for the control purpose has become popular now a day with the advancement in technology. The HT VFDs are rated among the following voltage level; 2.3kV, 3.3kV, 4kV, 6.6kV, 11kV. Traditionally for the application in the above mentioned voltages, a step down transformer is used at the front end followed by an LT VFD and output filter with a step up transformer at the output for stepping up the voltage.



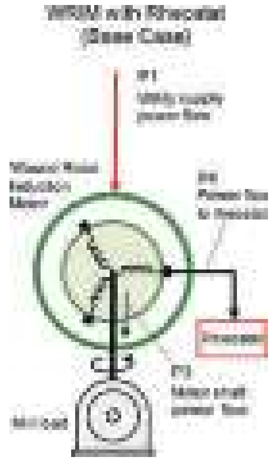
Presently HT VFDs are available without any need of voltage transformation. This allows the drive to be directly connected to the motor through an HT VFD without the step down/up transformer. The isolation transformer with multiple secondary windings is provided to mitigate the line side harmonics and common mode voltage. At present with the technology improvements the high voltage AC drives are available without the isolation transformer.



The HT VFDs are widely used in oil, petrochemical, cement, pulp & paper, sugar, steel industries etc. The reliability of the system has improved a lot and is successfully running in many of the plants. The energy savings achieved by the application of HT VFDs are tremendous when compared to other type of speed control for HT drives.

iii) Grid Rotor Resistance

The wound rotor induction motors are popular as large drives used for speed control necessary as part of process requirements. The rotor has a three-phase winding, usually connected in a wye (or star) circuit. The three terminals of the rotor winding are connected to separate slip rings. Brushes ride on these slip rings and the rotor winding is connected to an external liquid rheostat or resistor bank. This resistance, when inserted into the rotor circuit, adds to the rotor resistance and reduces starting currents. The motor speed can be adjusted by changing the resistance. The grid resistors are made up of punched stainless steel, of uniform cross section with high thermal capacity. These resistors will be connected in series of four or five sections, depending on the percentage of speed variation. The continuous power flowing into the resistor is lost as heat. Adding resistance to the rotor circuit also changes the speed at which maximum torque occurs for the motor, so high torques can be produced at low speed for starting loads with high breakaway torque requirements. The resistors have to be provided with adequate number of cooling fans, to dissipate the heat generated



Speed control using rotor resistance known as Grid Rotor Resistance (GRR) is popular in many of the process industries and the speed reduction has resulted in good savings. The speed can be controlled in the range of 60 to 100% of the rated speed of the motor with the help of GRR. But the introduction of resistance in the circuit to control the speed will result in resistance losses which will be dissipated as heat. The losses incurred in GRR can be calculated as follows

Losses in GRR= Total Power Measured at the motor terminal * S * (1-S^2)
Where, S represents the slip at which the motor is operating.

The slip of the motor can be calculated as S= (N_s-N)/N_s where N_s represents the synchronous speed and N is the speed of the motor corresponding to the GRR step at which it is operating.

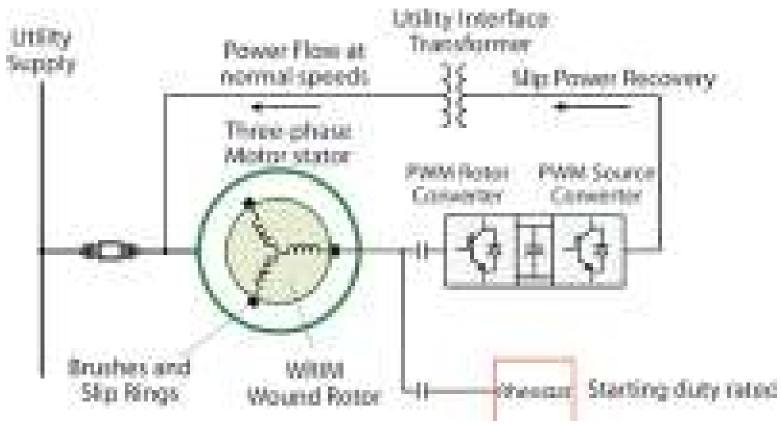
For example, consider a motor of capacity 2200 kW operating at 1636 kW whose speed is controlled by GRR. The GRR step is kept at 27 out of 32 and speed corresponding to 27th step is 88% of the rated value.

Hence GRR loss =1636 * 0.12 * (1 - 0.12^2) = 193kW

Even though the total power consumed is reduced by introducing the GRR, 12% of total power (193kW) is being lost as heat out of the total power 1636kW.

iv) Slip Power Recovery Systems (SPRS)

Most of the slip ring induction motors, especially HT and high capacity motors, connected to fans and blowers in the power intensive sectors such as cement, petrochemical require speed variation to match the process requirements. In the conventional methods of speed variation Grid Rotor Resistance is used. These proved speed variation, but operates at less efficiency. Consequently a new method of speed control known as Slip Power Recovery Systems (SPRS) was developed. The slip power recovery system is an external system connected to the rotor circuit in place of the external resistors. The SPRS provides speed and torque control like the resistors but can also recover the power taken off the rotor and feed it back into the power system to avoid energy waste. In usual practice, an SPRS drive consists of two interconnected power converters as shown in the figure. The rotor converter is connected to the three-phase rotor winding. The feedback power converter is connected to the power system, usually through a transformer that matches the output voltage of the converter to the power system. The regenerative or feedback power converter is controlled to modulate the amount of power put back into the power system, allowing control of the motor speed[6]. All the rotor energy previously lost as heat in the GRR system is saved now, and for large motors, these results in significant cost savings.



The speed control using SPRS system is possible efficiently in the range of 60 to 95% of the rated speed of the motor. Above 95% operating speed the recovery potential is very negligible and hence not recommended.

*GRR & SPRS control is only for Slip ring induction motor while VFD can be employed for both Slip ring and Squirrel Cage Induction motor.

6 ICR 2009

6.0 Intelligent MCCs

Power distribution systems used in large commercial and industrial applications can be complex. Power may be distributed through switchgear, switchboards, transformers, and panel boards. Power distributed throughout a commercial or industrial application is used for a variety of applications such as heating, cooling, lighting, and motor-driven machinery. Wherever motors are used, they must be controlled. In many commercial and industrial applications, quite a few electric motors are required, and it is often desirable to control some or all of the motors from a central location. The apparatus designed for this function is the motor control center (MCC)[7]. Motor control centers are simply physical groupings of combination starters in one assembly. A combination starter is a single enclosure containing the motor starter, fuses or circuit breaker, and a device for disconnecting power. Other devices associated with the motor, such as pushbuttons and indicator lights may also be included.

The distribution of electrical power must today satisfy ever-increasing needs for dependability and efficiency. Energy must be available not only to ensure the comfort and safety of users, but also to avoid the costs incurred by power failures. Electrical installations must therefore be monitored and be capable of reacting automatically to optimise power distribution. In this way the Intelligent MCC's have the ability to have real time and historical knowledge of conditions and factors that affect motors and their control. At the same time it also provides remote or automatic control of motors and the plant process. This will help in increasing the plant reliability and system efficiency.

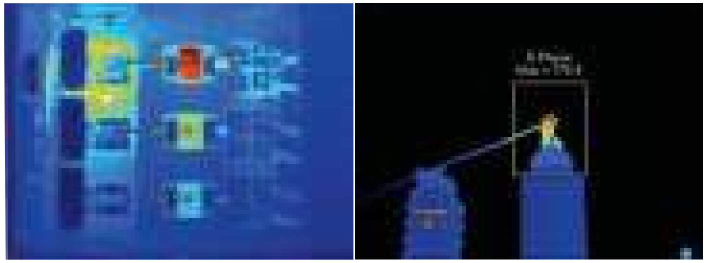
Advantages

- Historical database of the running hours of the motor
- Quality of power supplied to the motor
- Log of individual motor fault conditions

7 Siemens Technical Education Program (STEP)

7.0 Thermography

Thermography can be defined as the temperature profiling of an area. All objects radiate energy whether it is hot or cold. More energy is radiated as the surface temperature of the object increases and is radiated in the form of infrared rays. Infrared thermography (IR Cameras) can be used to detect the heat radiation from the object. It converts it into visible light and assigns a colour related to the intensity of energy being released. Thermography instrument is used for monitoring the condition of electrical systems and equipments. When a system is energized current starts flowing and produces heat. If there is any defect exists in any part of the system, more heat will be generated from that point due to high resistance. The infrared camera can be used to distinguish between the normal components with the defected parts.



Courtesy: Fluke

Advantages

- Accurate fault/hotspot detection
- Reduce the risk of fire in electrical control panels
- Improve the efficiency of electrical and mechanical equipment
- Predict insulation breakdown, so corrective services can be performed accordingly
- Prevent the unscheduled down time of equipment
- Increased Mean-Time-Between-Failures (MTBF)
- Increased productivity and profitability
- Increases the service life of the equipment

8.0 Lighting

Good lighting is required for good visibility. Although good visibility of relevant objects is a necessary condition, it is not always enough to perform activities easily and comfortably. In indoor areas, where a task is performed, the main function of lighting is to provide comfort for visual tasks in this place. However, in circulation areas, resting areas or living rooms, visual capacity criterion is not so important. Pleasantness and visual comfort is what matters. Thus, the most important criteria related to lighting design for a particular application are visibility and visual satisfaction. Moreover, such factors must be well balanced in relation to installation and working costs. Recent estimates indicate that energy consumption by lighting is about 20 - 45% of a commercial building's total energy consumption and about 3 - 10% in an industrial plant's total energy consumption.

Terminologies

Luminous Flux

A luminous flux produced by a source of light is the total amount of light, either emitted or radiated in all directions in one second. Luminous flux is represented by the Greek letter φ and is measured in lumens (lm).

Illuminance

Illuminance or luminous level of a surface is the ratio between the luminous flux received by the surface to its area. It is represented by the letter E, and its unit is the lux (lx). The illuminance is independent of the direction from which the luminous flux reaches the surface.

Luminous Intensity

Luminous intensity is the concept for the concentration of light in a specific direction, radiated per second. It is designated by the symbol L. The unit is the candela (cd).

Luminous Efficacy

Luminous performance of a source of light indicates the flux emitted by this source per unit of electrical output consumed to obtain it. It is represented by the Greek letter ϵ, and it is measured as lumen/watt (lm/W). The formula which expresses luminous efficacy is:

$$\epsilon = \varphi/P \text{ (lm/W)}$$

Colour Rendering Index (CRI)

Colour rendering index (CRI or R_a) is a measure of how far the surface colours can faithfully be reproduced under the artificial light source. The index number varies from 0 to 100. True colour rendition is possible with high CRI. The colour rendition of an object is dependent on the light source. Various light sources have different colour rendering index. The amount of colour rendition required depends on the type of the application. The amount of colour rendition required for different types of application is given below.

The colour rendering properties of a particular lamp are described by its colour rendering group or the CIE number (Commission Internationale de L'Eclairage) as below.

Group	R_a	Importance
1A	$R_a > 90$	Wherever accurate colour rendering is required e.g. colour printing inspection
1B	$80 < R_a < 90$	Wherever accurate colour judgments are necessary or good colour rendering is required for reasons of appearance e.g. display lighting
2	$60 < R_a < 80$	Wherever moderate colour rendering is required
3	$40 < R_a < 60$	Wherever colour rendering is of little significance but marked distortion of colour is unacceptable
4	$R_a < 40$	Wherever colour rendering is of no importance at all and marked distortion of colour is acceptable

Light Sources

Incandescent lamp

The incandescent lamp is the oldest source of electric light. Incandescent lamps produce light through the electric heating of a wire (the filament) at a high temperature, emitting radiation within the visible field of the spectrum. Most of the energy is lost as heat in the case of this type of lamps and hence it has very low luminous efficacy.

Compact Fluorescent Lamps (CFL)

CFLs work much like standard fluorescent lamps. They consist of two parts: a gas-filled tube, and magnetic or electronic ballast. The gas in the tube glows with ultraviolet light when electricity from the ballast flows through it. The UV light hits the white phosphor coating inside the fluorescent bulb and the coating changes it into light. Because fluorescent bulbs don't use heat to create light, they are far more energy-efficient than regular incandescent bulbs.

Fluorescent tubes

Fluorescent tubes are a low pressure mercury discharge lamp in which light is produced predominantly through fluorescent powder activated by the discharge of ultraviolet energy. The lamp, generally with a long tubular-shaped glass bulb and a sealed electrode for each terminal, contains low pressure mercury and a small amount of inert gas for ignition and arc regulation. The glass bulb inner surface is covered by a luminescent substance (fluorescent powder or phosphorous) whose composition determines the amount of emitted light. The fluorescent tubes have been gone through three generations. The first generation was T12 lamps of 40W, second was T8 lamps of 36W and the latest is T5 lamps with 28W.

Parameters	Incandescent Lamp	Compact Fluorescent Lamp (CFL)	Fluorescent Tubes		
			T12	T8	T5
Wattage (W)	3-1500	5-85	40	36	28
Lumen (lm)	18-36000	220-5525	2450	2450	2900
Efficacy (lm/W)	6-24	44-65	60	68	104
Average Rated Life (hrs)	750-2000	10000	5000	8000	18000
CRI	100	80	65	72	85

High Intensity Discharge Lamps

HID lamps are that produce light directly from an arc discharge under high pressure. Metal Halide, High pressure sodium and mercury vapor lamps are the types of HID lamps.

High Pressure Mercury Vapour Lamp (HPMV)

Mercury vapour lamps uses mercury as the primary light producing element. Mercury vapor lamps are the oldest style of HID lamp. Although they have long life and low initial cost, they have poor efficacy.

Metal Halide Lamps

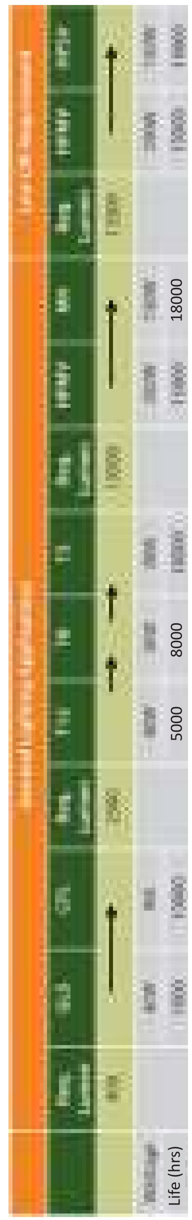
MH lamps are a type of high-intensity discharge (HID) lamp that offers long lamp life, high efficacy, and good color rendering properties. Metal halide lamps produce light by passing an electric arc through a mixture of gases. In a metal halide lamp, the compact arc tube contains a high-pressure mixture of argon, mercury, and a variety of metal halides.

High Pressure Sodium Vapour Lamp (HPSV)

High Pressure sodium vapour lamps uses sodium under high pressure as the primary light producing element. The high pressure sodium (HPS) lamp is widely used for outdoor and industrial applications. Its higher efficacy makes it a better choice than metal halide for these applications, especially when good color rendering is not a priority.

Parameters	Metal Halide	HPMV	HPSV
Wattage (W)	70-400	80-400	70-400
Lumen (lm)	5600-35000	3400-22750	5600-47500
Efficacy (lm/W)	80-90	40-55	80-120
Average Rated Life (hrs)	15000-20000	15000	18000
CRI	65-96	55-60	<40

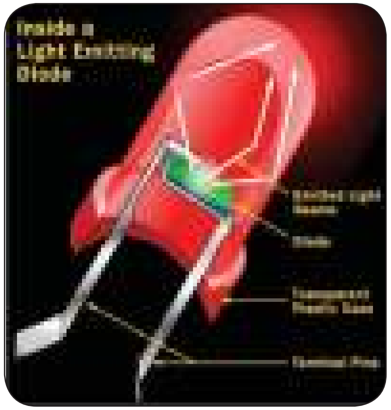
Selection Guideline for Energy Efficient Lamps



* Arrow mark indicates Change of light source from low efficacy to high efficacy lamps

Light Emitting Diodes

A Light-Emitting Diode (LED) is a P-N junction solid-state semiconductor diode that emits light when a current is applied though the device. Once used just as indicator lights for electronics, LEDs have evolved into a major lighting technology that changed the future of general illumination. LEDs are highly regarded for their long life, energy efficiency, non-toxicity, durability, and flexibility. The essential portion of the Light Emitting Diode is the semiconductor chip. The colour of the light output from the LED depends on the type of the semiconductor material used.

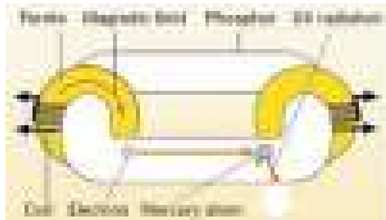


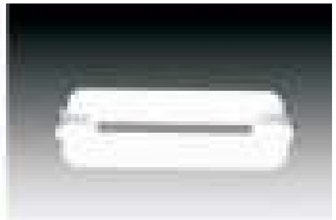
The advantages of LED lamps are

- Smaller in size
- Low power consumption
- Suitable for frequent on/off operation
- High resistance to vibration and shock
- Low specific power consumption for the corresponding light output of a conventional lamp
- Longer life as high 100,000 hrs of operation

Induction Lamps

Induction lamps are high frequency (HF) light sources, which work on the basic principle of converting electrical power into visible radiation as conventional fluorescent lamps. The fundamental difference between induction lamps and conventional fluorescent lamps is that the former operate without electrodes. The life of the induction lamps is longer due to the absence of the electrodes in the same. The induction lighting is based on the principles of induction and light generation through gas discharge.



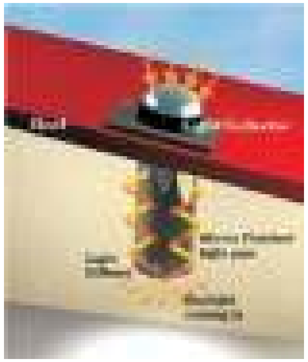


Parameters	Induction Lamps
Wattage (W)	72-150
Lumen (lm)	6500-12000
Efficacy (lm/W)	85
Average Rated Life (hrs)	80000
CRI	80

Day Lighting by light pipes

In the era of global warming and energy deficit the planned use of day lighting can bring up reduction in energy usage on lighting, heating and air conditioning. Day lighting provides ample light with good colour rendition. If not used in the proper way daylighting can cause uncomfortable solar glare and very high luminance reflection that affects the proper vision. The day lighting can be majorly of following types;

light shelves, using venetian blinds and by light transport systems. Light Transport Systems such as light pipes collect and transport sunlight over some distance to the core of a building.



Courtesy: Skyshade

Light pipe essentially has a top light collecting dome exposed to the sun light. The light collected by the top dome is then transferred through a reflective tube which reaches the diffuser at the bottom. The light diffuser distributes light evenly through out the place. The reflective pipe has a static air column that reduces the heat transfer which again reduces with the increase in length of the tube.

9.0 Approach to Energy Audit in Electrical Systems

In a world concerned about energy shortage, carbon emissions, global warming, and sustainable design, improving the energy efficiency has become a prime important matter. One way of achieving this is by conducting detailed energy audit in the industry. This section gives a detailed methodology of conducting energy audit in the electrical systems.

First and foremost requirement is to ensure that the following information is readily available in hand.

- Single Line diagram of the electrical power distribution system
- Section wise motor list of both the LT and HT drives with operating hours
- Transformer test certificate details
- Electricity bill for the past one year
- Distribution of capacitor banks if installed
- Area wise Lighting details in the plant (Type of lamps, Wattage, Quantity)

With the above mentioned details the audit can be kick started. After the collection of above mentioned details the measurements has to be made. For measurements a portable power analyzer is required for analyzing the loading pattern of motors and transformers. It can be a single phase or three phase power analyzer. If a well designed energy management system is available then measurement can be directly taken from the system.

The following measurements are required

- Power distribution side
  - Power factor
  - Measure V_{RY}, V_{YB}, V_{BR}
  - Frequency if island mode operation
- Transformer
  - Loading of the transformer
  - Power factor of operation

- Harmonics level
- Secondary voltage level (V_{RY}, V_{YB}, V_{BR})
- Set tap position of the transformer and available tap positions
- For more than one transformer operating in a single bus check whether ON/OFF position of the bus coupler

% Loading of the transformer= (Measured kVA / Rated kVA) x100

- Motor
  - Voltage, Current, Power Factor and Loading kW
  - For variable loads take a trend of the loading pattern
  - If VFD is provided for the motor, measure at the VFD input
  - If motor is driven by VFD, note down the operating speed
  - If motor is provided with GRR/SPRS note down the GRR step position/SPRS power recovery
  - Standard motor/ Energy efficient motor

% Loading of motor= (Measured kW / Rated kW) x100

- Lighting
  - Take single phase power measurement
  - Note down Voltage, Current, Power Factor and loading kW
  - If lighting transformer is provided take measurement at both primary and secondary
  - Take a note of the available tap setting at the secondary of the lighting transformer
  - Ensure that the measurement is taken when the lighting load is maximum

Distribution losses are common in all type of power systems. Voltage drops indicate the presence of losses in the distribution system. Voltage drops are inherent, but drops above 5V indicate the presence of distribution losses in the system. The possible reasons for voltage drop in a system could be

- Inadequate cable size
- Poor power factor
- Poor contact surface at cable joints, terminations, contactors/ switches

- Distribution losses study
  - Ensure that both the instruments are calibrated
  - Simultaneous measurement of voltage at the sending and receiving end of the feeder
  - Measure power factor and current
  - Note down the cable size

$$\text{Losses in the cable} = \sqrt{3}*(V_S-V_R)*I \text{ in Watts}$$

Where V_S is the sending end voltage
V_R is the receiving end voltage

List of Energy Saving Projects :

1. Change the electrical connection from delta to star for lightly loaded motors
   - This can be applied when the load is permanently less than 40%. The on load relay setting must be changed in this case
2. Install Auto-star-delta-star converters for variable and shock loads
   - If the load is less than the set point of 40%, it will operate in star mode otherwise it will operate in delta mode.
3. Install automatic power factor controllers and maintain high PF
   - Monitor and control the power factor and reduce the voltage drop and losses in the distribution system Maintaining higher power factor help in reaping the benefits from incentives provided by the electricity board
4. Install capacitor banks to improve power factor
   - For large size motors operating with poor PF, installing a capacitor bank at load end will improve power factor. This will also result in reduction of reactive current flow through the power system
5. Distribute load on transformer network in an optimum manner
   - Distribute the load on transformers such that the loading is 40 to 60% to operate the transformers at maximum efficiency.
   - For distribution transformer max. efficiency occurs at 40 to 60% of load

- For power transformer max. efficiency occurs at 60 to 80% of load

6. Minimise overall distribution losses, by proper cable sizing and addition of capacitor banks
   - By connecting capacitors, current can be reduced and there by voltage drop and I^2R loss can be minimised
   - Voltage drop should be less than 5 V
7. Optimise TG sets operating frequency, depending on user needs
   - In some cases where there is a margin, substantial savings can be achieved by optimising the TG set frequency during island mode of operation
8. Optimise the operating voltage
   - By reducing the operating voltage power consumption can be reduced provided the motor is lightly loaded and there is margin to reduce voltage
9. Use VFD for low / partial loads
   - Power consumption is proportional to cube of speed. This can be applied for varying centrifugal loads
10. Install maximum demand controller to optimize maximum demand
    - Helps to keep the maximum demand within the limits and saves from penalty
11. Replace rewound motors with energy efficient motors
    - As a thumb rule motor rewound for more than 5 times can be replaced with energy efficient motor
12. Replace V-belts with synthetic flat belts/Cogged 'V' belts
    - Wedge in and wedge out losses can be avoided
13. Install Soft Starter cum Energy saver for lightly loaded motors
    - Soft starter increases the voltage linearly keeping the starting current within the limits
14. Install on-load tap changer (OLTC) for the main transformer and optimising the voltage
    - By installing OLTC, tap position can be changed without interrupting the power supply
15. Avoid unbalance in voltage by proper distribution of load at the transformer secondary
    - Reduction in unbalance will improve the operating efficiency and increase winding life of motors
16. Replace GRR with VFD/SPRS for slip ring induction motor for speed control applications
    - Power loss in GRR can be avoided by installing VFD or by recovering the power by using SPRS
17. Install harmonic filters and reduce Total Harmonics Distortion
    - Harmonics are introduced by non linear loads. By installing proper harmonic filter they can be kept within the limit
18. Maintain voltage at 210-220V for lighting applications
    - Install lighting transformer if power is taken directly from the distribution transformer
    - Reduce the tap setting of the transformer (if already installed) to maintain the voltage in the range of 210-220V
19. Install T5 fluorescent lamps in place of T12/T8 lamps
    - Energy efficient T5 lamps consumes 28-30W when compared to 50W power consumption of T12/T8 lamps along with magnetic ballast
20. Install Metal halide lamps instead of mercury vapour lamps
    - For better colour rendition application use metal halide lamps of higher luminous efficacy (80 lm/W) when compared to the lower efficacy (55 lm/W) of mercury vapour lamps
21. Install light pipes for harvesting daylight and avoid artificial lighting during day time
    - Light pipes can be installed in offices, assembling areas, godowns etc and avoid the artificial lighting

Miscellaneous Energy Saving Tips :

- Use ceiling or table fan as first line of defense against summer heat.
- A good air conditioner will cool and dehumidify a room in about 30 minutes, so use a timer and leave the unit off for some time.
- Check for holes or cracks around your walls, ceilings, windows, doors, light and plumbing fixtures, switches, and electrical outlets that can leak air into or out of your home.
- Make sure your appliances and heating and cooling systems are properly maintained. Check your owner's manuals for the recommended maintenance.
- Turn off kitchen, bath, and other exhaust fans within 20 minutes after you are done cooking or bathing; when replacing exhaust fans, consider installing highefficiency, low-noise models.
- During the summer season, keep the window coverings closed during the day to prevent solar gain.
- Turn off the lights in any room you're not using, or consider installing timers, photo cells, or occupancy sensors to reduce the amount of time your lights are on.
- To maximize savings with a laptop, put the AC adapter on a power strip that can be turned off (or will turn off automatically); the transformer in the AC adapter draws power continuously, even when the laptop is not plugged into the adapter.
- Turn off your computer and monitor when not in use.
- Wash only full loads of dishes and clothes.

10.0 Basic Definitions in Electrical Systems

Active Power

The Active Power (Watt) is that portion of electrical power that is real. Utility charges are based on kilo-Watt hours.

Alternating Current

(AC)- A current which periodically changes its direction.

Alternating Voltage

A voltage which periodically changes its polarity.

Alternator

An alternating current generator.

Ammeter

An electric meter used to measure current, calibrated in amperes.

Amp

The unit of electrical current. (See Ampere)

Ampacity

The current-carrying capacity of conductors or equipment, expressed in amperes.

Ampere

The basic unit measuring the quantity of electricity. The unit of current flow. Represented by I.

Ampere-Hour Capacity

The quantity of electricity measured in ampere-hours (Ah) which may be delivered by a cell or battery under specified conditions.

Ampere-Hour Efficiency

The ratio of the output of a secondary cell or battery, measured in ampere-hours, to the input required to restore the initial state of charge, under specified conditions (also coulombic efficiency).

Amplification

Procedure of expanding the strength of a signal.

Amplifier

A device used to increase the strength of a signal.

Amplitude

The maximum value of a wave.

Apparent Power

Apparent Power (VA) is the product of the rms voltage and current which relates to the effective load seen by the transformer and current carrying conductors.

Armature

That part of an electric generator in which the voltage is induced.

Armature Coil

A winding that develops current output from a generator when its turns cut a magnetic flux.

Armored Cable

Cable with a metal sheathing.

Attenuation

The reduction of a signal from one point to another. For an electrical surge, attenuation refers to the reduction of an incoming surge by a limiter (attenuator). Wire resistance, arresters, power conditioners attenuate surges to varying degrees.

Attenuator

A device that reduces signal power.

Autotransformer

A transformer used to step voltage up or down. The primary and secondary windings share common turns, and it provides no isolation.

Auxiliary Contacts

Subordinate contacts which operate with the movement of the main contacts.

Auxiliary Source

A power source dedicated to providing emergency power to a critical load when commercial power is interrupted.

AWG

American Wire Gauge. This term refers to the U.S. standard for wire size.

Ballast

An auxiliary electrical device for fluorescent and other discharge light sources.

Battery

A device for turning chemical energy into electrical energy.

Bonding Bushing

A conduit bushing that has conductor terminal used to bond the conduit.

Bonding Jumper

A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.

Branch Circuit

The circuit conductors between the final over current device protecting the circuit and the outlet(s).

Breaker Tie

A metal device used to connect one or more circuit breaker handles, so that they switch at the same time.

BTU

British Thermal Unit. Energy required to raise one pound of water over one degree Fahrenheit. One pound of water at 32 degrees F requires the transfer of 144 BTUs to freeze into solid ice.

Buck-Boost Transformer

A small, low voltage transformer placed in series with the power line to increase or reduce steady state voltage.

Busbar

A heavy rigid conductor used for high voltage feeders.

Candlepower (or Candela)

Basic unit for measuring luminous intensity from a light source in a given direction.

Capacitance

The property of a capacitor that determines the quantity of electric energy that it can store.

Capacitor

A device consisting of two conducting surfaces separated by an insulator and having the ability of storing electric energy. Also called a condenser.

Conductor

Metal wires and cables that allow the flow of electrical current.

Connected Load

The combined continuous rating of all the equipment connected to the system or part of the system under consideration.

Continuous Load

A load where the maximum current is expected to continue for three hours or more. Rating of the branch circuit protection device shall not be less than 125% of the continuous load.

Controller

A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.

Converter

A device which changes electrical energy from one form to another. There are several types of converters.

Crest Factor

The ratio of the peak or maximum value of a wave, to the r.m.s. value.

Current

The movement of electrons through a conductor. Measured in amperes and its symbol is "I".

Current Ratio

The current ratio of a current transformer is the ratio of r.m.s. primary current to r.m.s. secondary current, under specified conditions of load.

Current Transformer-(or CT)

A transformer used in instrumentation to assist in measuring current. It utilizes the strength of the magnetic field around the conductor to form an induced current that can then be applied across a resistance to form a proportional voltage.

Cycle

One complete wave of positive and negative values of an alternating current. (See "Hertz").

Demand Factor

The ratio of the maximum demand of a system, or part of a system, to the total connected load of a system or the part of the system under consideration.

Displacement Power Factor, DPF

The ratio of real power to apparent power. Displacement Power Factor is the cosine of the phase angle between the fundamental current and the fundamental voltage. Inductive loads cause current to lag behind voltage, while capacitive loads cause current to lead voltage. The displacement power factor uses only the fundamental of the signal for its calculation. (see also: Power Factor)

Diversity Factor

The ratio of the sum of the maximum power demands of the subdivisions, or parts of a system, to the maximum demand of the whole system or of part of the system under consideration.

Eddy Current

Localized currents induced in an iron core by alternating magnetic flux. These currents translate into losses (heat) and their minimization is an important factor in lamination design.

Efficiency

The efficiency of an electrical machine or apparatus is the ratio of its useful power output to its total power input.

Electromotive Force

A synonym for voltage, usually restricted to generated voltage.

Encapsulated Winding

A motor which has its winding structure completely coated with an insulating resin (such as epoxy). This construction type is designed for exposure to more severe atmospheric conditions than the normal varnished winding.

Energy

The capacity for doing work.

Equipment Grounding Conductor

The conductor used to connect the non–current-carrying metal parts of equipment and other enclosures to the system grounded conductor, the grounding electrode conductor, or both, at the service equipment or at the source of a separately derived system.

Farad

The unit of measure for capacitance. It is the capacitance of a capacitor in which an applied voltage of one volt will store a charge of one coulomb. The more practical units of capacitance are the microfarad and Pico farad.

Feeder

All circuit conductors between the service equipment, the source of a separately derived system, or other power supply source and the final branch-circuit overcurrent device.

Field

A term commonly used to describe the stationary (Stator) member of a DC Motor. The field provides the magnetic field with which the mechanically rotating (Armature or Rotor) member interacts.

Filament

In a directly heated electron tube, a heating element which also serves as the emitter.

Fitting

An accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function.

Flashover

Flashing due to high current flowing between two points of different potential. Usually due to insulation breakdown resulting from arcing.

Fluctuation

A surge or sag in voltage amplitude, often caused by load switching or fault clearing.

Flux

The magnetic field which is established around an energized conductor or permanent magnet. The field is represented by flux lines creating a flux pattern between opposite poles.

The density of the flux lines is a measure of the strength of the magnetic field.

Form Factor

The ratio of the r.m.s. to the average value of a periodic wave.

Frequency

The rate at which alternating current makes a complete cycle of reversals. It is expressed in cycles per second. In India 50 cycles (Hz) is the standard. The frequency of the AC will affect the speed of a motor.

Full Load Current

The current flowing through the line when the motor is operating at full-load torque and full-load speed with rated frequency and voltage applied to the motor terminals.

Full Load Torque

That torque of a motor necessary to produce its rated horsepower at full-load speed sometimes referred to as running torque.

Fuse

An overcurrent protective device with a circuit opening fusible part that is heated and severed by the passage of overcurrent through it.

Generator

A machine designed for the production of electric power.

Ground

A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth or to some conducting body that serves in place of the earth.

Grounded, Effectively

Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages that may result in undue hazards to connected equipment or to persons.

Harmonic (component)

A sinusoidal component of an ac voltage or current that is a multiple of the fundamental frequency.

Harmonic Distortion

Periodic distortion of the sine wave. The waveform becomes distorted

when higher frequency components are added to the pure sine wave. (see also: Total Harmonic Distortion)

Harmonic Order

A number indicating the harmonic frequency: the first harmonic is the fundamental frequency (50 Hz or 60 Hz), the third harmonic is the component with three times the fundamental frequency (150 Hz or 180 Hz), and so on. Harmonics can be positive-sequence (+), zerosequence (0) or negative-sequence (-). Positivesequence harmonics try to run the motor faster than fundamental; negative-sequence harmonics try to run the motor slower than fundamental. In both cases the motor loses torque and heats up.

Henry

The basic unit of inductance. One henry is the inductance which induces an emf of 1 volt when the current is changing at the rate of 1 ampere per second.

Hertz

A measurement of frequency. One hertz is equal to one inverse second (1/s); that is, one cycle per second, where a cycle is the duration between similar portions of a wave. Hz

High Intensity Discharge Lamps (HID.)

A general group of lamps consisting of mercury, metal halide, high-pressure sodium, and low pressure sodium lamps.

High-Pressure Sodium Lamps

A sodium vapor lamp in which the partial pressure of the vapor during operation is of the order of 0.1 atmospheres.

Impedance

Forces which resist current flow in AC circuits, i.e. resistance, inductive reactance, capacitive reactance.

Inductive Load

An inductive load is a load in which the current lags behind the voltage across the load.

Inductance

The ability of a coil to store energy and oppose changes in current flowing through it. A function of the cross sectional area, number of turns of coil, length of coil and core material.

Induction Motor

An alternating current motor, either single phase or polyphase, comprising independent primary and secondary windings, in which the secondary receives power from the primary by electromagnetic induction.

Inrush current

The initial surge of current required by a load before resistance or impedance increases to its normal operating value.

Instrument Transformer

A transformer (current or potential) suitable for use with measuring instruments; i.e., one in which the conditions of the current, voltage and phase angle in the primary circuit are represented with acceptable accuracy in the secondary circuit.

Interrupting Rating

The highest current at rated voltage that a device is intended to interrupt under standard test conditions.

kVA

(Kilovolt amperes) (volts times amperes) divided by 1000. 1 kVA=1000 VA. kVA is actual measured power (apparent power) and is used for circuit sizing.

kW

(Kilowatts) watts divided by 1000. kW is real power and is important in sizing and equl to one thousand watts. Expressed by kW.

kWH

(Kilowatt hours) kW times hours. A measurement of power and time used by utilities for billing purposes.

K-factor

It indicates the transformers ability to tolerate the additional losses associated with the non-linear wave form.

Lagging Load

An inductive load with current lagging voltage. Since inductors tend to resist changes in current, the current flow through an inductive circuit will lag behind the voltage. The number of electrical degrees between voltage and current is known as the "phase angle". The cosine of this angle is equal to the power factor (linear loads only).

Linear Load

A load in which the current relationship to voltage is constant based on relatively constant load impedance.

Luminaire

A complete lighting unit consisting of a lamp or lamps together with the parts designed to distribute the light, to position and protect the lamps and ballast (where applicable), and to connect the lamps to the power supply.

Motor Induction Type

An alternating current motor, either single phase or polyphase, comprising independent primary and secondary windings, in which the secondary receives power from the primary by electromagnetic induction.

Motor Synchronous Type

An alternating current motor which operates at the speed of rotation of the magnetic flux.

Nonlinear Load

A load where the wave shape of the steady-state current does not follow the wave shape of the applied voltage.

Ohm

The derived unit for electrical resistance or impedance; one ohm equals one volt per ampere. The unit of electrical resistance. Represented by R.

Ohmmeter

An instrument for measuring resistance in ohms.

Oscillator

An electronic device for converting dc energy into ac energy

Outage

Long term power interruption, longer than 1 minute.

Over-current

Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault.

Overload

Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload.

Overvoltage

The voltage is above its nominal value on a long term (longer than 10 cycles).

Peak Value

The highest or maximum value of an alternation of alternating current or voltage. This peak value occurs twice during each cycle.

Peak-to-Peak Value

The maximum voltage change occuring during one cycle of alternating voltage or current. The total amount of voltage between the positive peak and the negative peak of one cycle or twice the peak value.

Phase

The factional part of the period of a sinusoidal wave, usually expressed in electrical degrees and referenced to the origin.

Phase Difference

The difference in phase between two sinusoidal waves having the same period, usually expressed in electrical degrees. The voltage wave if generally taken as the reference, so in an inductive circuit the current lags the voltage, and in a capacitive circuit the current leads the voltage. Sometimes called the phase angle

Phase Displacement

The difference in phase between the primary and secondary current vectors, the direction of the vectors being so chosen that the angle is zero for a perfect transformer. The phase displacement is said to be positive when the secondary current vector leads the primary current vector. It is usually expressed in minutes.

Point of Common Coupling (PCC)

Point where utility responsibiltity ends and building / industry owner responsibility begins. Usually at the main transformer or at the revenue meter.

Poly phase

A general term applied to any system of more than a single phase. This term is ordinarily applied to symmetrical systems.

Potential Transformer

A transformer designed for shunt or parallel connection in its primary circuit, with the ratio of transformation appearing as a ratio of potential differences.

Power

Rate of work, equals work divided by time.

Power Factor (PF)

The ratio of real power to apparent power. Inductive loads cause current to lag behind voltage, while capacitive loads cause current to lead voltage. Also the presence of harmonic currents decrease the Power Factor. The power factor uses the total rms value, thus including all harmonics, for its calculation. (see also: Displacement Power Factor)

Primary

The windings of a transformer which receive energy from the supply circuit.

Rating

The rating of an electrical device includes (1) the normal r.m.s. current which it is designed to carry, (2) the normal r.m.s. volt-age of the circuit in which it is intended to operate, (3) the normal frequency of the current and the interruption (or withstand) rating of the device.

Reactance

Opposition to the flow of alternating current. Capacitive reactance is the opposition offered by capacitor, and inductive reactance is the opposition offered by a coil or other inductance.

Reactive Power

The Reactive Power (VAR) is the reactive component of the apparent power, caused by a phase shift between ac current and voltage in inductors (coils) and capacitors. VARs are present in a distribution system as a result of inductive loads, such as motors, reactors, and transformers. VAR's are compensated for by correction capacitors.

Real Power (see Active Power)

Sag

A sag is a temporary voltage decrease caused by, for example, large equipment starting up. The duration is usually from one cycle to a few seconds.

Secondary

The windings which receive the energy by induction from the primary.

Separately Derived System

A premises wiring system whose power is derived from a battery, from a solar photovoltaic system, or from a generator, transformer, or converter windings, and that has no direct electrical connection, including a solidly connected grounded circuit conductor, to supply conductors originating in another system.

Signaling Circuit

Any electric circuit that energizes signaling equipment.

Single-Phase

A term characterizing a circuit energized by a single alternating voltage source.

Slip Rings

The rotating contacts which are connected to the loops of a generator.

Spike (see Transient)

Solar Photovoltaic System

The total components and subsystems that, in combination, convert solar energy into electrical energy suitable for connection to a utilization load.

Surge

A short duration high voltage condition

Swell

A swell is a temporary voltage increase. The duration is usually from one cycle to a few seconds.

Three Phase

A term characterizing a combination of three circuits energized by alternating voltage sources which differ in phase by one-third of a cycle, 120 degrees.

Total Harmonic Distortion (THD)

THD is the amount of harmonics in a signal as a percentage of the total RMS value or as a percentage of the fundamental. It is a measure of the degree to which a waveform deviates from a purely sinusoidal form. 0% indicates that there is no distortion.

Transformer

A static electrical device which , by electromagnetic induction, regenerates AC power from one circuit into another. Transformers are also used to change voltage from one level to another

Transient

A very short and sharp increase or decrease in the voltage (or current) on a waveform. (Also: impulse, spike)

True Power (see Active Power)

Under-voltage

The voltage is below its nominal value on a long term (longer than 10 cycles).

Volt

The unit of voltage or potential difference. The unit of electromotive force, electrical pressure, or difference of potential. Represented by E or V.

Volt Amperes

The product of the voltage across a circuit and the current in the circuit. Expressed in VA.

Voltage

Electrical pressure, the force which causes current to flow through a conductor.

Voltage (of a circuit)

The greatest root-mean-square (rms) (effective) difference of potential between any two conductors of the circuit concerned.

Voltage Drop

The loss of voltage between the input to a device and the output from a device due to the internal impedance or resistance of the device. In all electrical systems, the conductors should be sized so that the voltage drop never exceeds 3% for power, heating, and lighting loads or combinations of these.

Voltage to Ground

For grounded circuits, the voltage between the given conductor and that point or conductor of the circuit that is grounded; for ungrounded circuits, the greatest voltage between the given conductor and any other conductor of the circuit.

Voltage Ratio

The voltage ratio of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary voltage, under specified conditions of load.

Watt

The unit of power. Equal to one joule per second. The unit of electrical power. Represented by P.

Appendix

I) Additional Formulae

Ohms Law :

Ohms $= \dfrac{\text{Volts}}{\text{Amperes}}$

Amperes $= \dfrac{\text{Volts}}{\text{Ohms}}$

Volts $=$ Amperes x Ohms

Power - AC Circuits:

Power Factor $= \dfrac{\text{Watts}}{\text{Volts x Amperes}}$

Three Phase Kilowatts $= \dfrac{\text{Three Phase Volts x Amperes x 1.732 x Cos } \varphi}{1000}$

Three Phase Amperes $= \dfrac{\text{746 x Horsepower}}{\text{1.732 x Volts x Efficiency x Cos } \varphi}$

Single Phase Kilowatts $= \dfrac{\text{Volts x Amperes x Cos } \varphi}{1000}$

Single Phase Amperes $= \dfrac{\text{746 x Horsepower}}{\text{Volts x Efficiency x Cos } \varphi}$

Power - DC Circuits:

Watts $=$ Volts x Amperes

Amperes $= \dfrac{\text{Watts}}{\text{Volts}}$

Horsepower $= \dfrac{\text{Volts x Amperes x Efficiency}}{746}$

$$N_s = \frac{120f}{P} \text{ rpm}$$

$$S = \frac{N_s - N_r}{N_s} \times 100\%$$

$$T \alpha \phi_m I_2$$

$$\phi = \phi_m \sin\omega t$$

$$P = \frac{T N}{974}$$

$$e_2 = 4.44 K_w \phi_m Z_2 f_2$$

$$T \alpha \frac{S e_2^2}{R_2}$$

N_s = synchronous speed

f = supply frequency in Hz

p = no. of poles in stator winding

N_r = rated speed

S = slip

ϕ_m = max flux

I_2 = rotor current

P = rotor power in kw

T = torque in kg-m

N = speed in rpm

e_2 = rotor induced e.m.f.

K_w = winding factor

f_2 = rotor frequency = s.f.

Z_2 = no. of turns in the rotor circuit per phase.

R_2 = rotor resistance per phase

II) Identification of Cooling method for Transformer[8]

Identification Symbols - Transformers shall be identified according to the cooling method employed. Letter symbols for use in connection with each cooling method shall be as given in Table1

NOTE - In transformers with forced directed oil circulation a certain proportion of the forced oil flow is channelled so as to pass through the windings. Certain windings, however, may have a non-directed oil flow, for instance, separate tapping windings,auxiliary windings and stabilizing windings.

Letter Symbols

i)	KInd of Coolong Medium	Symbol
	a) Mineral oil or equinvalent flammahle synthetic	O
	b) Non-Flammable synthetic insulating liquid	L
	c) Gas	G
	d) Water	W
	e) Air	A
ii)	Kind of Circulation	
	a) Natural	N
	b) Forced (Oil not directed_	F
	c) Forced (directed oil)	D

Arrangement of Symbols — Transformers shall be identified by four symbols for each cooling method for which a rating is assigned by the manufacturer.

Dry-type transformers without protective enclosures are identified by two symbols only for the cooling medium that is in contact with the windings of the surface "coating of windings with an overall coating (for example, epoxy resin).

The order in which the symbols are used is as per the table below. Oblique strokes shall be used to separate the group symbols for different cooling methods.

8 IS Standard

For example, an oil-immersed transformer with forced directed oil circulation and forced air circulation shall be designated ODAF.

For oil-immersed transformers in which the alternatives of natural or forced cooling with non-directed oil flow are possible, typical designations are : ONAN/ONAF ONAN/OFAF

The cooling method of a dry-type transformer without a protective enclosure or with a ventilated enclosure and with natural air cooling is designated by : AN

For a dry-type transformer in a non-ventilated protective enclosure with natural air cooling inside and outside the enclosure the designation is : ANAN

Order of Symbols

1st Letter	2nd Letter	3rd Letter	4nd Letter
Kind of cooling medium indicating the cooling medium that is in contact with the winding	Kind of circulation	Kind of coooling medium indicating the cooling medium that is in contact with the external cooling systems	Kind of circulation

III) Description of Relay Numbers[9]

CODE	DESCRIPTION OF DEVICE
1	Master Element
2	Time Delay Starting or Closing
3	Checking or Interlocking Relay
4	Master Contactor
5	Stopping Device
6	Starting Circuit Breaker
7	Anode Circuit Breaker
8	Control Power Disconnecting Device
9	Reversing Device
10	Unit Sequence Switch
12	Over Speed Device
13	Synchronous Speed Device
14	Under Speed Device
15	Speed or Frequency Matching Device
17	Shunting or Discharge Switch
18	Accelerating or Decelerating Device
19	Starting or Running Connection Control
20	Valve
21	Distance Relay
22	Equalizer Circuit Breaker
23	Temperature Control Device
25	Synchronizing Check
26	Apparatus Thermal Device
27	Under Voltage Relay
28	Flame Detector
29	Isolating Contactor
30	Annunciator Relay
31	Separate Excitation Relay

9 ANSI Standard

32	Directional Power Relay
33	Position Switch
34	Master Sequence Device
35	Brush Operating or Slip Ring Short Circuiting Device
36	Polarizing Voltage Device
37	Under Current or Under Power Relay
38	Bearing Protective Device
39	Mechanical Condition Monitor
40	Field Relay
41	Field Circuit Breaker
42	Running Circuit Breaker
43	Manual Transfer or Selector Switch
44	Unit Sequence Starting Relay
45	Atmospheric Condition Monitor
46	Reverse Phase or Phase Balance Relay
47	Phase Sequence Voltage Relay
48	Incomplete Sequence Relay
49	Machine or Transformer Thermal Relay
50	Instantaneous Over Current or Rate of Rise Relay
51	A.C. Time Over Current Relay
52	A.C. Circuit Breaker
53	Exciter or D.C. Generator Relay
55	Power Factor Relay
56	Field Application Relay
57	Short Circuiting Device
58	Rectification Failure Relay
59	Over Voltage Relay
60	Voltage or Current Balance Relay
62	Time Delay Stopping or Opening Relay
63	Liquid or Gas Pressure or Vaccum Relay
64	Ground Protection Relay

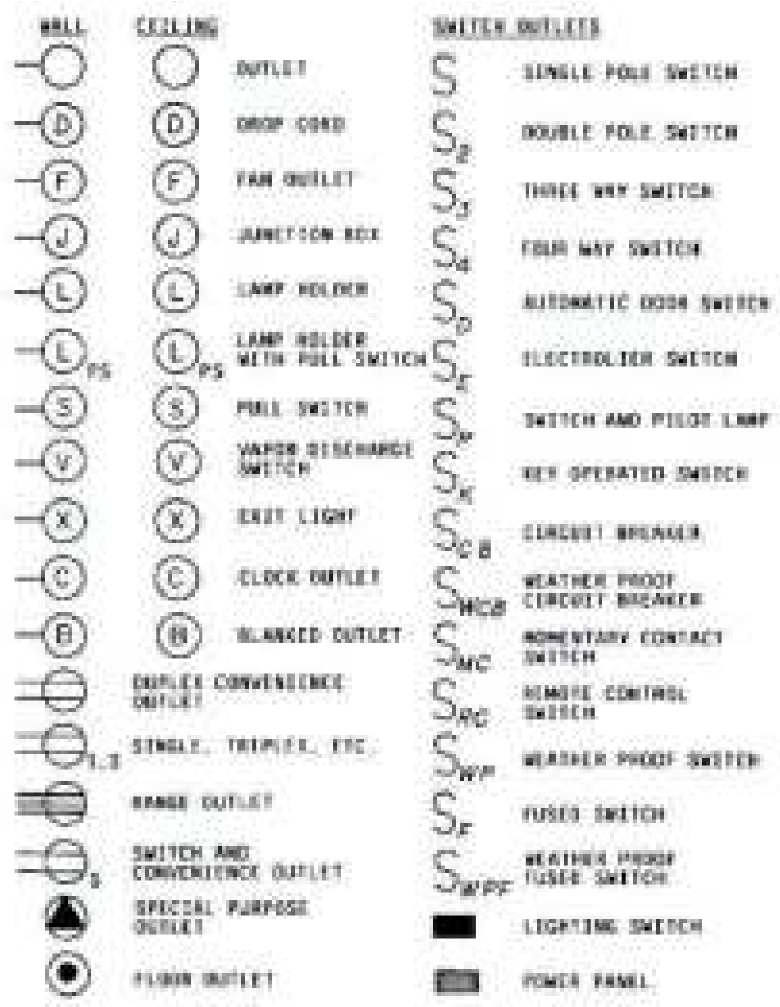
65	Governor
66	Notching or Jogging Device
67	A.C. Directional Over Current Relay
68	Blocking Relay
69	Permissive Control Device
70	Rheostat
71	Liquid or Gas Level Relay
72	D.C. Circuit Breaker
73	Load Resistor Contactor
74	Alarm Relay
75	Position Changing Mechanism
76	D.C. O/C Relay
77	Pulse Transmitter
78	Phase Angle Measuring or Out Of Step Relay
79	A.C. Reclosing Relay
80	Liquid or Gas Flow Relay
81	Frequency Relay
82	D.C. Reclosing Relay
83	Automatic Selective Control or Transformer Relay
84	Operating Mechanism
85	Carrier Relay
86	Locking out Relay
87	Differential Protective Relay
88	Aux. Motor or Motor Generator
89	Line Switch
90	Regulating Device
91	Voltage Directional Relay
92	Voltage And Power Directional Relay
93	Field Changing Contactor
94	Tripping or Trip Free Relay

IV) Commonly used Prefixes and SI Units

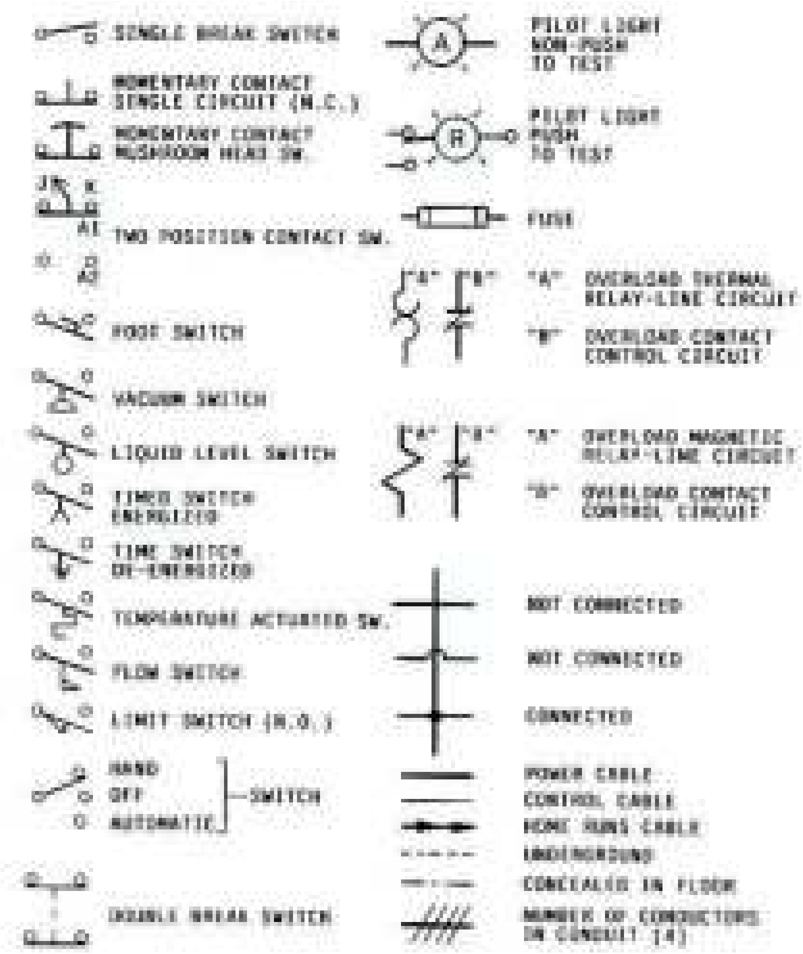
Prefix	Symbol	Power of 10	Prefix	Symbol	Power of 10
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	µ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
deka	da	10^{1}	atto	a	10^{-18}

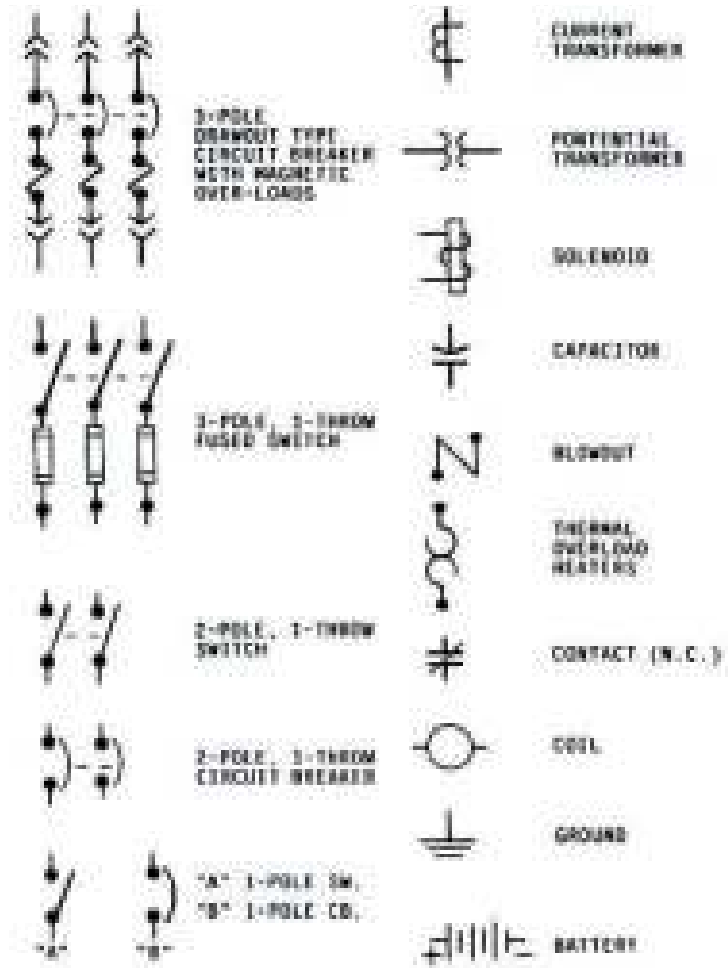
Parameter	Unit	Symbol	Parameter	Unit	Symbol
Capacitance	Farad	F	Conductance	Siemens	S
Electric Charge	Coulomb	C	Electric Current	Ampere	A
Electric Potential	Volt	V	Energy	Joule	J
Force	Newton	N	Inductance	Henry	H
Magnetic Flux	Weber	Wb	Magnetic Flux Density	Tesla	T
Pressure	Pascal	Pa	Power	Watt	W

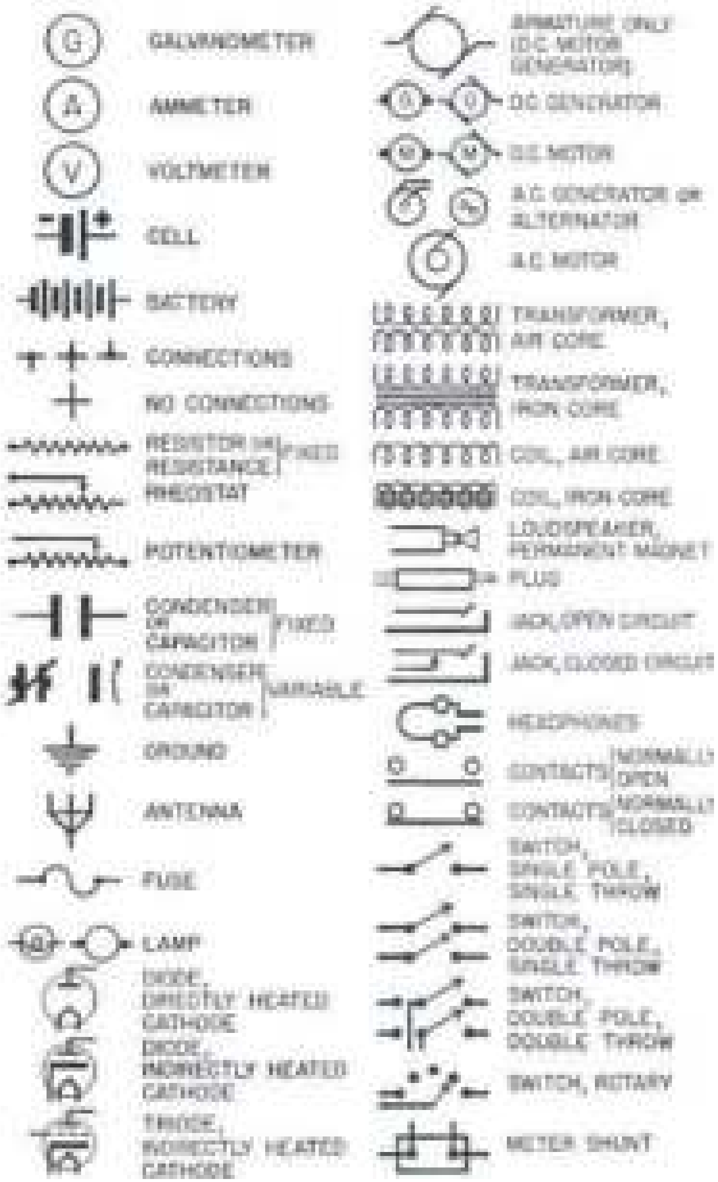
V) Electrical Symbols[10]



10 IEEE Standard


SINGLE BREAK SWITCH
MOMENTARY CONTACT SINGLE CIRCUIT (N.C.)
MOMENTARY CONTACT MUSHROOM HEAD SW.
A1
TWO POSITION CONTACT SW.
A2
FOOT SWITCH
VACUUM SWITCH
LIQUID LEVEL SWITCH
TIMED SWITCH ENERGIZED
TIME SWITCH DE-ENERGIZED
TEMPERATURE ACTUATED SW.
FLOW SWITCH
LIMIT SWITCH (N.O.)
HAND
OFF
AUTOMATIC
SWITCH
DOUBLE BREAK SWITCH
A
PILOT LIGHT NON-PUSH TO TEST
R
PILOT LIGHT PUSH TO TEST
FUSE
"A" "B"
"A" OVERLOAD THERMAL RELAY-LINE CIRCUIT
"B" OVERLOAD CONTACT CONTROL CIRCUIT
"A" "B"
"A" OVERLOAD MAGNETIC RELAY-LINE CIRCUIT
"B" OVERLOAD CONTACT CONTROL CIRCUIT
NOT CONNECTED
NOT CONNECTED
CONNECTED
POWER CABLE
CONTROL CABLE
HOME RUNS CABLE
UNDERGROUND
CONCEALED IN FLOOR
NUMBER OF CONDUCTORS IN CONDUIT (4)


3-POLE DRAWOUT TYPE CIRCUIT BREAKER WITH MAGNETIC OVER-LOADS
3-POLE, 1-THROW FUSED SWITCH
2-POLE, 1-THROW SWITCH
2-POLE, 1-THROW CIRCUIT BREAKER
"A" 1-POLE SW.
"B" 1-POLE CB.
"A"
"B"
CURRENT TRANSFORMER
POTENTIAL TRANSFORMER
SOLENOID
CAPACITOR
BLOWOUT
THERMAL OVERLOAD HEATERS
CONTACT (N.C.)
COIL
GROUND
BATTERY


GALVANOMETER
AMMETER
VOLTMETER
CELL
BATTERY
CONNECTIONS
NO CONNECTIONS
RESISTOR OR RESISTANCE FIXED
RHEOSTAT
POTENTIOMETER
CONDENSER OR CAPACITOR FIXED
CONDENSER OR CAPACITOR VARIABLE
GROUND
ANTENNA
FUSE
LAMP
DIODE, DIRECTLY HEATED CATHODE
DIODE, INDIRECTLY HEATED CATHODE
TRIODE, INDIRECTLY HEATED CATHODE
ARMATURE ONLY (D.C. MOTOR GENERATOR)
D.C. GENERATOR
D.C. MOTOR
A.C. GENERATOR OR ALTERNATOR
A.C. MOTOR
TRANSFORMER, AIR CORE
TRANSFORMER, IRON CORE
COIL, AIR CORE
COIL, IRON CORE
LOUDSPEAKER, PERMANENT MAGNET
PLUG
JACK, OPEN CIRCUIT
JACK, CLOSED CIRCUIT
HEADPHONES
CONTACTS NORMALLY OPEN
CONTACTS NORMALLY CLOSED
SWITCH, SINGLE POLE, SINGLE THROW
SWITCH, DOUBLE POLE, SINGLE THROW
SWITCH, DOUBLE POLE, DOUBLE THROW
SWITCH, ROTARY
METER SHUNT

Notes :

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About CII

The Confederation of Indian Industry (CII) works to create and sustain an environment conducive to the growth of industry in India, partnering industry and government alike through advisory and consultative processes.

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The Centre sensitises key stakeholders to embrace green practices and facilitates market transformation, paving way for India to become one of the global leaders in green businesses by 2015.

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