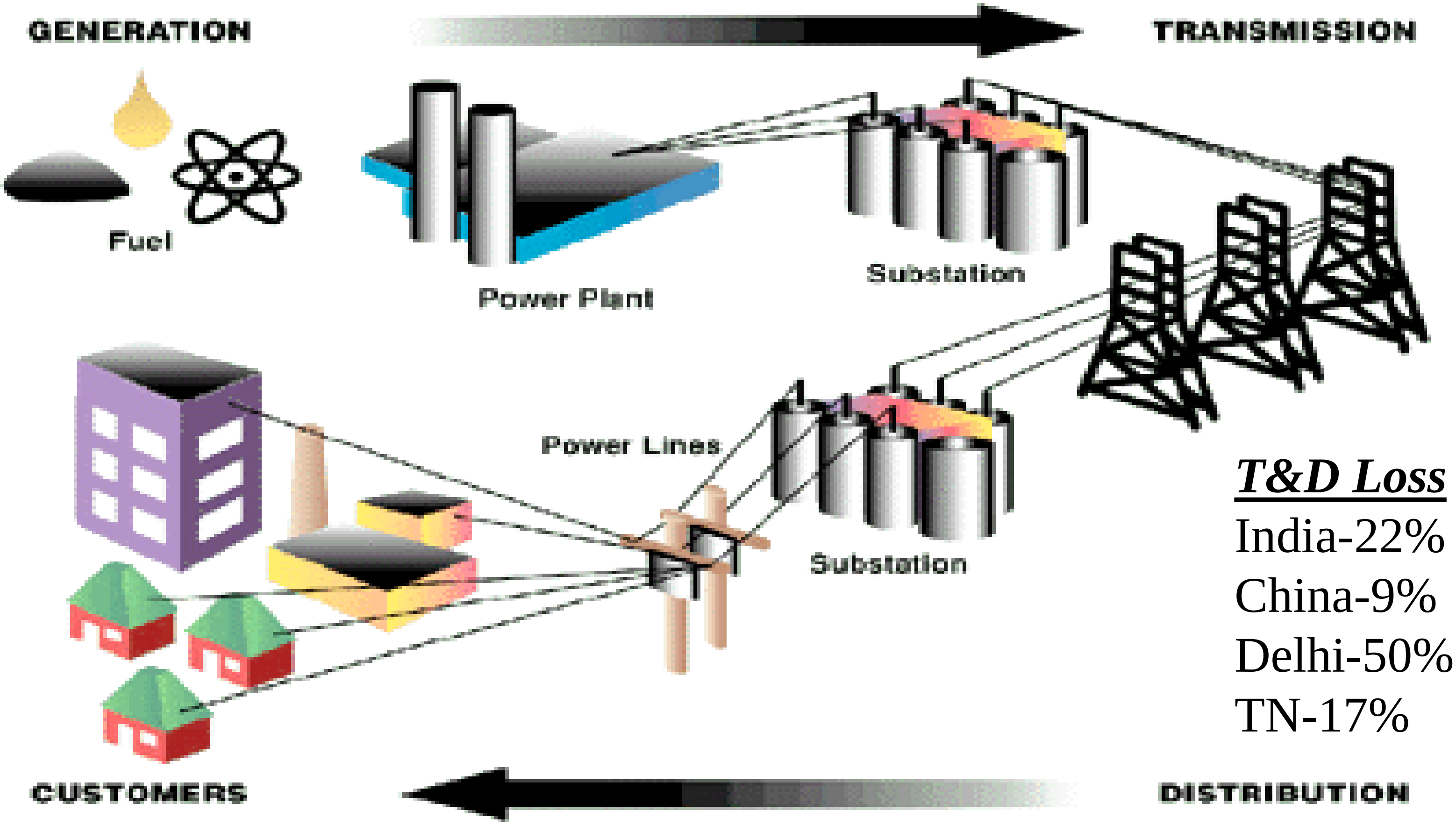
Energy Efficiency in Electrical Systems

Electric Power Supply Systems



__T&D Loss__

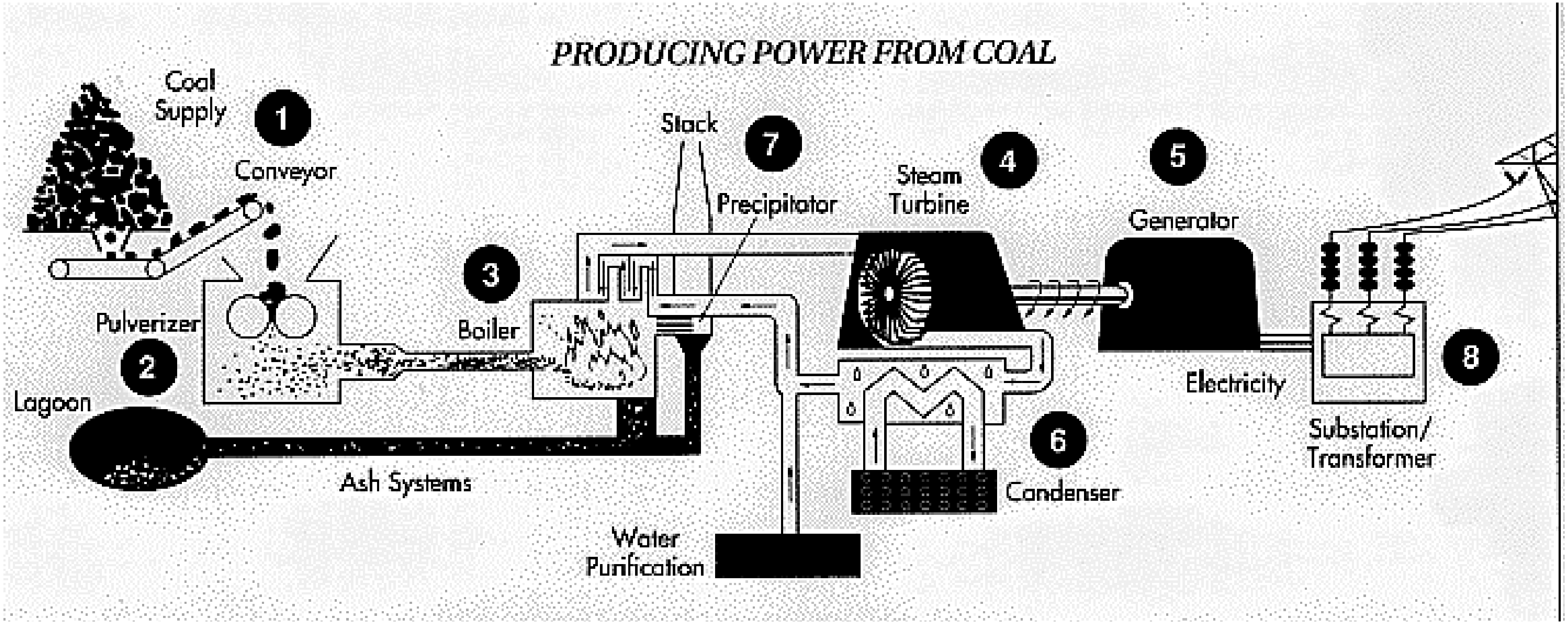
India-22%

China-9%

Delhi-50%

TN-17%

Power Generation Plant



How Energy is converted in each stage?
What is efficiency and heat rate?

Transmission and Distribution Lines

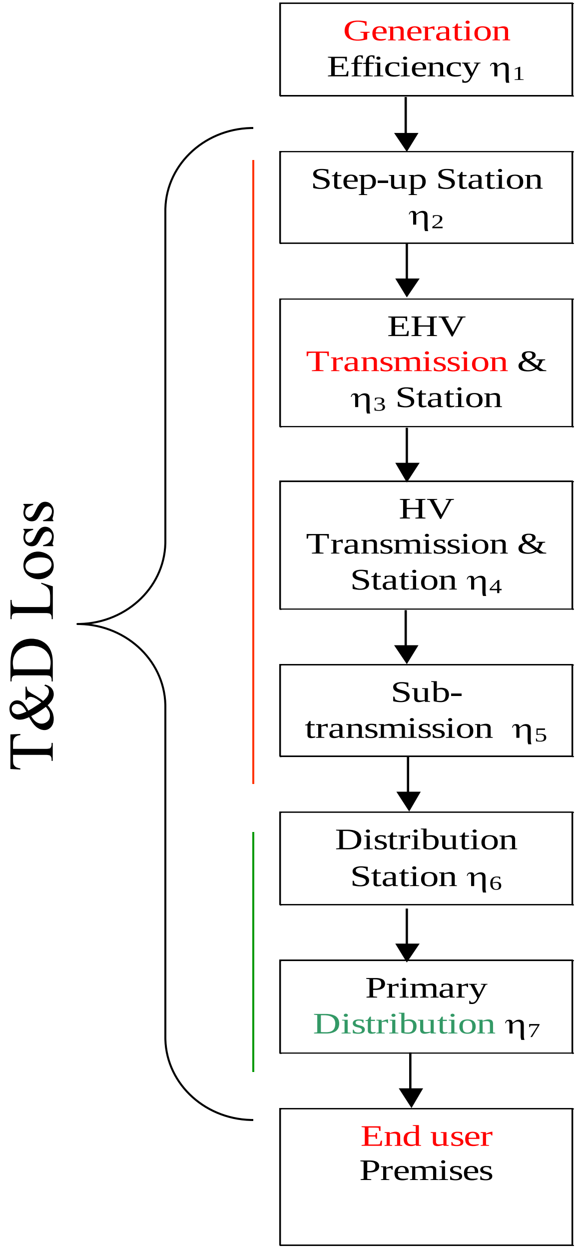
The power plants produce 50 cycle/second (Hertz), (AC) electricity with voltages between 11kV and 33kV.

At the power plant site, the 3-phase voltage is stepped up to a higher voltage for transmission on cables strung on cross-country towers.

High voltage (HV) and extra high voltage (EHV) transmission is the next stage from power plant to transport A.C. power over long distances at voltages like; 220 kV & 400 kV.

Where transmission is over 1000 kM, high voltage direct current transmission is also favoured to minimize the losses.

- Sub transmission at 132 kV,110 kV, 66 kV ,33kV,22kV
- Distribution at 11kV, 6.6 kV, 3.3 kV



T&D Loss

Generation Efficiency η_1

Efficiency ranges 28-35 % with respect to size of thermal plant, age of plant and capacity utilisation

Step-up Station η_2

Step-up to 400 / 800 kV to enable EHV transmission.
Envisaged max. losses 0.5 % or efficiency of 99.5 %

EHV Transmission & η_3 Station

EHV transmission and substations at 400 kV / 800 kV.
Envisaged maximum losses 1.0 % or efficiency of 99 %

HV Transmission & Station η_4

HV transmission & Substations for 220 / 400 kV.
Envisaged maximum losses 2.5 % or efficiency of 97.5 %

Sub-transmission η_5

Sub-transmission at 66 / 132 kV
Envisaged maximum losses 4 % or efficiency of 96 %

Distribution Station η_6

Step-down to a level of 11 / 33 kV.
Envisaged losses 0.5 % or efficiency of 99.5 %

Primary Distribution η_7

Distribution is final link to end user at 11 / 33 kV.
Envisaged losses maximum 5 % of efficiency of 95 %

End user Premises

Cascade efficiency from Generation to end user

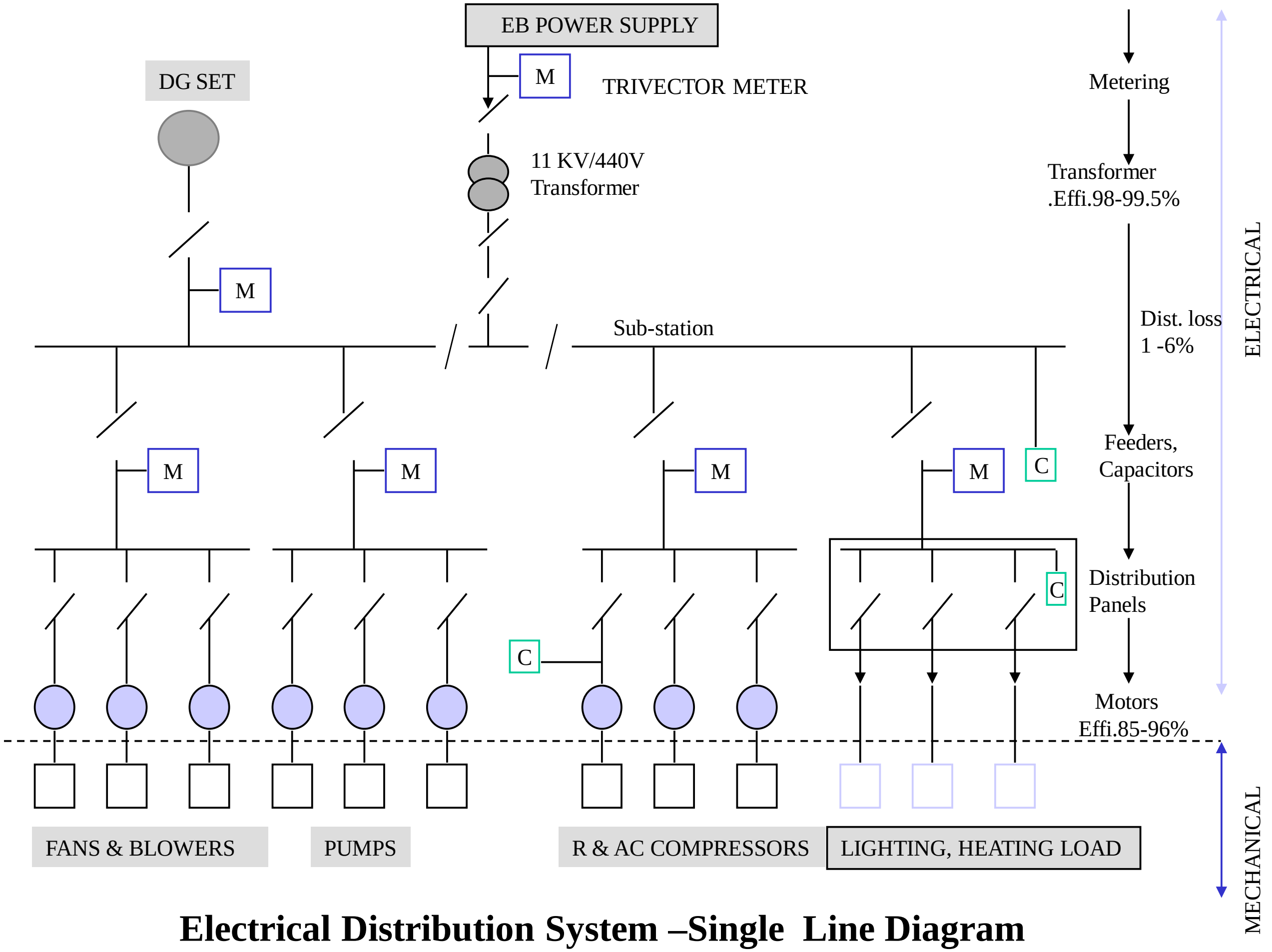
$$= \eta_1 \times \eta_2 \times \eta_3 \times \eta_4 \times \eta_5 \times \eta_6 \times \eta_7$$

The cascade efficiency in the T&D system from output of the power plant to the end use is 87% (i.e. 0.995 x 0.99 x 0.975 x 0.96 x 0.99.5 x 0.95 = 87%)

Why high voltage is preferred in T&D?

- V=IR
  - Higher the voltage lesser the Voltage drop
  - Voltage drop proportional to the ratio of voltages
- Power loss = I^2R
  - Higher the voltage, lesser the current and lesser the power loss
- For ex. If voltage is raised from 11 kV to 33 kV the voltage drop would be lowered by a figure of 1/3 and line loss would be lowered by $(1/3)^2$
- Higher voltage can also bring down the conductor sizes on account of lower currents handled

Industrial End User



Electrical Distribution System –Single Line Diagram

ONE Unit saved = TWO Units Generated

What are the components of Electricity Billing?

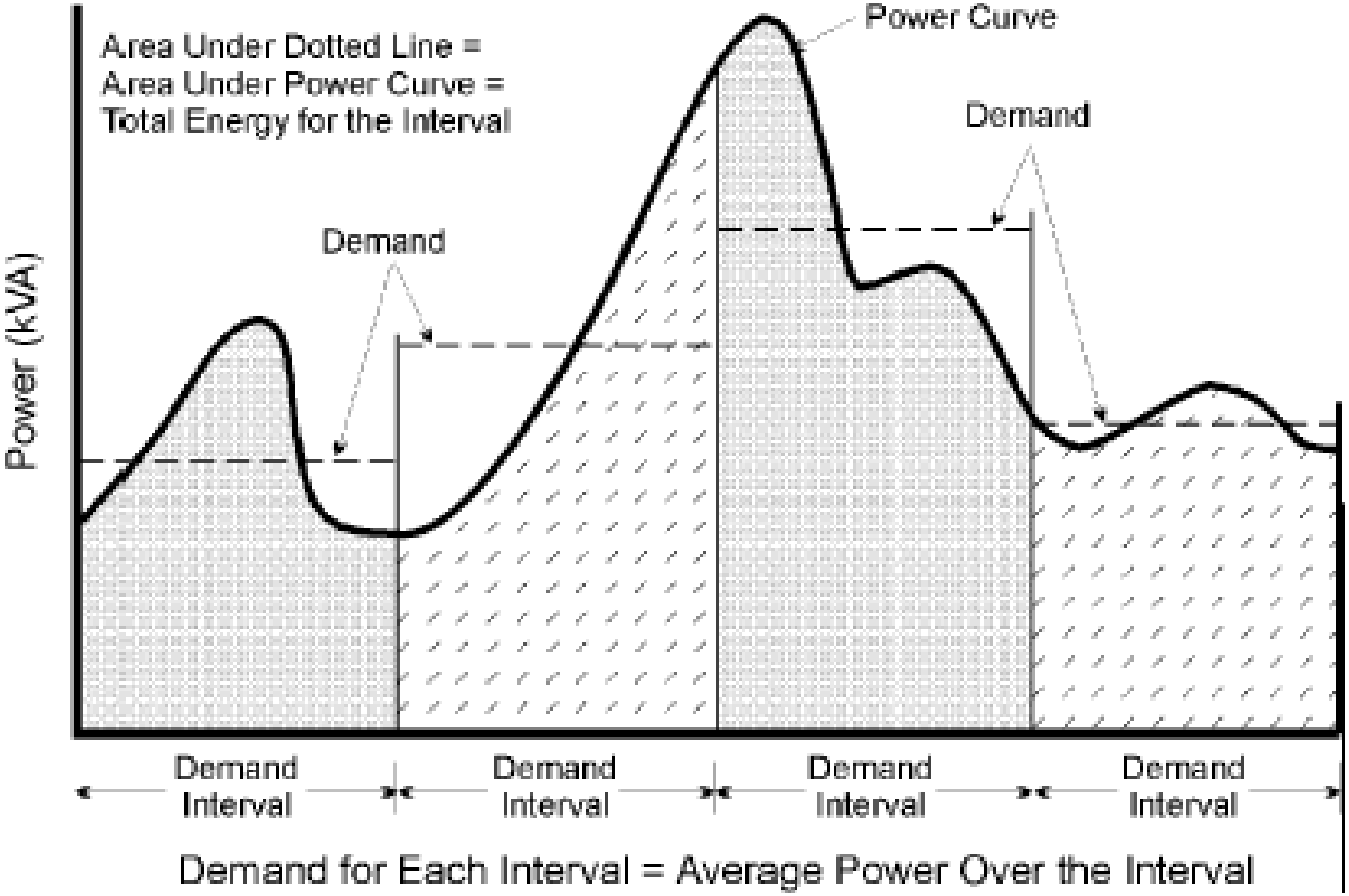
For Industry: Two Part tariff for HT Consumers

The consumer pays for two components.

- Energy Charges for kWh consumed
- Maximum demand Charges (kVA) registered
- Plus
  - PF penalty or PF incentives
  - Fuel Cost adjustments
  - Electricity Duty Charges
  - Meter rentals
  - Lighting and fan power consumption
  - TOD, (peak and non-peak)
  - Penalty for exceeding contract demand
  - Surcharge if metering is at LT side in some of the utilities

- As an example, in an industry, if the drawl over a recording cycle of 30 minutes is :
    - » 2500 kVA for 4 minutes
    - » 3600 kVA for 12 minutes
    - » 4100 kVA for 6 minutes
    - » 3800 kVA for 8 minutes
- The MD recorder will be Computing MD as ?

Month's maximum demand

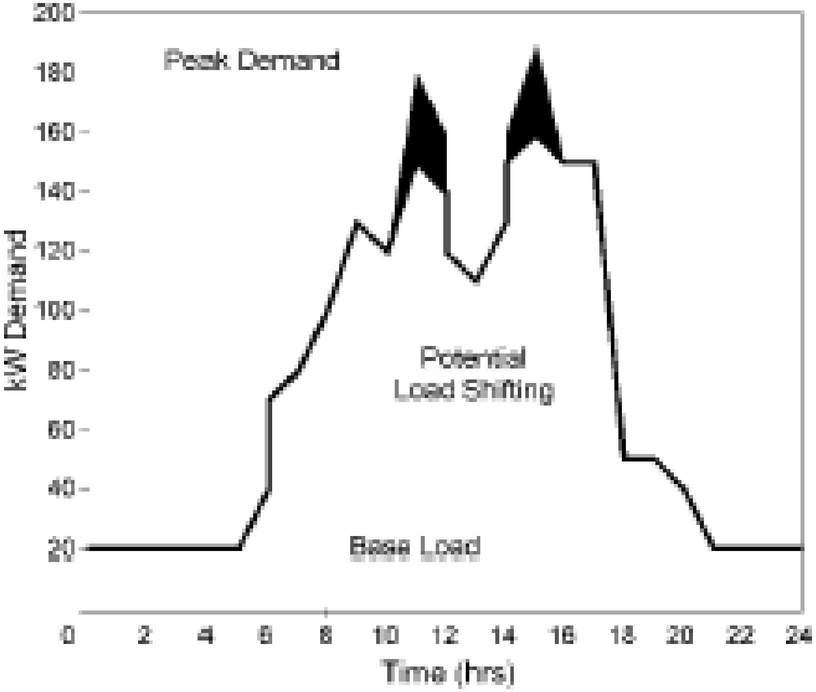


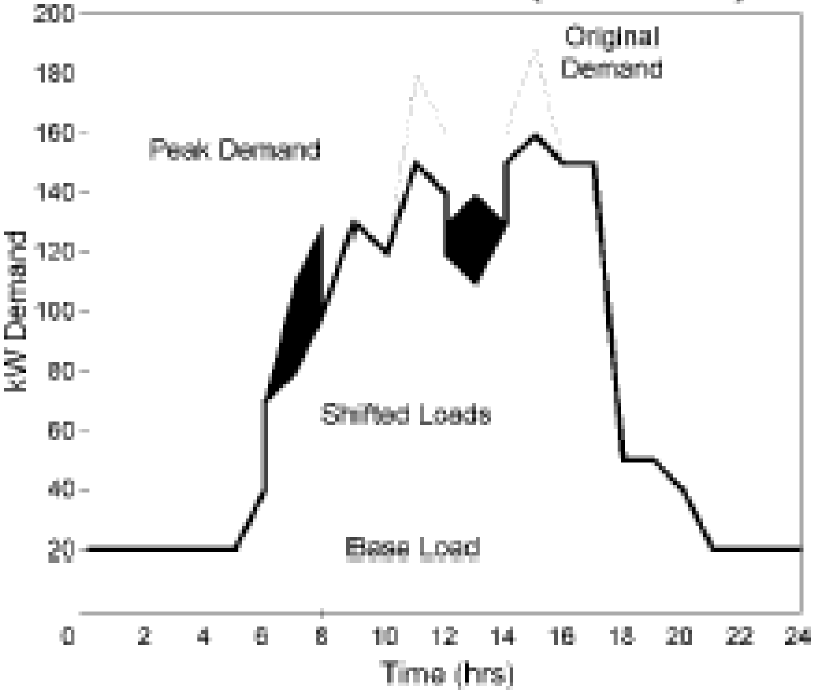
As can be seen from the figure above the demand varies from time to time. The demand is measured over predetermined time interval and averaged out for that interval as shown by the horizontal dotted line.

What are the Load Management Strategies

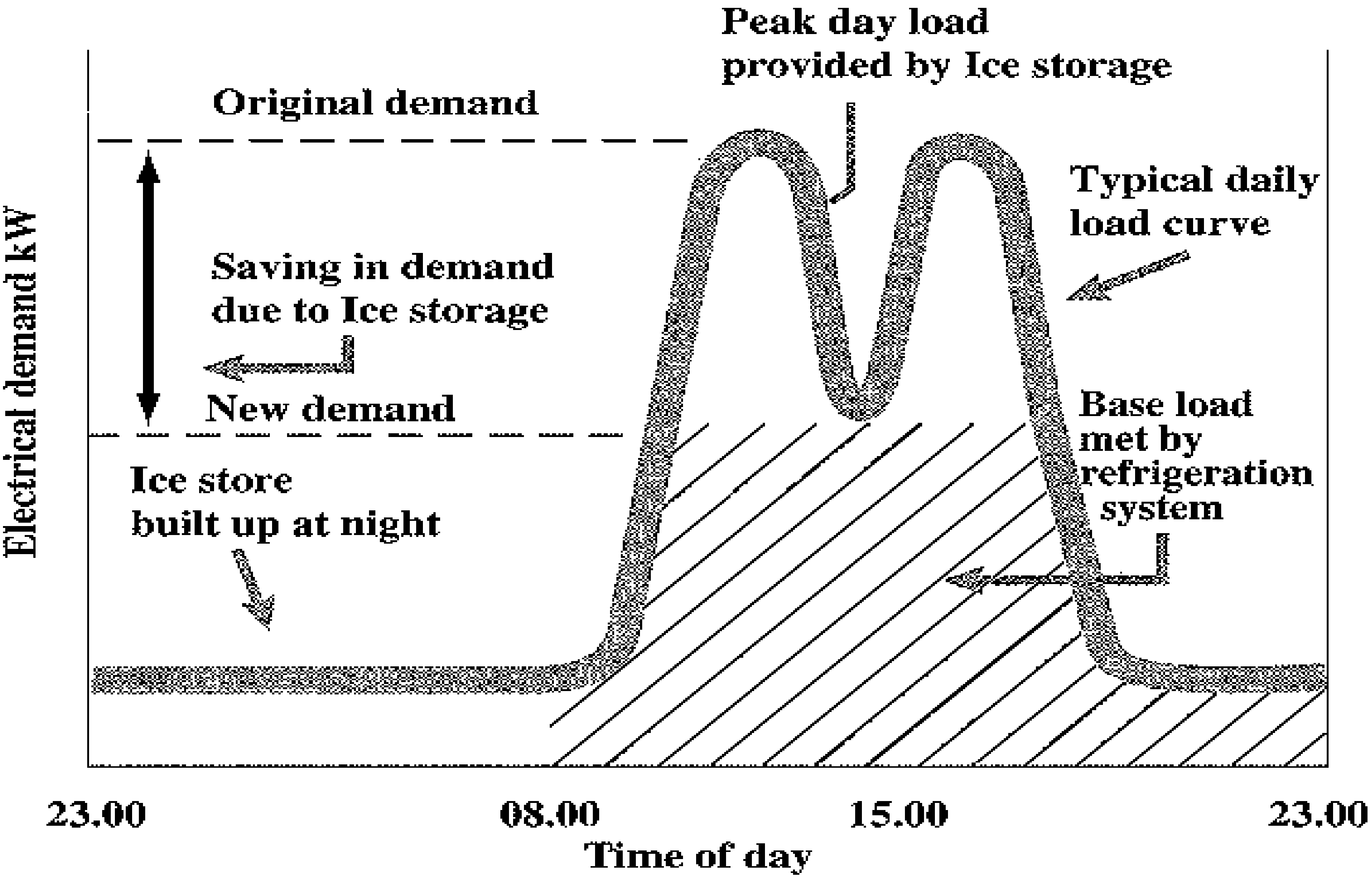
1. Load Curve Generation
2. Rescheduling of Loads
3. Storage of Products/in process material/ process utilities like refrigeration
4. Shedding of Non-Essential Loads
5. Operation of Captive Generation and Diesel Generation Sets
6. Reactive Power Compensation

Load Management: Staggering of motors

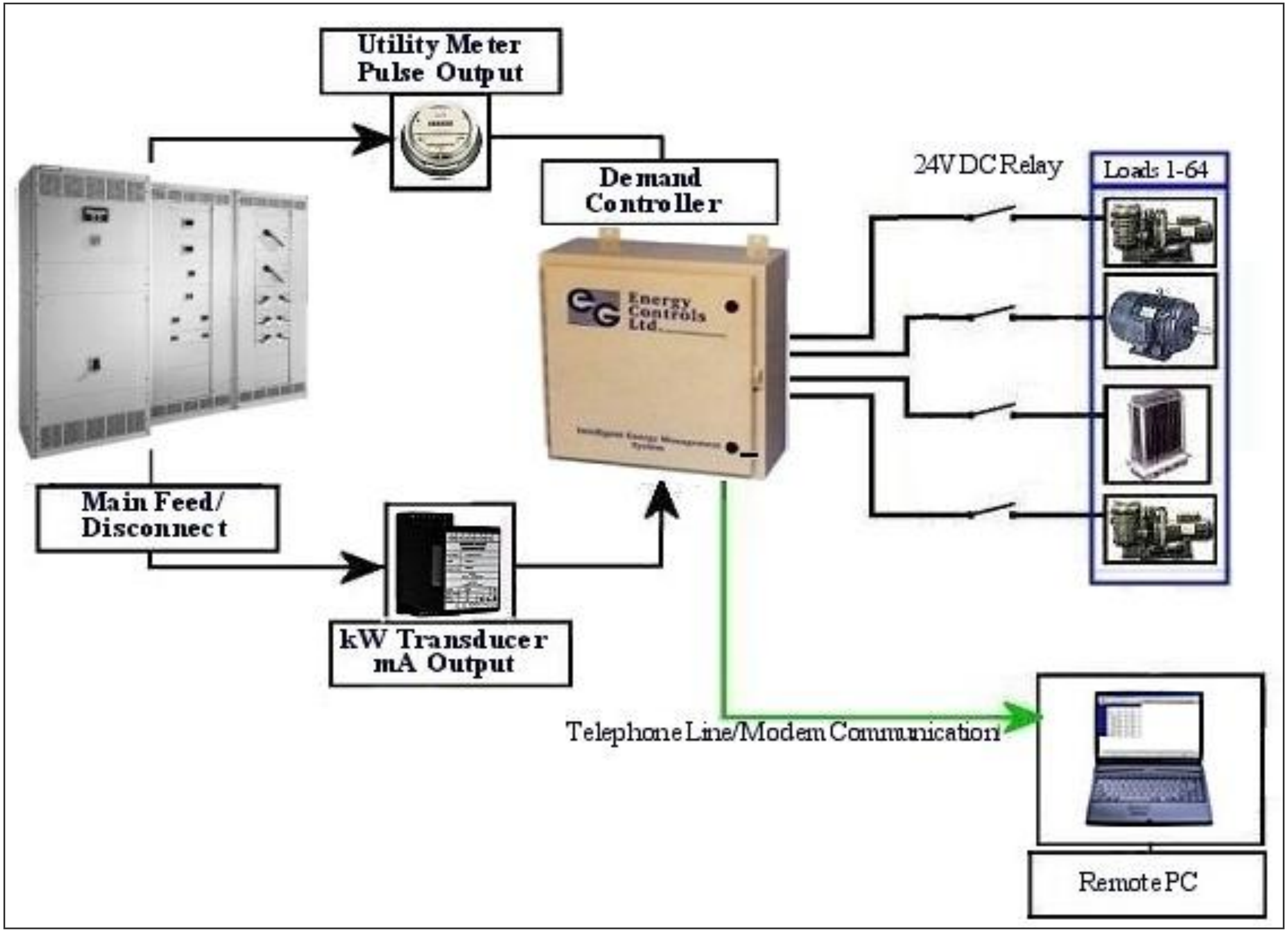

LOAD SHIFTING (BEFORE)


LOAD SHIFTING (AFTER)

How Ice Storage Reduces Daily Peak Demand



Maximum Demand Controller



Power Factor Improvement

Two types of Electrical loads in industries

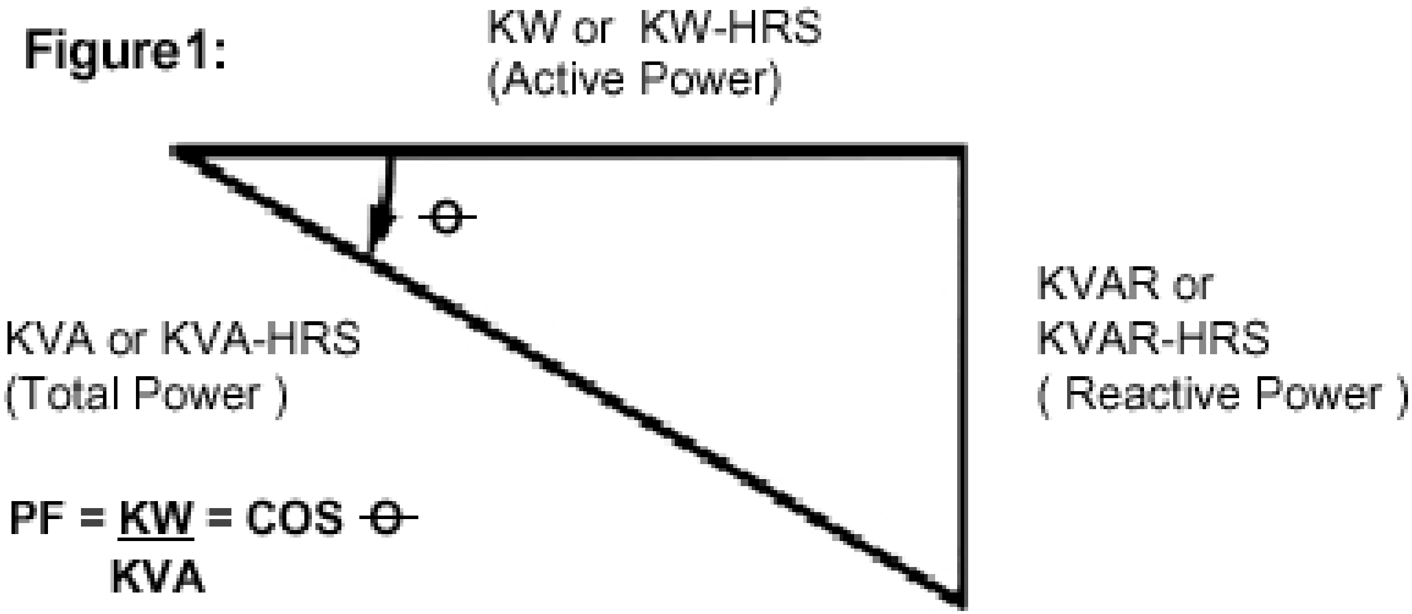
1) Resistive loads are incandescent lighting and resistance heating.
2) Inductive loads are A.C. Motors, induction furnaces, transformers and ballast-type lighting.

Inductive loads require two kinds of power:

1. Active (or working) power to perform the work (motion) and
2. Reactive power to create and maintain electro-magnetic fields.

The vector sum of the active power and reactive power make up the total (or apparent) power used. This is the power generated by the utility for the user to perform a given amount of work.

Figure1:



$$PF = \frac{KW}{KVA} = COS\ \theta$$

Advantages of PF Improvement

The advantages of PF improvement by capacitor addition

- Reactive component of the network is reduced and so also the total current in the system from the source end.
- I^2R power losses are reduced in the system because of reduction in current.
- Voltage level at the load end is increased.
- kVA loading on the source generators as also on the transformers and lines upto the capacitors reduces giving capacity relief. A high power factor can help in utilising the full capacity of the electrical system.

Cost benefits of PF improvement

While costs of PF improvement are in terms of investment needs for capacitor addition the benefits to be quantified for feasibility analysis are:

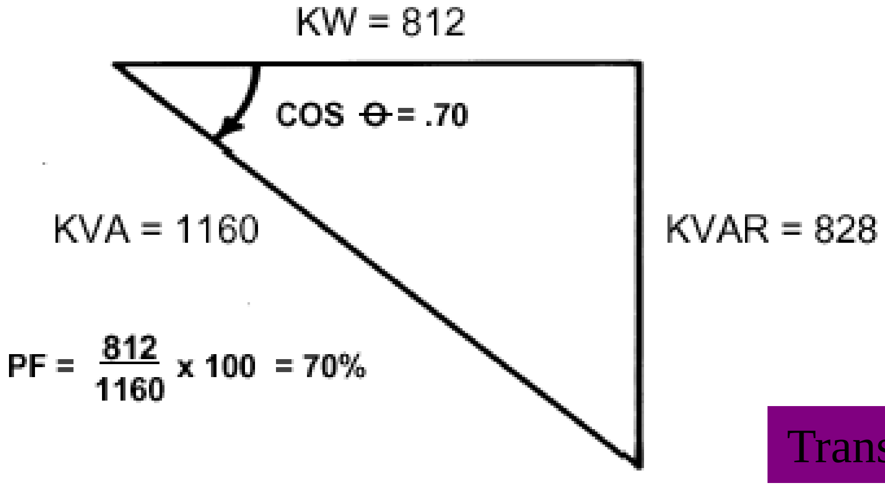
- Reduced kVA (Maximum demand) charges in utility bill
- Reduced distribution losses (KWH) within the plant network
- Better voltage at motor terminals and improved performance of motors
- A high power factor eliminates penalty charges imposed when operating with a low power factor
- Investment on system facilities such as transformers, cables, switchgears etc for delivering load is reduced.

Example

- A chemical industry had installed a 1500 kVA transformer. The initial demand of the plant was 1160 kVA with PF .70. The % loading of transformer was about 78 %. To improve PF and to avoid penality, the unit added 410 kVAr in motor load end.

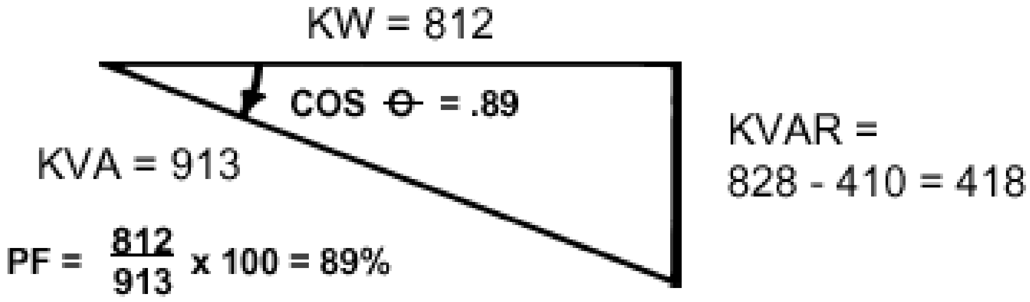
Example

Figure2:



Transformer loading – 1160/1500 = 78 %

Figure3:



Capacitors totaling 410 kVAr installed in each of the 13 large motors

Transformer loading – 913/1500 = 61 %

How to determine the Rating of capacitors required?

Example:

Method-1

The utility bill shows an average power factor of .72 with an average KW of 627. How much KVAR is required to improve the power factor to .95 ?

STEPS:

$$\mathrm{Cos}\ \Phi_1 = 0.72\ ,\ \mathrm{Tan}\ \Phi_1 = 0.963$$

$$\mathrm{Cos}\ \Phi_2 = 0.95\ ,\ \mathrm{Tan}\ \Phi_2 = 0.329$$

$$\textit{Kvar required} = P\ (\mathrm{Tan}\phi_1 - \mathrm{Tan}\phi_2)$$

$$= 627\ (0.964 - 0.329)$$

$$= \mathbf{398\ kVAr}$$

Method-2

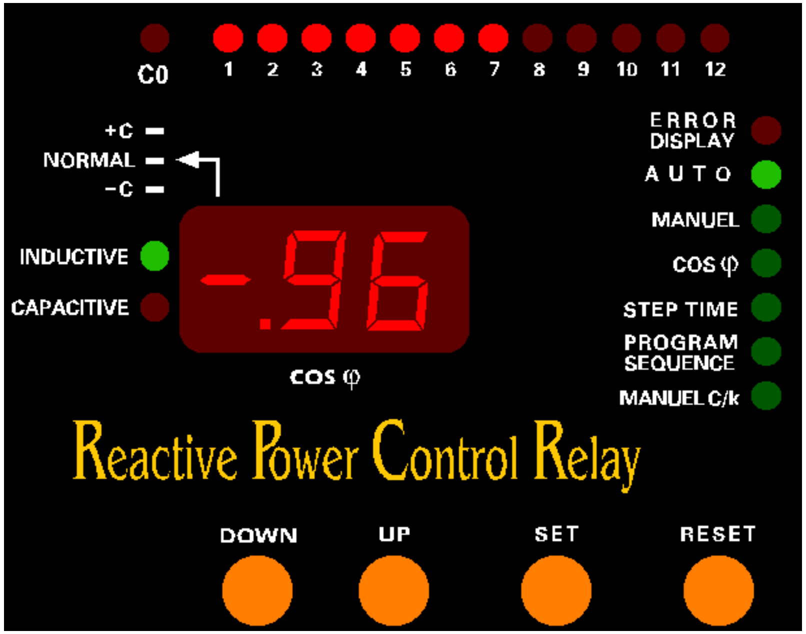
1. Locate 0.72 (original power factor) in column (1).Refer table.
2. Read across desired power factor to 0.95 column. We find .635 multiplier
3. Multiply 627 (average KW) by .635 = 398 KVAR.
4. Install 400 KVAR to improve power factor to 95%.

Now that we have determined that capacitors totaling 400 KVAR must be installed, we must decide where to locate them.

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**	**1.0**
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	1.068	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	0.685	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	0.609	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	0.079	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

Automatic Power Factor Controllers



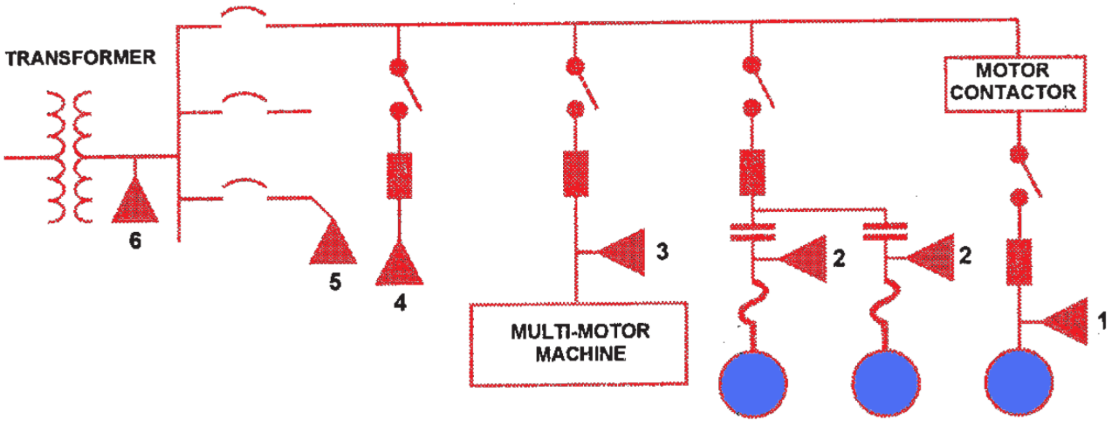
Automatic Power Factor Control Relay

Where to Locate Capacitors?

For motors of 50 hp and above, it is best to install power factor correction capacitors at the motor terminals since distribution circuit loading is reduced. (1,2)

The second arrangement shows capacitor banks connected at the bus for each motor control centre. This compromise to Method 1 will reduce installation costs. (3)

The least expensive method shows capacitor banks connected at the service entrance. However, the disadvantage is that higher feeder currents still flow from the service entrance to the end of line equipment. (4,5,6)



Power Distribution Diagram Illustrating Capacitor Locations

Reduction in Distribution Loss

As current flows through conductors, the conductorsheat. This heating is power loss

Power loss is proportional to current squared (P Loss =I^2R)

Current is proportional to P. F.:

Conductor loss can account for as much as 2- 5% of total load

Capacitors can reduce losses by 1- 2% of the total load

$$\textbf{\% Loss Reduction} = \left[1 - \left(PF_1 / PF_2\right)^2\right] \textbf{ x 100}$$

Reduced Maximum demand charges

Example:
If the maximum demand is 1500 kVA at 0.85 p.f. calculate the reduction in demand at 0.95 p.f.

$$\text{kW} = \text{kVA} \times \mathbf{Cos}\ \Phi$$

Active Power = 1500 x 0.85 = 1275 kW

Maximum demand after pf improvement,
kVA at 0.95 p.f. = 1275/0.95 = 1342 kVA

Performance Assessment of Power Factor Capacitors

- **Voltage effects**: Ideally capacitor voltage rating is to match the supply voltage. If the supply voltage is lower, the reactive kVAr produced will be the ratio V_1^2 / V_2^2 where V_1 is the actual supply voltage, V_2 is the rated voltage. On the other hand, if the supply voltage exceeds rated voltage, the life of the capacitor is adversely affected.

- **Material of capacitors:** Power factor capacitors are available in various types by dielectric material used as; paper/ polypropylene etc. The watt loss per kVAr as well as life vary with respect to the choice of the dielectric material and hence is a factor to be considered while selection.

- **Connections:** Shunt capacitor connections are adopted for almost all industry/ end user applications, while series capacitors are adopted for voltage boosting in distribution networks.

- **Operational performance of capacitors:** This can be made by monitoring capacitor charging current vis- a- vis the rated charging current. Capacity of fused elements can be replenished as per requirements. Portable analyzers can be used for measuring kVAr delivered as well as charging current. Capacitors consume 0.2 to 6.0 Watt per kVAr, which is negligible in comparison to benefits.

What are the Types of Transformers

- **Power transformers :** Used in transmission network of higher voltages, deployed for step-up and step down transformer application
(400 kV, 200 kV, 110 kV, 66 kV, 33kV,22kW)

- **Distribution transformers:** Used for lower voltage distribution networks as a means to end user connectivity.
(11kV, 6.6 kV, 3.3 kV, 440V, 230V)

Rating & Location of Transfomers

- Rating of the transformer is calculated based on the connected load and applying the diversity factor on the connected load, applicable to the particular industry and arrive at the kVA rating of the Transformer.

  Diversity factor = overall maximum demand of the plant : to the sum of individual maximum demand of various equipment.

  Diversity factor varies from industry to industry and depends on various factors such as individual loads, load factor and future expansion needs of the plant. Diversity factor will always be less than one.

- Location of the transformer is very important as far as distribution loss is concerned. Transformers should be placed close to the load centre, considering other features like optimization needs for centralized control, operational flexibility etc. This will bring down the distribution loss in cables.

How to calculate Transformer losses ?

1. Load loss (or copper loss)
2. No load loss (or iron loss)

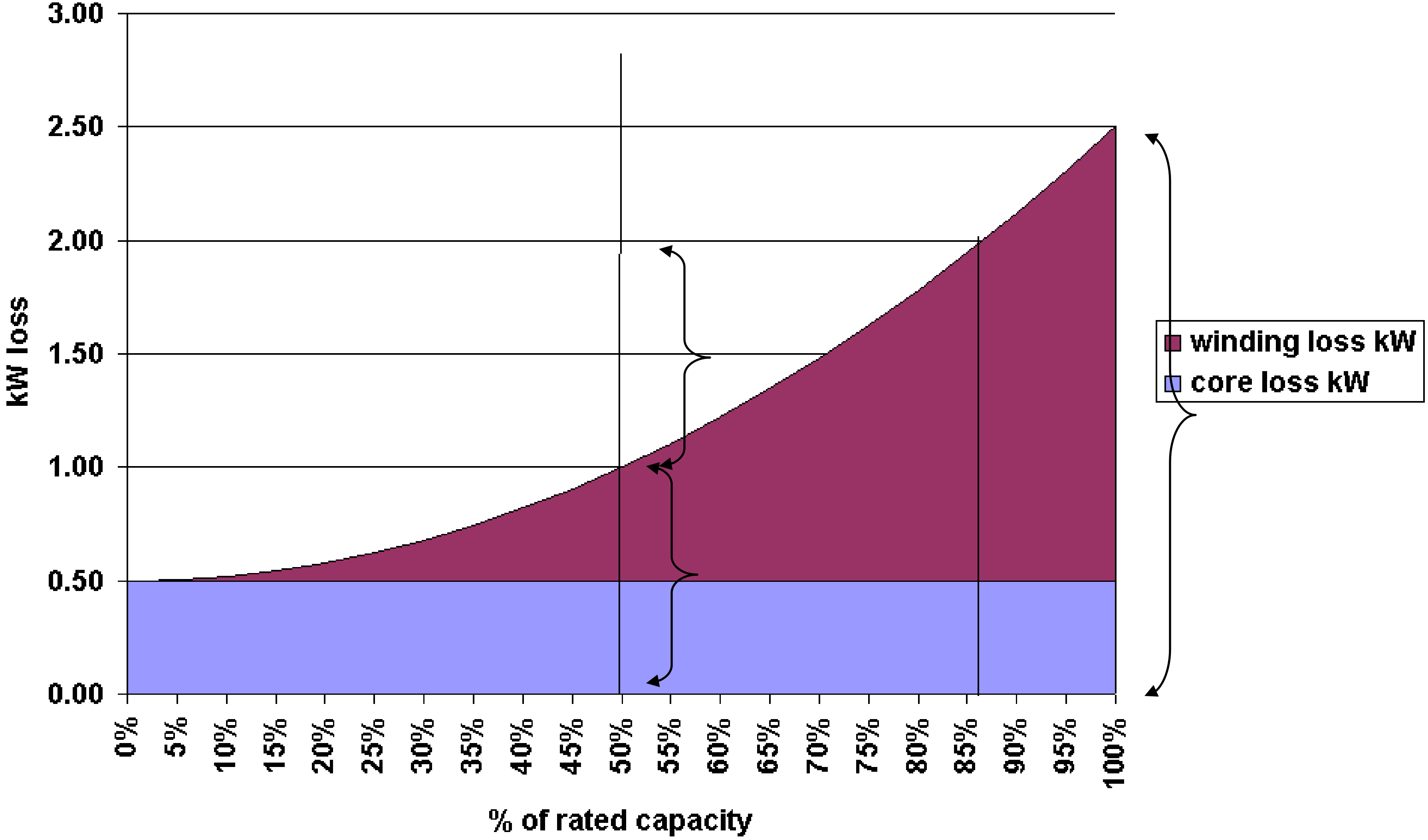
- The total transformer loss, P_{TOTAL}, at any load level can then be calculated from:

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

- Where transformer loading is known, the actual transformers loss at given load can be computed as:

$$= No\,load\,loss + \left(\frac{kVA\,load}{Rated\,kVA}\right)^2 x\,(full\,load\,loss)$$

Transformer Loss vs. Load



Case Example:

For a load of 1500 KVA the plant has installed three numbers of 1000 KVA transformers. The No load loss is 2.8 KW and the full load loss 11.88 KW. Estimate the total loss with 3 transformers in operation and 2 transformers in operation.

a) 2 transformers in operation :

No load loss = $2 \times 2.8 = 5.6$

Load loss = $2 \times \frac{(750)}{(1000)}^{2} \times 11.88$

= 13.36 kW

Total Loss = 5.6 + 13.36 = 18.96

b) 3 transformers in operation :

No load loss = 3 x 2.8 = 8.4 KW

Load loss = $3 \times \frac{(500)}{(1000)}^{2} \times 11.88 = 8.91$ KW

Total loss = 17.31 KW

Savings by loading all the 3 transformers = 13200 kWh.

Voltage fluctuation control

- *Off-circuit tap changer*
  - It is a device fitted in the transformer, which is used to vary the voltage transformation ratio. Here the voltage levels can be varied only after isolating the primary voltage of the transformer.

- *On load tap changer (OLTC)*
  - Here the voltage levels can be varied without isolating the connected load to the transformer.

Parallel Operation of Transformers

- The design of Power Control Centre (PCC) and Motor Control Centre (MCC) of any new plant should have the provision of operating two or more transformers in parallel. Additional switchgears and bus couplers should be provided at design stage.

- Whenever two transformers are operating in parallel, both should be technically identical in all aspects and more importantly should have the same impedance level. This will minimise the circulating current between transformers.

- Where the load is fluctuating in nature, it is preferable to have more than one transformer running in parallel, so that the load can be optimised by sharing the load between transformers. The transformers can be operated close to the maximum efficiency range by this operation.

Energy Efficient Transformers

- Most energy loss in dry-type transformers occurs through heat or vibration from the core. The new high-efficiency transformers minimise these losses.
- The iron loss of any transformer depends on the type of core used in the transformer. However the latest technology is to use amorphous material – a metallic glass alloy for the core the expected reduction in energy loss over conventional (Si Fe core) transformers is roughly around 70%, which is quite significant.
- By using an amorphous core– with unique physical and magnetic properties- these new types of transformers have increased efficiency even at low loads - 98.5% efficiency at 35% load.

1600 kVA Amorphous Core Transformer

Standards & Labeling Programme for Distribution Transformers

- The standard transformer ratings covered under the energy labeling scheme is 16, 25, 63, 100, 160 and 200 kVA and non standard ratings from 16 kVA to 200 kVA. In the BEE labeling programme, the total transformer losses at 50% and 100% loading have been defined.

	1 star		2 star		3 star		4 star		5 star	
Rating kVA	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)	Max Losses at 50% (Watts)	Max Losses at 100% (Watts)
16	200	555	165	520	150	480	135	440	120	400
25	190	785	235	740	210	695	190	635	175	595
63	490	1415	430	1335	380	1250	340	1140	300	1050
100	700	2020	610	1910	520	1800	475	1650	435	1500
160	1000	2800	880	2550	770	2200	670	1950	570	1700
200	1130	3300	1010	3000	890	2700	780	2300	670	2100

Ways to minimise distribution losses

- Relocating transformers and sub-stations near to load centers
- Re-routing and re-conducting such feeders and lines where the losses / voltage drops are higher.
- Power factor improvement by incorporating capacitors at load end.
- Optimum loading of transformers in the system.
- Opting for lower resistance All Aluminum Alloy Conductors (AAAC) in place of conventional Aluminum Cored Steel Reinforced (ACSR) lines
- Minimizing losses due to weak links in distribution network such as jumpers, loose contacts, and old brittle conductors.

Losses in Electrical Distribution Equipment

S.No	Equipment	% Energy Loss at Full Load Variations	
		Min	Max
1.	Outdoor circuit breaker (15 to 230 KV)	0.002	0.015
2.	Generators	0.019	3.5
3.	Medium voltage switchgears (5 to 15 KV)	0.005	0.02
4.	Current limiting reactors	0.09	0.30
5.	Transformers	0.40	1.90
6.	Load break switches	0.003	0.025
7.	Medium voltage starters	0.02	0.15
8.	Bus ways less than 430 V	0.05	0.50
9.	Low voltage switchgear	0.13	0.34
10.	Motor control centers	0.01	0.40
11.	Cables	1.00	4.00
12.	Large rectifiers	3.0	9.0
13.	Static variable speed drives	6.0	15.0
14.	Capacitors (/ kVAr)	0.50	6.0

Demand Side Management (DSM)

- DSM refers to "*Actions taken on the customer's side of the meter to change the amount (kWh) or timing (kVA) of energy consumption. Electricity DSM strategies have the goal of maximising end use efficiency to avoid or postpone the construction of new generating plants*".

- The key objectives of DSM include the following.

1. Improve the efficiency of energy systems.
2. Reduce financial needs to build new energy facilities (generation).
3. Minimize adverse environmental impacts.
4. Lower the cost of delivered energy to consumers.
5. Reduce power shortages and power cuts.
6. Improve the reliability and quality of power supply.

DSM methodology

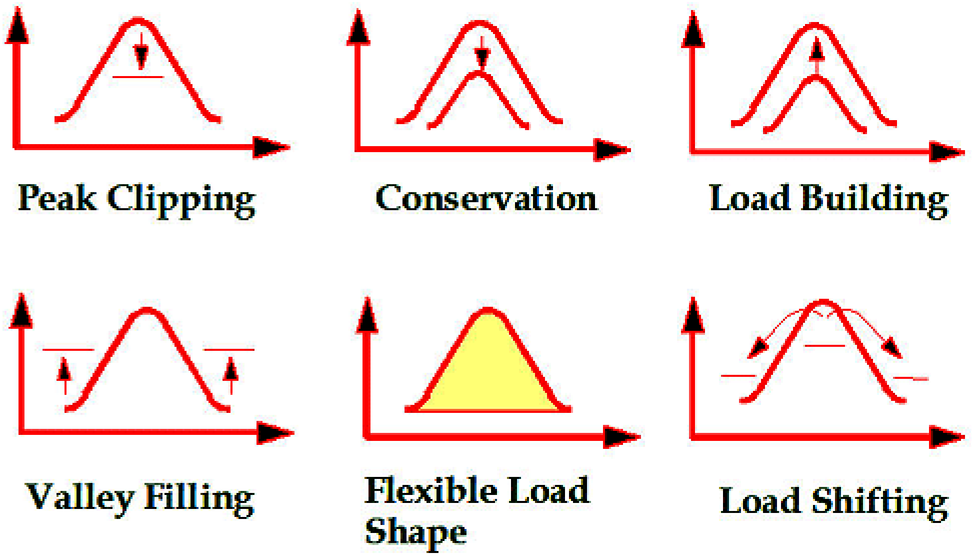
Step 1: Load Research

Step 2: Define load-shape objectives

Step 3: Assess program implementation strategies

Step 4: Implementation

Step 5: Monitoring and Evaluation


Peak Clipping
Conservation
Load Building
Valley Filling
Flexible Load Shape
Load Shifting

Load Shape Profiles and Objectives

Types of DSM measures & benefits

Types of DSM measures

a) Energy reduction programmes - Efficient Lighting (CFLs, Using natural light), Appliance Labelling, Building regulations, Efficient and alternative energy use, Efficient use of electric motors and motor driven systems, Preventative maintenance, Energy management and audit.

b) Load management programmes - Load Levelling (Peak clipping, Valley filling and load shifting), Load growth, Tariff Incentives or Penalties (Time-of-Use & real time pricing, power factor penalties)

Benefits of DSM:

Customer benefits	**Societal benefits**	**Utility benefits**
Satisfy electricity demands Reduce / stabilise costs (bills) Improve value of service Maintain/improve lifestyle and productivity	Reduce environmental degradation Conserve resources Protect global environment Maximise customer welfare	Lower cost of service Improve operating efficiency, flexibility Reduce capital needs Improve customer service

What are Harmonics ?

- Harmonics are multiples of the fundamental frequency of an electrical power system.
- If, for example, the fundamental frequency is 50 Hz, then the 5th harmonic is five times that frequency, or 250 Hz.
- Likewise, the 7th harmonic is seven times the fundamental or 350 Hz, and so on for higher order harmonics.

Some of the Harmonic problems are

1. **Blinking of Incandescent Lights**
2. **Capacitor Failure**
3. **Conductor Failure**
4. **Flickering of Fluorescent Lights**
5. **Motor Failures (overheating)**
6. **Transformer Failures**

What is linear/non -linear loads ?

- In AC network, flow of current depends upon the voltage applied and the impedance (resistance to AC) provided by elements like resistances, reactances of inductive and capacitive nature. As the value of impedance in above devices is constant, they are called linear whereby the voltage and current relation is of linear nature.
- However in real life situation, various devices like diodes, silicon controlled rectifiers, thyristors, voltage & current chopping reactors, induction & arc furnaces are also deployed for various requirements and due to their varying impedance characteristic, these NON LINEAR devices cause distortion in voltage and current waveforms which is of increasing concern

What are the devices that creates Harmonics

Devices that convert Frequently AC to DC create harmonics.
Some of these devices are listed below:

- Computers, Uninterruptible power supplies (UPS), Solid-state rectifiers
- Electronic process control equipment, PLC’s, etc
- Electronic lighting ballasts, including light dimmer

Total Harmonic Distortion

Harmonics can be discussed in terms of **current or voltage**.

Total Harmonic Distortion (THD) expresses the amount of harmonics.

The following is the formula for calculating the THD for current:

$$THD_{current} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{I_n}{I_1} \right)^2} \times 100$$

When expressed as a percentage of fundamental voltage THD is given by,

$$\mathrm{THD}_{\mathrm{voltage}} = \sqrt{\sum_{n=2}^{n=n} \left(\frac{V_n}{V_1} \right)^2} \times 100$$

Mostly, 3^{rd},5^{th} and 7^{th} harmonics causes distortion.

Harmonics Limits

Maximum Harmonic Current Distortion in % of IL					
Isc/IL	**<11**	**11 ≤ h < 17**	**17 ≤ h < 23**	**23 ≤ h < 35**	**TDD**
< 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
➢1000					

Total Harmonic Distribution for Different Voltage Levels in %		
Bus Voltage at PCC	**Individual Voltage Distortion (%)**	**Total Voltage Distortion THD (%)**
69 kV and below	3.0	5.0
69.001 kV Thru 161 kV	1.5	2.5
161 kV and above	1.0	1.5

Harmonic filters

- **Tuned Harmonic filters consisting of a capacitor bank and reactor in series are designed and adopted for suppressing harmonics, by providing low impedance path for harmonic component. The Harmonic filters connected suitably near the equipment generating harmonics help to reduce THD to acceptable limits.**

- **Benefits of Harmonic Filters**

  Improve power factor ratings through harmonic recombination
  Isolate harmonic currents
  Minimize equipment problems through THD cancellation
  Reduce wasted energy
  Minimize current carried in plant cables