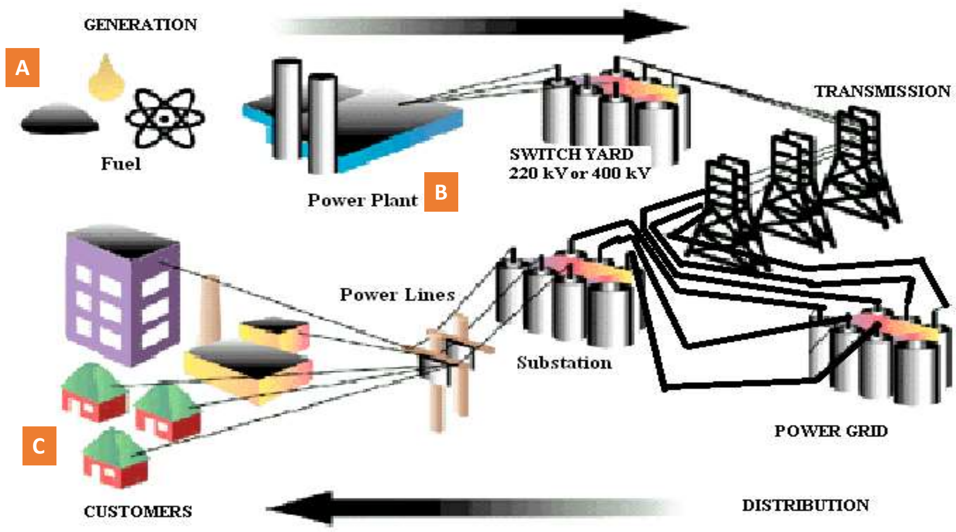
Chapter-1 Electrical System

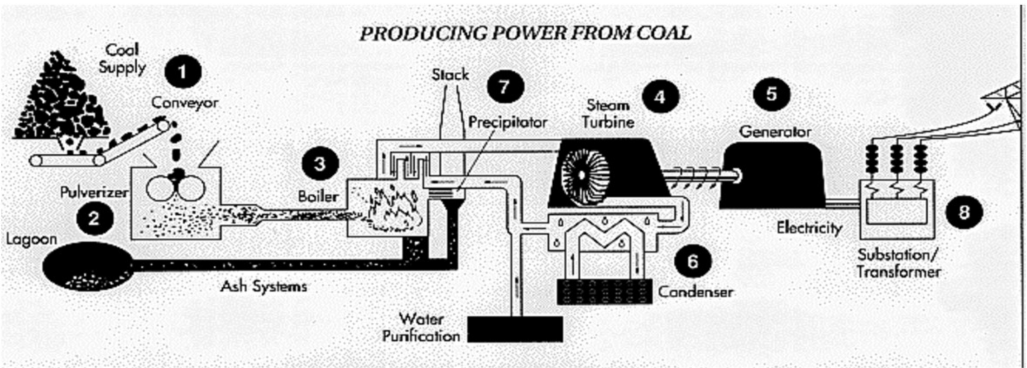
Contents

1.1 Typical Electric Power Supply Systems



ONE Unit saved here@ C equals to……….at B ?

Thermal Power Generation Plant



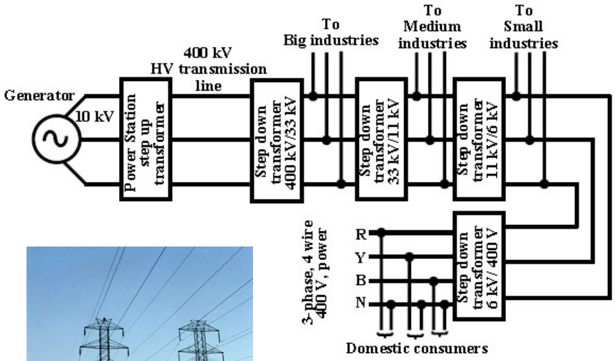
How Energy is converted in each stage?
What is efficiency and heat rate?

Thermal power plant efficiency is ………………proportional to heat rate?

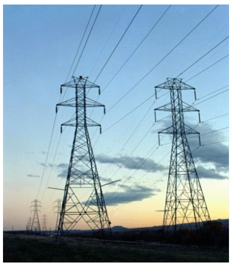
Transmission and Distribution Lines

Power plants produce 50 cycle/second AC electricity with voltages between 11kV and 33kV.
At the power plant site, 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 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.



Typical Voltage Levels in a Power System



Cascade Efficiency

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 line?

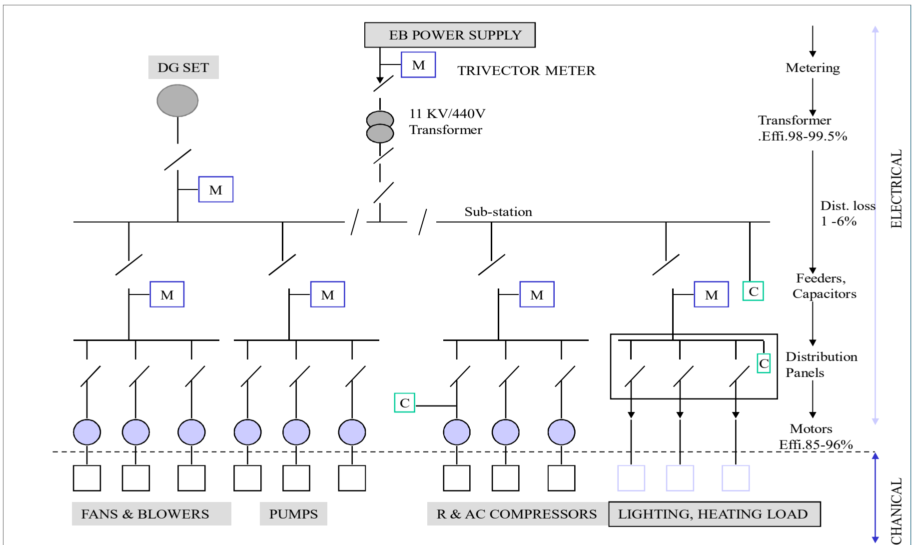
- **V=IR**
  - Higher the voltage lesser the Voltage drop
  - Voltage drop proportional to the ratio of voltages
- **Power loss = I^2R**
  - Higher the voltage, lesser the current and lesser the power loss
- Ex.
- If voltage is raised from 11 kV to 33 kV the voltage drop would be lowered by a figure of **1/3** and line loss would be lowered by **$(1/3)^2$,** (1/9)
- Higher voltage can also bring down the conductor sizes on account of lower currents handled

Electrical Distribution Single line diagram

Industrial End User

Plant network elements **Transformers** at receiving sub-station, **switchgear**, and **cables**, load-break switches, **capacitors** cause losses.

These losses are meager and unavoidable.



Electrical Distribution System –Single Line Diagram

1.2 Electricity Billing?

What are the components of Electricity Billing?

For Industry: Two Part tariff for HT Consumers

The consumer pays for two components.

1. **Energy Charges for kWh consumed**
2. **Maximum Demand Charges (for kVA) registered**

- Plus
  - **PF penalty** or PF incentives
  - **Penalty for exceeding MD**
  - **TOD**, (peak and non-peak)
  - Fuel Cost adjustments
  - Electricity Duty Charges

Month's maximum demand

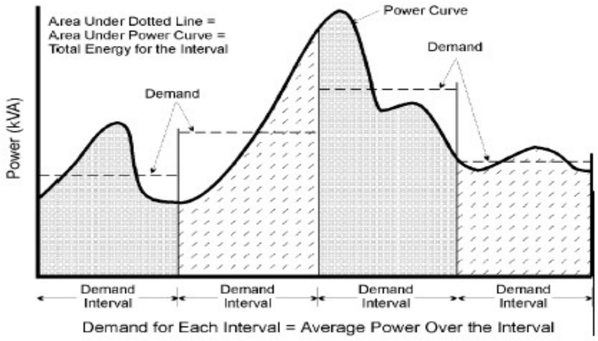
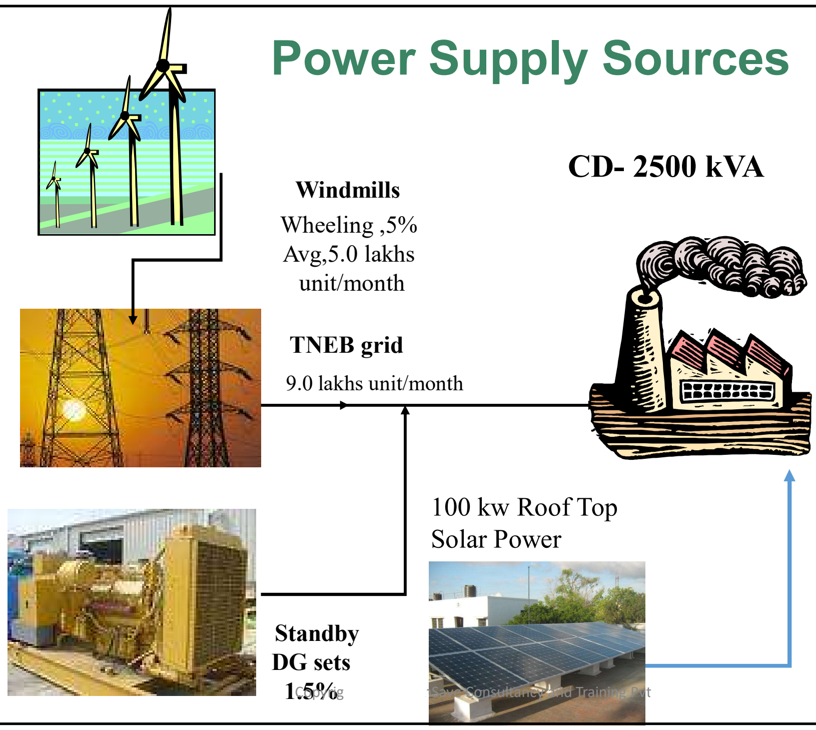


Fig. Demand varies from time to time. It is measured **over predetermined time interval** and averaged out for that interval as shown by the horizontal dotted line.

Power Supply Sources

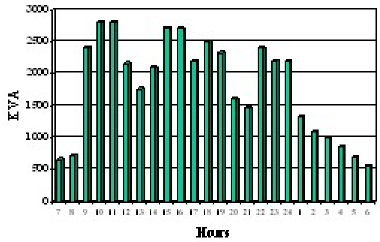


1.3 Electrical Load Management & Maximum Demand Control

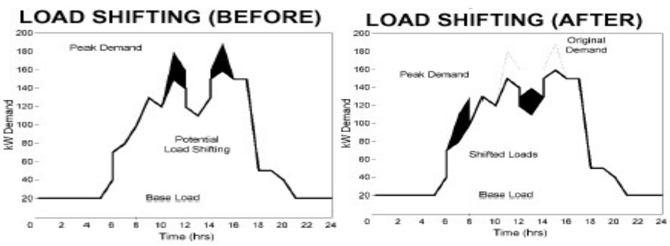
What are the Load Management Strategies

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

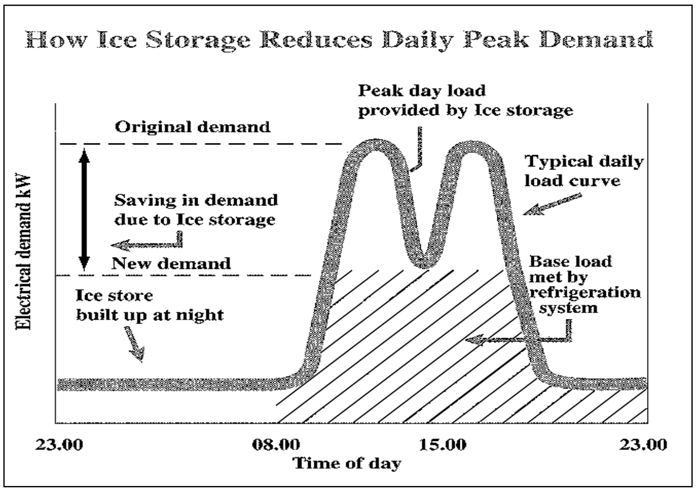
Load Curve Generation



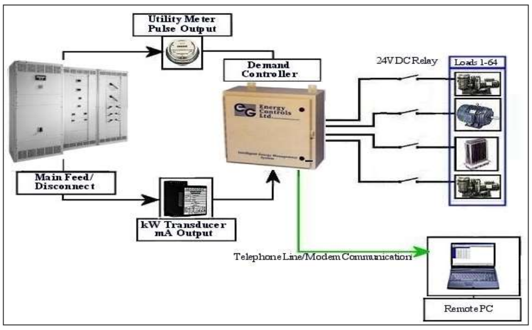
Rescheduling of Loads: Staggering of motors



Storage of Products/process material



Maximum Demand Controller



1.4 Power Factor Improvement and Benefits

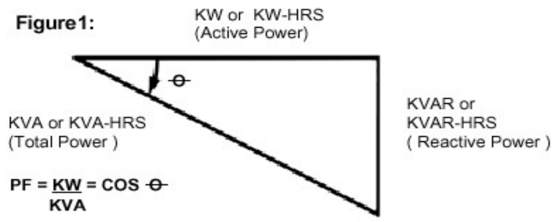
Two types of Electrical loads in industries

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 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 (apparent) power used. This is the power generated by the utility for the user to perform a given amount of work.



Advantages of PF improvement Cost benefits

- Reduced kVA (Maximum demand) charges in utility bill
- Reduced distribution losses (KWH) within the plant network (I^2R power losses)
- Better voltage at motor terminals and improved performance of motors
- A high power factor eliminates penalty charges
- Investment on system facilities such as transformers, switchgears

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 ?

$$Cos\ \Phi_1 = 0.72\ ,\ Tan\ \Phi_1 = 0.963$$

$$Cos\ \Phi_2 = 0.95\ ,\ Tan\ \Phi_2 = 0.329$$

$$Kvar\ required = P\ (\ Tan\phi_1 - Tan\phi_2\ )$$

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

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

Method-2

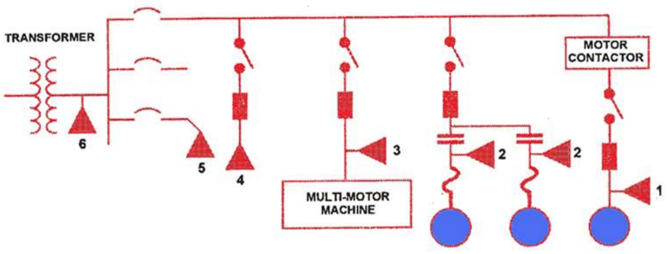
1. Locate 0.72 (original PF) in column (1).Refer table.
2. Read across desired power factor to 0.95 column. We find 0.635 multiplier
3. Multiply 627 (avg. KW) by 0.635 = 398 KVAR.
4. Install 400 KVAR to improve power factor to 95%.

Now we have determined 400 KVAR required.
But, where to be located in network?.

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

Where to Locate the Capacitors to improve PF?

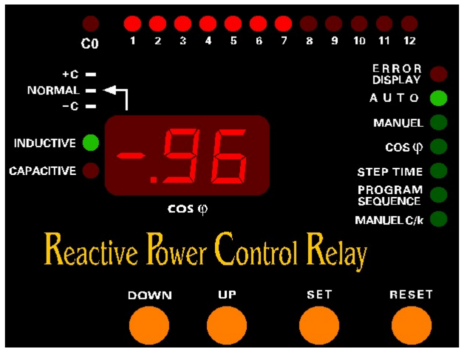


Power Distribution Diagram Illustrating Capacitor Locations

.First : For motors of 50 hp & above, it is best to install capacitors at the motor terminals. **(1,2)**

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

Least expensive location 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)**



Automatic Power Factor Control Relay

Reduction in Distribution Loss

As current flows through conductors, the conductors heat. This heating is power loss .Power loss is proportional to current squared **(P Loss =I²R)**

Current is proportional to P. F.. Conductor loss can account for 2- 5% of total load. **Capacitors can reduce losses by 1- 2% of the total load**

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

Voltage effects:

- 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.
- if the supply voltage exceeds rated voltage, the life of the capacitor is adversely affected.

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.

$$kW = kVA \times \textit{Cos } \Phi$$

Active Power = 1500 x 0.85 = **1275 kW**

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

1.5 .Transformers

How to calculate Transformer losses ?

Load loss (or copper loss)

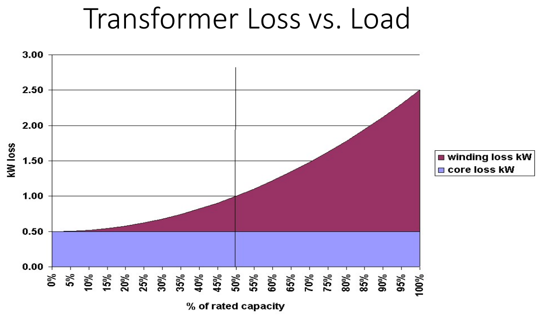
No load loss (or iron loss)

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

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

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

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



- **Voltage fluctuation control** by
  - *Off-circuit tap changer*
  - *On load tap changer (OLTC)*

Case Example:

For a load of 1500 KVA, plant has installed three numbers of 1000 KVA transformers. No load loss is 2.8 KW and 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 x 2.8 = 5.6

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

= 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 $= 3 \times \left(\frac{500}{1000}\right)^2 \times 11.88 = 8.91$ **KW**

Total loss = 17.31 KW

Savings by loading all the 3 transformers = 13200 kWh.

Energy Efficient Transformers

1600 kVA Amorphous Core Transformer

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.

Standards & Labeling Programme for Distribution Transformers

BEE made mandatory S&L for distribution transformers from 2007 , scheme covered upto 200 kVA. Total transformer losses at 50% and 100% loading have been defined. (IS 1180)

	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

1.6 Distribution losses in Industrial Systems

What are the measures 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.

Ex
The cable losses in any industrial plant will be up **to 6 %** depends on size and complexity of the distribution system

1.7 Assessment of Transmission and Distribution (T&D) Losses in Power Systems

For an electric utility **(DISCOMs)** the distribution losses which are more predominant, can be categorized as

1.Technical Losses

2.Commercial Losses

Technical losses primarily due to

- Transformation Losses (at various levels)
- High I^2R losses in distribution lines due to inherent resistance and poor PF

Normative Technical loss limits in Transmission and Distribution network in Indian Context

System Component	Loss Limit % Min	Loss Limit % Max
STEP-UP Transformers & EHV Transmission System	0.5	1.0
Transmission to intermediate voltage level, transmission system & Step-down to sub transmission Voltage level	1.5	3.0
Sub transmission System & step down to distribution voltage level	2.0	4.5
Distribution lines and Service connections	3.0	7.0
TOTAL LOSSES	**7.0**	**15.5**

1.8 Estimation of Technical Losses in Distribution System

Two methods of determining the energy losses:

Direct method: Install energy meters at all locations starting from the input point of the feeder to the individual consumers. The difference between input energy and sum of all consumers over a specific duration is accounted as distribution loss of the network. This calls for elaborate and accurate metering and collection of simultaneous data.

Indirect method essentially involves;

- Energy metering at critical locations in substation and feeders.
- Compiling the network information, length/ feeders, size, DTR , capacitor .
- Conducting load flow studies (peak load /normal load durations.
- Application of suitable software to assess the system losses.
- Softwares simulation for identifying improvements and network optimization.

Computation of AT & C Losses

AT & C Losses = {1- (Billing Efficiency x Collection Efficiency) } x 100

$$Billing\ Efficiency,\% = \frac{Total\ units\ sold, MU}{Total\ input, MU} \times 100$$

$$Collection\ Efficiency,\% = \frac{Revenue\ collected, Rs.}{Amount\ billed, Rs} \times 100$$

Aggregate Technical & Commercial losses.

Technical losses

Causes:

Lengthy distribution lines- *more lengths, more resistance and higher I2r loss*

Inadequate Size of Conductors

voltage regulation % Drop = 100 (Es - Er) / Er

Es = Sending end voltage, Er = Receiving end voltage

Distribution Transformers(DTR) not located at load center

Low Power Factor

Measures:

High Voltage Distribution System (HVDS) - *Discoms installing more Nos*

Amorphous Core Transformers- *70% no-load loss saving*

Commercial Losses

Commercial losses are primarily attributable

- Illegal consumption, defective not correctly metered, billed and revenue collected, causes commercial losses to the utilities.

1. Meter Reading
2. Metering
3. Collection efficiency

Measures to reduce commercial losses

- Accurate Metering .
- Appropriate range of meter with reference to connected load.
- Installation of Electronic meters with (TOD, tamper proof, data and remote reading Intensive inspections.
- Compulsory metering/average billing
- Eradication of theft.
- Above losses are collectively calledas AT & C (Aggregate Technical & Commercial) losses.

1.9 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.

Types of DSM measures & benefits

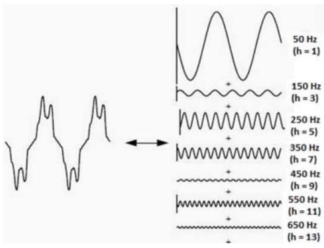
a) Energy reduction programmes - Efficient Lighting (CFLs, Using natural light), Appliance Labelling, Building regulations, Efficient and alternative energy use, Efficient use of electric motors and motor driven systems, Preventative maintenance, Energy management and audit.

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)

1.10 Harmonics

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.



Effects of Harmonic problems

1. Capacitor Failure,Fuses Blowing
2. Conductor Failure
3. Flickering of Lights
4. Motor Failures ,
5. Transformer Failures
6. Circuit Breakers Tripping

Causes of Harmonics

Devices that convert Frequently AC to DC create harmonics. Non-Linear systems

- Computers, UPS, Solid-state rectifiers
- VFDs, PLC's, Electronic ballasts, light dimmer

Total Harmonic Distortion (THD) expressed as

Current Distortion:

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

Voltage Distortion:

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

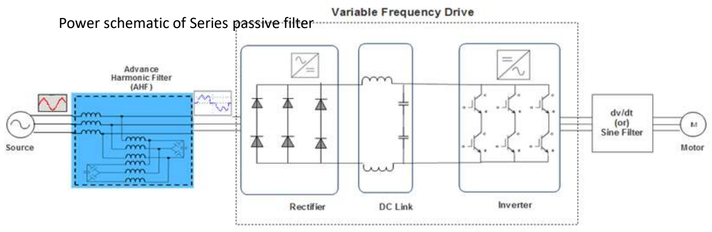
Mostly, 3^{rd},5^{th} and 7^{th} harmonics causes distortion.

Overcoming Harmonics in Power systems

Passive filter

Combinations of capacitors, inductors and resistors. Used for all voltage levels. It is designed either single tuned/double tuned . Offer very low impedance to divert all the harmonic current at the tuned frequency.

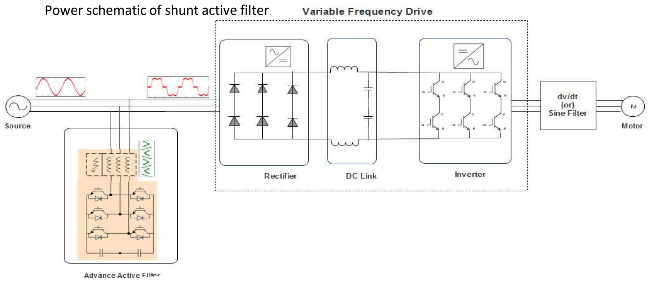
Power schematic of Series passive filter



Active filter: It is ***connected parallel***.
Inserting negative phase compensating harmonics into the AC-Network, thus eliminating the undesirable harmonics

It consists of a wide percentage of harmonics produced by non- linear loads.Active filters (Fig) compensate current harmonics by injecting equal magnitude but opposite phase harmonic compensating current.

Power schematic of shunt active filter



1.11 Analysis of Electrical Power Systems

System Problem	Common Causes	Possible Effects	Solutions
Voltage imbalances among the three phases	**Improper transformer tap settings**, Single-phase loads not balanced among phases, bad conductors, transformer grounds or faults.	**Motor vibration**, premature motor failure. A 5% imbalance causes a 40% increase in motor losses.	**Balance loads among phases.**
Poor connections in distribution or at connected loads.	**Loose bus bar connections**, loose cable corroded connections, poor crimps, worn contactors	**Produces heat, causes failure** at connection site, leads to voltage drops and voltage imbalances	**Use Infra Red camera to locate hot-spots and correct.**
Undersized conductors.	Facilities expanding beyond original designs, poor power factors	**Voltage drop** and energy wastage.	Reduce the load by conservation scheduling.
Insulation leakage	Degradation over time due to **extreme temperatures, abrasion, moisture, chemicals**	May leak to ground or to another phase. Variable energy waste.	Replace conductors, insulators
Low Power Factor	Inductive loads such as motors, transformers, and lighting ballasts Non-linear loads	Reduces current-carrying capacity of wiring, voltage regulation effectiveness, and equipment life.	Add capacitors to counter reactive loads.
Harmonics	UPSs, VFDs, high intensity discharge lighting, and electronic ballasts.	Over-heating of neutral conductors, motors, transformers, switch gear. Voltage drop, low power factors, reduced capacity.	Take care with equipment selection and isolate sensitive electronics from noisy circuits.

Solved Example:
An energy audit of electricity bills of a process plant was conducted. The plant has a contract demand of 5000 kVA with the power supply company. The average maximum demand of the plant is 3850 kVA/month at a power factor of 0.95. The maximum demand is billed at the rate of Rs.600/kVA/month. The minimum billable maximum demand is 75 % of the contract demand. An incentive of 0.5 % reduction in energy charges component of electricity bill are provided for every 0.01 increase in power factor over and above 0.95. The average energy charge component of the electricity bill per month for the plant is Rs.18 lakhs.

The **plant decides to improve the power factor to unity.** **Determine** the power factor capacitor kVAr required, annual reduction in maximum demand charges and energy charge component.
What will be the simple payback period if the cost of power factor capacitors is Rs.900/kVAr.

kW drawn	3850 x 0.95 = 3657.5 kW
kVAr required to improve power factor from 0.95 to 1	kW (tan θ_1 – tan θ_2)
	kW (tan ($\cos^{-}\theta_1$) – tan ($\cos^{-}\theta_2$)
	3657.5 (tan ($\cos^{-}$0.95) – tan ($\cos^{-}$1)
	3657.5(0.329 - 0)= 1203
Cost of capacitors @Rs.900/kVAr	1203 x 900 kVAr
	Rs.10,82,700
Maximum demand at unity PF	3657.5/1 = **3657.5 kVA**
75 % of contract demand	5000x0.75=**3750 kVA**
Reduction in Demand charges . As the plant has to pay MD charges on minimum billable demand of 3750, and not on the improved MD of 3657.5 kVA	3850-3750= 100 kVA
	100kVA/month x 12 months x Rs.600 kVA/ month= Rs.7,20,000
%reduction in energy charge from 0.95 to 1 @ 0.5 % for every 0.01 increase	2.5 %
Monthly energy cost component bill	Rs.18,00,000
Reduction in energy cost component	18,00,000 x (2.5/100)
	Rs.45,000/month
Annual reduction	Rs.45,000 x 12
	Rs.5,40,000
Savings in electricity bill	Rs.7,20,000+ 5,40,000= 12,60,000
Investment	Rs.10,82,700
Payback period	10,82,700/12,60,000
	0.859 years or 10.31months

	Objective Type Questions
1.	If the distribution voltage is raised from 11 kV to 33 kV, the line loss would be lower by a factor a) 1/9 b) 9 c) 3 d) none
2.	The kVAr rating required for improving the power factor of a load operating at 500 kW and 0.85 power factors to 0.95 is ___. a) 145 kVAr b) 500 kVAr c) 50 kVAr d) 100 kVAr
3.	The rating of the capacitor at motor terminals should not be greater than ________. a) magnetizing kVAr of the motor at full load b) magnetizing kVAr of the motor at no load c) magnetizing kVAr of the motor at half load d) magnetizing kVAr of the motor at 75% load
4.	If voltage applied to a 415 V rated capacitors drops by 10%, its VAR output drops by ____. a) 23% b) 87% c) 19% d) 10%
5.	The sum of individual maximum demand of the plant to the sum of individual maximum demand of various equipments is __. a) load factor b) diversity Factor c) demand Factor d) maximum demand

AABCB

6.	The approximate kVA rating required for a DG set with 1000 kW connected load, with diversity factor of 1.5 and 84% loading and 0.8 power factor is a) 500 kVA b) 1000 kVA c) 1500 kVA d) 2000 kVA
7.	Commercial losses in distribution net work is due to a) theft b) average billing c) defective meters d) all the above
8.	The Star rating programme of distribution transformers is based on losses at a) no load b) full load c) at 25 % load d) at 50 % & 100 % load
9.	Demand side Management helps a) to reduce the energy losses b) to reduce system peak demand c) to promote energy efficiency among users. d) all the above
10.	If the reactive power drawn by a particular load is zero, it means the load is operating at a) lagging power factor b) leading power factor c) unity power factor d) none of the above

CDDDC

Thank You

Save energy and water for Sustainable Life