CHAPTER 6 Energy Efficient Electrical Systems

6.1 Guideline

Achieve an energy-efficient and reliable electrical system design for buildings. Also the guideline should comply with the existing BESCOM regulations.

6.2 Proposed mandatory clause

- The power factor of the building should be maintained above 0.95 for LT three-phase supply having a maximum current of 100 A.
- The transformer no-load and full-load losses should be in accordance with the conditions specified in ECBC 2007.

6.3 Technical guidelines

Technical guidance to achieve the recommendations

Electrical systems

The electrical system in a building comprises the infrastructure that brings in electrical supply. The main infrastructures are the electrical substation, transformers, distribution systems, circuit breakers, electrical meters, capacitors, etc.

The objective of having an efficient electrical system in a building installation is to have energy-efficient delivery systems, thereby keeping the losses in the electrical infrastructure to minimum. Also the installed electrical system should have suitable safety mechanisms for providing reliable power supply.

6.3.1 Guidelines for electrical system design

A typical electrical distribution facility in a building will generally include the following:

- Power distribution systems for equipments, including indoor substation, transformers, building distribution, process control systems, building electrical service systems, and protection systems
- Power outlet system for movable equipments, material-handling systems, and transportation system
- Auxiliary systems, like air conditioning and refrigeration, compressed air systems, lighting, fire alarm systems, communication and computer-based equipments.
- DG sets/cogeneration equipments/UPS/inverter

Any system planning should include certain basic considerations as given below that will support the overall flexible design and efficient operation of the electrical system:

- Safety of life and property including equipments.
- Reliability of the system input supply and tolerance limit of interruptions
- Flexibility of the plant distribution system
- Location of the plant substation and its deployment
- Data of electrical equipments, regulation, and initial cost, including capitalization
- Simplicity/flexibility of operation and maintenance
- Overall cost, including the running cost
- Providing quality service
- Technical parameters and specifications of materials to follow standards in construction, installation, protection, operation, and maintenance
- Adherence to laid-down procedures with accountability

Table 6.3.1 indicates possible loss as percentage of the full load for few electrical equipments.

Table 6.3.1: Loss percentage in electrical equipments

Sl. No.	Equipment	% loss of max load
A C motors		
i.	750 Watts–7.5 kW	14–35

	7.5 kW–150 kW	6–12
	150 kW–1000 kW	4–7
	Above 1000 kW	2.3 –4.5
ii.	Transformers	0.4 –1.9
iii.	Cables	1–4
iv.	Switch gear	
	L.T.	0.13–0.34
	Medium voltage up to 11 kV	0.005–0.02

6.3.2 Guidelines on optimization of electrical load

The following steps should be a guideline for initial planning and sanction of the electrical design.

1. Involves load details such as:

    - Load in kW and demand in kVA
    - Diversity factor
    - Load characteristics
    - Future expansion

This includes peak load, load fluctuations under various operating conditions, nature of load, PF and its variation, calculated daily, monthly and annual load factor, and anticipated seasonal variation and effect of large motor starting.

1. Involves anticipation of the present demand over a period of time, peak load, maximum demand, and demand, diversity and load factors.
2. Future demand forecasting and planning (building expansion plans).
3. Determination of the voltage level required for the building. Power is fed to a building through a transmission and distribution (T&D) network. This can be provided using either high voltage and low current or vice versa. The selection of the voltage level is determined by the current national and international standards, safety regulations and, of course, the economic considerations. Large consumers can reduce energy losses by drawing power at a high voltage level

and distribute it inside their premises at required load centers using their own step-down transformers to match the voltage level to the equipment.

4. Voltage application required in the plant and voltage drops at all levels and at critical points. An industry classification, based on load and preferred incoming voltage, is given in Table 6.3.2.

Table 6.3.2: Industry classification of voltage preferences

Industry	Preferred incoming voltage level	Voltage class as per the I.E. Rule
100 MW and above	220 kV	Extra
Between (10–50 MW)	132 - 66 kV	High
Between (1–10 MW)	33 - 11 kV	High
Up to 50 kW	3 ϕ, 440 V	Medium/low

1. Calculation of a short circuit analysis and selection of the correct rating for a circuit breaker with a review of selection of protective devices.
2. Station house service unit requirement (parallel, standby, or emergency operation).
3. Preliminary layout drawing, including provisions for future expansion.
4. Detailed single-line diagrams, covering all loads/supplies, including main and distribution transformers, switch gear, primary and secondary cabling, protection, insulation level coordination, motor starter panels, and capacitor banks.

6.3.3 Guidelines on transformer rating and selection

Most of the transformers used in electrical power systems are three-phase transformers. They can be characterized by the vector group and the type of cooling. The vector group (e.g. star connection, delta connection) depends on the internal connection of windings of the high-voltage and low-voltage side.

Cooling of the transformer is performed by air or a liquid, e.g. oil or askarel, with a natural or forced flow. The heat is drawn off using cooling ribs at the surface of the tank.

In most cases, the power losses can only be ascertained through the test certificate issued by the manufacturer or by carrying out field measurements.

Power transformers of the proper ratings and design must be selected to satisfy the minimum acceptable efficiency at 50% and full load rating. In addition, the transformer must be selected such that it minimizes the total initial cost in addition to the present value of the cost of its total lost energy while serving its estimated loads during its respective lifespan.

The transformer losses for an oil-cooled transformer for 11 kV and 33 kV is given in table 6.3.3 When a new transformer is procured, the no-load and full-load losses of the transformer should be in accordance with the ECBC recommended figures as given in table below.

Table 6.3.3: Oil filled transformers- total losses for oil filled transformers should confirm as per the following table as specified in Central Electricity Authority Norms

Rating kVA	Maximum losses at 50% loading kW	Maximum losses at 100% loading kW	Total losses at 50% loading kW	Total losses at 100% loading kW
	Up to 11 kV		Up to 33 kV	
100	0.5	1.8	0.6	1.8
160	0.8	2.2	0.8	2.6
200	0.9	2.7	0.9	3.0
250	1.1	3.3	NA	NA
315	1.1	3.6	1.3	4.3
400	1.5	4.6	1.5	5.1
500	1.6	5.5	2.0	6.5
630	2.0	6.6	2.3	7.6
1000	3.0	9.8	3.5	11.4
1250	3.6	12.0	4.0	13.3
1600	4.5	15.0	4.9	16.0
2000	5.4	18.4	5.7	18.5
2500	6.5	22.5	7.1	23.0

At the time of installation of a new transformer, the size is decided based on the expected loading on the transformer. Normally, the maximum efficiency of the transformer is designed at the loading in the range of 50–65% of' its full load capacity. If the average load is 80% or more of the rated power, a bigger transformer or a second transformer should be considered, because the short-circuit losses form a large portion of the total losses.

Capacity and number of transformers

The main factors that should be taken into account when determining the number and capacity of shop transformers are:

The number of transformers depends upon the operating duty of the station or industry. The load curve may show that the installation of two transformers instead of one is more attractive economically. This is usually the case when the load capacity factor is low (less than or equal to 0.5). In this case, disconnecting devices are necessary to connect and disconnect the power transformers to ensure economical operation. Wherever possible the installation of either one transformer or two transformers connected through a common circuit breaker should be contemplated. If the reliability of supply necessitates, the installation of more than one transformer should be sought. When designing substations, redundancy features (reserve facility) should be taken care of as per the following:

The building should be supplied from two independent sources, where continuity of supply is required. The capacity of the transformers should be so selected that if one of the transformers fails, the remaining transformer shall ensure supply to the equipments without undue overload.

In selecting the transformer capacity, it should be ensured for economical operation so that when one of the transformers is out of service, the load on the other transformer in operation, as far as the temperature is concerned, shall not affect its service life.

It is always a good practice to provide or install transformers of one step higher in capacity. For example, if two transformers, each rated for 1000 kVA, are installed, then their foundations and structures should be so designed as to make possible the installation of two transformers of 1500 kVA each without much material modification.

Reduction in transformer losses through proper load distribution

The objective of the review of the transformer system is to provide better quality of power to different load centers in the plant at high overall efficiency. In a medium and large industrial unit, there are a number of transformers feeding power to the loads in the plant. These distribution transformers are sometimes not optimally loaded and there exists an energy-saving opportunity by shifting the load from the overloaded transformer to the underloaded one.

6.3.4 Guidelines on selection of electrical motors

Motors shall comply with the following:

1. All permanently wired polyphase motors of 0.375 kW or more serving the building and expected to operate more than 1500 h/yr and all permanently wired polyphase motors of 50 kW or more serving the building and expected to operate more than 500 h/yr shall have a minimum acceptable nominal full load motor efficiency not less than IS 12615 for energy-efficient motors. The technical features and benefits of energy-efficient motors are listed below:

    - High-efficiency motors are usually manufactured from materials, which incur lower energy losses compared with standard motors. More care is taken with the design and geometry of the motor construction. The high-efficiency motors have been improved in four areas:
        - Longer core lengths of low-loss steel laminations to reduce flux densities and iron losses
        - Maximum utilization of the slots and generous conductor sizes in the stator and rotor to reduce copper losses
        - Careful selection of slot numbers and tooth/slot geometry to reduce stray losses
        - Less heat is produced by a more efficient motor, so the cooling fan size is reduced. This leads to lower windage losses and therefore less wastage of power.

The advantages of the usage of high-efficiency motors are as follows:

- Optimum use of energy as operating losses are lower
- Reduced magnetic loss resulting in cooler applications
- Low lifecycle cost
- Robust design to take care of wider supply variations (10%) and an ambient temperature up to 80°C
- Efficiency figures remain constant up to 75% of the rated output and drop maximum by 1% at 50% rated output

2. Motors of horsepower differing from those listed in the table shall have efficiency greater than that of the kW motor listed next.
3. Motor horsepower ratings shall not exceed 20% of the calculated maximum load.
4. Motor nameplates shall list the nominal full load motor efficiencies and the full load power factor.
5. Motor users should insist on proper rewinding practices for rewound motors. If the proper rewinding practices cannot be assured, the damaged motor should be replaced with a new, efficient one, rather than suffering the significant efficiency penalty associated with typical rewind practices.
6. Certificates shall be obtained and kept on record, indicating the motor efficiency. Whenever a motor is rewound, appropriate measures shall be taken so that the core characteristics of the motor are not lost due to thermal and mechanical stress during removal of damaged parts. After rewinding, a new efficiency test shall be performed and similar records shall be maintained.
7. Motors should be installed with soft start energy savers and variable speed drives based on the application required.

6.3.5 Guidelines on improvement of the power factor

Methods of improving the power factor

1. Streamlining the process by improving the electrical performance of the plant.
2. Replacing induction motors by synchronous motors of equal rating wherever possible.
3. Replacement of underloaded motors with motors of lower rating.

4. Reduction of voltage of motors, which are regularly underloaded.
5. Restricting no-load operation of motors.
6. Improving the motor-repair quality.
7. Replacement or relocation of underloaded transformers.
8. Installation of capacitors

Measurement of the power factor

- By a direct reading of the power factor meter for an instantaneous value
- By recording the VAr meter, which allows to obtain a record over a period of time of the current, voltage, and power factor. Readings taken over an extended period provide a useful means of estimating an average value of the power factor for an installation.

Power factor improvement by installing capacitors

Power factor improvement by installing capacitors is the widely followed method. Capacitors can be significant energy savers, if they are properly applied. A capacitor bank is also a load albeit with very low loss (0.2–0.4 W/kVAr). So, it should be disconnected when VAr support is not required. If a fuse blows on a large capacitor, an unbalanced voltage occurs along with resultant increases in system and motor losses. Therefore, the fuse integrity of capacitor banks should be closely monitored. A high harmonic content in the power supply has been known to cause either capacitor failure or unplanned operation of protective devices. Hence, use of latest semiconductor devices with appropriate technology can prove beneficial in the long run.

Capacitors should be installed across the terminals of motors. However, the capacitor value should not exceed the no-load kVAr value of the motor. Table 6.3.3 gives the approximate value of capacitors that need to be connected for different rating of the motors.

Table 6.3.3: Recommended capacitor rating for direct connection to induction motors (to improve the power factor to 0.95 or better)

Motor H.P.	Capacitor rating in KVAr when motor speed is						Motor H.P.	Capacitor rating in KVAr when motor speed is					
	3000 r.p.m.	1500 r.p.m	1000 r.p.m	750 r.p.m	600 r.p.m	500 r.p.m		3000 r.p.m	1500 r.p.m	1000 r.p.m	750 r.p.m	600 r.p.m.	500 r.p.m.
2.5	1	1	1.5	2	2.5	2.5	105	22	24	27	29	36	41
5	2	2	2.5	3.5	4	4	110	23	25	28	30	38	43
7.5	2.5	3	3.5	4.5	5	5.5	115	24	26	29	31	39	44
10	3	4	4.5	5.5	6	6.5	120	25	27	30	32	40	46
12.5	3.5	4.5	5	6.5	7.5	8	125	26	28	31	33	41	47
15	4	5	6	7.5	8.5	9	130	27	29	32	34	43	49
17.5	4.5	5.5	6.5	8	10	10.5	135	28	30	33	35	44	50
20	5	6	7	9	11	12	140	29	31	34	36	46	52
22.5	5.5	6.5	8	10	12	13	145	30	32	35	37	47	54
25	6	7	9	10.5	13	14.5	150	31	33	36	38	48	55
27.5	6.5	7.5	9.5	11.5	14	16	155	32	34	37	39	49	56
30	7	8	10	12	15	17	160	33	35	38	40	50	57
32.5	7.5	8.5	11	13	16	18	165	34	36	39	41	51	59
35	8	9	11.5	13.5	17	19	170	35	37	40	42	53	60
37.5	8.5	9.5	12	14	18	20	175	36	38	41	43	54	61
40	9	10	13	15	19	21	180	37	39	42	44	55	62
42.5	9.5	11	14	16	20	22	185	38	40	43	45	56	63
45	10	11.5	14.5	16.5	21	23	190	38	40	43	45	58	65
47.5	10.5	12	15	17	22	24	195	39	41	44	46	59	66
50	11	12.5	16	18	23	25	200	40	42	45	47	60	67
55	12	13.5	17	19	24	26	205	41	43	46	48	61	68
60	13	14..5	18	20	26	28	210	42	44	47	49	61	69
65	14	15.5	19	21	27	29	215	42	44	47	49	62	70
70	15	16.5	20	22	28	31	220	43	45	48	50	63	71
75	16	17	21	23	29	32	225	44	46	49	51	64	72
80	17	19	22	24	30	34	230	45	47	50	52	65	73
85	18	20	23	25	31	35	235	46	48	51	53	65	74
90	19	21	24	26	33	37	240	46	48	51	53	66	75
95	20	22	25	27	34	38	245	47	49	52	54	67	75
100	21	23	26	28	35	40	250	48	50	53	55	68	76

Note: The recommended capacitor rating given in the above table is only for guidance purpose. (The capacitor rating should correspond approximately to the apparent power of the motor on no-load).

Another chart for calculating the capacitors required for improving the power factor in a building is given in table 6.3.4.

Table 6.3.4: Multiplying factor for calculating the sizes of capacitor for power factor improvement

Power factor of load before applying capacitors	Size of capacitors in kVAr per kW of load for raising the power factor to												
	0.80	0.85	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	Unity
0.45	1.230	1.360	1.501	1.532	1.561	1.592	1.626	1.659	1.695	1.737	1.784	1.846	1.988
0.46	1.179	1.309	1.446	1.473	1.502	1.533	1.567	1.600	1.636	1.677	1.725	1.786	1.929
0.47	1.130	1.260	1.397	1.425	1.454	1.485	1.519	1.552	1.588	1.629	1.677	1.758	1.881
0.48	1.076	1.206	1.343	1.370	1.400	1.430	1.464	1.497	1.534	1.575	1.623	1.684	1.826
0.49	1.030	1.160	1.297	1.326	1.355	1.386	1.420	1.453	1.489	1.530	1.578	1.639	1.782
0.50	0.982	1.112	1.248	1.276	1.303	1.337	1.369	1.403	1.441	1.481	1.529	1.590	1.732
0.51	0.936	1.066	1.202	1.230	1.257	1.291	1.323	1.357	1.395	1.435	1.483	1.544	1.686
0.52	0.894	1.024	1.160	1.188	1.215	1.249	1.281	1.315	1.353	1.393	1.441	1.502	1.644
0.53	0.850	0.980	1.116	1.144	1.171	1.205	1.237	1.271	1.309	1.349	1.397	1.458	1.600
0.54	0.809	0.939	1.075	1.103	1.130	1.164	1.196	1.230	1.268	1.308	1.356	1.417	1.559
0.55	0.769	0.899	1.035	1.063	1.090	1.124	1.156	1.190	1.228	1.268	1.316	1.377	1.519
0.56	0.730	0.860	0.996	1.024	1.051	1.085	1.117	1.151	1.189	1.229	1.277	1.338	1.480
0.57	0.692	0.822	0.958	0.986	1.013	1.047	1.079	1.113	1.151	1.191	1.239	1.300	1.442
0.58	0.655	0.785	0.921	0.949	0.976	1.010	1.042	1.076	1.114	1.154	1.202	1.263	1.405
0.59	0.618	0.748	0.884	0.912	0.939	0.973	1.005	1.039	1.077	1.117	1.165	1.226	1.368
0.60	0.584	0.714	0.849	0.878	0.905	0.939	0.971	1.005	1.043	1.083	1.131	1.192	1.334
0.61	0.549	0.679	0.815	0.843	0.870	0.904	0.936	0.970	1.008	1.048	1.096	1.157	1.299
0.62	0.515	0.645	0.781	0.809	0.836	0.870	0.902	0.936	0.974	1.014	1.062	1.123	1.265
0.63	0.483	0.613	0.749	0.777	0.804	0.838	0.870	0.904	0.942	0.982	1.030	1.091	1.233
0.64	0.450	0.580	0.716	0.744	0.771	0.805	0.837	0.871	0.909	0.949	0.997	1.058	1.200
0.65	0.419	0.549	0.685	0.713	0.740	0.774	0.806	0.840	0.878	0.918	0.966	1.027	1.169
0.66	0.388	0.518	0.654	0.682	0.709	0.743	0.775	0.809	0.847	0.887	0.935	0.996	1.138
0.67	0.358	0.488	0.624	0.652	0.679	0.713	0.745	0.779	0.817	0.857	0.905	0.966	1.108
0.68	0.329	0.459	0.595	0.623	0.650	0.684	0.716	0.750	0.788	0.828	0.876	0.937	1.079
0.69	0.299	0.429	0.565	0.593	0.620	0.654	0.686	0.720	0.758	0.798	0.840	0.907	1.049
0.70	0.270	0.400	0.536	0.564	0.591	0.625	0.657	0.691	0.729	0.769	0.811	0.878	1.020
0.71	0.242	0.372	0.508	0.536	0.563	0.597	0.629	0.663	0.701	0.741	0.783	0.850	0.992
0.72	0.213	0.343	0.479	0.507	0.534	0.568	0.600	0.634	0.672	0.712	0.754	0.821	0.963
0.73	0.186	0.316	0.452	0.480	0.570	0.541	0.573	0.607	0.645	0.685	0.727	0.794	0.936
0.74	0.159	0.289	0.425	0.453	0.480	0.514	0.546	0.580	0.618	0.658	0.700	0.767	0.909
0.75	0.132	0.262	0.398	0.426	0.453	0.487	0.519	0.553	0.591	0.631	0.673	0.740	0.882
0.76	0.105	0.235	0.371	0.399	0.426	0.460	0.492	0.526	0.564	0.604	0.652	0.713	0.855
0.77	0.079	0.209	0.345	0.373	0.400	0.434	0.466	0.500	0.538	0.578	0.620	0.687	0.829
0.78	0.053	0.183	0.319	0.347	0.374	0.408	0.440	0.474	0.512	0.552	0.594	0.661	0.803
0.79	0.026	0.156	0.292	0.320	0.347	0.381	0.413	0.447	0.485	0.525	0.567	0.634	0.776
0.80	-	0.130	0.266	0.294	0.321	0.355	0.387	0.421	0.459	0.499	0.541	0.608	0.750
0.81	-	0.104	0.240	0.268	0.295	0.329	0.361	0.395	0.433	0.473	0.515	0.582	0.724
0.82	-	0.078	0.214	0.242	0.269	0.303	0.335	0.369	0.407	0.447	0.489	0.556	0.698
0.83	-	0.052	0.188	0.216	0.243	0.277	0.309	0.343	0.381	0.421	0.463	0.530	0.672
0.84	-	0.026	0.162	0.190	0.217	0.251	0.283	0.317	0.355	0.395	0.437	0.504	0.645
0.85	-	-	0.136	0.164	0.191	0.225	0.257	0.291	0.329	0.369	0.417	0.478	0.620
0.86	-	-	0.109	0.140	0.167	0.198	0.230	0.264	0.301	0.343	0.390	0.450	0.593

Power factor of load before applying capacitors	Size of capacitors in kVAr per kW of load for raising the power factor to												
	0.80	**0.85**	**0.90**	**0.91**	**0.92**	**0.93**	**0.94**	**0.95**	**0.96**	**0.97**	**0.98**	**0.99**	**Unity**
0.87	-	-	0.083	0.114	0.141	0.172	0.204	0.238	0.275	0.317	0.364	0.424	0.567
0.88	-	-	0.054	0.085	0.112	0.143	0.175	0.209	0.246	0.288	0.335	0.395	0.538
0.89	-	-	0.028	0.059	0.836	0.117	0.149	0.183	0.230	0.262	0.309	0.369	0.512
0.90	-	-	-	0.031	0.058	0.089	0.121	0.155	0.192	0.234	0.281	0.341	0.484
0.91	-	-	-	-	0.027	0.058	0.090	0.124	0.161	0.203	0.250	0.310	0.453
0.92	-	-	-	-	-	0.031	0.063	0.097	0.134	0.176	0.223	0.283	0.426
0.93	-	-	-	-	-	-	0.032	0.066	0.103	0.145	0.192	0.252	0.395
0.94	-	-	-	-	-	-	-	0.034	0.071	0.113	0.160	0.220	0.363
0.95	-	-	-	-	-	-	-	-	0.037	0.079	0.126	0.186	0.329
0.96	-	-	-	-	-	-	-	-	-	0.042	0.089	0.149	0.292
0.97	-	-	-	-	-	-	-	-	-	-	0.047	0.107	0.250
0.98	-	-	-	-	-	-	-	-	-	-	-	0.060	0.203
0.99	-	-	-	-	-	-	-	-	-	-	-	-	0.143

Example: Given 100-kW load to be improved from 0.77 to 0.95 power factor. The power factor from the table is 0.500.
Therefore, the capacitor required (kVAr) = 100 x 0.500 = 50 kVAr.

6.3.6. Guidelines on check metering and monitoring

Energy accounting, monitoring, and control is the very first step to be observed in any energy conservation management.

a. Energy accounting
Metering of the energy consumed by an establishment is necessary so that:

- Energy consumed by an equipment can be analysed in detail and corrective methods can be opted for improving equipment performances.
- The consumption of active energy in the individual major equipments, shops, sections, and plants can be monitored and variation in energy consumption in relation to production levels can be analysed.
- The above analysis helps in benchmarking to arrive at optimum specific energy consumption and reduce process irregularities.
- The production of reactive energy by the compensating units of the building may be monitored and corrective steps can be adopted.
- It helps in identifying the optimum usage of demand allocation, thereby improving the load factor.

- Any consumers supplied via the building substation may be charged.
- Energy accounting for the corresponding sections (i.e. individual profit center concept) can be initiated towards input cost analysis.
- Energy accounting shall help in correlating the daily, fortnightly, monthly, or annual energy consumption index with indication of deviation from the benchmark or the set target.

b. Monitoring and control

It is always the best practice to install energy meters, hour meters (time totalizers) on major equipments/systems (HVAC system, compressed air system, pumping system, etc.,) consuming significant amount of energy. This shall help in accounting energy consumption on a shift-wise basis, daily basis, month-wise and yearly basis. A correlation of these consumption patterns with the production details (shift-wise production, equipment-wise production) shall lead to identify energy-saving opportunities.

The summation of all submeter energy consumption should be compared with the summation of the main plant energy meter (check meter for grid energy meter) and the energy meters of the DG sets. Energy accounting error of about 3-4% (accounting for cable and equipment losses) between the summed values of submetering, main plant check meter and DG set energy meter to that of grid energy meters is reasonable. Enormous percentage error in the readings recorded needs to be viewed seriously.

6.3.7 Guidelines on distribution system losses

The distribution losses in the system are mainly on account of the losses in the cables and bus bars. The parameters that affect the cable losses are mainly cable resistance, power factor, and voltage levels.

Losses

In-plant cable losses are in the range of 1–4 %. Table 6.3. 5 gives cable loss for various sizes of aluminum conductors.

Table 6.3.5: I2R losses per phase (in watts) of various sizes (in mm^2) of aluminum cables of 10 m length in a three-phase system

Size (mm^2) Amps	25	35	50	70	95	120	150	185	240	300
15	2.7	1.95	1.4	0.99	-	-	-	-	-	-
30	10.8	7.8	5.8	4.0	-	-	-	-	-	-
45	24.8	17.6	13.0	9.0	6.5	-	-	-	-	-
60	43.2	31.2	23.1	15.9	11.5	9.1	7.4	5.9	-	-
75	-	48.8	36.1	24.9	18.0	14.2	11.6	9.2	7.0	5.6
90	-	-	51.9	35.9	25.9	20.5	16.7	13.3	10.1	8.1
105	-	-	70.7	48.8	35.3	27.9	22.7	18.1	13.8	11.0
120	-	-	-	63.8	46.1	36.4	29.7	23.6	18.0	14.4
135	-	-	-	80.7	58.3	46.1	37.5	29.9	22.8	18.2
150	-	-	-	-	70.0	56.9	46.4	36.9	28.1	22.5
165	-	-	-	-	87.1	68.9	56.1	44.6	34.0	27.2
180	-	-	-	-	-	82.0	66.7	53.1	40.5	32.4
195	-	-	-	-	-	-	78.3	62.4	47.5	38.0
210	-	-	-	-	-	-	90.8	72.3	55.1	44.1
225	-	-	-	-	-	-	-	83.0	63.3	50.0
240	-	-	-	-	-	-	-	94.5	72.0	57.6
255	-	-	-	-	-	-	-	-	81.3	65.0
270	-	-	-	-	-	-	-	-	91.1	72.9
285	-	-	-	-	-	-	-	-	101.1	81.2
300	-	-	-	-	-	-	-	-	112.5	90.0
315	-	-	-	-	-	-	-	-	-	99.2
330	-	-	-	-	-	-	-	-	-	108.9
345	-	-	-	-	-	-	-	-	-	119.0

Loss reduction

Power losses in lines depend upon the resistance of the lines and the current carried. The resistance of lines may be considered constant. Then it follows that the only way to reduce the loss of power is to reduce the current. The current may be reduced by using as many reserve lines as possible. Dual lines should be connected in parallel for a more economical operation.

Cable laying should be done strictly in accordance with carefully and systematically planned schedule. Drawing of this should be available at site and should be preserved at sub-stations. All cable ends should be suitably labelled to facilitate easy identification. In all control cables adequate number of spare cores should be included. For cables, use IS:1255-1958, IS:962-1965 and IS:3043-1966 standards.

6.3.8 Guidelines on Power back up systems

A. DG Sets

With the rampant power shortage, poor power quality, disturbances, increased energy costs, as seen in the present SEB grid power distribution, industries are put to tremendous difficulties resulting in production losses, etc. This has led to the need for captive power generation.

Industries/buildings have several advantages in going for Captive Generating sets. Captive power generation offers the following advantages:

1. Continuous availability of power, free from utility power breakdown and grid disturbances, etc., leading to better productivity, less interruptions in process restart etc.,
2. Good power system control obtained when operated in parallel with the utility supply system
3. Possibility of heat and electrical energy generation (Cogeneration) resulting in energy conservation and reduced energy cost,
4. Excess electrical energy generation can be supplied to the utility grid and earning income/wheeling charges.

Selection of Captive Generation Equipment

Based on the energy requirements, availability of fuels, availability and reliability of grid power at the plant location, industries should take up a detailed and careful study to decide the type of generating equipment, its rating and other specifications. Different modes of operating the Captive generation units are defined based on IEEE standard 446.

Following modes of operation may be considered:

- Standby Power supply Mode (Emergency Power Supply): Captive power generation set utilized in this mode shall meet the plant part load or total load requirement during the failure of utility power supply (Grid supply system).
- Peak Loading Mode (Peak Lopping/Peak Shaving):

The captive power generation units are chosen to come into operation during peak load periods to supplement the utility supply (Grid supply) to limit the peak demand drawn from utility and thereby saving the electricity cost paid towards maximum peak demand.

Base Load Mode (Primary Supply Mode):

This mode of operation is required in locations where there is no utility power supply or the utility supply is highly unreliable with frequent outages. A part or whole of the plant load is supplied on a continuous basis in this mode of operation. This mode of operation can also be termed as Total Energy mode. Industries where the requirement of heat and cooling water supply, apart from electricity opt for this mode of operation in the initial design stages.
The specific energy generation (SEGR) of the DG sets varies with size and loading on the DG sets. A SEGR of 4 kWh/l is said to be an efficient design.

B. UPS/ Inverters
An uninterruptible power supply, also uninterruptible power source, UPS or battery back-up, is an electrical apparatus that provides emergency power to a load when the input power source, typically the utility mains, fails. A UPS differs from an auxiliary or emergency power system or standby generator in that it will provide instantaneous or near-instantaneous protection from input power interruptions by means of one or more attached batteries and associated electronic circuitry. The on-battery runtime of most uninterruptible power sources is relatively short—5–15 minutes being typical for smaller units—but sufficient to allow time to bring an auxiliary power source on line, or to properly shut down the protected equipment. While not limited to protecting any particular type of equipment, a UPS is typically used to protect computers, data centers, telecommunication equipment or other electrical equipment where an unexpected power disruption could cause injuries, fatalities, serious business disruption and/or data loss. UPS units range in size from units designed to protect a single computer without a video monitor (around 200 VA rating) to large units powering entire data centers, buildings.
The efficiency level of the inverters varies from 92 -95 % based on the capacity.

6.3.9 Guidelines on Power Quality

A Voltage Range, and Tolerance

The voltage ranges in which the AC installations can be classified (as per IS: 12360 - 1988), according to their normal voltage for earthed and not effectively earthed systems, and the tolerances on declared voltages are given below in Table 6.

Table 6.3.6: Voltage Ranges in AC Installations

Ranges	Line-to-Line rms. Values	Standard Nominal A.C. System Voltages	Tolerance on Declared Voltage	Voltage adopted for the system
I	50 V ≤ u ≤ 1000 V	Three phase - 415 V Single phase - 240 V	± 6 %	Distribution system
II A	1 kV < u ≤ 52 kV	3.3, 6.6, 11, 33 kV	+ 6 % & - 9%	Sub-transmission
II B	52 kV < u ≤ 300 kV	66, 132, 220 kV	± 12.5 %	Transmission
III C	U > 300 kV	400 kV	± 12.5 %	Transmission

u = Nominal voltage of the installation

The primary sub-transmission voltage is 33 kV (in a few states, it is 66 kV). The 33 kV network is extended from 220 / 132 / 33 kV substations. The secondary sub-transmission voltage is standardised at 11 kV. The low-tension voltage is either 415 V or 240 V, supplied to consumers.

B. Phase Voltage Imbalance in a Three Phase System

Most utilities adopt a three-phase, four-wire, grounded-star primary distribution system, so that single-phase distribution transformers can be connected directly to supply lines to cater to single-phase loads, such as residences and street lights. Variations in single-phase load distribution cause the currents in the three-phase system to vary, producing different voltage drops and causing the phase voltage to become unbalanced.

Phase to phase voltage imbalances by even 2.5 % of the nominal voltage can reduce motor efficiency up to 10 %. This causes excessive heating due to the high negative sequence current. Imbalance of more than 5 % should therefore not be permitted.

Perfect balance can never be maintained since loads continuously change. Blown fuses on three phase capacitor banks also unbalance the load and cause phase voltage imbalance.

Proper balancing of single-phase loads on the three phases on both branch circuits and feeders is necessary to keep the load and corresponding phase-voltage imbalance within reasonable.

C. Effects of Phase Voltage Imbalance

Unequal loads on individual phases, negative and zero phase sequence components cause overheating of transformers, cables, conductors and motors thus increasing the losses and motor malfunction. The limit of negative phase sequence as per 1EC34-1 is 2% of the voltage.

When unbalanced phase voltages are applied to three phase motors, additional negative sequence currents circulate in the motor, increasing heat losses in the rotor. The most severe condition occurs when one phase is open and the motor runs on single-phase power.

In general, single-phase loads should not be connected to three phase circuits supplying equipment sensitive to phase-voltage imbalance. A separate circuit should be used to supply such equipment.

6.4 Benefits:

Tangible and intangible benefits of Power factor improvement

Power factor improvement allows the use of smaller transformers, switchgear and cables, etc. as well as reducing power losses and voltage drop in an installation.

A high power factor allows the optimization of the components of an installation. Overrating of certain equipment can be avoided, but to achieve the best results the correction should be effected as close to the individual equipment in the building possible.

Losses in cables are proportional to square of the current and Power factor improvement reduced the distribution losses up to **1.0 %** from the existing levels.

By improving the power factor of a load supplied from a transformer, the current through the transformer will be reduced thereby allowing more loads to be added. In practice, it may be less expensive to improve the power factor, than to replace the transformer by a larger unit.

Tangible and intangible benefits of Energy efficient transformers

Energy efficient transformers the losses for transformer at 50 % load and 100 % load are lower than the conventional transformers. This result in lower transformation losses in the transformer compared to the normal transformer. As the heating in the transformer is less it also results in fewer failure of transformer because of high winding temperature.