ENERGY EFFICIENCY FOR ELECTRICAL SYSTEMS

Organised by:

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Learning Outcome

- To understand and operate electrical systems in an efficient manner to reduce energy consumption.

- To learn the efficient power distribution arrangements, power quality issues, building load management techniques, uninterruptible power system and renewable energy generation system.

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Programme Outline

- **UNDERSTANDING OF BUILDING ELECTRICAL SYSTEM**
- **ENERGY EFFICIENT OF POWER DISTRIBUTION ARRANGEMENTS**
  - Optimizing Substation Locations
  - Optimizing LV Distributing Arrangements
- **REAL POWER, POWER FACTORS AND CORRECTION**
- POWER QUALITY ISSUES
  - Power Factor Correction and Harmonic Filtering
- BUILDING LOAD MANAGEMENT
  - Demand Control Techniques
  - Economic justification for Load Management Systems
- MOTOR POWER FOR FANS AND PUMPS
  - Selection of Efficient Motors
  - Optimizing Performance of Motors for Fan and Pumps
  - Application of Frequency Drives
- LIFTS SYSTEM
  - Optimising Lift Usage
  - Lift Control Systems
- UNINTERRUPTIBLE POWER SUPPLY (UPS)
- METERING AND MONITORING
- RENEWABLE ELECTRICITY GENERATION

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Introduction

Reduce energy w/o compromising the performance

- **What Is Energy Efficiency?**
  Energy is the ability to change or move matter. Energy efficiency means changing or moving the MOST matter with the LEAST amount of energy.

- **Why Energy Efficiency Is Important**
  Using energy efficiently saves our earth's precious energy resources, helps the environment, and reduces the energy costs $$$.

- **Efficient Technology**
  Some newer equipment/appliances and equipment are built to run super efficiently. These appliances use a fraction of the energy that no efficient equipment/appliances use to do the same job.

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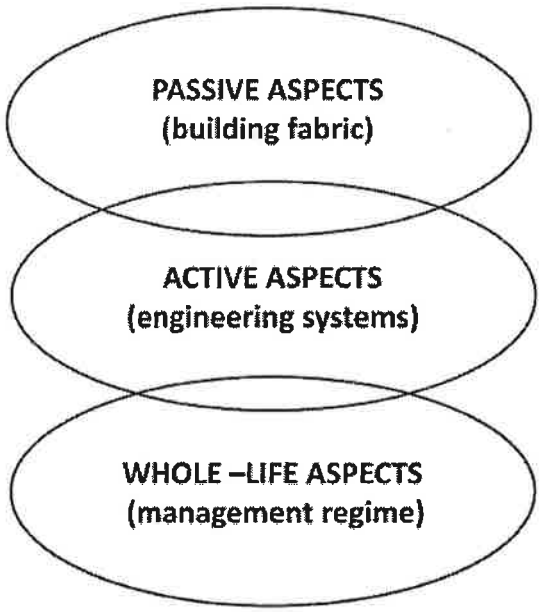
T8 - 36W
T5 - 28W

Key considerations for energy efficiency



Energy Sustainability

- demand control (off when not in use)

- Efficiency and Conservation are key components of energy **sustainability**.
  - Energy sustainability focuses on long-term energy strategies and policies that ensure adequate energy to meet today's needs, as well as tomorrow's.

- **Sustainability** also includes investing in research and development of:
  - advanced technologies for producing conventional energy sources,
  - promoting the use of alternative energy sources, and
  - encouraging sound environmental policies.

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UNDERSTANDING OF BUILDING ELECTRICAL SYSTEM

The typical electrical systems in a building includes:

- **High Voltage System – 22kV, 6.6kV distribution**
- **Low Voltage System – 400V and 230V distribution**
- **Emergency Standby Power System – Medium voltage and Low voltage standby generators**
- **Uninterruptible Power Supply (UPS)**
- **Lighting Systems – External and Internal**
- Earthing System
- Lightning Protection System

- Security Systems – CCTV, Access Control System and Intruder Alarm
- Data & Communication infrastructure
- Telephone System (PABX)
- Electronic Car Parking System (EPS)
- Audio and Visual System
- Public Address System (PA) include Intercom System
- Master Antennae Television System (MATV)
- Nurse Call System
- Queue Management System
- **Vertical Transportation – Lifts and Escalator Systems**
- Automatic Guarded Vehicle System

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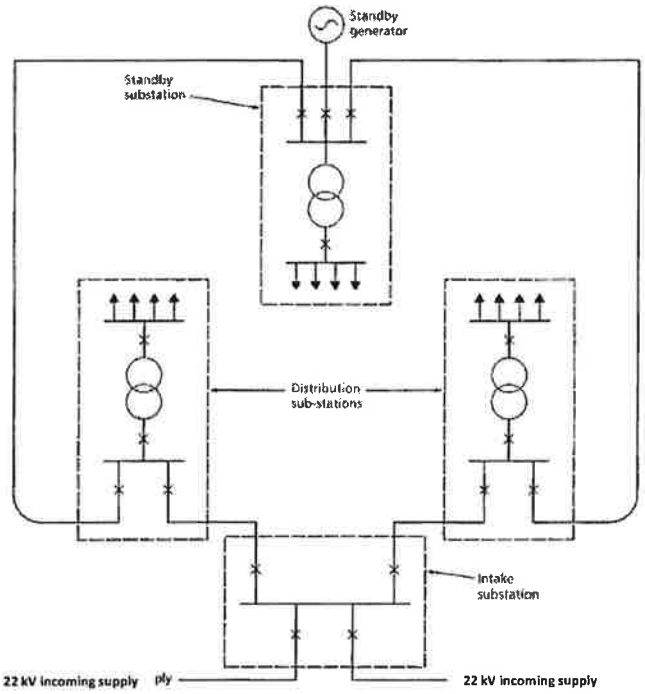
Schematic arrangements of substations serving an industrial site to illustrate different substation types

(not building)



Ring Main Unit (RMU) — no protection

22kV — 15 to 30MVA (1nf) (2feeders)

66kV — more than 30MVA

UNDERSTANDING OF BUILDING ELECTRICAL SYSTEM

A brief outline of the typical arrangement and principal components in a building's electrical distribution system

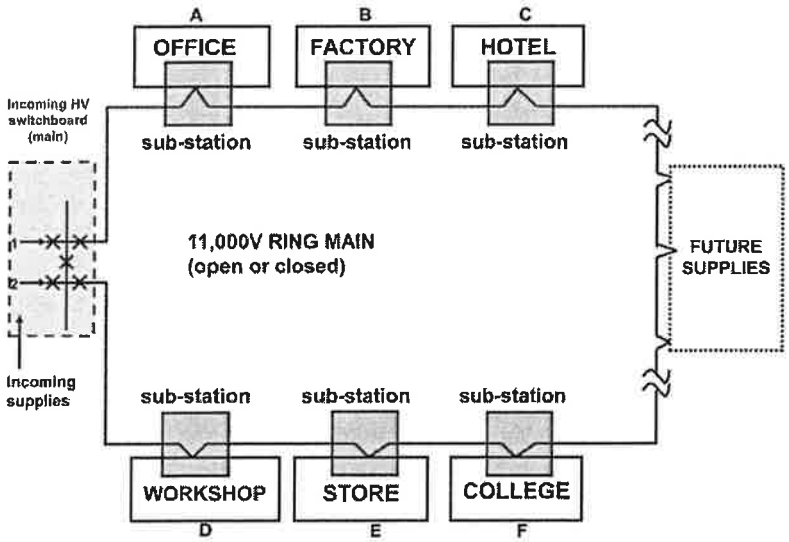
- High Voltage System – Switchgears, Transformers, Cables etc
- Low Voltage System – Switchboard, Cables etc
- Emergency Standby Power System – Standby generators
- Uninterruptible Power Supply (UPS)
- Vertical Transportation – lifts and escalators
- Motor driven systems

Key consideration for any active engineering system

- Centralized Plant - considerable impact on the energy losses due to distribution, and hence the overall energy efficiency.
- To locate the plant close to the main load centre(s), to minimise distribution losses in relation to the anticipated annual load pattern.
- The selection should consider base-load capacities and shared part-load efficiencies. Selection of multiple equal-sized modules or components to provide the best opportunity for optimised energy performance for the anticipated load pattern, and for future load growth.
- It will also be necessary to minimise standing losses in all systems and equipment. It also applies to electrical systems, including lift systems, multiple parallel UPS systems and standby loads for process equipment.

ENERGY EFFICIENT OF POWER DISTRIBUTION ARRANGEMENTS

Optimising substation locations



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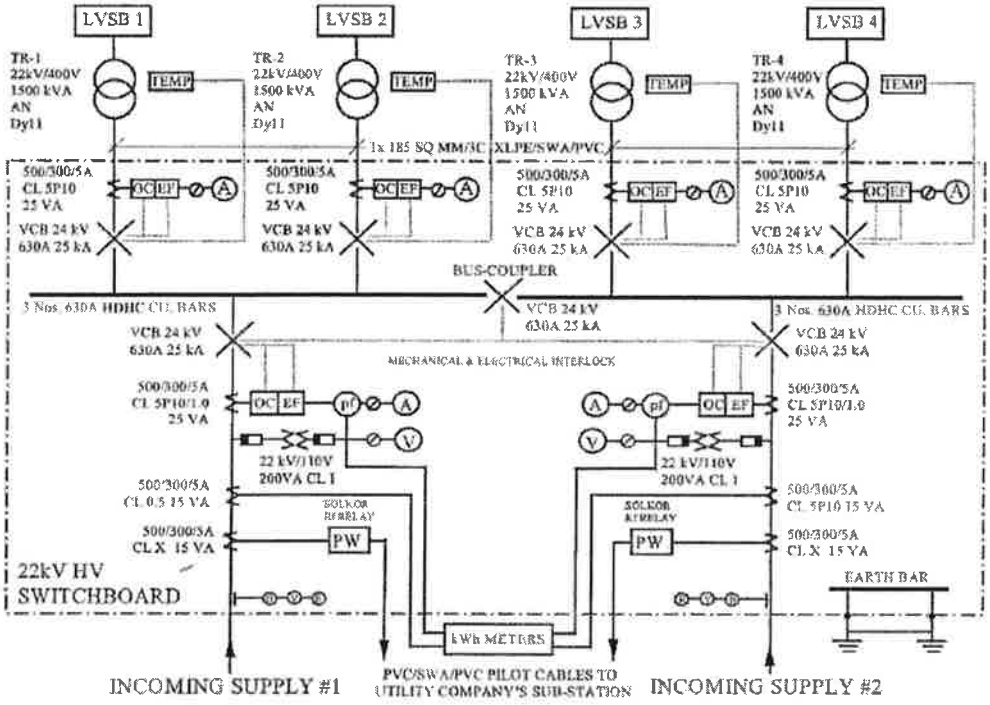
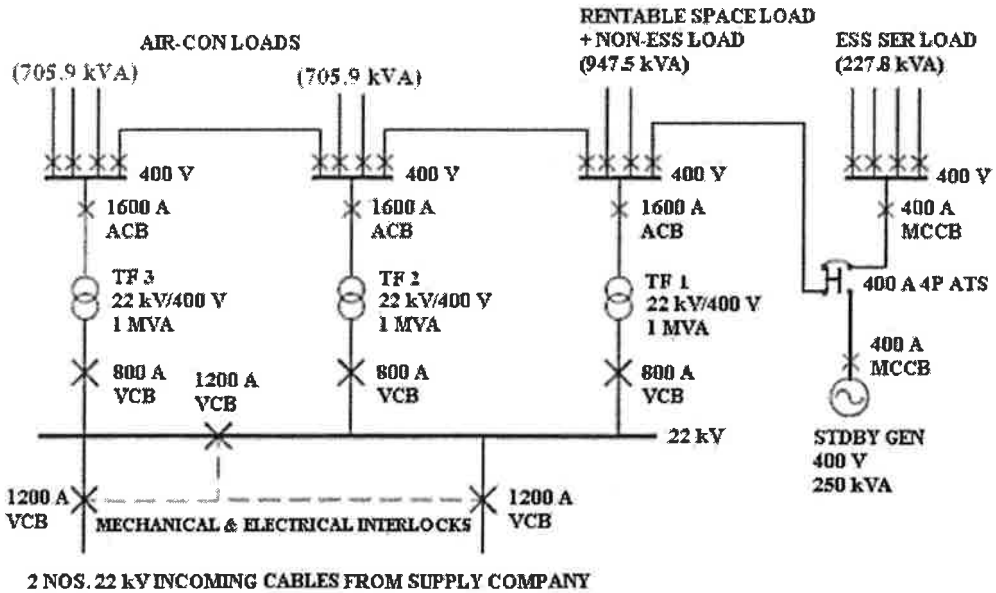
Typical consumer's 22 kV distribution system



HT or LT ⇒ Licence?

HT – can kW w/o physical touch!

Single line diagram of the building's 22 kV distribution system



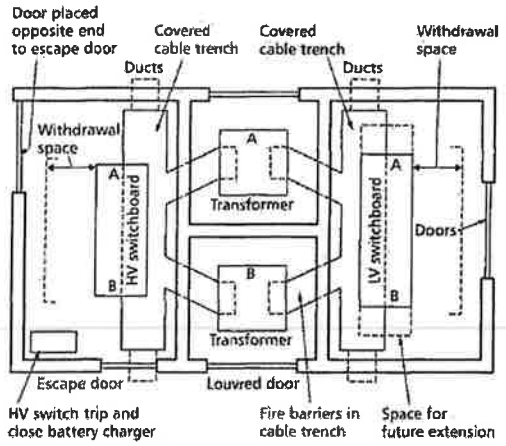
$P = I^2 R$

$P = \sqrt{3} \cdot V \cdot I \cos\theta$

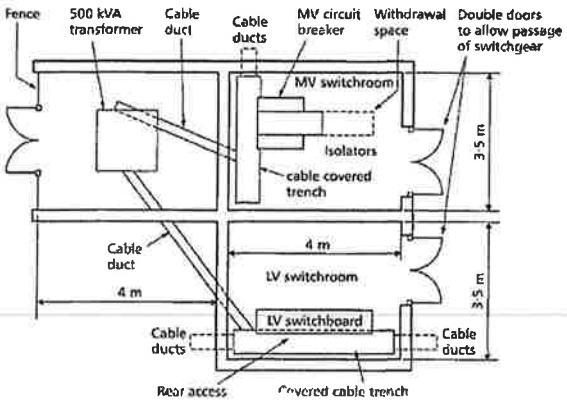
1 MVA = 1440 A.

Substation locations

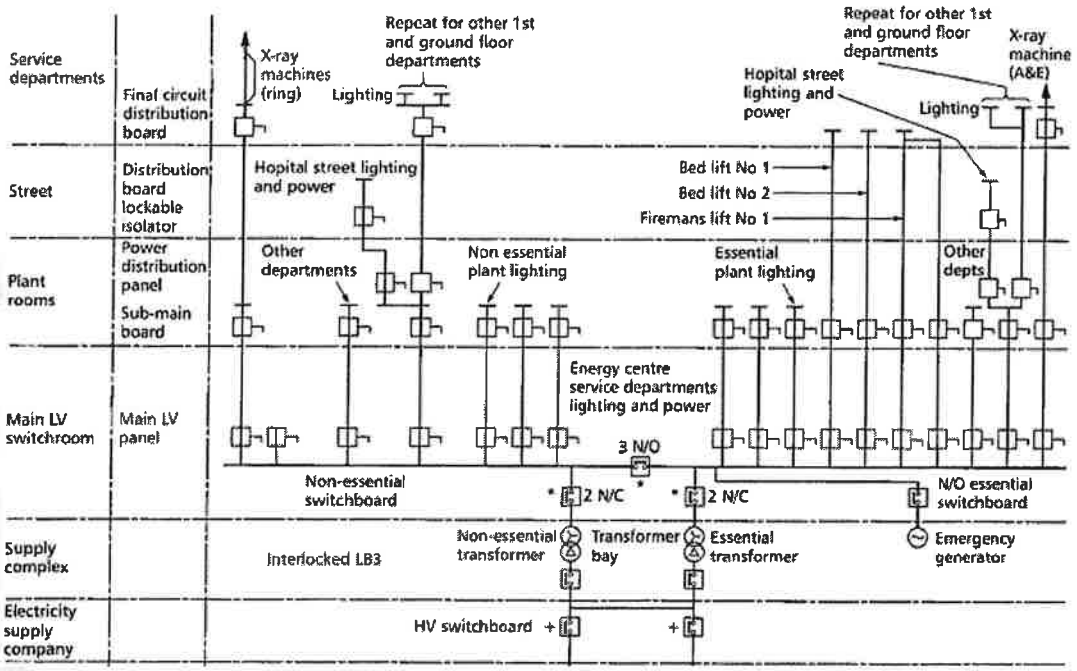
substation with HV switchboard, two transformers and LV cubicle-type switchboard



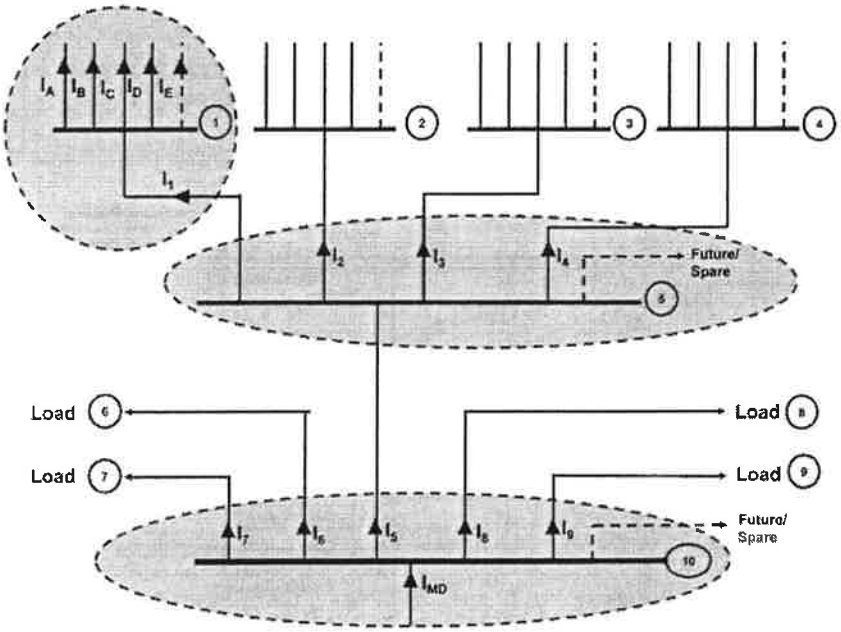
small substation with indoor transformer and HV ring main unit switchgear



Consumer's typical LV distribution system

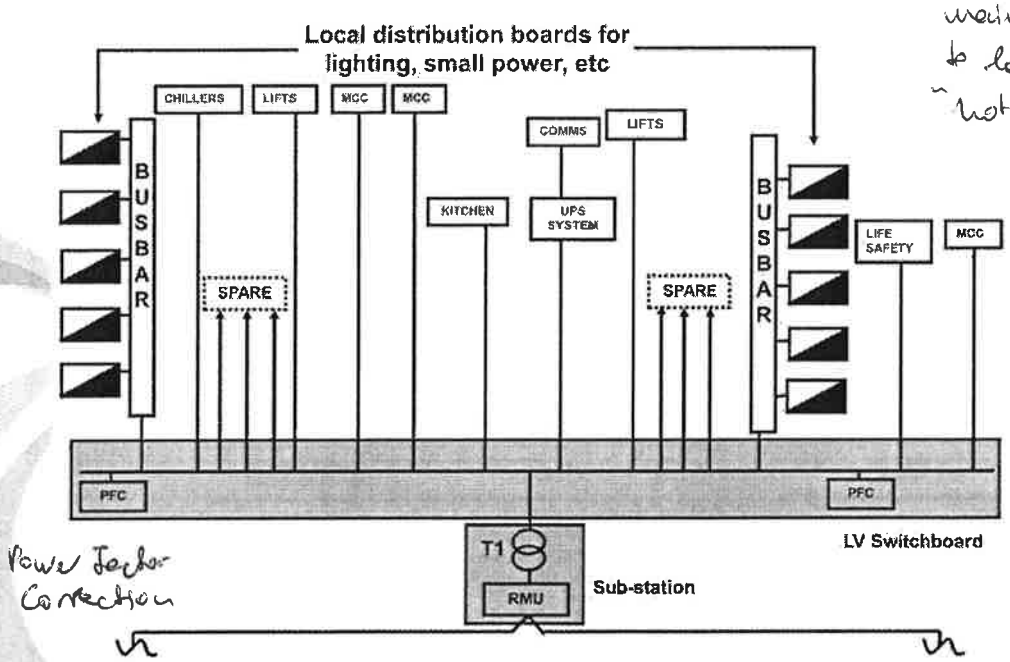


Electrical Distribution Planning



Building Electrical Distribution

Bus-bar need more maintenance to look out for "hot spot".



Power Factor Correction

Optimising LV distribution arrangements

- For large sites and systems, with widely dispersed loads, the most important design consideration is to plan the location of the substations on the site so that they are close to the main load centres. This will mean that the lengths of low voltage (LV) distribution cables are kept short, thereby reducing I2R power losses on cables.

$P = I^2R$

- Where a single substation is to be provided for a group of buildings on a site, the location should be the optimum for minimising losses taking into account the load profile for each building.

- The selection of a location for a substation must take account of many factors, including the generic issues for space planning.

- The sizing of the distribution cabling will take into account the relevant electrical design factors, including:
  - protective device rating,
  - design current,
  - prospective fault level and
  - voltage drop;
  - together with any group rating applicable to the relevant installation arrangement.

↳ from cable spacing/arrangements.

- Optimum energy performance
  - The location should be selected so that energy losses on the LV distribution systems are minimised.
  - This is a different (although similar) approach to optimising substation location by reducing losses solely in relation to the maximum demand at each load centre.
  - Loads are dynamic, it is the summated load profiles over a whole year – taking account of the diurnal and seasonal load patterns.

Note: The losses are proportional to the square of the load. The only way to obtain a complete figure would be from computer modelling with a full annual load pattern.

T/f max efficiency @ 60% load

T/f to be kept soaked to prevent external fault such as rat biting cable during off condition.

Equipment Losses

- The step-down HV/LV transformers will have losses
  - Iron (no-load) losses
  - Copper (running) losses.

For most modern transformers the full load losses will be about 1–2%. However, the value of total losses, and the proportional split between iron and copper losses, will vary between transformer types.

The operating efficiency will be a function of the losses and the load profile and could be determined by calculation from published losses for different levels of load.

Where the transformer will be running on low load for much of the time, the iron loss value becomes more important.

Where the transformer will be running on a low load for a minimal amount of time, the copper loss value becomes more important.

→ It is not the case that transformers are most efficient at full load, as the optimum efficiency point can sometimes be at about two-thirds of the rated load

The transformer rating selection including prospective fault level, physical size, cost and the criteria for resilience and redundancy. It should also consider a sensible longer-term margin for load growth.

Transformer losses

- Transformer losses fall into three categories:
  - No-load loss, or iron loss (no load loss)
  - Load-loss, or copper loss (Load loss)
  - Stray-loss, which is largely load related (Load loss).

- For some larger transformers there are also losses absorbed by fans and pumps providing forced cooling. to the T/F

What's the Energy efficient Transformers

- Control of Core loss
  - Reduce the magnetic losses by using silicon or aluminum
  - Use of high permeability steel
- Control of Load loss
  - Use of lowest resistively material such as high-conductivity copper
  - Use as large a cross-section of copper as possible
  - Winding wire technology – to rectangular shape
  - Use the lowest practicable number of winding turns

Evaluation for each of the above alternative designs using three sets of loss values.

	Typical REC (10% TDR)	Typical Industry User (see page 56)	Typical REC (5% TDR)
Loss capitalisation values per kilowatt	£3,000/£625	£3,988/£814	£3,750/£780
Standard loss alternative			
No-load loss 0.735 kW	£2,205.00	£2,931.18	£2,756.25
Load loss 4.8 kW	£3,000.00	£3,907.20	£3,744.00
Price	£5,000.00	£5,000.00	£5,000.00
Totals	**£10,205.50**	£11,838.38	£11,500.25
Low loss alternative			
No-load loss 0.38 kW	£1,140.00	£1,515.44	£1,425.00
Load loss 4.08 kW	£2,550.00	£3,321.12	£3,182.40
Price	£6,690.00	£6,690.00	£6,690.00
Totals	£10,380.00	**£11,526.56**	**£11,297.40**
Amorphous steel alternative			
No-load loss 0.145 kW	£435.00	£578.26	£543.75
Load loss 4.77 kW	£2,981.25	£3,882.78	£3,720.60
Price	£7,315.00	£7,315.00	£7,315.00
Totals	£10,731.25	£11,776.04	£11,579.35

"K" factor Transformers

- In power transformers the main consequence of harmonic currents is an increase in losses, mainly in windings, because of the deformation of the leakage fields. Higher losses mean that more heat is generated in the transformer so that the operating temperature increases, leading to deterioration of the insulation and a potential reduction in lifetime.

- As a result, it is necessary to reduce the maximum power load on the transformer, a practice referred to as de-rating, or to take extra care in the design of the transformer to reduce these losses.

- To estimate the de-rating of the transformer, the load's K-factor may be used. This factor is calculated according to the harmonic spectrum of the load current and is an indication of the additional eddy current load losses. It reflects the excess losses experienced in a traditional wire wound transformer.

- Modern transformers use alternative winding designs such as foil windings or mixed wire/foil windings.

- For these transformers, the standardized K-factor – derived for the load current - does not reflect the additional load losses and the actual increase in losses proves to be very dependent on the construction method. It is therefore necessary to minimize the additional losses at the design stage of the transformer for the given load data using field simulation methods or measuring techniques.

Power cables

Selection of conductor size

Cable sizes should be specified larger than the IEE/CP5 Regulation minimum for any combination of a variety of reasons, including:
. Allowing cables to run cooler and save energy
. Nearest standard size up
. Standard fuse rating requiring larger cable for safety in overload conditions
. Allowing for future expansion in demand

Cost Considerations
In costing the installation, many factors have to be considered:
. Maximum rating when installed
. Resistance to possible short circuits
. Rate of growth of demand
. Cost of losses of power due to cable resistance $\Rightarrow I^2R$
. Cost of removal of excess heat
. Installation cost
. Maintenance costs
. Cost of performance losses of equipment running at reduced voltage
. First cost of cable
. Future costs of energy
. Interest and discount rates

Example 1

A cable of 16 mm^2 section can be rated at 109 amps and run at 90° C but over a 100 metre run would drop over 30 volts and waste nearly 3.5 kW. This would cost over $1,500 per year if electricity is bought at $0.05 per unit. (kWh)

The use of 35 mm2 section more than halves this wastage.

Optimum cable size

Useful guidance on the optimum costing of cable installations stated that-

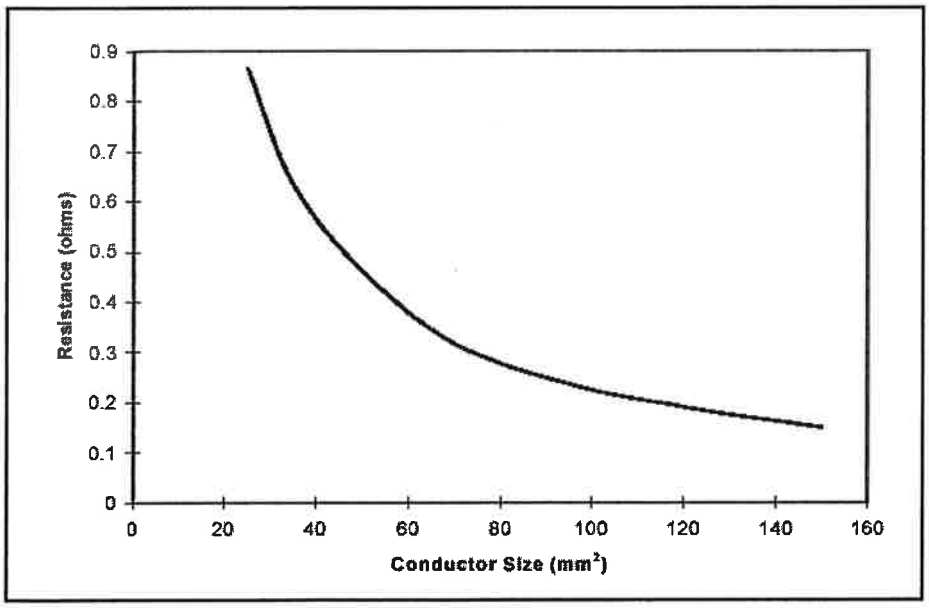
- **"Rather than minimising the initial cost only, the sum of the initial cost and the cost of losses over the economic life of the cable should be minimised".**
- For this latter condition a larger size of conductor than would be chosen based on minimum initial cost will lead to a lower power loss for the same current and will, when considered over its economic life, be much less expensive.'

Example 2

A design study for a 10 kV cable required to carry 160 amps showed that a 240 mm^2 section was the most economic although on IEE thermal safety rules a 70 m^2 section would be adequate.

70 mm^2 is minimum for safety
240 mm^2 is optimal to reduce losses.

Resistance per 1000m length against Conductor Cross-Section



LV Distribution Arrangements

Other

Optimising LV distribution arrangements

If the demand estimate is oversized, several issues could potentially arise:

- unnecessary capital cost and a waste of resources
- inefficiency and hence additional energy cost
- waste of space, and hence cost
- increased maintenance cost
- increased tariff cost and service charge penalty.

If the demand estimate is undersized, several issues could potentially arise:

- design does not meet relevant codes
- safety issues, such as overheating failures, faults or fire
- inadequate space for plant (substation, switchrooms, risers, etc.)
- the system cannot satisfy demand, with business implications.

Design Considerations

- Optimising substation locations
- Lengths of LV cables from the transformer to the main LV switchboard
- The main LV switchboard to distribution equipment, motor control centres (MCC) and other items, should be kept to a minimum to limit the losses. This will require attention to the distribution routes as part of the space planning.
- Distribution components used for LV mains and sub-mains power distribution – cables and busbars.
- To make the most efficient use of the cost and embodied energy in the distribution system, any factors that will limit the cable or busbar current-carrying capacity should be avoided. So, first, as a simple and fairly obvious measure, power distribution should be routed away from areas of high ambient temperature.
- Group rating factor (always less than unity) is used as a multiplier to determine its current-carrying capacity for power cables on cable ladders, cable trays, in ducts.

Consideration

The energy benefits that might be available from adjusting the voltage level at the origin, or at other locations, in an LV distribution system through incorporation of '**voltage optimisation**' equipment. While lowering the voltage could, potentially, save energy in certain types of loads in some legacy installations, it could give rise to risks and may not be the most appropriate energy reduction approach. Such measures always require careful technical assessment to assess their viability.

- There has been relatively little research or monitoring on the proportion and pattern of energy losses arising from power distribution in buildings, but this is clearly a worthwhile area of research to inform design decisions.

HT $ = A+B+C+D+E ☐ must pay.

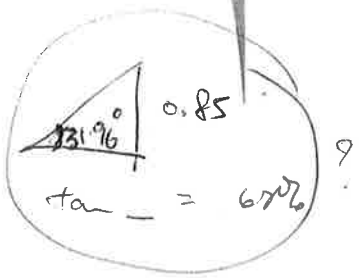
[A] = kW Contracted → to be paid even though not used.

B = Un Contracted

[C] = Peak (kWh)

[D] = Off-Peak (kWh) ← 40% discounted rate, 11pm to 7am

G = Reactive, kVArh 62% of kVArh



Q & A

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REAL POWER, POWER FACTORS AND HARMONIC FILTERING

Real Power, Power Factors and Correction

- Power Factor Consideration
- Current and Power Flow Fundamentals
- Benefits of Power Factor Improvement
- Techniques to Improve the Power Factor
- Calculation methods for Improving Power Factor

Power Factor Consideration

What's Power Factor (pf)

- An AC electric power system is defined as the ratio of the true power to the apparent power, and is a number between 0 and 1.
  - Ideally all the supply power should be converted into true power in a load.
- When this is not the case, **inefficiency** occurs and the ratio of TRUE POWER (P) in watts and the APPARENT POWER (S) is known as Power Factor and it has no unit. = Active Power
- Power Factor $= \frac{\text{True Power}}{\text{Apparent Power}}$ which is either less than or equal to unity.

Another expression can be obtained by using

Power Factor $= \frac{VI\cos\theta}{VI} = \cos\theta$

where θ is the phase angle between supply voltage and supply current.

Power Factor Concept



Mug Capacity = Apparent Power (KVA)

Foam = Reactive Power (KVAR)

Beer = Real Power (kW)

$$\text{Power Factor} = \frac{\text{Beer (kW)}}{\text{Mug Capacity (KVA)}}$$

Capacitors provide the Foam (KVAR), freeing up Mug Capacity so you don't have to buy a bigger mug and/or so you can pay less for your beer !

Power Factor

$P.F. = \cos\theta^{0} = 1.$

- **Unity Power Factor**
  If $\theta = 0$, then *V* and *I* are in phase and power factor will be unity. In this case, the volt-amperes from the supply will be completely dissipated as TRUE POWER in the load.

  Unity is the maximum possible value of POWER FACTOR. Other values are less than unity.

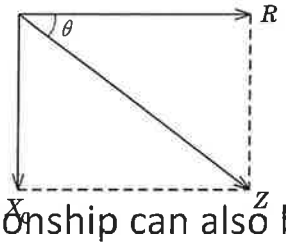
- **Leading and Lagging Power Factor**
  When *V* and *I* are not in PHASE, then $\cos\theta$ or power factor is less than unity. In this case, only a portion of supply volt-amperes is converted into useful power.

  If *I* leads *V*, then power factor is also a leading one and it implies that the load is a **capacitive** one.

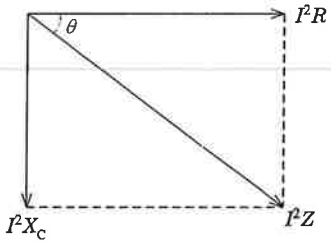
  However, if *I* lags *V*, then power factor is also a lagging one and the load is an **inductive** one.

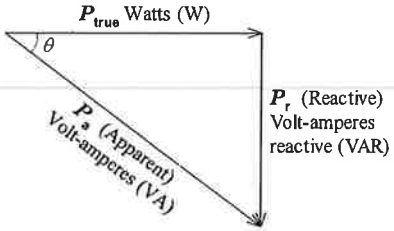
Relationship between True, Apparent and Reactive Power

- The generalised impedance diagram is shown below:

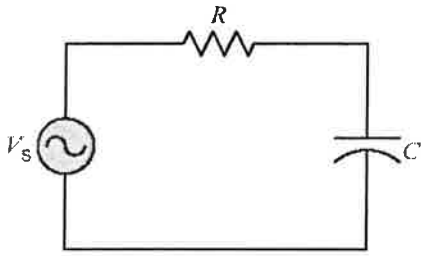


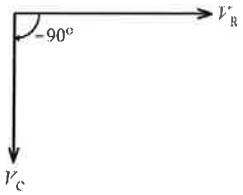
- A phasor relationship can also be represented by a similar diagram because the respective magnitudes of the powers, differ from R and XC by a factor of I^2.

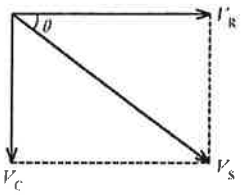


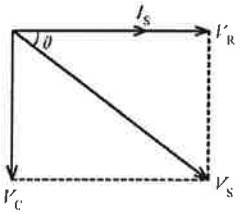


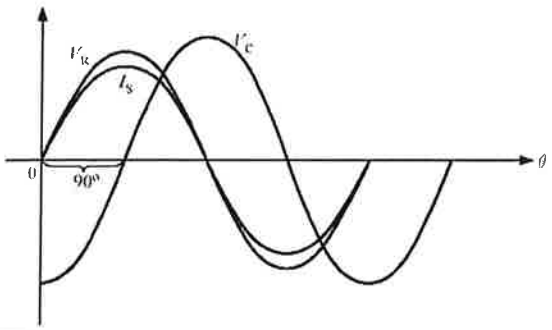
Impedance / Phasor Diagram for RC Circuit







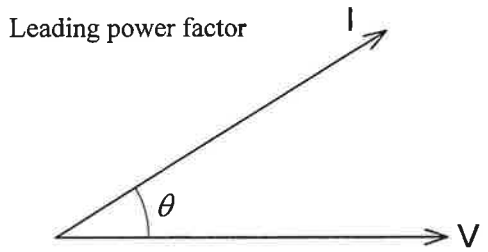


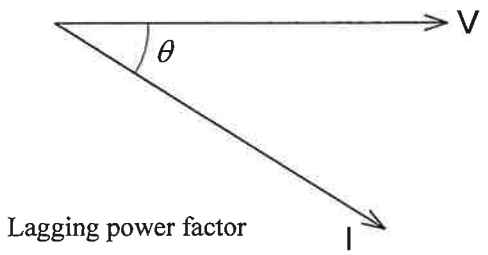


Phasor diagrams for leading and lagging power factor

- Consider a load being supplied at a voltage *V* and taking current *I* at a power factor cos θ.

- The phasor diagrams for a leading and lagging power factor are shown





Leady P.f. (Inductive) happens to Power station at night when all load ceased.

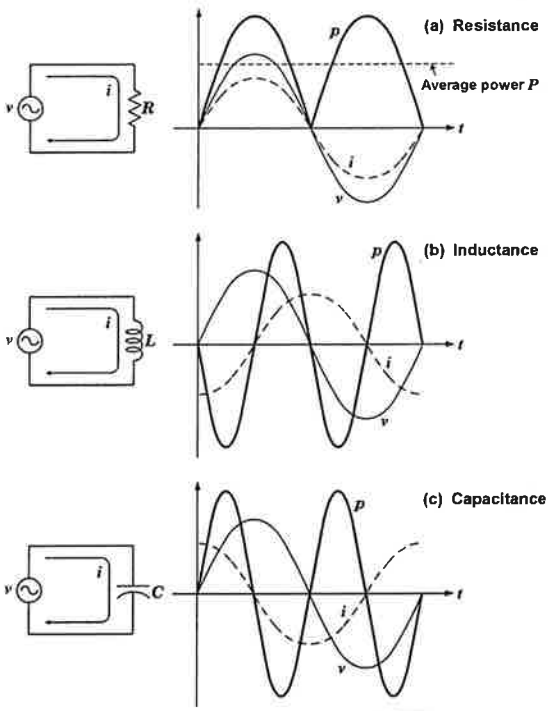
P.F. to be kept to below 0.85

saturated steam @ 300°C

superheated steam @ 500°C.

Fundamentals

- power waveforms for a pure resistor, a pure inductor and a pure capacitor



Power

$P = \sqrt{3}\ V \cdot I \cdot \cos\theta$ (P.F.)

True Power (kW)

- The power supplied to a resistance is sometimes referred to as Resistive Power or True Power.
- This is because the power supplied to a resistance is actually dissipated in the form of heat.
- The symbol used is *P* and is always measured in watts (W).
- The formula for TRUE POWER is
- $P = V_{rms} I_{rms} \cos\theta$
- where V_{rms} is the rms value of supply voltage.
- I_{rms} is the rms value of supply current.
- θ is the phase angle between *V* and *I*.

Power

Apparent Power

- The product of the voltage and current in an AC circuit is termed as the APPARENT POWER.
- The symbol used is *S* and the unit used is VOLT-AMPERE (VA).
- The formula for APPARENT POWER is:

$S = V_{rms} I_{rms}$ (VA)

Power

Reactive Power

- The power supplied to a reactance (inductive or capacitive) can be termed a REACTIVE POWER.
- The symbol used is *Q* and the unit used is VOLT-AMPERE REACTIVE (VAR).
- The formula for REACTIVE POWER is:

  Inductive Circuit :$QL = VLIL = V\text{rms}I\text{rms}\sin\theta$

  Capacitive Circuit :$QC = VCIC = V\text{rms}I\text{rms}\sin\theta$

Power factor in electrical installation

- Induction motor requires active power (kW) and reactive power (kVAR) to operate.
- kW – produces work and heat
- kVAR is to establishes the magnetic field within the motor to causes it to rotate
- A low power factor is indicate a possible low system electrical operating efficiency.
- Motor operate near it rated load, power factor is high
- Small loaded motors lead to low power factor
- Low power factor lead to increased in electricity bill
- Low power factor can be improved by installing external capacitors at the main plant or individual pieces of equipment
- Lower power factor correction by minimize operation of idling or light loaded motors and avoiding operation of equipment above its rated voltage.

WHY RAISE POWER FACTOR (pf)

Low (or "unsatisfactory") power factor is caused by the use of inductive (magnetic) devices and can indicate possible low system electrical operating efficiency.

These devices are:

- non-power factor corrected fluorescent and high intensity discharge lighting fixture ballasts (40%-80% pf)
- arc welders (50%-70% pf)
- solenoids (20%-50% pf)
- induction heating equipment (60%-90% pf)
- lifting magnets (20%-50% pf)
- small "dry-pack" transformers (30%-95% pf)
- and most significantly, induction motors (55%-90% pf)

Benefits of power factor improvement

Why need to improve the power factor?

a. Reduction in the cost of electricity bill
b. Use of smaller transformers, switchgear
c. Reduction of cable size
d. Reducing power losses
e. Reduction of voltage drop
f. Increase in available power

Singapore Tariff

Why the Utilities imposed "power factor penalty" in their Tariff?

REVISION OF ELECTRICITY TARIFFS FROM 1ST APRIL 2009

		Existing Tariff (without GST)	New Tariff (without GST)	New Tariff (with 7% GST)
LOW TENSION SUPPLIES, DOMESTIC All units, ¢/kWh		22.93	18.03	19.29
LOW TENSION SUPPLIES, NON-DOMESTIC All units, ¢/kWh		22.93	18.03	19.29
HIGH TENSION SMALL (HTS) SUPPLIES				
Contracted Capacity Charge S$/kW/month	A	6.96	6.96	7.45
Uncontracted Capacity Charge S$/chargeable kW/month	B	10.44	10.44	11.17
kWh charge, ¢/kWh				
Peak period (7am to 11pm)	C	20.80	15.46	16.54
Off-peak period (11pm to 7am)	D	12.62	9.08	9.71
Reactive power Charge ¢/chargeable kVARh	E	0.59	0.59	0.63
HIGH TENSION LARGE (HTL) SUPPLIES				
Contracted Capacity Charge S$/kW/month		6.96	6.96	7.45
Uncontracted Capacity Charge S$/chargeable kW/month		10.44	10.44	11.17
kWh charge, ¢/kWh				
Peak period (7am to 11pm)		20.65	15.31	16.38
Off-peak period (11pm to 7am)		12.61	9.07	9.70
Reactive power Charge ¢/chargeable kVARh		0.59	0.59	0.63
EXTRA HIGH TENSION (EHT) SUPPLIES				
Contracted Capacity Charge S$/kW/month		6.52	6.52	6.98
Uncontracted Capacity Charge S$/chargeable kW/month		9.78	9.78	10.46
kWh charge, ¢/kWh				
Peak period (7am to 11pm)		19.67	14.39	15.40
Off-peak period (11pm to 7am)		12.45	8.93	9.55
Reactive power Charge ¢/chargeable kVARh		0.48	0.48	0.51

Max Demand based on ½ hour block.

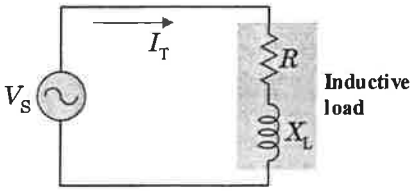
Techniques to Improve the Power Factor

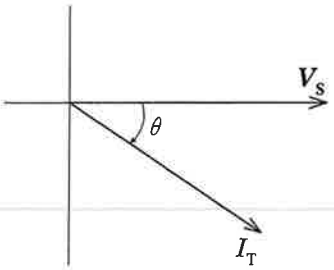
How to improve the power factor?

- Fixed capacitor – employs one or more capacitor(s) to form a constant level of compensation. Control may be:
  - Manual: by circuit breaker or load break switch
  - Semi-automatic: by contactor
  - Direct connection to an appliance and switched with it

Techniques to Improve the Power Factor

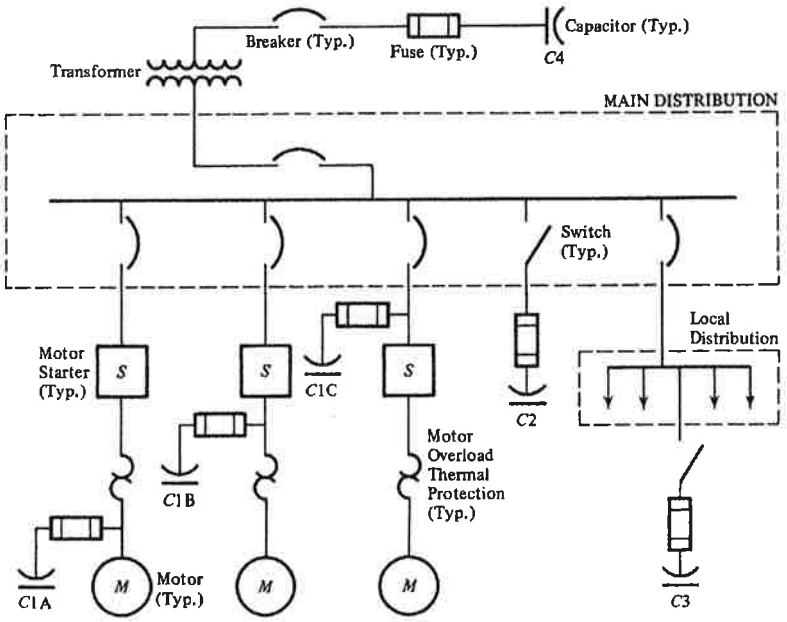
- Industrial loads are mostly inductive and a RL series circuit can be used to represent the load for analysis purpose.
- A phasor diagram for an inductive load is shown in Figure 3-6, where the current is lagging the voltage.
- The power factor (PF) is $\cos\theta$. To improve the power factor is to **reduce** the angle θ.
- There are two main methods of improving the power factor of a system, namely using:
  a. shunt capacitors
  b. synchronous condensers



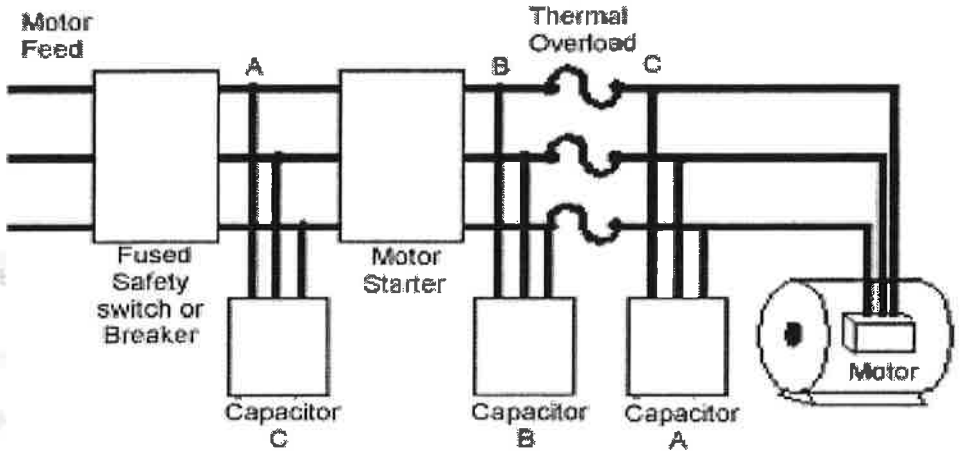


Phasor diagram

WHERE TO CORRECT POWER FACTOR



Locating Capacitors on Motor Circuits



WHERE TO CORRECT POWER FACTOR

Locations *C*1A, *C*1B and *C*1C of Figure 4-2 indicate three different arrangements at the load. Note that in all three locations extra switches are not required, since the capacitor is either switched with the motor starter or the breaker before the starter. Case *C*1A is recommended for new installation, since the maximum benefit is derived and the size of the motor thermal protector is reduced. In Case *C*1B, as in Case *C*1A, the capacitor is energized only when the motor is in operation. Case *C*1B is recommended in cases where the installation is existing and the thermal protector does not need to be re-sized. In position *C*1C, the capacitor is permanently connected to the circuit but does not require a separate switch, since it can be disconnected by the breaker before the starter.

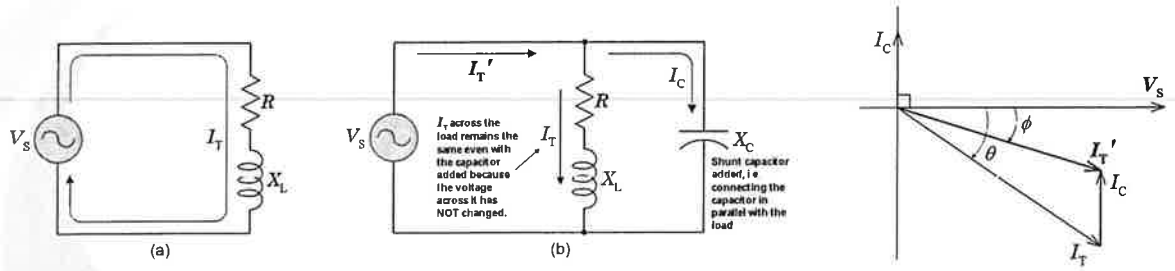
It should be noted that the rating of the capacitor should *not* be greater than the no-load magnetizing KVAR of the motor. If this condition exists, damaging overvoltage or transient torques can occur. This is why most motor manufacturers specify maximum capacitor ratings to be applied to specific motors.

The next preference for capacitor locations as illustrated by Figure 4-2 is at locations *C*2 and *C*3. In these locations, a breaker or switch will be required. Location *C*4 requires a high voltage breaker. The advantage of locating capacitors at power centers or feeders is that they can be grouped together. When several motors are running intermittently, the capacitors are permitted to be on-line all the time, reducing the total power regardless of load.

Power factor improvement

Shunt capacitors

- When a capacitor is connected in parallel with a RL series element, the new current /T' in is less than the /T.
- This can be seen by the phasor diagram shown below.
- Since θ decreases to ϕ, $\cos\phi$ is greater than $\cos\theta$, so the power factor increases.



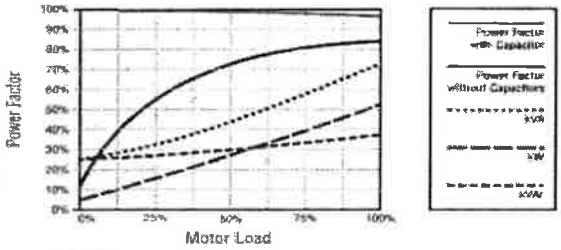
Power Factor Improvement

Some strategies for improving the power factor:

- Use the highest-speed motor that an application can accommodate
- Size motors as close as possible to the horsepower demands of the load
- Add power factor correction capacitors to your in-plant distribution system

Power Factor Improvement

Power Factor as a Function of Motor Load



Industries That Typically Exhibit Low Power Factor

Industry	Uncorrected Power Factor
Saw mills	45% - 60%
Plastics (extruders)	55% - 70%
Machine shops	40% - 65%
Plating, textiles, chemicals, breweries	65% - 75%
Foundries	50% - 80%
Chemicals	65% - 75%
Textiles	65% - 75%
Arc welding	35% - 60%
Cement Works	70% - 80%
Printing	55% - 70%

Power factor for various loads

Equipment and appliances		cos φ	tan φ
Common induction motor loaded at	0%	0.17	5.80
	25%	0.55	1.52
	50%	0.73	0.94
	75%	0.80	0.75
	100%	0.85	0.62
Incandescent lamps		1.0	0
Fluorescent lamps (uncompensated)		0.5	1.73
Fluorescent lamps (compensated)		0.93	0.39
Discharge lamps		0.4 to 0.6	2.29 to 1.33
Ovens using resistance elements		1.0	0
Induction heating ovens (compensated)		0.85	0.62
Dielectric type heating ovens		0.85	0.62
Resistance-type soldering machines		0.8 to 0.9	0.75 to 0.48
Fixed 1-phase arc-welding set		0.5	1.73
Arc-welding motor-generating set		0.7 to 0.9	1.02 to 0.48
Arc-welding transformer-rectifier set		0.7 to 0.8	1.02 to 0.75
Arc furnace		0.8	0.75

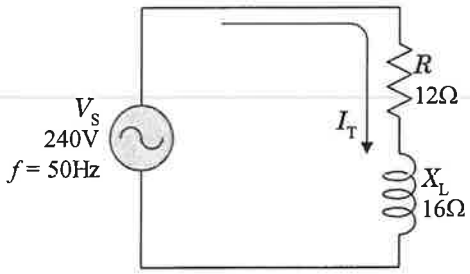
Calculation methods for Improving Power Factor

Example 1

A coil that has a resistance of 12Ω and an inductive reactance of 16Ω is connected to a 240V supply as shown in Figure below. Find:

(a) the power factor (PF).

(b) the shunt capacitor value requires to raise the power factor to 0.9 lagging.



Calculation methods for Improving Power Factor

(a) $Z_T = R + jX_L = 12 + j16 = 20\angle 53.13^\circ\ \Omega$

$$I_T = \frac{V_S}{Z_T}$$

$$= \frac{240\angle 0^\circ}{20\angle 53.13^\circ}$$

$$= 12\angle -53.13^\circ$$

$$= 7.2 - j9.6\ \text{A}$$

PF = cos 53.13° = 0.6 lagging (It can be measured at the power factor meter)

Calculation methods for Improving Power Factor

(b) From the phasor diagram,

$\tan 25.84° = \frac{x}{7.2}$ $x = 3.49$

$= 9.6 - x = 9.6 - 3.49 = 6.11$

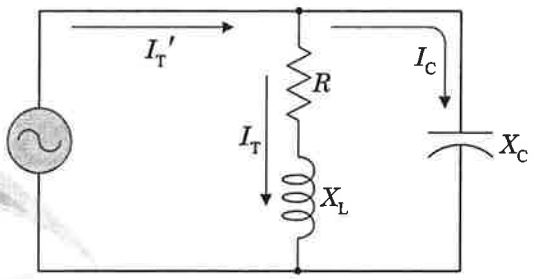
$|I_C|$ $\therefore IC = 6.11\angle 90°$ A

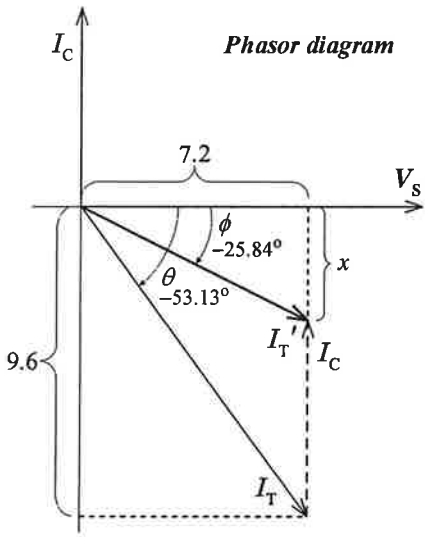
$$Z_C = \frac{V_S}{I_C} = \frac{240\angle 0°}{6.11\angle 90°} = 39.28\angle -90° \ \Omega$$

$$X_C = \frac{1}{2\pi fC} \Rightarrow \frac{1}{2\pi fC} = 39.28$$

$$C = \frac{1}{2\pi(50)(39.28)} = 81.04\mu F$$

Calculation methods for Improving Power Factor





If the new PF is 0.9 lagging,

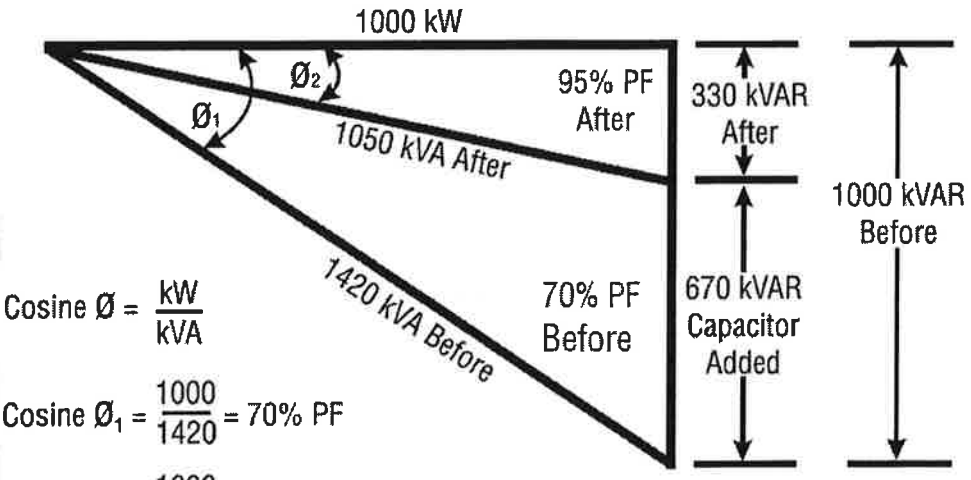
$\cos\phi = -0.9$

$\phi = -25.84°$

MAJOR BENEFITS OF POWER FACTOR IMPROVEMENT

- increased plant capacity
- reduced power factor "penalty" charges for the electric utility
- improvement of voltage supply
- less power losses in feeders, transformers and distribution equipment.

Example: Power Factor Correction



$\text{Cosine } Ø = \frac{kW}{kVA}$

$\text{Cosine } Ø_1 = \frac{1000}{1420} = 70\%\ PF$

$\text{Cosine } Ø_2 = \frac{1000}{1050} = 95\%\ PF$

Problem 1

kW = kVA × pf

$W_i = kW/\eta$

kW does not change with p.f. but kVA does.

A total motor horsepower load of 854 is made up of motors ranging from 40–100 horsepower. Calculate the connected KVA.

It is desired to operate the plant at a power factor of .95. What approximate capacitor bank is required?

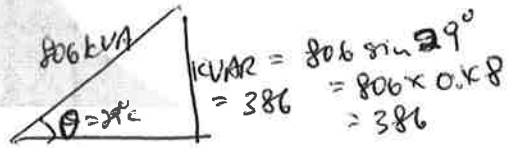
$$kVA = \frac{HP \times 0.746}{\text{Motor eff} \times \text{Motor P.F.}}$$

From Table 4-1 at full load

Eff = 0.909 and P.F. = 0.87

$$kVA = \frac{854 \times 0.746}{0.909 \times 0.87} = 806$$

The plant is operating at p.f. of 0.87 which corresponds to 29°



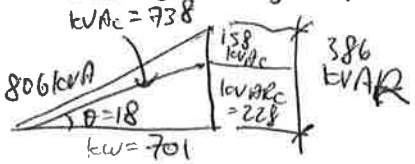
kW = 806 cos θ = 806 × 0.87 = 701

P.F. of 0.95 is required

$\cos\theta = 0.95$

$\theta = 18°C$

kVAR of 386 need to be reduced by adding capacitors



$\cos\theta = 0.95$

$\theta = 18°$ $\sin 18° = 0.31$

$$kVA_c = \frac{701}{\cos\theta} = \frac{701}{0.95} = 738$$

$kVAR_c = 738 \sin 18° = 738 \times 0.31 = 228$

Capacitor bank = 386 − 228

= 158 kVAc

Problem 2

The client wishes to know the expected power factor for a new plant. The lighting load is 40 kW. The plant is composed of two identical modules (2 motors for each equipment number listed). Remember that KVAs at different power factors cannot be added directly.

Motor List — Module 1

Motor No.	*Description*	*HP*	*Voltage*	*Phase*
AG-1	Agitator Motor	60	460	3
CF-3	Centrifuge Motor	100	460	3
FP-4	Feed Pump Motor	30	460	3
TP-5	Transfer Pump Motor	10	460	3
CTP-6	Cooling Tower	25	460	3
CT-9	Cooling Tower Motor	20	460	3
HF-10	H&V Supply Fan Motor	40	460	3
HF-11	H&V Exhaust Fan Motor	20	460	3
BC-13	Brine Compressor Motor	50	460	3
C-16	Conveyor Motor	20	460	3
H-17	Hoist Motor	5	460	3

Problem 3

Calculate the savings for correcting to 80% power factor? How much capacitance (in kVARs) would be necessary to obtain this correction? The following information is given as:

In working with a company, you find they have averaged 65% power factor over the past year. They are on the rate schedule shown below and have averaged 1,000 kW each month.

Neglect any ratchet clause and assume their demand and power factor are constant each month.

Assume they are on transmission service (level 1).

Demand Charge

- On-peak $10.59/kW/mo June-October 5 months/year
- Off-peak $3.84/kW/mo November -May 7 months/year

Problem 4 – Power Factor

Utility Rate Schedule: The utility measures and bills based upon total current used (working plus reactive current) at $3.50/kVA Demand.

Plant Conditions: Assume a constant 4,600 kVA demand with an 80 percent power factor. Correct to 95 percent power factor.

Billing Before Power Factor Correction	Billing After Power Factor Corrected to 95%
4,600 kVA x $3.50 = $16,100/month	$kW_{demand} = kVA_{demand\ 1} \times PF_1$ $= 4,600 \times 0.8 = 3,680$ $kVA_{demand\ 2} = \frac{kW_{demand}}{PF_2}$ $kVA_{demand\ 2} = \frac{3,680}{0.95} = 3,873$ Where: $kVA_{demand\ 1}$ = kVA demand before PF correction $kVA_{demand\ 2}$ = kVA demand after PF correction kW_{demand} = Electric demand in kW PF_1 = Original power factor PF_2 = Power factor after correction *Corrected Billing* *3,873 kVA x $3.50 = $13,555/month*

Savings are ($16,100-$13,555) x 12 months = $30,540/year

Up to $61,000 could be spent on power factor correction equipment if plant management would support a two-year simple payback on investment.[6-8]

Problem 5 – Power Factor

Utility Rate Schedule: In this scenario, the utility charges according to kW demand ($4.50/kW) and includes a surcharge or adjustment for low power factor. The following formula shows a billing adjustment based upon a desired 95 percent power factor.

$$kW_{billed} = kW_{demand} \times \frac{0.95}{PF}$$

Where:

kW_{billed}	= Adjusted or billable demand
kW_{demand}	= Measured electric demand in kW
PF	= Power factor as a decimal

The multiplier applies to power factors up to 0.95.

Plant Conditions: For our sample facility, the original demand is 4,600 kVA *x* 0.80 or 3,680 kW.

Billing Before Power Factor Correction	Billing After Power Factor Corrected to 95%
$\frac{3{,}680 \text{ kW} \times 0.95}{0.80}$	
= 4,370 × $4.50	*= 3,680 × $4.50*
= $19,665/month or $235,980/year	*= $16,560/month or $198,720/year*

Savings are $37,260/year

Problem 6 – Power Factor Correction

Consider a case where a 1200 kVAR capacitor is to be installed on a 12.47 kV system at a location where the three phase short circuit current is 2800 amps.

$$MVA_{shortcircuit} = 2800 \text{ amps} \times 12.47 \text{ kV} \times \frac{\sqrt{3}}{1{,}000{,}000} = 60.5$$

$$MVAR_{capacitor} = 1200 \text{ kVAR}/1000 = 1.2 \text{ MVAR and } h_f = \sqrt{\frac{60.5}{1.2}} = 7.1$$

Problem 7

Problem: What is the power factor of this motor?

Given: During an energy audit at the Orange and Blue Plastics Company you saw a 100-hp electric motor that had the following information on the nameplate:

460 v

114 a

3 phase

95% efficient.

100 hp = 74.6 kW

$$P(kW) = 1.732 \times \overbrace{V \times i}^{(kVA)} \times pf \times \underbrace{0.95}_{(\eta)}$$

$$pf = \frac{P(hp) \times 0.746}{1.732 \times V \times i \times 0.95}$$

$$= \frac{100 \times 0.746}{1.732 \times 460 \times 114 \times 0.95}$$

$$= 0.863$$

Problem 8

Problem: Even though the motor is expected to last another five years, you think that the company might be better off replacing the motor with a new high-efficiency model. Provide an analysis to show whether this is a cost-effective suggestion.

Given: During an audit trip to a wood products company, you note that they have a 50-hp motor driving the dust collection system. You are told that the motor is not a high efficiency model, and that it is only 10 years old. The dust collection system operates 6,000 hours each year.

ɔolution to Problem 8:

Since cost premiums range from 10% to 30%, we use 20% to calculate the cost of the high efficiency motor from the premium column in Table 12-1. Therefore, the cost of a 50-hp high-efficiency motor is 5 times $469:

$2,345

Assume energy cost (EC) $0.05 /kWh
Assume demand cost (DC) $7. 00 /kW/mo
Assume the motor load factor is 0.6
DR = 50 hp × 0.746 kW/hp × 0.6 × [(1/0.915) - (1/0.938)]
= 0.60 kW

Therefore, the cost savings (CS) from using the high-efficiency motor over the standard efficiency motor can be calculated as follows:

CS = DR × DC × 12 mo/yr + DR × 6,000 h/yr × EC
= 0.6 kW × $7/kW/mo × 12 mo/yr + 0.6 kW × 6,000 h/yr × $0.05/kWh
= $230.30/yr

SPP = Cost/CS
= $2,345/$230.30/yr
= ***10. 2 years***

ROI = *5.28%*
NPV = ***($998)*** assuming a MARR of 15%

Therefore, it seems to be a bad project to change the motor now.

Problem 9

Problem: Using the data in Table 12-1, determine whether Ruff should purchase the high efficiency model or the standard model motor? Find the SPP, ROI, and BCR.

Given: Ruff Metal Company has just experienced the failure of a 20-hp motor on a waste-water pump that runs about 3,000 hours a year. Assume the new motor will last for 15 years and the company's investment rate is 15%.

Problem 10

Problem:

What is the load factor?

Given:

A three-phase 50-hp motor draws 27 amps at 480 volts. It is 92% efficient and has a reactive power of 10 kVAR.

Apparent power = $1.732 \times V \times I = 1.732 \times 480V \times 27A = 22.45$ kVA

Reative power = 10 kVAR

$\sin\theta = 10\text{kVAR} / 22.45\text{kVA} = 0.445$

$\theta = 26.4°$

$\cos(26.4°) = 0.895$

Real power = $1.732 \times V \times I \times 0.895 = 20.1$ kW

Rated power = $50\text{hp} \times 0.746 / 0.92 = 40.54$kW

Load factor = $20.1\text{kW} / 40.54\text{kW} = 49.6\%$.

Problem 11

Compute the monthly facility electric load factor (FLF)

Given:

Peak kW 1,250 kW

Energy use 500,000 kWh

Time 720 hours

$$\text{FLF} = \frac{\text{Actual kWh used}}{\text{peak kW} \times \text{time}}$$

$$= \frac{500{,}000}{1250 \times 720}$$

$$= 55.56\%.$$

Q & A

Solution to Problem 3

Demand Charge:
On-peak $10.59/kW/mo June-October 5 months/year
Off-peak $3.84/kW/mo November -May 7 months/year

Billed Demand = Actual Demand × (base pf/actual pf) = 1000 kW × 0.8/0.65 = 1231 kW

pf correction savings = 231 kW × (5 mo/yr × $10.59/kW/mo + 7 mo/yr × 3.82/kW/mo)
= ***$18,422/yr***

pf = cos(θ) = 0.65
θ= 0.86321189 radians
kVAR initial = 1000 kW × tan (0. 86) = 1169 kVAR

pf = cos(θ) = 0.8
θ = 0.643501109 radians
kVAR initial = 1000 kW × tan (0. 86) = 750 kVAR
capacitor size needed = ***419 kVAR***

Also, using a pf correction table for 0.65 => 0.80
kVAR = (0.419) × (1000 kW) = ***419 kVAR***

Solution to Problem 7

P (kW) = 1.732 × v × i × pf × 0.95

pf = P (hp) × 0.746 /(1.732× v × i) x0.95
= 100 hp × 0.746 / (1.732 × 460 × 114) x 0.95
= ***0.863***

Solution to Problem 10

Apparent power = 1.732 x V x I
= 1.732 x 480V x 27A
= 22.45 kVA

Reactive power = 10 kVAR

Sin θ = 10 kVAR / 22.45 kVA
= 0.445

θ = 26.4°

Cos θ = Cos (26.4°) = 0.895

Real power = 1.732 x V x I x 0.895 = 20.1 kW

Rated power = 50hp x 0.746 kW / 0.92
= 40.54 kW

Load factor = 20.1 kW / 40.54 kW
= 49.6 %

Problem 11

Compute the monthly facility electric load factor (FLF)

Given:

Peak kW 1,250 kW

Energy use 500,000 kWh

Time 720 hours

Solution to Problem 11

FLF = Actual kWh used/(peak kW × time)

= 500,000 kWh/(1,250 kW × 720 hours)

= 55.56%

Solution 1

Power/Equipment	Condenser Water Pumps	Chilled Water Pumps
Input Power Before replacement	$\frac{2 \times (60 \times 0.746)}{0.83}$ = 107.86 kW	$\frac{2 \times (75 \times 0.746)}{0.83}$ = 134.82 kW
Input Power After replacement	$\frac{2 \times (60 \times 0.746)}{0.9}$ = 99.47 kW	$\frac{2 \times (75 \times 0.746)}{0.9}$ = 124.33 kW
Energy Savings	8.39 kW	10.49 kW

The total energy saved = 8.39 kW + 10.49 kW = 18.88 kW

Savings in electricity charges = 18.88 x 24 x 365 x S$0.14

= $ 23,154.43 per annum

Solution 2:

- Total Bill = Contracted Capacity + Uncontracted Capacity + Peak (kWh) + Off Peak (kWh)

- Total Bill = (1200kW*$6.96) + (200kW*$10.44) + (250,000kWh*$0.2908) + (80,000kWh*$0.1777)
  = $8,352 + $2,088 + $72,700 + $14,216
  = **$97,356.00**

POWER QUALITY ISSUES
Addressing In-Plant Electrical Distribution and Power Quality Issues

- **Voltage Problems**
  - Outages
  - Sags
  - Overvoltage and Undervoltage
  - Unbalances
  - Transients and Surges
- **Power Factor**
- **Harmonics**
- **Electromagnetic Interference**

Power Quality Issues, Voltage Dips and Effects on Sensitive Facilities

- **Power Quality Considerations**
- **Sourced Power Quality Problems**
  - Economic Impact
    - Energy Losses
    - Higher subscription costs
    - Oversizing of equipment
    - Reduced service life of equipment
    - Nuisance tripping and installation shutdown

Power Quality Considerations

- Types of Power Quality Problems:
  - Harmonic distortion
  - Blackouts
  - Under or over voltage
  - Dips (or sags) and swell
  - Transients

Sourced Power Quality Problems

Harmonic distortion-Internal such as electronic devices:

- Damage: causes additional losses in the transformer that lead to earlier failure due to hot spots in the winding
- Solution: by good design practice and well proven reduction equipment, Shunt connected harmonic filter and/or harmonic-suppression reactors or Active power filters or Hybrid filters

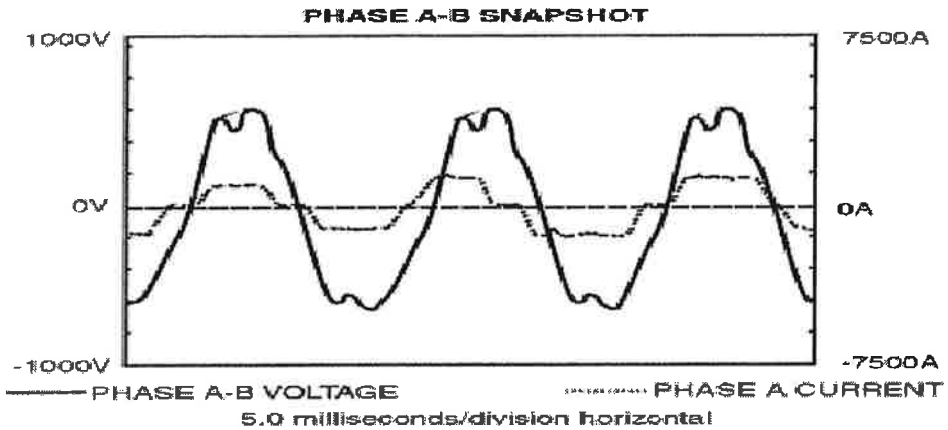
Sourced Power Quality Problems

- Blackouts-External/Internal such as power failure or failure of on-site equipment, cables and terminations
  - Damage: power cut
  - Solution: design with good redundancy equipment or alternative supply
- Transients-switching or lightning strikes on the network and switching of reactive loads on the consumer's site
  - Damage: installation, equipment or data corruption
  - Solution: suppression techniques and high integrity earthing system
- Dips (or sags) and surges-External such as network faults
- Under or over voltage-External

Harmonic and Distortions

Harmonics

The mathematical representation of the distortion of the pure sine wave. Frequency of these harmonics are obtained by multiplying the harmonic number by the Fundamental Frequency (50/60 Hz).



Distortion Factor

The ratio of the root-mean-square of the total harmonic content to the root-mean-square value of the fundamental quantity, expressed as a percentage.

Origin of Harmonics

Devices and systems that cause harmonics are present in all sectors i.e. industrial, commercial and residential.

Harmonics are caused by non-linear loads (i.e. loads that draw current with a waveform that is not the same as that of the supply voltage).

Examples of non-linear loads are:

- –Industrial equipment (welding machines, arc furnaces, induction furnaces, rectifiers)
- –Variable-speed drives for asynchronous or DC motors
- –Office equipment (computers, photocopy machines, fax machines, etc.)
- –Home appliances (television sets, micro-wave ovens, fluorescent lighting)
- –Certain devices involving magnetic saturation (transformers)

Disturbances caused by non-linear loads: harmonic current and voltage

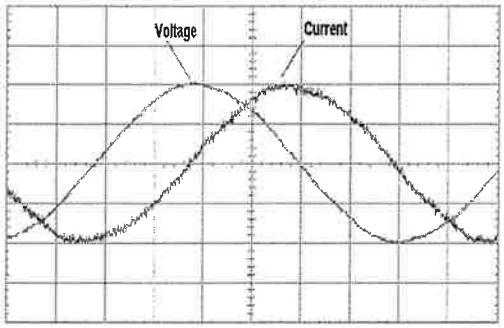
- –Non-linear loads draw harmonic currents that flow in the distribution network.
- –Harmonic voltages are caused by the flow of harmonic currents through the impedances of the supply circuits

Harmonics

Linear Load Waveform

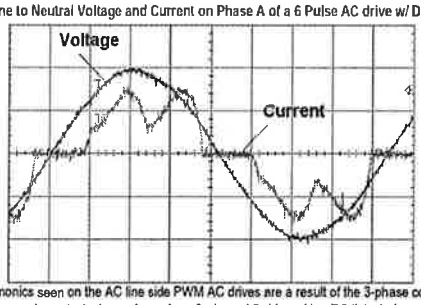
Non-Linear Load Waveform

Input Line to Neutral Voltage and Input Current on phase A of a Linear Load



Nonlinear load: in a nonlinear load, current is not proportional to voltage. The waveform is distorted.

Input Line to Neutral Voltage and Current on Phase A of a 6 Pulse AC drive w/ DC Link Choke



Current harmonics seen on the AC line side PWM AC drives are a result of the 3-phase converter section. The figure above shows typical waveforms for a 3-phase AC drive with a DC link choke.

THD (Total Harmonic Distortion)

- Harmonic distortion measurements are normally given in "total harmonic distortion" or THD.

- THD defines the harmonic distortion in terms of the fundamental current drawn by a load:

$$THD\ \% = \frac{\sqrt{\sum_{h=2}^{h=\infty} (M_h)^2}}{M_{fund}} \times 100\ \%$$

max 3% or 4% based on voltage!

TDD (Total Demand Distortion)

- TDD (total demand distortion) to express current distortion in terms of the maximum fundamental current that the consumer draws:

$$TDD\ \% = \frac{\sqrt{\sum_{h=2}^{h=\infty} (I_h)^2}}{I_{load}} \times 100\ \%$$

- I_{load} is the maximum fundamental current that the consumer draws and it could be measured over a specified time period, or estimated.

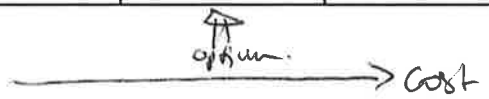
- TDD is only used to measure current distortion, not voltage distortion. Because TDD uses the maximum fundamental current consumed as the denominator.

- TDD will most likely less that THD.

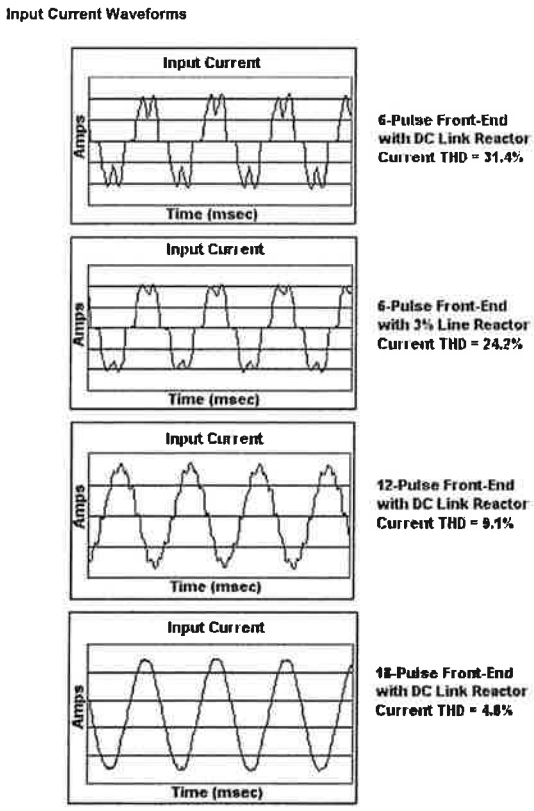
Typical Harmonic Current Spectrum

Typical harmonic current spectrum for a 3-phase, PWM AC drive with DC link choke:

Category	6-Pulse Drive	12-Pulse Drive	18-Pulse Drive
Current THD	30-35%	6.5-9.5%	4.5-5%
Power Factor	0.92-0.95	0.97-0.98	0.98-0.99
DPF	0.95-0.97	0.96-0.98	0.98-0.99
K-Factor	3.0-5.0	2.0-3.0	1.0-2.0
Efficiency	96.5-97.5	97.0-98.0	97.5-98.0
5th	20-30%	4.0-6.0%	2.0-3.0%
7th	4.0-7.0%	2.0-4.0%	1.5-2.5%
11th	3.0-5.0%	4.0-7.0%	1.0-2.5%
13th	2.5-4.5%	3.5-5.0%	1.0-2.0%
17th	1.5-2.5%	1.0-2.0%	0.5-1.5%
19th	1.0-2.0%	1.0-1.5%	0.5-1.0%



Input Current Waveforms



Techniques for Reducing Harmonics in PWM AC Drives

- **DC Link Choke**

  A DC Link Choke installed right in the drive significantly reduces current peaks.

- **AC Line Reactor**

  Especially for drives with no DC Link Choke, this can be an effective means of reducing harmonics and will provide a similar level of harmonic reduction as a DC link choke.

- **Passive Filter**

  A network of capacitors and inductors tuned to reduce mainly the 5th and 7th harmonics.

- **12-Pulse Converter with phase-shifting transformer**

  A 12-pulse converter replaces the standard 6-pulse converter to give a more sinusoidal input current waveform.

Techniques for Reducing Harmonics in PWM AC Drives

- **Active Filter**

  This technique works by using an active switch arrangement (IGBTs) that looks very much like the inverter side of a drive. Using current sensors this device adds the sine wave complement of the current it measures to the line, making the current up stream from the drive look sinusoidal.

- **Active (Regenerative) Converter**

  This technique uses an active switch arrangement (IGBTs) that looks very much like the inverter side of a drive. The active converter takes the place of the diode or SCR converter section of the drive. This technique has the added benefit of being able to regenerate to the AC line.

- **18-Pulse Converter with phase-shifting transformer**

  An 18-pulse converter replaces the standard 6-pulse converter to give a more sinusoidal input current waveform.

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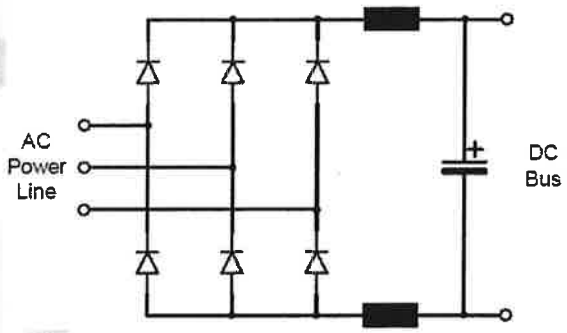
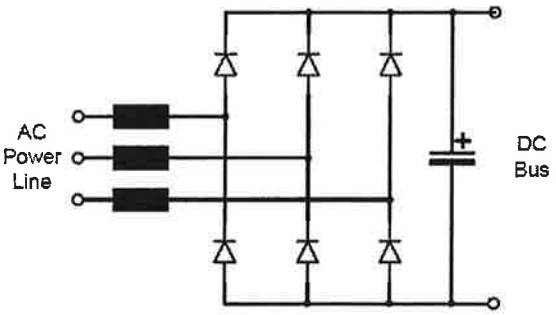
Techniques for Reducing Harmonics

AC/DC Converter with DC Link Chokes



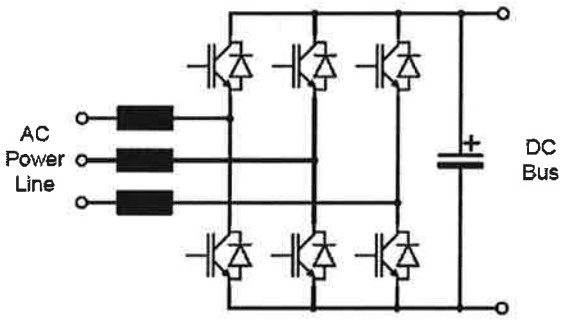
AC/DC Converter with AC Line Reactors



Techniques for Reducing Harmonics

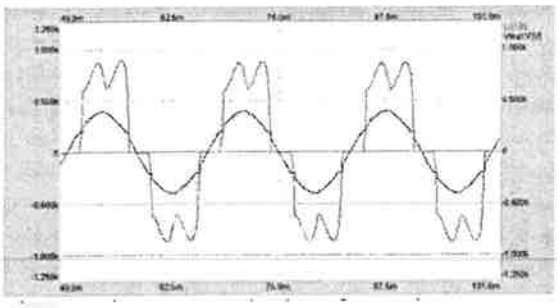
- IGBTs added in parallel with rectifiers
- synchronous converters,
- Other name such as active converter; active rectifier, active front-end, synchronous rectifier, line supply unit, regenerative unit or regenerative converter etc

AC/DC synchronous converter

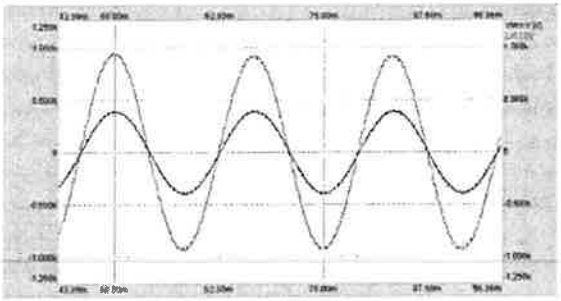


Using a Synchronous Converter for Harmonic Mitigation with AC Drives

Line current / voltage for 6 pulse converter



Line current / voltage with synchronize converter



Main effects of harmonics in installation

- **Increased losses**
  - Losses in transformers
  - Losses in conductors
  - Losses in capacitors
  - Losses in asynchronous machines
- **Overloads on equipment**
  - Generators
  - Uninterruptible power supplies (UPS)
  - Transformers
  - Neutral conductors
- **Disturbances affecting sensitive loads**
  - Effects of distortion in the supply voltage
  - Distortion of telephone signals
- **Resonance** — due to zero impedance

$X_L = X_C$

$\uparrow \quad \uparrow$

$2\pi f L = 2\pi f C$

Harmonic problem within installation

- **Problem caused by harmonic currents:**
  - Overloading of neutrals: **Figure 1**
  - Overheating of transformers
  - Nuisance tripping of circuit breakers
  - Over-stressing of power factor correction capacitors: **Figure 2**
  - Skin effect
  - **Problem caused by harmonic voltages:**
  - Voltage distortion : **Figure 3**
  - Induction motors
  - Zero-crossing noise

Figure 1 - Triple-N currents add in the neutral

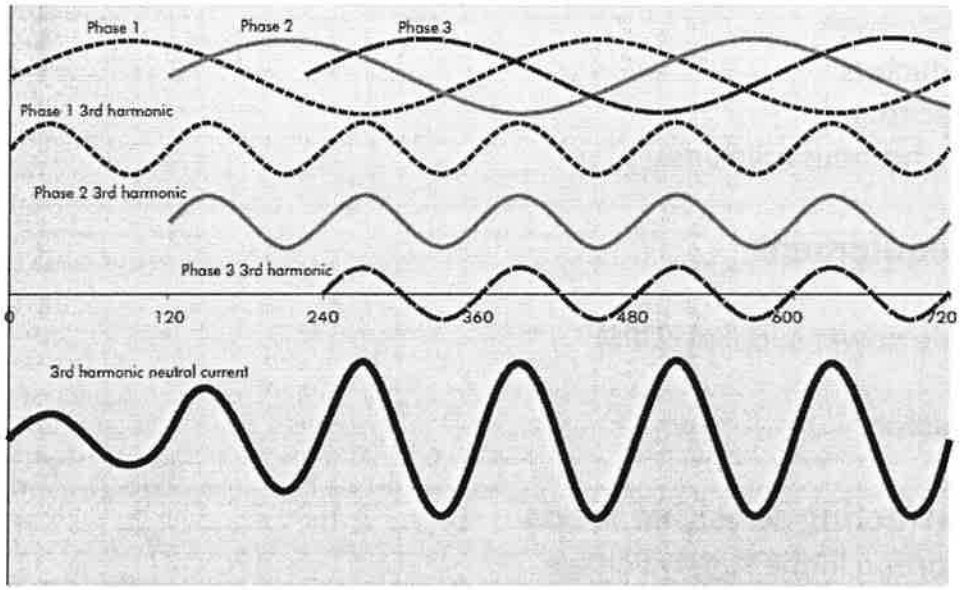


Figure 2 - Equivalent circuit of a non-linear load with a PFC capacitor

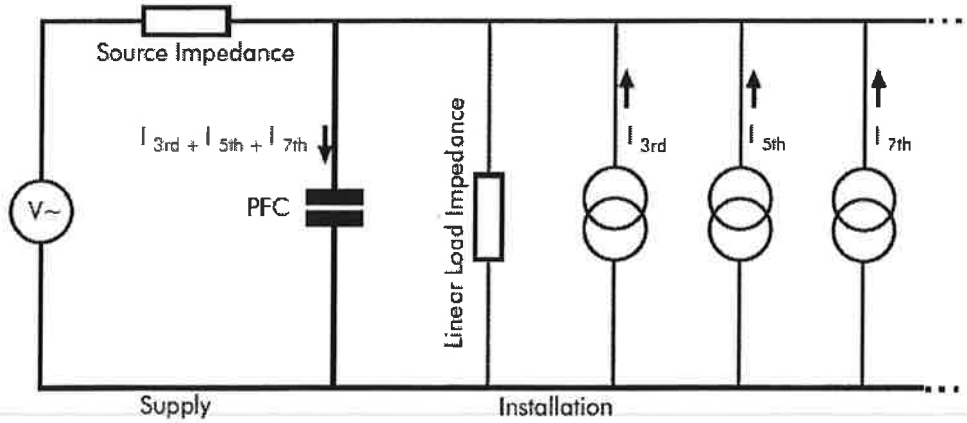
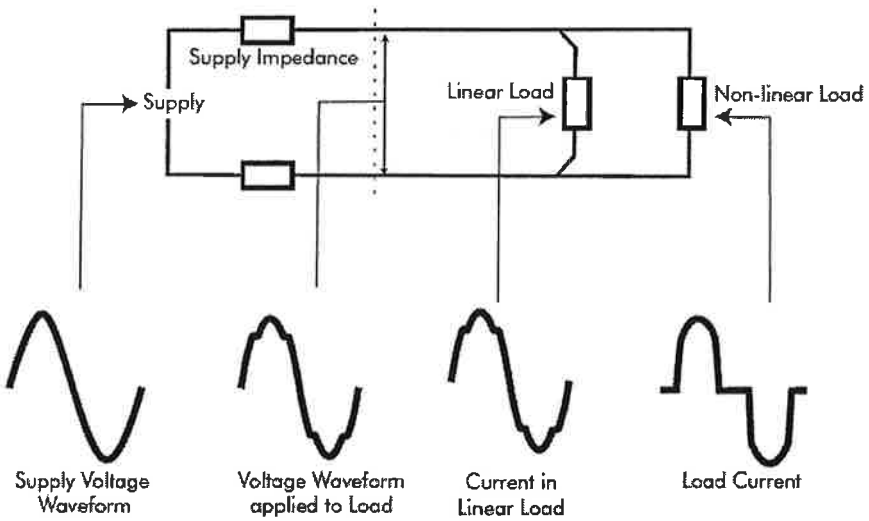


Figure 3 - Voltage distortion caused by a non-linear load



Induction Motors

- Harmonic voltage distortion causes increased eddy current losses in motors in the same way as in transformers. However, additional losses arise due to the generation of harmonic fields in the stator, each of which is trying to rotate the motor at a different speed either forwards or backwards. High frequency currents induced in the rotor further increase losses.

- Where harmonic voltage distortion is present,motors should be de-rated to take account of the additional losses.

Zero-crossing noise

- Many electronic controllers detect the point at which the supply voltage crosses zero volts to determine when loads should be turned on.

- This is done because switching reactive loads at zero voltage does not generate transients, so reducing electromagnetic interference (EMI) and stress on the semiconductor switching devices.

- When harmonics or transients are present on the supply the rate of change of voltage at the crossing becomes faster and more difficult to identify, leading to erratic operation. There may in fact be several zero-crossings per half cycle.

How harmonics affecting the motor operation

- Harmonic voltage: cause extra losses in direct connected motors and the torque pulsing causes wear and tear on couplings and bearings
  - 5th harmonic creates a counter-rotating field
  - 7th harmonic creates a rotating field beyond motor's sync. Speed
- Harmonic current: causes extra heating at rotor/stator air gap and reduces the motor efficiency

How harmonics affecting the motor operation

Other disturbance caused by harmonic on the electrical network:

- Overloads on distribution networks due to the increase in rms current
- Overloads in neutral conductors due to the cumulative increase in third-order harmonics created by single-phase loads
- Overloads, vibration and premature ageing of generators, transformers and motors as well as increased transformer hum
- Overloads and premature ageing of power-factor correction capacitors
- Distortion of the supply voltage that can disturb sensitive loads
- Disturbances in communication networks and on telephone lines

Harmonic affecting others

- Overheating of conductors due to skin effect
- Problems with power factor correction equipment
- Correct functioning of process control equipment such as PLC
- Problems with specific (long) lines or when switching heavy loads
- Overloaded neutrals
- Nuisance tripping of protective deices

Economic impact of disturbances by Harmonic

Harmonics have a major economic impact:

- Premature ageing of equipment means it must be replaced sooner unless oversized right from the start
- Oversizing of equipment such as cables, generators, transformers and UPS.
- Overloads on the distribution network can require higher subscribed power levels and increase losses
- Distortion of current waveforms provokes nuisance tripping that can stop production

Standard-Harmonics

Standards governing compatibility between distribution networks and products

- The harmonics caused by a device must not disturb the distribution network beyond certain limits
- Each device must be capable of operating normally in the presence of disturbances up to specific levels
- Standard IEC 61000-2-2 for public low-voltage power supply systems
- Standard IEC 61000-2-4 for LV and MV industrial installations

Standard-Harmonics

Standards governing the quality of distribution networks

- Standard EN 50160 stipulates the characteristics of electricity supplied by public distribution networks
- Standard IEEE 519 presents a joint approach between Utilities and customers to limit the impact of non-linear loads. Utilities encourage preventive action in view of reducing the deterioration of power quality, temperature rise and the reduction of power factor. They will be increasingly inclined to charge customers for major sources of harmonics

Standard-Harmonics

Standards governing equipment

- Standard IEC 61000-3-2 or EN 61000-3-2 for low-voltage equipment with rated current under 16 A
- Standard IEC 61000-3-12 for low-voltage equipment with rated current higher than 16 A and lower than 75 A

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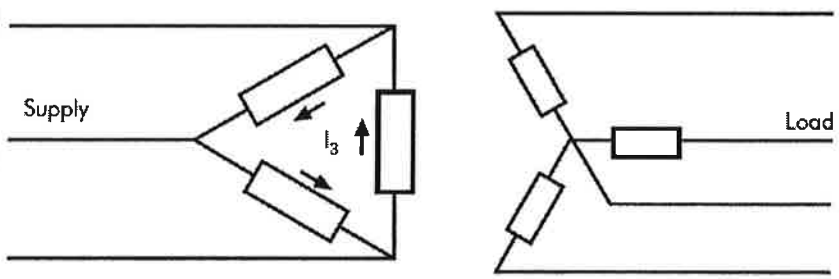
Harmonic mitigation measures

- **Passive filter -** Passive filters are used to provide a low impedance path for harmonic currents so that they flow in the filter and not the supply
- **Isolation transformers -**



Hospital of earth are broken to avoid shock to patient w/o tripping system.

Harmonic mitigation measures

The solutions mentioned so far have been suited only to particular harmonics, the isolating transformer being useful only for triple-N harmonics and passive filters only for their designed harmonic frequency.

- **Active Filters :** In some installations the harmonic content is less predictable. In many IT installations, for example, the equipment mix and location is constantly changing so that the harmonic culture is also constantly changing. A convenient solution is the active filter or active conditioner.

Active Filters

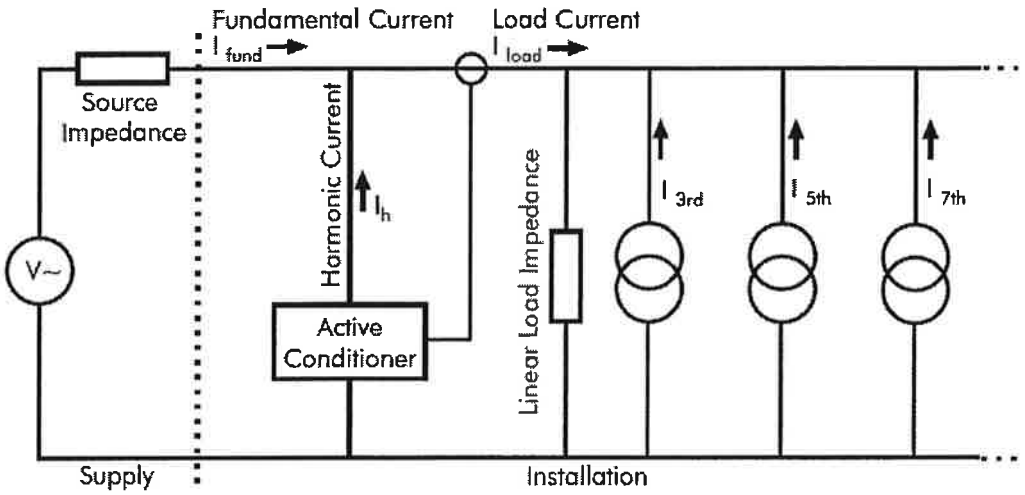
The active filter is a shunt device.

A current transformer measures the harmonic content of the load current, and controls a current generator to produce an exact replica that is fed back onto the supply on the next cycle.

Since the harmonic current is sourced from the active conditioner, only fundamental current is drawn from the supply.

In practice, harmonic current magnitudes are reduced by 90 % and, because the source impedance at harmonic frequencies is reduced, voltage distortion is reduced.

Active Filters



Eliminate Voltage Unbalance

- Regularly monitor voltages at the motor terminals to verify that voltage unbalance is maintained below 1%.
- Check your electrical system single line diagrams to verify that single phase loads are uniformly distributed.
- Install ground fault indicators as required and perform annual thermo graphic inspections. Another indicator that voltage unbalance may be a problem is 120 Hz vibration. A finding of 120 Hz vibration should prompt an immediate check of voltage balance

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Eliminate Voltage Unbalance

Common causes of voltage unbalance include:

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

Motor Efficiency* Under Conditions of Voltage Unbalance			
Motor Load % of Full	Motor Efficiency, %		
	Voltage Unbalance		
	Nominal	1%	2.5%
100	94.4	94.4	93.0
75	95.2	95.1	93.9
50	96.1	95.5	94.1

* Results vary depending upon motor design, speed, full-load efficiency, and horsepower rating. Typically, electric motors have peak efficiency near 75% load, but the above motor tested in the lab showed otherwise.

Eliminate Voltage Unbalance

Example:

Assume that the motor tested as shown in the above table was fully loaded and operated for 8,000 hours per year, with an unbalanced voltage of 2.5%. With energy priced at $0.05/kWh, the annual energy and dollar savings, after corrective actions are taken, are:

motor efficiency

Annual Energy Savings = 100 hp x 0.746 kW/hp x 8,000 hrs/yr x (100/93 – 100/94.4)

= 9,517 kWh Annual Dollar Savings

= 9,517 kWh x $0.05/kWh

= $476

Overall savings may be much larger because an unbalanced supply voltage may power numerous motors.

Eliminate Excessive In-plant Distribution System Voltage Drops

- Conduct a voltage drop survey.
- The voltage drop is simply the voltage difference across the connection.
- Voltage drop information can be used to determine energy losses and excess energy consumption due to loose and dirty connections.
- Voltage drop measurements should be taken at each phase.
- The total energy loss in a three-phase component is determined by summing the losses for each phase.
- Limit the load on each circuit or install larger-than-code minimum conductors if the voltage drop exceeds 3%.

Eliminate Excessive In-plant Distribution System Voltage Drops

Energy Savings Example

Measurements at a motor control center (MCC) breaker indicate voltage drops of 8.1, 5.9, and 10.6 volts on L1, L2, and L3, respectively.

The driven equipment is continuously operated. Measured line currents are : 199.7, 205.7, and 201.8 amps for L1, L2, and L3.

Voltage drop measurements for circuits serving similar loads indicate that a voltage drop of 2.5 volts should be obtainable.

The potential annual energy and electrical demand savings due to correcting the problem are:

Table 1. Excess Energy Consumption at a MCC Breaker

Circuit	Measured Voltage Drop, Volts	Excess Voltage Drop, Volts	Current, Amps	Excess Power, kW	Excess Energy Use, kWh
L_1	8.1	5.6	199.7	1.12	9,796
L_2	5.9	3.4	205.7	0.7	6,126
L_3	10.6	8.1	201.8	1.63	14,318
			Totals:	**3.45**	**30,240**

Assuming a utility energy charge of $0.05/kWh with a demand charge of $8.00/ kW per month, potential savings are valued at:

= 3.45 kW x $8.00/kW/month x 12 months/year + 30,240 kWh/year x $0.05/kWh

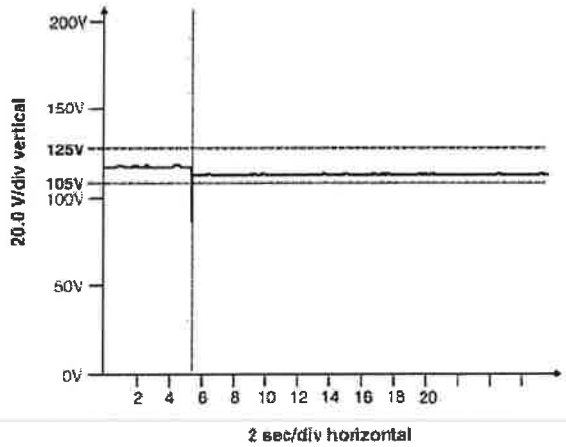
= $331 + $1,512

= $1,843 per year (for a single breaker)

Sag

Sag

Momentary: A temporary RMS reduction in the normal AC voltage, at the power frequency, for durations from a half-cycle to two seconds.



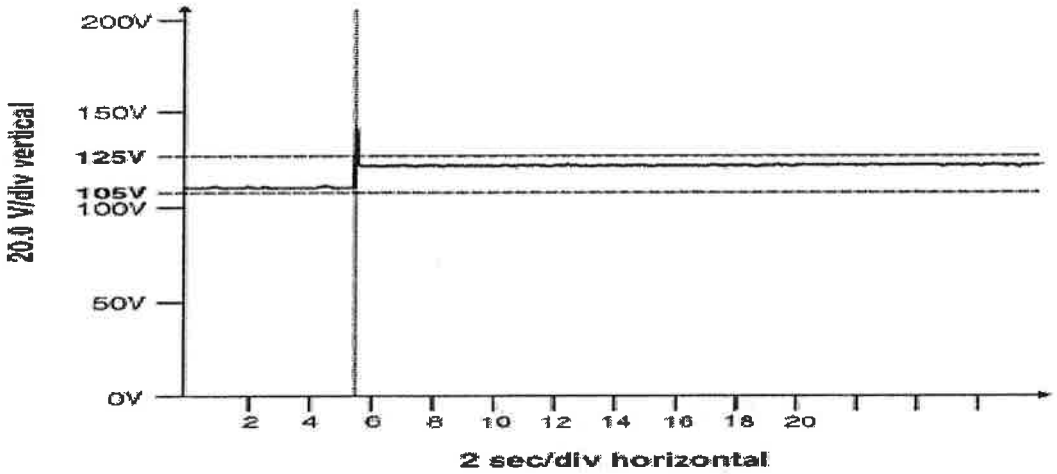
LINE-NEUT VOLTAGE SAG

Sustained: A RMS reduction in the nominal AC voltage, at the power frequency, for durations greater than two seconds.

Swell

Swell

Momentary: A temporary RMS increase in the normal AC voltage, at the power frequency, for durations from a half-cycle to two seconds.



Sustained: A RMS increase in the nominal AC voltage, at the power frequency for durations greater than two seconds.

Sag / Swell

The picture of a momentary and sustained sag (remember that the sagging definition is a slow, average decrease in voltage) is showing the RMS. This is the reduction by means of the line to neutral voltage sag as experienced by a BMI type of power disturbance analyzer.

The opposite of sagging, the new terminology now for the slow, average increase of voltage or temporary increase, is swelling.

Surge / Transient

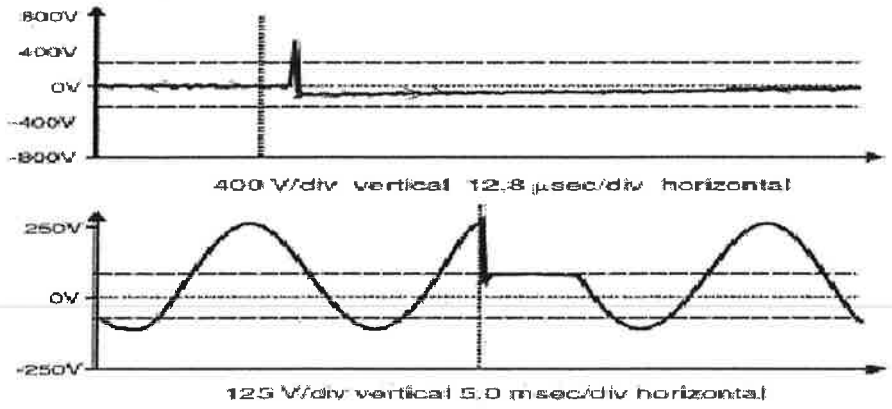
What we used to call transients, spikes or impulses are now formally known as surges. This is of a very abrupt sub cycle type of disturbance, a very brief and very steep wave front.

It shows the line to neutral impulse first taking place on a very short millisecond trace at the bottom of the page and then taking place on a microsecond per division so that the centre of the bottom trace is now expanded to 128 microseconds from left to right on the upper trace. Now we get to see what that actual peak is, something far different from what we see on the bottom where we notice that there is somewhere in the neighborhood of 600 volts of impulse now known by the term surge.

Surge (Transient)

Surge (Transient/Impulse)

A sub-cycle voltage wave in an electric circuit, which is evidenced by a sharp, brief disturbance of the input-power voltage waveform. The duration is less than a half-cycle of the normal voltage waveform and generally less than a ms. The term derives from the appearance of the abrupt disturbance of the normal voltage waveform. Often it is oscillatory-decaying. Surges are often characterized by excessive voltage.



LINE-NEUT IMPULSE

Interruption

The momentary loss for something having

a half cycle up to two seconds worth of duration and then the definition of having

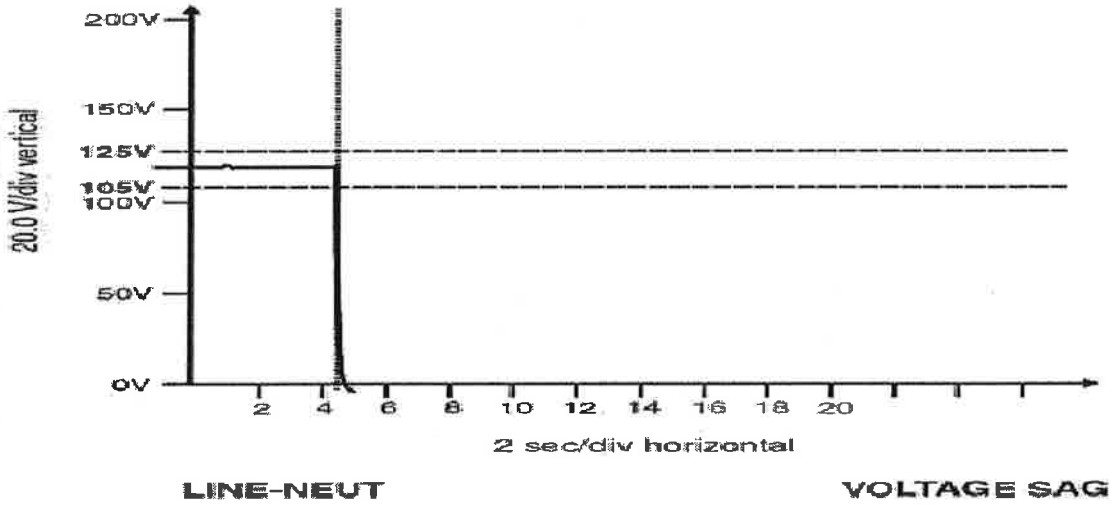
a complete loss would be that power interruption that takes place over a two

second long period.

Interruption

Interruption (Outage)

Momentary: The complete loss of voltage for a time period between a half-cycle and two seconds.



Sustained: The complete loss of voltage for a time period greater than two seconds.

Q & A

BUILDING LOAD MANAGEMENT

- To control of usage of electrical or other forms of energy by reducing or optimizing the amount of such usage and the rate of such usage (*demand*)
- The control element is the electrical demand (to reduce kW, kWh)
- It must have a good understanding of utilities rates, auditing and metering and the process and operation.

Load Management

What are the controlled need to be considered in the load management?

- Electrical energy usage: measured in term of
  - kilowatt hours (kWh),
  - reactive energy usage in kilovar-hours (kvarh),
  - real power (kW),
  - apparent power kilovoltamperes (kVA),
  - reactive power in kilovars (kvar),
  - power factor (p.f) and
  - load factor (L.F) are the item to be controlled or managed.
- Electrical demand: measured in term of kW

Demand control techniques

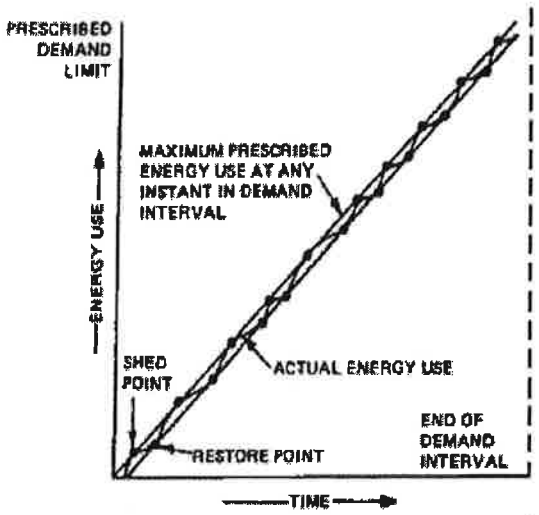
- **Manual demand control** - Maximum benefits can be attained from a plant power survey focused on those areas of the plant where it will pay to have continuous records made through the installation of permanent instrumentation.

- Total plant records will show how each piece of equipment contributes to the total load picture and will reveal whether equipment is operating within specifications. Areas of energy waste should be identified.

Demand control techniques

Automatic controllers have the following:

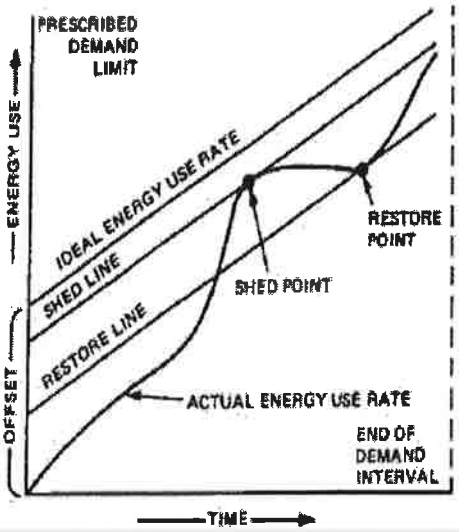
a. Instantaneous demand – action is taken when instantaneous demand exceeds the established prescribed set-point value.



(a)

Demand control techniques

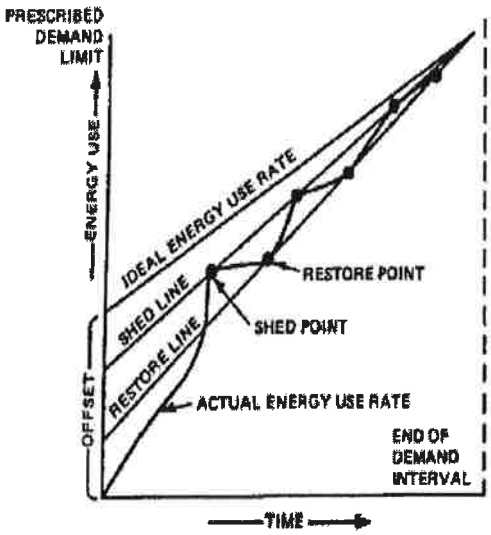
b. Ideal rate - ultimate demand limit is prescribed and a slope is established to define when usage indicates that this limit is likely to be exceeded.



(b)

Demand control techniques

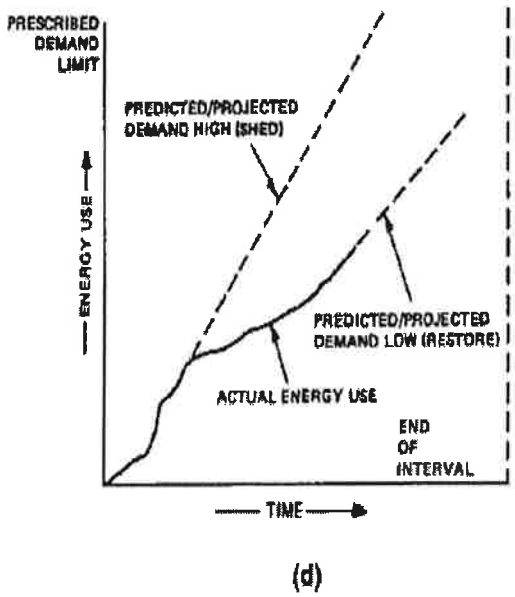
c. Converging rate – work like the ideal rate controller, but it operates on an accumulated usage curve whose upper limit is defined by the specified maximum demand



(c)

Demand control techniques

d. Predicted demand - average usage is monitored periodically through the demand interval and compared with the instantaneous usage at that particular moment.



(d)

Demand control techniques

Microprocessor-based system –

Using a keyboard input to a computer to specify the maximum demand that can be tolerated, based on previous experience.

The microprocessor continually monitors the plant's electric consumption and determines if the demand limit will be exceeded.

If demand is well below the limit, control action is not taken.

If the computer predicts that demand may exceed the limit, the pre-selected loads can be automatically turned off to reduce demand or an alarm can alert the building engineer who then makes a manual adjustment decision.

Energy metering

Reasons to meter:

- Charge out energy to individual departments
- Accountability for energy used
- Efficiency of equipment and system
- Provide information for audits of energy projects
- Maintenance work: Identify location of performance problems, and provide feedback

Load Management

- To control of usage of electrical or other forms of energy by reducing or optimizing the amount of such usage and the rate of such usage (*demand*).
- The control element is the electrical demand (to reduce kW, kWh)
- It must have a good understanding of utilities rates, auditing and metering and the process and operation.

Load Management

What are the controlled need to be considered in the load management?

- Electrical energy usage: measured in term of
  - kilowatt hours (kWh),
  - reactive energy usage in kilovar-hours (kvarh),
  - real power (kW),
  - apparent power kilovoltamperes (kVA),
  - reactive power in kilovars (kvar),
  - power factor (p.f) and
  - load factor (L.F) are the item to be controlled or managed.
- Electrical demand: measured in term of kW

Load management

- To reduce the demand for electricity during peak use periods
- To increase the demand during off-peak periods.
- The utility rate structure penalizes a customer for peak power demands.
- Other structures have penalties to discourage the use of electricity during certain times of the day.
- Load management enables the utility company to use its power generating equipment more efficiently.

WHAT HAVE BEEN SOME OF THE RESULTS OF LOAD MANAGEMENT?

- Rescheduled the start-up of its tempering ovens to night-time hours
- rescheduled the time for recharging lift truck batteries
- Installed demand-limiting equipment and started using waste heat from some of its process operations to supplement heat to its building
- Rescheduled furnace loading from its first shift to its second shift

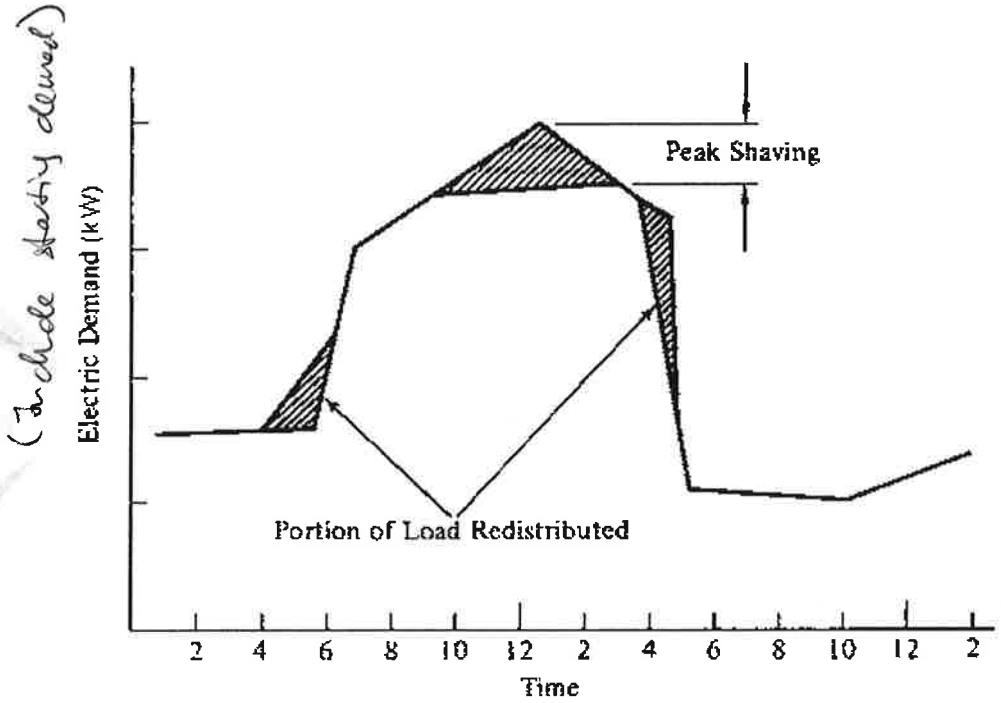
Load Management Techniques

1. Reschedule energy-related activities to non-peak hour times
2. Automatically shed loads by use of a load demand controller or computer.

Needs:

- Make a load audit - indicates the electrical energy characteristics for the billing period. The electric characteristics are compared with plant operations to determine what has caused the peak power usages.

Load Management Techniques



Basic steps for conducting a load analysis

1) Collect historical load data
   - compile data for at least one year
2) Organize data by month for
   - kWh consumption
   - maximum kW demand
   - load factor
3) Review data for
   - seasonal patterns of use
   - peak demands
4) Determine what demand or use can be eliminated or reduced
5) Review load data with utility

Energy Monitoring and Forecasting

- Energy management is a continuous process and it is important to monitor energy usage and the result will be used to gauge future actions.

- It is also important to budget the anticipated energy usage so that performance can be evaluated and plans can be made. A measure against budget also provides input to determine if additional action is required.

- Some typical reports are
  - percent energy reduction method;
  - product energy-rate method;
  - activity method.

Energy Monitoring and Forecasting

- The use of a budget, and / or a projected usage allows evaluation of energy efforts and properly gauges the energy portion of the cost of doing business.

- Energy usage can be classified into two groups :
  - *Baseline energy* is the energy component that is constant over the measurement period and does not vary with production, weather, etc.
  - *Variable energy* is the component that changes with production, weather, occupancy, etc.

Demand control techniques

- **Manual demand control** - Maximum benefits can be attained from a plant power survey focused on those areas of the plant where it will pay to have continuous records made through the installation of permanent instrumentation.

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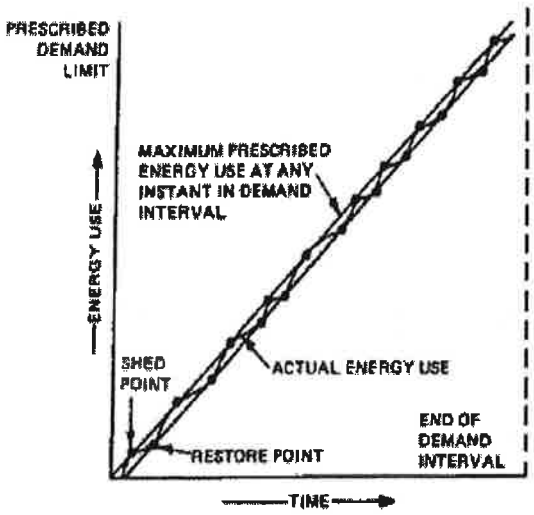

(a)

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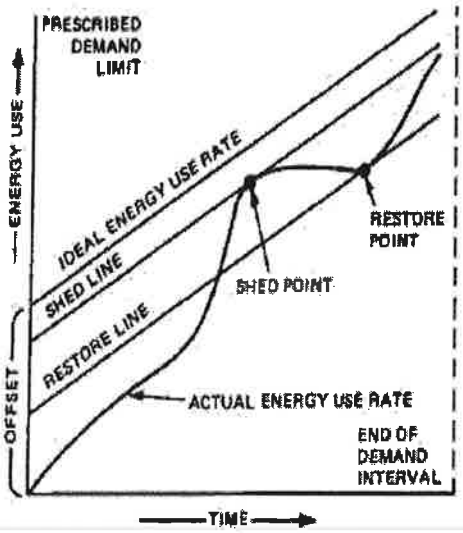

(b)

Demand control techniques

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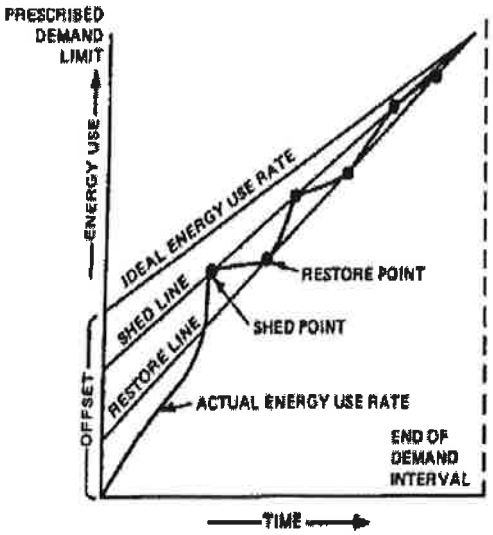
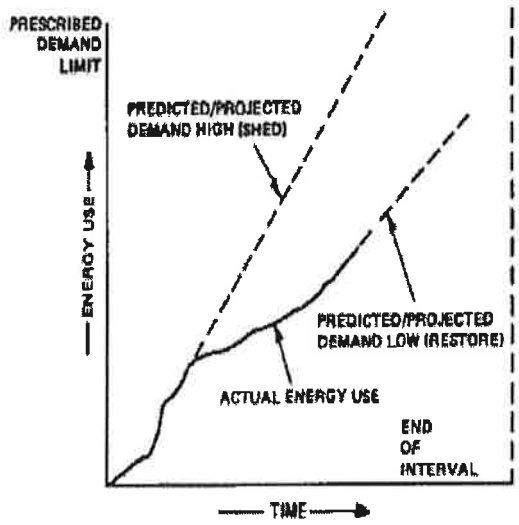


(c)

Demand control techniques

d. Predicted demand - average usage is monitored periodically through the demand interval and compared with the instantaneous usage at that particular moment.



(d)

Demand control techniques

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Energy metering

Reasons to meter:

- Charge out energy to individual departments
- Accountability for energy used
- Efficiency of equipment and system
- Provide information for audits of energy projects
- Maintenance work: Identify location of performance problems, and provide feedback

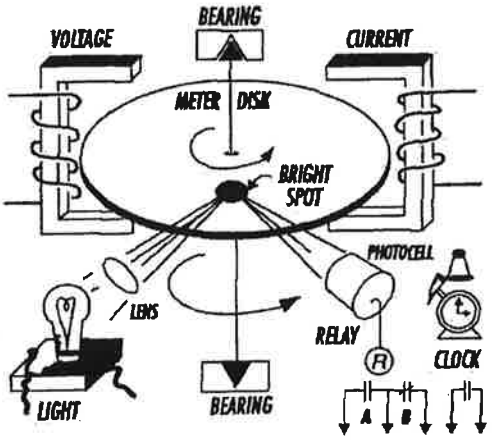
Energy metering

- Metering to provides the opportunity to monitor and control the rate of energy consumption.
  - kW (maximum demand)
  - kWh (energy usage)
  - Power factor
  - Voltage
  - Current
  - Harmonic etc



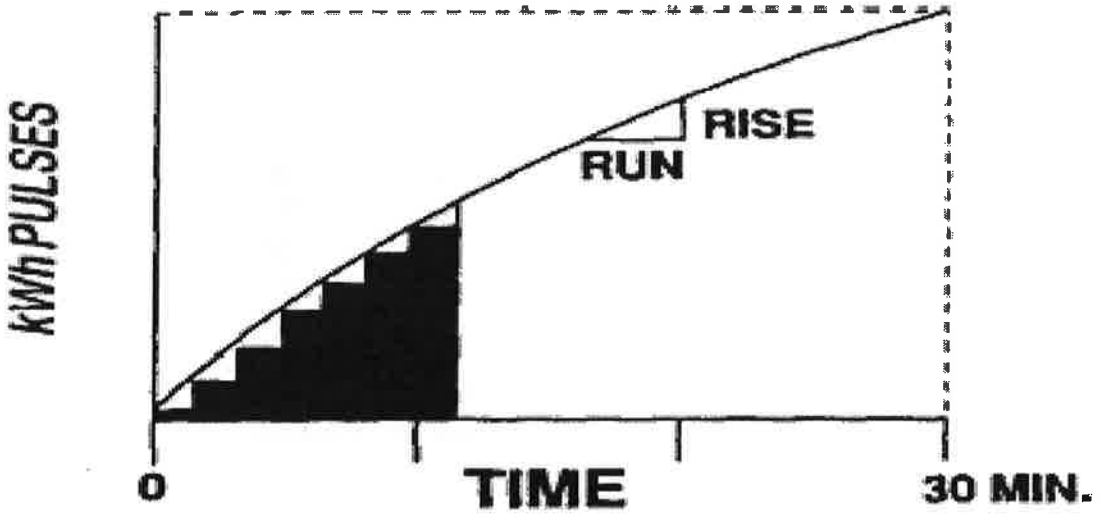
- Types:
  - Electro-mechanical (EM)
  - Digital Metering
  - EM Type

kWh Meter



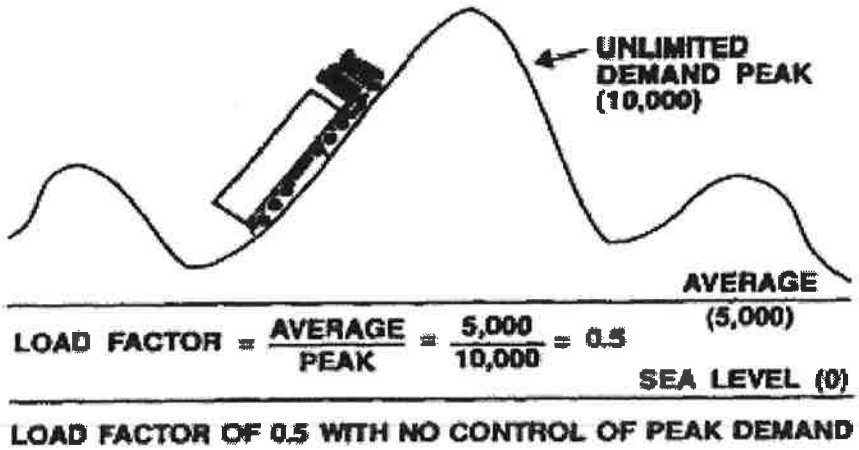
- To measured maximum demand (kW), interval of 30min.
- To measured energy usage (kWh)
- Current Transformer (CTs)
- Potential Transformer (PTs)

Demand Curve



$$SLOPE = \frac{RISE}{RUN} = \frac{kWh}{h} = kW$$

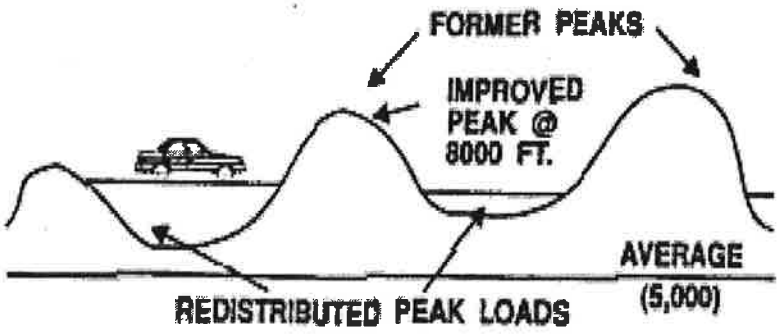
Load factor without peak demand control



$$\text{LOAD FACTOR} = \frac{\text{AVERAGE}}{\text{PEAK}} = \frac{5{,}000}{10{,}000} = 0.5$$

LOAD FACTOR OF 0.5 WITH NO CONTROL OF PEAK DEMAND

Load factor with redistribution of peak load



$$\text{LOAD FACTOR} = \frac{\text{AVERAGE}}{\text{PEAK}} = \frac{5{,}000}{8{,}000} = 0.63$$

SEA LEVEL (0)

IMPROVED LOAD FACTOR OF 0.63 WITH
REDISTRIBUTION OF PEAK LEVEL

Economic justification for load management

- A load management system can provide substantial savings through
  - reduced energy costs,
  -increased production without corresponding increases in energy requirements.

- Load management system is essential as some industries may be required by the government to reduce energy demands.

- Other industries will have to prove that their use of energy already meets or exceeds the industry's standards for efficiency in terms of energy consumed per unit or product.

Q & A

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Rate Structure and Analysis

- Translating Energy Into Cost –Economic models
- Energy Rate Structures
- Calculating Energy Saving
- Calculation the Cost of Electricity

Translating Energy Into Cost

- Concepts in an economic analysis
  - Usually two or more alternatives are considered in an economic analysis and investment is usually evaluate over a period of time.
  - Other consideration made in an economic analysis such as:
    - The capital cost represents the total expenditure for a physical plant or facility such as direct cost and indirect cost.
    - Depreciation is the distribution of a capital cost over the anticipated life of the process or equipment.
    - Equipment, material, and buildings have two values used for life expectancy such as book lift and useful life.
    - The salvage value is the amount of money that can be returned to the company at the end of the expected life of the
    - capital investment.

Economic models

Simple break-even analysis – do not use the time value of money.

$$\text{Break-even point} = \frac{\text{net capital investment}}{\text{savings/unit}}$$

It is useful for a large energy savings for a small investment type of project.

Example: the installation of a timer on an exterior light circuit that will significantly reduce "on" time or a decision to switch off unused equipment may not need an economic evaluation.

Direct cost and Indirect cost

- Direct cost – material, labor for design and construction, and start-up cost
- Indirect costs – expenditures that cannot be directly assigned to a project such as taxes, rent, employee benefits, management, corporate offices etc

Economic models

2. Life cycle costing (LCC) is the evaluation of a proposal over a reasonable time period considering all pertinent costs and the time value of money. The evaluation can take the form of present value analysis etc.

Life cycle costing is most likely needed when the project costs are large compared to the energy savings or when there are significant future costs.

Example: when concerning future operations are appropriate, a more sophisticated method of analysis is justified, particularly if the minimum payback period exceeds several years. A complete, long-term analysis is well worth considering in determining energy savings.

Break-even analysis method

- Do not use the time value of money
- At what point will get back the back
- Other common terms use for this model are: simple payback, break-even point.
- Relate to the capital investment to the savings
- It is not restricted to time as a base.
- It no a good evaluation method if future operations are appropriate such as minimum payback period exceeds several years.

Life cycle costing (LCC) method

- The evaluate over a reasonable time period all cost and time value money

- All cost and investments at appropriate points in time and converts them to current costs:
  - Design cost
  - Initial investment
  - Overheads
  - Annual maintenance costs
  - Annual operating costs
  - Recurring costs
  - Energy costs
  - Salvage values
  - Economic life
  - Tax credits
  - Inflation

Time value of money

The time value of money is important for us to evaluate alternatives by translating a dollar of expenses or investment at various times to equivalent amounts.

Calculating the time value of money

•**annuity:** A series of equal amounts evaluated at the end of equal time periods (usually 1 yr) for a specified number of periods.

•**capital investment:** The amount of money invested in a project or piece of equipment (this includes labor, material, design, and debugging monies).

•**compound interest:** Interest that is applied to both the accumulated principal and interest. For example, a 12% annual interest rate compounded at 1% each month on $1.00 is (1.01)12 or $1.13, which results in a 12.7% effective (simple) annual interest rate.

•**constant dollars:** The worth of a dollar amount in a reference year, including the effect of inflation. Constant dollars are used in economic indicators.

Time value of money

- **current dollars:** The worth of a dollar today
- **depreciation:** The mathematical distribution of the capital investment over a given period of time, which may or may not concur with the estimated useful life of the item.
- **discount rate:** The percentage rate used by a corporation that represents the time value of money for use in economic comparisons.
- **future worth (value):** The value of a sum of money at a future time.
- **initial cost:** Synonymous with capital investment. Capital investment is a more proper and clearly recognized term.
- **present worth (value):** The value of an amount discounted to current dollars using the time value of money.

Energy Rate Structures

- The PG tariff is shown in the following slide.

REVISION OF ELECTRICITY TARIFFS FROM 1st OCTOBER 2008	Last Qtr Tariff	New Tariff
LOW TENSION SUPPLIES, DOMESTIC		
All units, ¢/kWh	25.07	30.45
LOW TENSION SUPPLIES, NON-DOMESTIC		
All units, ¢/kWh	25.07	30.45
HIGH TENSION SMALL (HTS) SUPPLIES		
Contracted Capacity Charge S$/kW/month	7.04	6.96
Uncontracted Capacity Charge S$/chargeable kW/month	10.56	10.44
kWh charge, ¢/kWh		
Peak period (7am to 11pm)	22.96	29.08
Off-peak period (11pm to 7am)	13.81	17.77
Reactive power Charge ¢/chargeable kVARh	0.59	0.59
HIGH TENSION LARGE (HTL) SUPPLIES		
Contracted Capacity Charge S$/kW/month	7.04	6.96
Uncontracted Capacity Charge S$/chargeable kW/month	10.56	10.44
kWh charge, ¢/kWh		
Peak period (7am to 11pm)	22.81	28.93
Off-peak period (11pm to 7am)	13.80	17.76
Reactive power Charge ¢/chargeable kVARh	0.59	0.59
EXTRA HIGH TENSION (EHT) SUPPLIES		
Contracted Capacity Charges$/kW/month	6.74	6.52
Uncontracted Capacity Charges$/chargeable kW/month	10.11	9.78
kWh charge, ¢/kWh		
Peak period (7am to 11pm)	21.64	27.83
Off-peak period (11pm to 7am)	13.64	17.58
Reactive power Charge¢/chargeable kVARh	0.48	0.48

Calculation on energy saving

Example 1

An energy audit of an office block shows that electrical power can be reduced by replacing the condensing and chilled water pump motors of the air-conditioning installation with newer, more efficient motors of the same horse-power ratings.

There are 2 sets of condensing water pumps and 2 sets of chilled water pumps. All four pumps operate continuously for 24 hours per day.

The existing condensing water pumps are rated at 60 hp with an efficiency of 83% and the existing chilled water pumps are rated at 75 hp with an efficiency of 83%.

If the new motors have an efficiency of 90%, calculate the annual savings in the electricity consumed. The electricity charge is S$0.14 per kWh

	CWP	CHWP
Before replace	$\frac{2\times(60\times0.746)}{0.83} = 107.86\,kW$	$\frac{2\times(75\times0.746)}{0.83} = 134.82\,kW$
After	$\frac{2\times(60\times0.746)}{0.9} = 99.47\,kW$	$\frac{2\times(75\times0.746)}{0.9} = 124.33\,kW$
Savings	$107.86 - 99.47 = 8.39\,kW$	$134.82 - 124.33 = 10.49\,kW$

Total Cost $8.39 + 10.49 = 18.88\,kW \times 24 \times 365 \times \$0.14 = \$23,154.45$ per annum

Calculation the Cost of Electricity

Example 2:

A development takes in HT (Small) supply. Calculate the electric bill for the owner. Assume power factor is 0.9.

~~Lowest~~ P.F. for reactive charge is < 0.85.

- Contracted capacity = 1,200 kW × $6.96 = $ 8,352
- Uncontracted capacity = 200 kW × $10.44 = $ 2,088
- Maximum demand = 900 kW × $0
- Peak consumption = 250 MWh × $0.2908 = $72,700
- Off-peak consumption = 80 MWh × $0.1777 = $14,216

$97,356

Sample Electrical Bil

Energy Charge (Peak/Off Peak)	$ 0.13442
UOS Charge-Off Peak	$ 0.0013
UOS Charge-Peak	$ 0.0119
Retail Market Systems Related Charge	$ 0.0016109
AFP Charge	$ 0.0014286
Monthly Energy Uplift Charge	$ 0.00025
PSO Administrative Charge	$ 0.0001955
EMC Administrative Charge	$ 0.00334
Total Charge	**$ 0.1531450**
SP Peak Rates	**$ 0.1882**

SERAYA ENERGY

TAX INVOICE from 01-Jul-2006 to 31-Jul-2006

Page 2 of 2

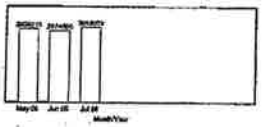
Account No. | MSSL No. 8300010289 | Invoice No. 680000049147

Supply Address

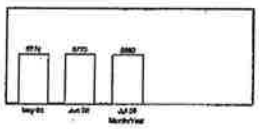
High Tension

Current Charge	Usage		Rate ($GD/Usage)	Amount ($GD)	Total ($GD)
Energy Charges					
Off Peak Energy Charge	752,496.800	kWh	0.13442	101,150.62	
Peak Energy Charge	2,283,580.800	kWh	0.13442	304,270.53	405,421.15
Transmission Charges (Unadjusted)					
Off Peak UOS Charge	752,496.800	kWh	0.0013	978.25	
eak UOS Charge	2,283,580.800	kWh	0.0119	26,936.61	
Contracted Capacity Charge	5,240.000	kW	7.04	36,889.60	
Uncontracted Capacity Charge	441.600	kW	10.56	4,663.30	
Reactive Energy Charge	106,332.800	kVArh	0.0059	639.18	70,106.94
MSSL, EMC and PSO Charges (Adjusted)					
Billing and Collection Charge	1.000		0.63	0.63	
MSSL Basic Services Charge	1.000		2.89	2.89	
Meter Reading and Data Management Charges	2.000		10.66	21.32	
Retail Market Systems Related Charge	3,031,562.142	kWh	0.0016109	4,883.54	
AFP Charge	3,031,562.142	kWh	0.0014286	4,330.85	
Monthly Energy Uplift Charge	3,031,562.142	kWh	0.00025	757.89	
PSO Administrative Charge	3,031,562.142	kWh	0.0001955	592.70	
EMC Administrative Charge	3,031,562.142	kWh	0.000334	1,012.51	11,602.24
Other Charges					
etail Service Charge			99.57	99.57	
Late Payment Charges			0	2,939.56	3,039.53
Sub-Total					490,169.86
Goods and Services Tax (5%)					24,508.49
Total Current Charges					514,678.35

Electricity Consumption (kWh)



Maximum Demand (kW)



Q & A

MOTOR POWER FOR FANS AND PUMPS

- The main motor-driven components within the HVAC systems are circulation pumps for heating or chilled water systems, and fans for mechanical ventilation systems.
- The motors that drive pumps and fans can consume a considerable amount of energy.
- This can be optimised through selection of the motor drive equipment; and through selecting suitable parameters for the hydronic or ventilation systems.

Energy Efficiency Motor and Variable Frequency Drives

- Efficiencies of Electrical Equipment
- Selection of Efficiency Motors
- Optimizing Performance of Motors
- Application of Frequency Drives

Energy Efficiency Motor

- The efficiency of a motor is the ratio of the mechanical power output to the electrical power input. This may be expressed as:

$$Efficiency = \frac{Output}{Input} = \frac{Input - Losses}{Input} = \frac{Output}{Output + Input}$$

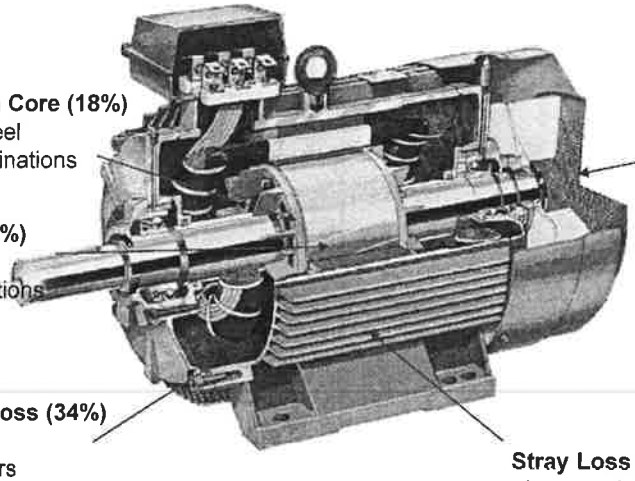
- In 1989, NEMA developed standard definition for energy-efficient motors to help users identify and compare electric motor efficiencies on an equal basis.

$$\eta = \frac{Output}{(Output + Losses)} \leftarrow Input$$

What make up for an efficient motor

- Design changes – size of air gap
- Better materials
- Manufacturing improvements reduce motor losses (reduced losses mean that an energy-efficient motor produces a given amount of work with less energy input than a standard motor)
  a) Core loss – Hysteresis and eddy current loss
  b) Windage and friction loss
- Making premium or energy-efficient motors more efficient than standard motors.

What make motor energy efficiency?



Motor losses

- Standard motor efficient ~ 83% to 92%
- An efficiency gain from only 92% to 94% resulted in a 25% reduction in losses
- **Core loss** – the energy required to magnetize the core material (hysteresis) and includes losses due to creation of eddy currents that flow in the core. Core losses are decreased through the use of improved permeability electromagnetic (silicon) steel and by lengthening the core to reduce magnetic flux densities. Eddy current losses are decreased by using thinner steel laminations.
- **Windage and friction loss** – this loss occur due to bearing friction and air resistance. Improved bearing selection, air flow, and fan design are employed to reduce these losses. Therefore smaller fan can be used

Both core losses and Windage friction losses are **INDEPENDENT** of motor load.

Motor losses

- **Stator losses** – It appear as heating due to current flow through the resistance of stator winding. ($I^2 R$). Loss can be decreased by modifying the stator slot or by decreasing insulation thickness to increase the volume of wire in the stator.

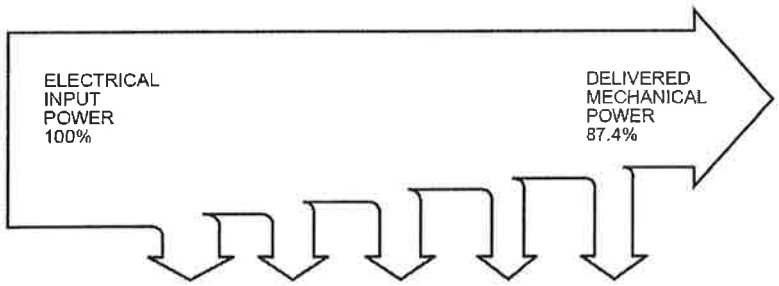
- **Rotor losses** – It appear as $I^2 R$ heating in the rotor. It can be reduce by increasing the size of the conductive bar and end rings to produce an lower resistance , or by reducing the electrical current.

- **Stray load losses** – Is a result of leakage fluxes induced by load currents.

All these losses is also known as on load losses and it depending on the motor loading condition.

Typical Motor Losses

15 HP, 4 POLE, 3 PHASE MOTOR
TYPICAL ENERGY FLOW



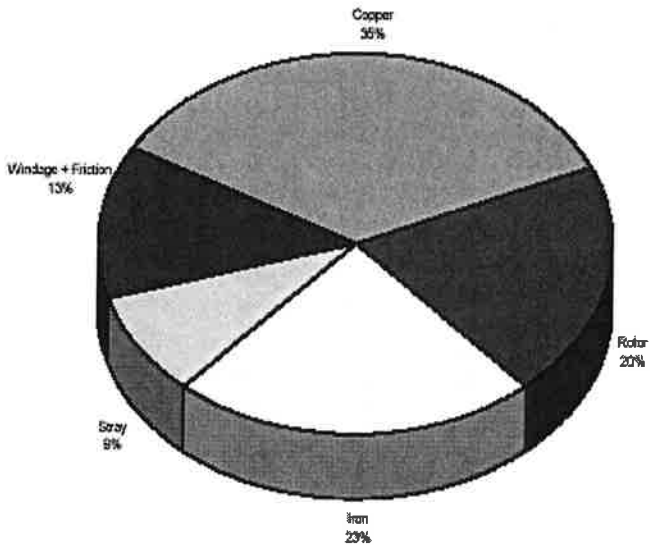
	STATOR RES. LOSS	ROTOR RES. LOSS	CORE LOSS	FRICTION & WINDAGE LOSS	STRAY LOAD LOSS	TOTAL
PERCENT OF LOSSES	30%	20%	19%	13%	18%	100%
PERCENT OF INPUT	3.8%	2.5%	2.4%	1.6%	2.3%	12.6%

Motor loss categories

Motor Loss Categories

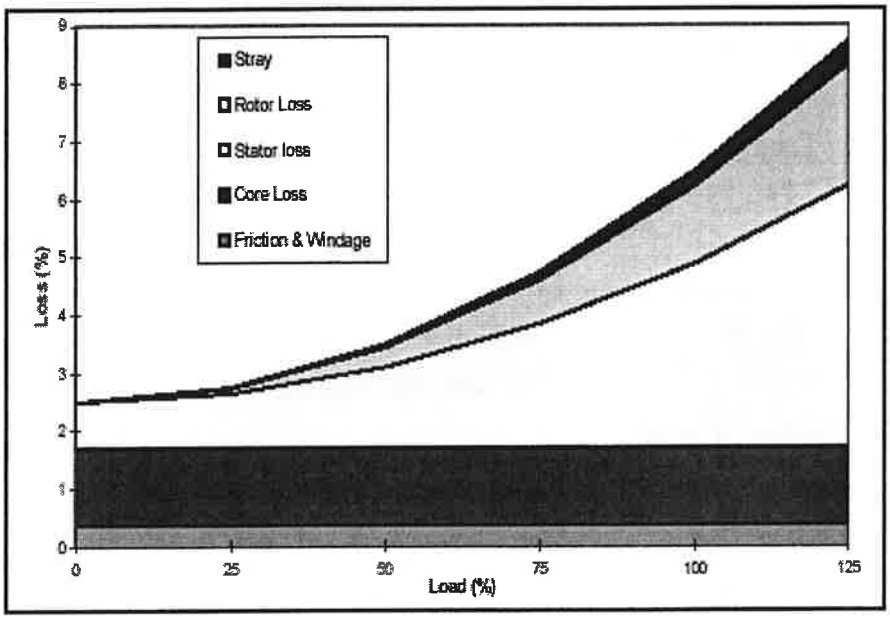
No Load Losses	Typical Losses (%)	Factors Affecting these Losses
Core Losses	15 -25	Type and quantity of magnetic material
Friction and Windage Losses	5 - 15	Selection and design of fans and bearings
Motor Operating Under Load		
Stator I^2R Losses	25 - 40	Stator conductor size
Rotor I^2R Losses	15 - 25	Rotor conductor size
Stray Load Losses	10 - 20	Manufacturing and design methods

Typical losses for a 75kW Induction motor



Distribution of losses in a standard 75kW Induction Motor

Motor Losses versus Load Condition



Loss Against Load Condition for a Typical Standard Motor

NEMA Threshold Nominal Full Load Efficiencies for Energy Efficient Motor

NEMA Threshold Nominal Full Load Efficiencies for Energy Efficient Motors

	ODP			12-6B	TEFC			
HP	3600	1800	1200	900	3600	1800	1200	900
1	82.5	77	72	80.5	75.5	72		
1.5	80	82.5	82.5	75.5	78.5	81.5	82.5	75.5
2	82.5	82.5	84	85.5	82.5	82.5	82.5	82.5
3	82.5	86.5	85.5	86.5	82.5	84	84	81.5
5	85.5	86.5	86.5	87.5	85.5	85.5	85.5	84
7.5	85.5	88.5	88.5	88.5	85.5	87.5	87.5	85.5
10	87.5	88.5	90.2	89.5	87.5	87.5	87.5	87.5
15	89.5	90.2	89.5	89.5	87.5	88.5	89.5	88.5
20	90.2	91	90.2	90.2	88.5	90.2	89.5	89.5
25	91	91.7	91	90.2	89.5	91	90.2	89.5
30	91	91.7	91.7	91	89.5	91	91	90.2
40	91.7	92.4	91.7	90.2	90.2	91.7	91.7	90.2
50	91.7	92.4	91.7	91.7	90.2	92.4	91.7	91
60	93	93	92.4	92.4	91.7	93	91.7	91.7
75	93	93.6	93	93.6	92.4	93	93	93
100	93	93.6	93.6	93.6	93	93.6	93	93
125	93	93.6	93.6	93.6	93	93.6	93	93.6
150	93.6	94.1	93.6	93.6	93	94.1	94.1	93.6
200	93.6	94.1	94.1	93.6	94.1	94.5	94.1	94.1

Big motors have better efficiency than small motors.

NEMA Standard Definition of Efficient Motor (cont'd)

	ODP				TEFC			
HP	3600	1800	1200	900	3600	1800	1200	900
1	82.5	80	74	75.5	82.5	80	74	
1.5	82.5	84	84	75.5	82.5	84	85.5	77
2	84	84	85.5	85.5	84	84	86.5	82.5
3	84	86.5	86.5	86.5	85.5	87.5	87.5	84
5	85.5	87.5	87.5	87.5	87.5	87.5	87.5	85.5
7.5	87.5	88.5	88.5	88.5	88.5	89.5	89.5	85.5
10	88.5	89.5	90.2	89.5	89.5	89.5	89.5	88.5
15	89.5	91	90.2	89.5	90.2	91	90.2	86.5
20	90.2	91	91	90.2	90.2	91	90.2	89.5
25	91	91.7	91.7	90.2	91	92.4	91.7	89.5
30	91	92.4	92.4	91	91	92.4	91.7	91
40	91.7	93	93	91	91.7	93	93	91
50	92.4	93	93	91.7	92.4	93	93	91.7
60	93	93.6	93.6	92.4	93	93.6	93.6	91.7
75	93	94.1	93.6	93.6	93	94.1	93.6	93
100	93	94.1	94.1	93.6	93.6	94.5	94.1	93
125	93.6	94.5	94.1	93.6	94.5	94.5	94.1	93.6
150	93.6	95	94.5	93.6	94.5	95	95	93.6
200	94.5	95	94.5	93.6	95	95	95	94.1

12-6C

Note: Full-load efficiencies are given. The numbers in parenthesis indicate either the number of motors considered or number of motor manufacturers using the identical list price. List prices are extracted from 1990 manufacturers' brochures.

Average Efficiencies and Typical List Prices for Standard and Energy-Efficient Motors

1800 RPM Open Drip-Proof Motors

hp	Average Standard Motor Efficiency, %	Average Energy-Efficient Motor Efficiency, %	Efficiency Improvement, %	Typical Standard ODP Motor List Price	Typical Energy-Efficient ODP Motor List Price	List Price Premium
5	83.8 (15)	87.9 (12)	4.7	$329 (4)	$370 (4)	$41
7.5	85.3 (14)	89.6 (15)	4.8	408 (6)	538 (5)	130
10	87.2 (21)	91.1 (7)	4.3	516 (6)	650 (5)	134
15	87.6 (15)	91.5 (11)	4.3	677 (5)	864 (5)	187
20	88.4 (14)	92.0 (11)	3.9	843 (6)	1055 (5)	212
25	89.2 (14)	92.8 (11)	3.9	993 (5)	1226 (5)	233
30	89.2 (12)	92.8 (12)	3.9	1160 (4)	1425 (5)	265
40	90.2 (12)	93.6 (11)	3.6	1446 (4)	1772 (5)	326
50	90.1 (11)	93.6 (13)	3.7	1688 (6)	2066 (4)	378
60	91.0 (11)	94.1 (12)	3.3	2125 (7)	2532 (5)	407
75	91.9 (11)	94.5 (12)	2.8	2703 (5)	3084 (5)	381
100	91.7 (9)	94.5 (14)	3.0	3483 (6)	3933 (5)	450
125	91.7 (7)	94.4 (16)	2.9	4006 (6)	4709 (5)	703
150	92.9 (8)	95.0 (12)	2.2	5760 (5)	6801 (5)	1041
200	93.1 (8)	95.2 (12)	2.2	7022 (3)	8592 (3)	1570

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200	93.1 (8)	95.2 (12)	2.2	7022 (3)	8592 (3)	1570

Energy Efficient Motors

The energy efficient motor differs from a standard motor in both **design** and **manufacturing techniques**.

The energy efficient motor have the followings:

- Employs larger stator conductors with higher conductivity.
- The rotor bars are larger as well, to reduce the overall copper (or aluminum) loss which comprises 55-60% of total motor losses.
- The motor flux density and air gap are reduced to minimize the magnetizing current required.

Stator and rotor laminations are thinner to increase resistance to the flow of eddy currents.

- More laminations are added to the core stacks as well, producing a longer stator and rotor for increased torque.
- Hysteresis losses, which are normally 20-25% of the total motor losses, are reduced by utilizing silicon steel, instead of low carbon steel for the laminations.
- As a results, the motor uses less current, has better power factor, and runs cooler.

Premium Efficiency Motors

- Annual energy savings are dependent upon operating profile, duty cycle, and efficiency gain

Table 1. Annual Savings from Specifying NEMA Premium Motors

Horsepower	Full-load Motor Efficiency (%)		Annual Savings from Use of a NEMA Premium Motor	
	Energy Efficient Motor	NEMA Premium Efficiency Motor	Annual Energy Savings, kWh	Dollar Savings $/year
10	89.5	91.7	1,200	$60
25	92.4	93.6	1,553	78
50	93.0	94.5	3,820	191
100	94.5	95.4	4,470	223
200	95.0	96.2	11,755	588

Note: Based on purchase of a 1,800 rpm totally enclosed fan-cooled motor with 8,000 hours per year of operation, 75% load, and an electrical rate of $0.05/kWh.

Premium Efficiency Motors

Example:

An old, 75-hp standard efficiency boiler forced-draft fan motor is to be replaced with a NEMA Premium efficiency motor. The existing motor operates at a 75% load for 8,000 hours per year with an efficiency (ηstd) of 91.0%. Determine the annual energy savings if the replacement motor has an efficiency (ηPE) of 95.4% and electricity is priced at $0.05/kWh.

Energy Savings = hp x load x 0.746 x hours x (100/ηstd – 100/ηPE)
= 75 x 0.75 x 0.746 x 8,000 x (100/91 – 100/95.4)
= 17,014 kWh/year
Energy Cost Savings = 17,014 x $0.05 = $851/year

Over a 10-year operating period for a 75-hp motor, the purchase price might represent just 2% of the total motor installation and operating costs. Energy and maintenance costs account for the remaining 98%.

Even a small improvement in motor operating efficiency can produce significant energy and dollar savings and provide a rapid return on investment.

Estimating Motor Efficiency in the Field

Actions:

- Conduct predictive maintenance tests to reveal whether efficiency is below the original or nameplate level. Decreased efficiency may be due to: – Higher winding resistance compared to manufacturer specifications or an earlier measurement. This may be caused by winding being at a higher temperature than that of the manufacturer's resistance specifications or by rewinding with smaller diameter wire. A low resistance ohmmeter is often required for winding resistance tests.

- Increase in no-load power or core losses. Core loss testing requires motor disassembly and is performed in a motor service center.

- Significant current unbalance when voltage is balanced.

- Evidence of cage damage.

Estimating Motor Efficiency in the Field

Table 1. What is an extra point of motor efficiency improvement worth?

Horsepower	Full-load Motor Efficiency (%)		Annual Savings	
	Original Efficiency	Final Efficiency	Annual Energy Savings, kWh	Dollar Savings $/year
10	89.5	90.5	605	30
25	92.4	93.4	1,420	71
50	93.0	94.0	2,803	140
100	94.5	95.5	5,431	272
200	95.0	96.0	10,748	537

Note: Based on purchase of a 1,800 rpm totally enclosed fan-cooled motor with 8,760 hours per year of operation, 75% load, and an electrical rate of $0.05/kWh.

Estimating Motor Efficiency in the Field

Motor losses fall into several categories that can be measured in various ways:

- Stator electric power (I2R) losses
- Rotor electric power (I2R) losses
- Friction and windage losses (including bearing losses, wind resistance, and cooling fan load)
- Stator and rotor core losses
- Stray load losses (miscellaneous other losses).

Estimating Motor Efficiency in the Field

Some of the available field motor-efficiency estimation methods include:

- **Loss accounting methods.** These measure most of the above losses using either special dedicated "lab-in-a-box" devices or very accurate conventional instruments, for example, power meters, thermometers, and micro-ohmmeters.

  The necessary instruments are costly and the process is very time and labor consumptive. Power meters must be accurate at very low power factors that occur when motors operate unloaded.

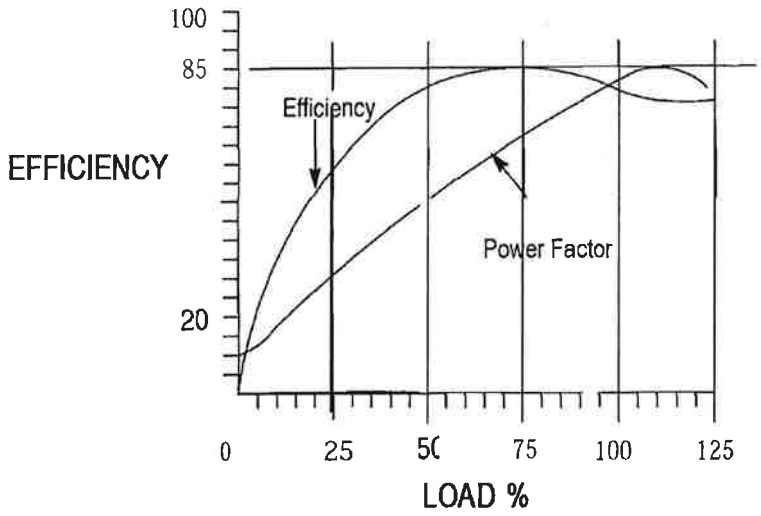
- **Slip method.** The slip method has largely been discredited as a viable technique for estimating motor efficiency. This method computes shaft output power as the rated horsepower multiplied by the ratio of measured slip to the slip implied by the nameplate. Slip is the difference between synchronous and shaft speed.

- **Current signature predictive maintenance devices.** A number of sophisticated devices are marketed for analyzing motor condition, particularly current harmonics, based upon electrical measurements of an operating motor. While the accuracy of these devices has not been verified, the marginal cost and labor of using these devices is small if they are already deployed for predictive maintenance uses.

Power Factor and Efficiency

- Input Power Measurements
- Line Current Measurements
- The Slip Method
- Variable Load Levels
- Determine Motor Efficiency
- Computerized Load and Efficiency Estimation Techniques

Power Factor and Efficiency



Constant Speed.

Input Power Measurements

Equation 1

$$P_i = \frac{V \times I \times PF \times \sqrt{3}}{1000}$$

Where:

P_i	= Three phase power in kW
V	= RMS voltage, mean line to line of 3 phases
I	= RMS current, mean of 3 phases
PF	= Power factor as a decimal

Input Power Measurements

Equation 2

$$P_{ir} = P_{or} \times \frac{0.7457}{e_{fl}}$$

Where:

P_{ir}	= Input power at full rated load in kW
P_{or}	= Nameplate rated horsepower
e_{fl}	= Efficiency at full rated load

Input Power Measurements

Equation 3

$$\text{Load} = \frac{P_i}{P_{ir}} \times 100\%$$

Where:

Load	= Output power as a % of rated power
P_i	= Measured three phase power in kW
P_{ir}	= Input power at full rated load in kW

Example 1: Input Power Calculation

An existing motor is identified as a 40 hp, 1,800 rpm unit with an open drip-proof enclosure. The motor is 12 years old and has not been rewound.

The electrician makes the following measurements:

Measured Values:

Vab = 467V	*Ia= 36 amps*	*PFa = 0.75*
Vbc = 473V	*Ib = 38 amps*	*PFb = 0.78*
Vca = 469V	*Ic = 37 amps*	*PFc = 0.76*

V=(467+473+469)/3=469.7 volts

I=(36+38+37)/3=37 amps

PF=(0.75+0.78+0.76)/3=0.763

V I p.f.

$$P_i = \frac{469.7 \times 37 \times 0.763 \times \sqrt{3}}{1000} = 22.97 \text{ kw}$$

The Slip Method

Equation 4

$$\text{Load} = \frac{I}{I_r} \times \frac{V}{V_r} \times 100\%$$

Where:

Load	= Output power as a % of rated power
I	= RMS current, mean of 3 phases
I_r	= Nameplate rated current
V	= RMS voltage, mean line to line of 3 phases
V_r	= Nameplate rated voltage

The Slip Method

Equation 5

$$\text{Load} = \frac{\text{Slip}}{S_s - S_r} \times 100\%$$

Where:

Load	= Output power as a % of rated power
Slip	= Synchronous speed - Measured speed in RPM
S_s	= Synchronous speed in RPM — from frequency × no. of pole.
S_r	= Nameplate full load speed

The Slip Method

Equation 6

$$\text{Load} = \frac{\text{Slip}}{S_s - S_r \times V_r/V^2} \times 100\%$$

Where:

Load	= Output power as a % of rated power
Slip	= Synchronous speed - Measured speed in RPM
S_s	= Synchronous speed in RPM
S_r	= Nameplate full load speed
V	= RMS voltage, mean line to line of 3 phases
V_r	= Nameplate rated voltage

Example 2 – Slip Load Calculation

Given:

Synchronous speed in RPM = 1,800

Nameplate full load speed = 1,750

Measured speed in RPM = 1,770

Nameplate rated horsepower = 25 HP

Determine actual output horsepower.

$$\text{Load} = \frac{1{,}800 - 1{,}770}{1{,}800 - 1{,}750} \times 100\% = 60\%$$

Actual output horsepower would be 60%x25HP=15HP

Determining Motor Efficiency

Equation 7

$$e = \frac{0.7457 \times P_{or} \times Load}{P_i}$$

Where:

e	= Efficiency as operated in %
P_{or}	= Nameplate rated horsepower
Load	= Output power as a % of rated power
P_i	= Three phase power in kW

Determining Motor Efficiency

Equation 8

$$Load = \frac{P_i \times e}{P_{or} \times 0.7457}$$

Where:

Load	= Output power as a % of rated power
P_i	= Three phase power in kW
e	= Efficiency as operated in %
P_{or}	= Nameplate rated horsepower

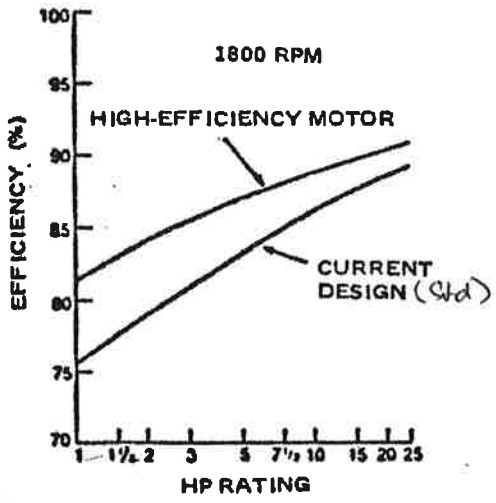
Performance and Price

- Energy-efficient motors are typically from
  2 to 6 percent more efficient than their standard motor counterparts.

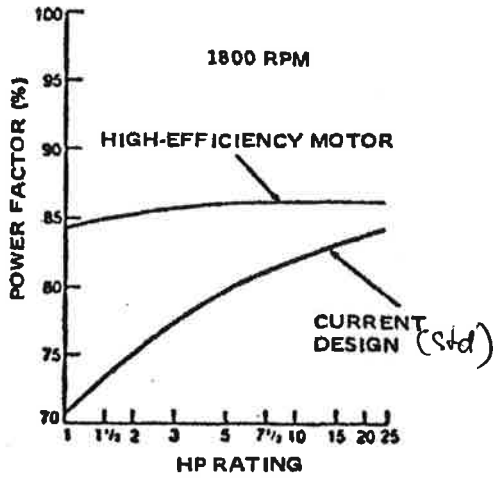
- The price premium for an energy-efficient motor is typically 15 to 30 percent above the cost of a standard motor.

Comparison between Energy Efficient and Standard Motors

Efficiency Vs. Horsepower Rating (Dripproof motors)

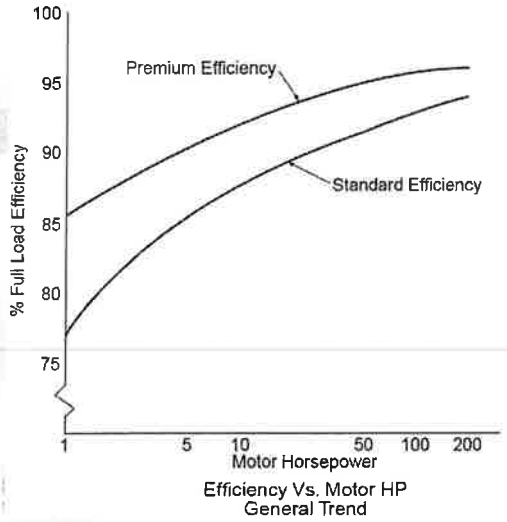


Power Factor Vs. Horsepower Rating (Dripproof motors)



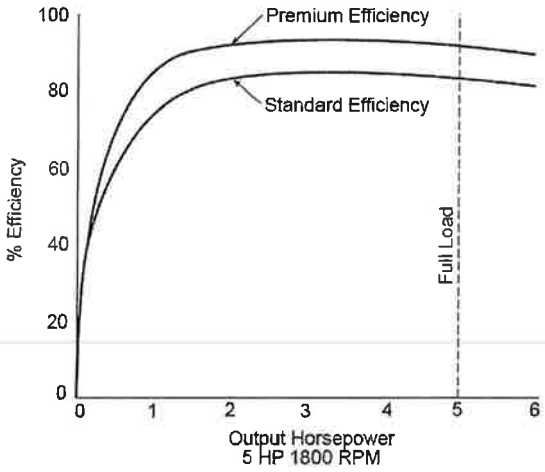
Comparison of Energy Efficient vs. Standard Motor

Efficiency vs. Horsepower



Efficiency Vs. Motor HP
General Trend

Efficiency vs. Loading Condition



Determining and Comparing Motor Efficiencies

It is difficult to accurately compare manufacturer's quoted or tested efficiencies. The following are the common definitions:

- **Average or Nominal Efficiency-**These terms are identical and refer to the average full-load efficiency value obtained through testing a sample population of the same motor model. These are the most common standards used to compare motors.

- **Guaranteed minimum or expected minimum efficiency-**All motors purchased are guaranteed to have efficiencies that equal or exceed this full-load value (Based on NEMA table)

- **Apparent efficiency** – is the product of motor power factor and minimum efficiency.

- **Calculated efficiency** - Refer to an average expected efficiency based upon a relationship between design parameters and test results.

Motor efficiency Testing Standards

No single standard efficiency testing method that is used throughout the industry. The common standard are:

- IEEE 112-1984 (US)
- IEC 34-2 (International Electrotechnical Commission) ← European.
- JEC-37 (Japanese Electrotechnical Committee)
- BS-269 (UK)
- C-390 (Canadian Standards Association)
- ANSI C50.20 (US)

The motor efficiency testing standards differ primarily in their treatment of stray load losses.

Comparison of Efficiency result from various motor Testing Standards

Efficiency Results From Various Motor Testing Standards

Standard	Full-Load Efficiency (%) 7.5 hp	20 hp
Canadian (CSA C390)	80.3	86.9
United States (IEEE-112, Test Method B)	80.3	86.9
International (EC - 34.2)	82.3	89.4
British (BS - 269)	82.3	89.4
Japanese (JEC - 37)	85.0	90.4

Energy-Efficient Motor Selection Guidelines

- Motor failure and rewind scenario
  - Rewound – severe efficiency losses
  - New energy-efficient motor
  - Standard efficient motor

Consideration on such variables as

- Rewind cost
- Expected rewind loss
- Energy efficient motor purchase price
- Annual operating hours
- Electricity price
- Simple payback

Energy-Efficient Motor Selection Guidelines

- Replacement of operable standard-efficiency motors?

  Usually it has a longer payback period >10 years. It can be effective if:

  - The standard efficiency motor has been rewound several times
  - The standard efficiency motor is oversized and under loaded

Energy-Efficient Motor Selection Guidelines

- Oversized and Under loaded Motors
  - Oversized mean motor running on partial load. It efficiency of the motor reduced, increase operating cost.
  - Undersized have a reduced life

- Why industries use oversized motors?
  - To ensure against motor failure in critical processes
  - When plant personnel do not know the actual load condition
  - To build an capability to accommodate future increases in production
  - To conservatively ensure that the unit has ample power to handle load fluctuations
  - Replace a failure motor with the next larger unit if one if one of the correct size is not available
  - When process requirements have been reduced
  - To operate under adverse conditions such as voltage imbalance

Energy-Efficient Motor Selection Guidelines

- Cost penalties associated with using an oversized motor:
  - Higher motor purchase price
  - Increased electrical supply equipment cost due to increased kVA and kVAr requirements
  - Increase energy costs due to decreased part-load efficiency
  - Power factor penalties

Selection of Efficiency Motors

Energy-efficient motors should be considered in the following instances:

- For new facilities or when modifications are made
- To existing installations or processes
- When procuring equipment packages
- Instead of rewinding failed motors
- To replace oversized and underloaded motors
- As part of an energy management or preventative
- Maintenance program
- When utility rebates am offered that make high-efficiency
- When utility conservation programs, rebates, or incentives are offered that make energy-efficient motor retrofits cost-effective

Oversized Motor Replacement Analysis

Motor Load and Operating Cost Analysis Form

Employee Name _____ Date _____

Company _____ Facility/Location _____

1. General Data

Application _____
What type of equipment the motor drives.

Energy rate _____cents/kWh

Monthly Demand Rate _____

Annual Operating Hours _____

2. Motor Nameplate Data

Make/Model _____

Serial Number _____

Phase and Hz _____

Voltage Rating _____

Horsepower Rating _____

Enclosure Type _____

Synchronous Speed _____

Frame Size _____

NEMA Torque Class _____

Service Factor Rating _____

Insulation Class _____

Temperature Rise _____

FL Amperes Rating _____

FL RPM Rating _____

3. Measured Data

Input Volts _____
By Voltmeter

Input Amps _____
By Ampmeter

Input kW _____
By Powermeter if available, otherwise calculate below

Operating Speed _____
By Tachometer

4. Calculated Values

Full Load (FL) Slip _____
[Synchronous RPM - FL RPM Rating]

Operating Slip _____
[Synchronous RPM - Operating Speed]

Load Factor _____
[Operating Slip/FL Slip]

HP output _____
[Rated HP x Load Factor]

kVA input _____
[Input Volts x Input Amps x 0.001732]

Power factor _____
[(Average kW/kVA) x 100%, or based on Figure 2, using measured Input Amps/nameplate FL Amperage]

Input kW _____
[Input Volts x Input Amps x Power Factor x 0.001732]

Annual Operating Cost _____
[Input kW x Annual Operating Hours x Energy Rate]

Annual Demand Cost (if any) _____
[Monthly Demand Rate x number of months motor operates during peak demand period]

Total Annual Operating Cost _____
[Annual Energy + Demand costs]

Power factor improvement

- Induction motor requires active power (kW) and reactive power (kVAR) to operate.
- kW – produces work and heat
- kVAR is to establishes the magnetic field within the motor to causes it to rotate
- A low power factor is indicate a possible low system electrical operating efficiency.
- Motor operate near it rated load, power factor is high
- Small loaded motors lead to low power factor
- Low power factor lead to increased in electricity bill
- Low power factor can be improved by installing external capacitors at the main plant or individual pieces of equipment
- Lower power factor correction by minimize operation of idling or light loaded motors and avoiding operation of equipment above its rated voltage.

Energy efficient motor and variable frequency drives

What is an Energy Efficient Motor?

An "energy efficient" motor, simply put, is a motor that gives you the same output strength by consuming lesser amounts of power.

How is an energy efficient motor different from a standard motor?

- Energy efficient motors are manufactured using the same frame as a standard T-frame motor, but these have:
- Higher quality and thinner steel laminations in the stator.
- More copper in the windings.
- Optimized air gap between the rotor and stator.
- Reduced fan loses.
- Closer matching tolerances.
- A greater length.

Overall motor performance

- Acceleration capabilities
- Insulation class
- Breakdown torque
- Power factor
- Efficiency
- Service factor
- Enclosure type
- Sound level
- Heating
- Speed
- Inrush current
- Start torque

Squirrel-cage induction motors torque classifications

Squirrel-cage induction motors are divided into torque classifications by the specifications in NEMA MG 1-1993

- ***Design A.*** These motors are usually designed for a specific use. They have a higher starting current and
- breakdown torque than Design B motors and have a slip of 5% or less.
- ***Design B.*** These are the general purpose motors. Slip is 5% or less.
- ***Design C.*** These motors have high starting torque with normal starting current and low slip. Slip is 5% or less.
- ***Design D.*** These motors have high slip, high starting torque, low starting current, and low full-load speed.
- Slip is about 5–8%.
- ***Design E***. These motors are general purpose motors having speed-torque-current performance equivalent to those of international standards with a minimum level established for the nominal efficiency. The starting current can be higher than that for Design B motors. Slip is 3% or less.

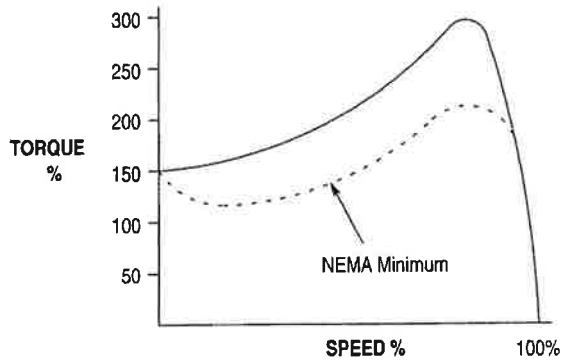
Common NEMA Standard Insulation Classes.

INSULATION CLASS	RECOMMENDED TEMPERATURE LIMIT
A	105° C (221° F)
B	130° C (275° F)
F	155° C (311° F)
H	180° C (356° F)

Δ 25°C

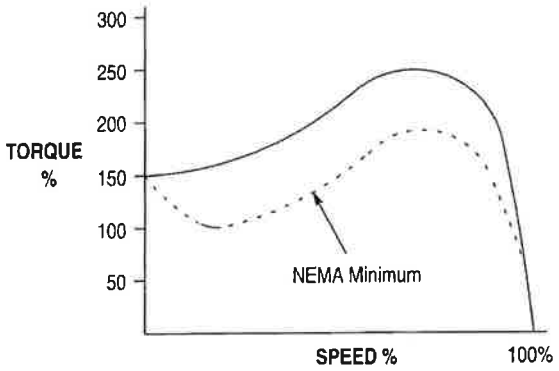
NEMA Design "A" Types

- **Design A :**
  - Motors have a low resistance,
  - Low inductance rotor producing low starting torque and high breakdown torque.
  - The low resistance characteristic causes starting current to be high.
  - It is a high efficiency design;
  - The slip is usually 3% or less.



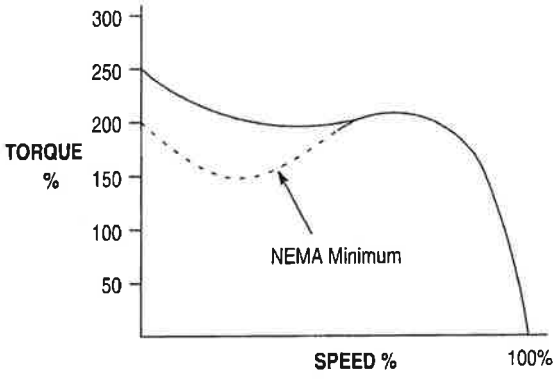
NEMA Design "B" Types

- **Design B :**
  - Motors have a higher impedance rotor producing a slightly higher starting torque and lower current draw.
  - Design B motors are a general-purpose type motor and account for the largest share of induction motors sold.
  - The slip of a Design B motor is approximately 3-5% or less.



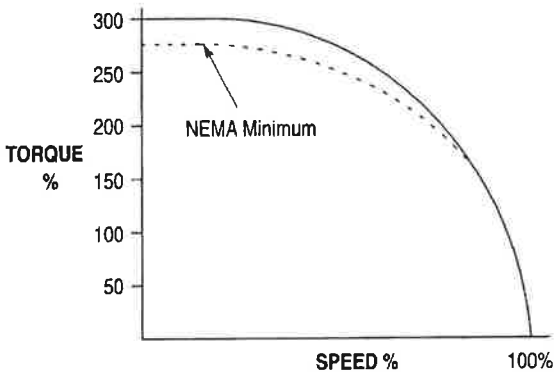
NEMA Design "C" Types

- **Design C (combined of Design A & D):**
  - Motors use a two-cage rotor design, high resistance for starting low resistance for running.
  - This creates a high starting torque with a normal starting current and low slip.
  - During starting, most of the current flows in the low inductance outer bars. As the rotor slip decreases, current flows more in the inner low resistance bars.
  - The Design C motor is usually used where breakaway loads are high at starting, but are normally run at rated full load, and are not subject to high overload demands after running speed has been reached.
  - The slip of the Design C motor is 5% or less.

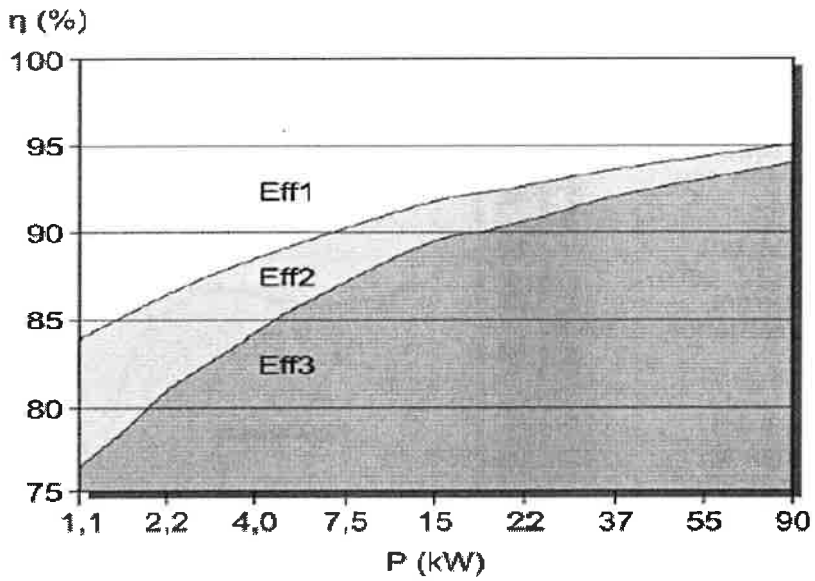


NEMA Design "D" Types

- **Design D:**
  - Motors have the highest resistance rotor creating high slip, high starting torque and low starting current.
  - Because of the high amount of slip, the speed varies dramatically with load.
  - The slip of this type motor is approximately 5 to 8%.
  - This high slip characteristic relates to a low efficiency design and a motor that runs hot.



European efficiency classification scheme



The EU has published energy efficiency categories for motors. There are three class levels: Eff1, Eff2, and Eff3, applying to low voltage two- and four-pole motors rated from 1.1 to 90 kW. The aim is to phase out production of less energy efficient machines.

Motor Insulation System/Service factor

- Standard for insulation design, temperature rating : Class A, B, F and H
- Service factor (1.0 ~1.15) – a safety margin and refers to the motor's ability to continuously deliver power beyond its nameplate rating under specified conditions. E.g.. Motor with Class F insulation, but operating within class B temperature limitations, is operating far below its maximum operating limitations. It is thus running "cooler" relative to its thermal capability.
- Premium or energy efficient motors are typically equipped with Class F insulation and rated with a 1.15 service factor.

Temperature Limitations for Insulation Classes

Service Factor	Insulation Temperature	Class B	Class F
1.0/1.15	Ambient Temperature	40°C/104°F	40°C/104°F
1.0	Allowable Temperature Rise	80°C/176°F	105°C/221°F
1.0	Operating Temperature Limitation	120°C/248°F	145°C/293°F
1.15	Allowable Temperature Rise	90°c/194°F	115°C/239°F
1.15	Operating Temperature Limitation	130°C/266°F	155°C/311°F

Enclosures - NEMA vs. IEC

Enclosures

Nema Designations

Nema Type 1 – General Purpose Enclosure is designed for indoor use, primarily to provide a degree of protection against contact with the enclosed equipment.

Nema Type 3 – Rain Tight Enclosure is designed for outdoor use primarily to provide a degree of protection against windblown dust, rain and sleet; undamaged by the formation of ice.

Nema Type 4 - Water Tight Enclosure is designed for outdoor use primarily to provide a degree of protection against windblown dust and rain, splashing water, and hose directed water; undamaged by the formation of ice.

Nema Type 12 – Industrial Enclosure is designed for indoor use primarily to provide a degree of protection against dust, falling dirt, and dripping non-corrosive liquids.

IEC Designations

Characteristic letters **IP 2 0**

The 1st characteristic numeral (2) identifies the protection against solid objects.

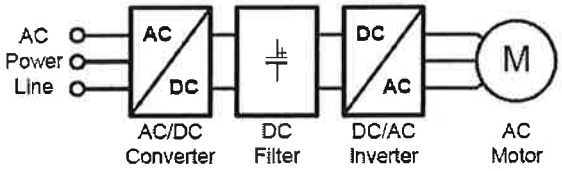
The 2nd characteristic numeral (0) identifies the protection against liquids.

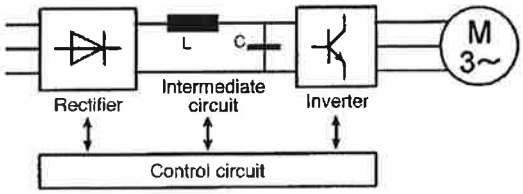
First Numeral	Second Numeral
0 – No protection	0 – No protection
1 – Protected against solid objects up to 50 mm from accidental touch	1 – Protected against vertically falling drops of water
2 – Protected against solid objects up to 12 mm from accidental touch	2 – Protected against direct sprays of water up to 15 degrees from vertical
3 – Protected against solid objects up to 2.5 mm from accidental touch	3 – Protected against sprays up to 60 degrees from vertical
4 – Protected against solid objects up to 1 mm from accidental touch	4 – Protected against water sprayed from all directions
5 – Protected against dust	5 – Protected against low pressure jets of water from all directions
6 – Totally protected against dust	6 – Protected against strong pressure jets of water from all directions
	7 – Protected against the effects of immersion between 15cm and 1cm

IP20 – General Purpose Enclosure is designed for indoor use, primarily to provide a degree of protection against contact with the enclosed equipment (objects up to 12mm).

Variable Speed Drives

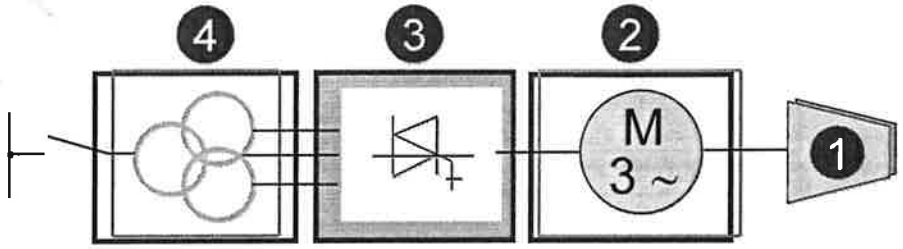
- is an electronic device, which controls the speed of induction motors by changing frequency and voltage according to load and desired motor speed





What's a VSD System?

- The **application (1)**, driven by a drive system, can be a pump, a compressor, an extruder ...
- A **motor (2)** is needed to drive it.
- The most efficient way to control the process is to control the speed, and the most efficient way to control the speed is to use an electric variable speed drive – a **frequency converter (3)**.
- A **transformer (4)** is usually necessary to adapt to the network and to isolate the network and drive or to relieve the motor from common mode voltages.



AC Variable Speed Drive

- A VSD controls the speed, torque or power on the shaft of an electric motor by converting the fixed voltage, fixed frequency at the network, into a variable voltage, variable frequency on the output to the motor.
- In this way the drive can control the variables of a process, such as flow, by controlling the speed of a pump
- Variable speed drives can save large amounts of energy and money in applications where demand varies. They enable users to minimize their equipment life cycle cost and improve performance.
- The energy efficiency of many motor installations can be dramatically improved with variable speed drives which ensure that the motors only run at the speeds and times required. Drives are inexpensive and easy to install, but most motors are nevertheless left running at a single speed for long periods of time, often without any working load.

Why Use Variable Speed Drives

Energy saving:

Energy is saved if the motor runs at a speed corresponding to the load requirement at that moment. This applies to pumps and fans in particular. Current consumption is also reduced during low speed and high torque conditions.

Process optimization:

Adapting the speed to the production process results in several advantages, for example: efficient production and optimum use of systems. The speed can be adapted optimally to the external conditions detected by sensors mounted on the process itself.

Reducing Mechanical Stress:

The number of starts and stops can be increased compared to DOL operation. This means that an unnecessarily high stress on the machine mechanics can be reduced. (Improved belt wear etc)

Low maintenance requirement:

AC drives require only periodic maintenance (fans, filters, connections) and since they are usually digital, require only occasional adjustment.

Improved working surroundings:

A conveyor belt's speed can be adapted to the working speed, so slow starts and stops, which prevent the products on the conveyor belt from falling over, can be avoided.

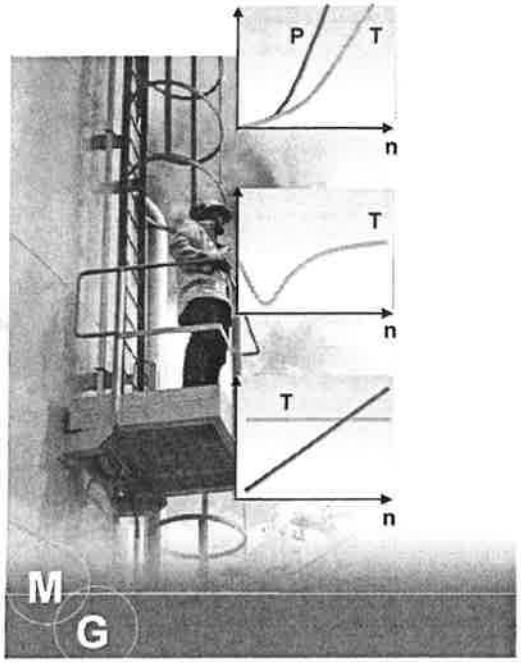
Why variable speed drives?

- 60-65% of industrial electrical energy is consumed by electric motors
- For each 1USD spent to purchase a motor, 100USD are spent for energy cost during its lifetime
- Today, only 5% of these motors are controlled by variable speed drives
- 30% of existing motors can be retrofitted with variable speed drives

AC Variable Speed Drive application

- The potential savings are significant – a pump or a fan running at 80% speed only uses slightly more than 50% of the energy used by one running at full speed.
- The problem is exacerbated by the fact that many motors are oversized, using more energy than the application actually needs. This is because motors are only available with a certain number of fixed speeds. Users tend to get the next bigger sized motor relative to the requirement and then throttle the output, for instance by using a valve to reduce the water flow in a pumping application. By reducing the speed of the motor, a drive can help to ensure that a pump, for instance, uses no more energy than necessary to achieve the required flow.
- In addition to the energy savings, other benefits include accurate control and less mechanical wear, reducing maintenance and extending the lifetime expectancy of the system. Payback is often less than six months on the basis of energy savings alone.

Typical applications



- Pumps
  - Quadratic load
- Compressor
  - Quadratic or constant torque
- Extruders
  - Constant torque

Using Variable Frequency Drives

- **Common Applications**
  - Fluid Systems
  - Material Handling Systems
  - Machining and Fabrication
- **Alternatives**
  - Mechanical
  - Electrical
- **Competitive Advantages**
- **Misapplications**
  - Bearing Currents
  - Power Quality Effects

Variable Speed Drives Component

Rectifier:

- The rectifier is connected to the supply network and generates a DC voltage supply which feeds the main DC link elements.

Intermediate circuit:

- The intermediate circuit stores and smoothes the pulsating direct voltage by using capacitors and inductors

Inverter:

- Using the DC derived from (A) and (B), the inverter synthesises a variable frequency and voltage with the required frequency and supply which can be varied to control speed/torque of a 3 phase induction motor.

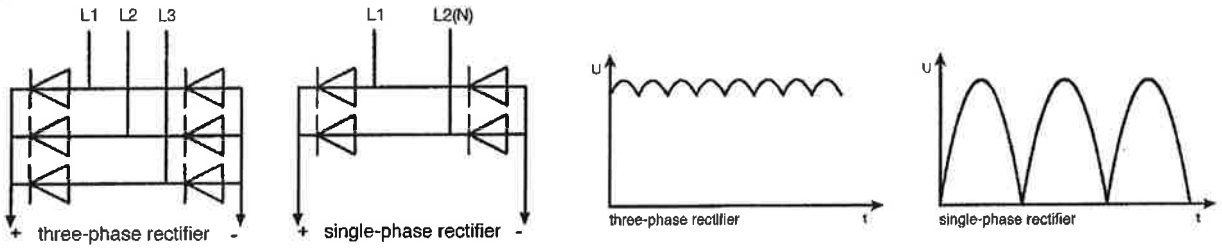
Control circuit:

- The control circuit is responsible for the operation, monitoring and protection of the entire AC drive. It is here that all input signals to the drive are acted upon to generate the most appropriate way to control the Inverter itself.

VSD Components (Input)

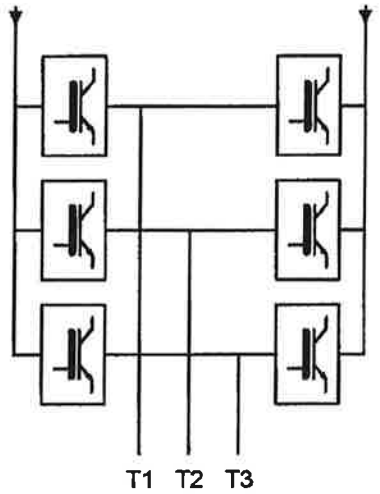
Main Rectifier Circuits

Main Rectifier Waveform



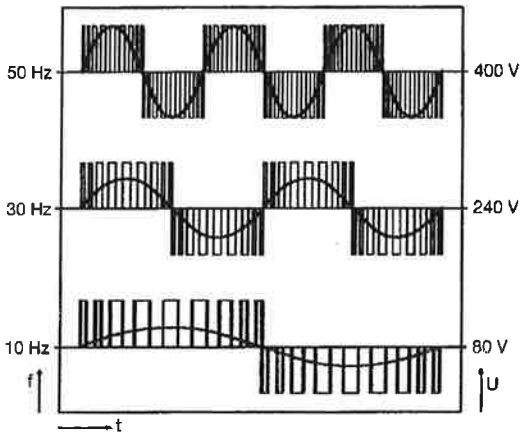
VSD Component (Output)

Inverter



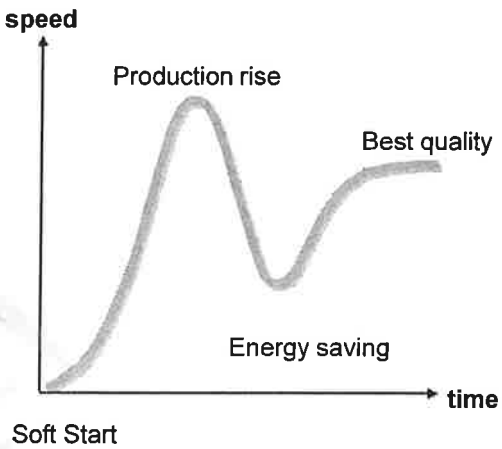
IGBT-Inverter

Drives Output Waveform



Pulse width modulation

Benefits of VSD system control



- Energy savings
- Improved product quality through better process control
- Reduced process equipment wear and longer lifetime of equipment
- Soft start and stop reduce waste and save raw material
- Noise reduction
- Improved process efficiency

Energy-Efficient Motors

- What is an energy-efficient motor?
- How is an energy-efficient motor different than a standard motor?
- Are all new motors energy-efficient motors?
- Are energy-efficient single-phase motors available?
- Do energy-efficient motors require more maintenance?
- Should I rewind my standard efficient motor or purchase an energy-efficient motor?
- Can a standard motor be rewound as an energy-efficient motor?
- How reliable are energy-efficient motors?
- What is the power factor of an energy-efficient motor? What are NEMA, IEC 34.2 and JEC 37?
- I have heard different types of efficiencies quoted. What are they?
- How much do energy-efficient motors cost?
- What is the payback period for selecting a energy-efficient versus standard efficient motors?

Fan Systems

Fan applications:

- Used for cooling, heating and ventilation removal of contaminants etc

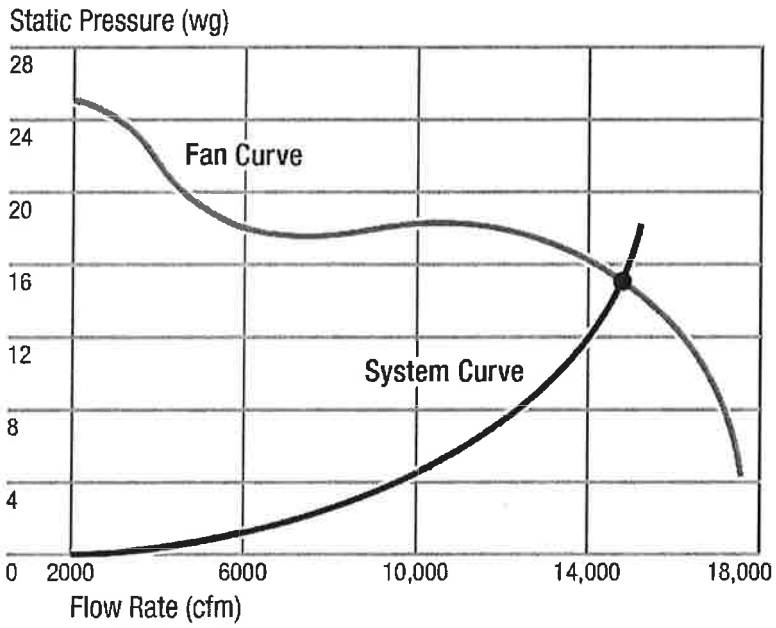
Type of Fans:

a) Centrifugal Fans:
   1. backward curved
   2. forward curved
   3. radial blade and
   4. tubular centrifugal

   Where 1 & 2 are commonly used fans types in air distribution systems

b) Axial -Flow Fans

Typical Fan and System Curves



Comparison of Fans Performance

Fan Type	Air flow	Pressure	Efficiency	Application
Axial flow	High	Low	60-80%	High air volumes or no static pressure
Centrifugal – Forward Curves	High	Low	50-70%	Operate at low speed and high air volumes @ low static pressure
Centrifugal – Backward Curves	Low	High	65-85%	High static pressure application

Fans System

- **Sizing of Fans and Fan Systems**
  - Rated capacity based on pressure and flow rate
  - Both parameters are dependence to each others
- **System Curve**
  - Parabolic in shape, square of the air flow
  - Plot of the system resistance @ different volumes of air flow
  - System resistance of a ducting system due to all pressure losses such as fittings, ducting, dampers and various equipment

Fans System Characteristic

- Fans are rated based on flow rate and pressure head
- Pressure developed by fans is used to overcome resistances in the system
- Pressure losses are proportional to square of air flow rate.
- **Note that when the flow and pressure laws are combined, that the result is a formula that matches the system curve formula :**

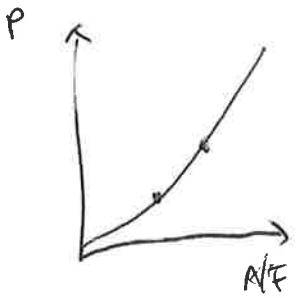
  $P = K \times (CFM)^2$.

System Characteristics

Example

The air flow rate and total pressure developed by the fan in a ventilation system are 10000 CMH and 250 Pa.

Plot the system curve and estimate the total system pressure if the air flow is increased to 12000 CMH



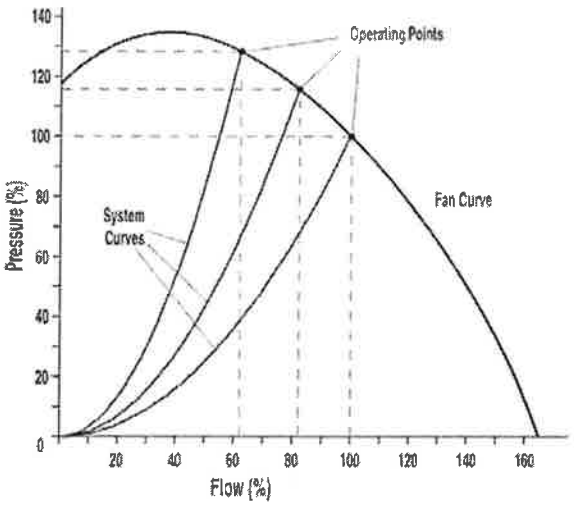
$$\frac{P_2}{P_1} = \left(\frac{cfm_2}{cfm_1}\right)^2$$

$$\frac{P_2}{250} = \left(\frac{12000}{10000}\right)^2$$

$$P_2 = 360 \text{ Pa.}$$

Fan Selection

- **Fan Curve** - The relationship between the flow and pressure developed by a fan
- Fan are selected so that the fan curve intersects the system curve at the desired **operating point**



Fans Configuration

Fans can be installed to operate as a single fan or multiple fan systems in:

a) **Series** – total air remains the same as the air flow for one fan but the pressure developed is the sum of the pressure developed by the individual fans

b) **Parallel** – the pressure developed by the fans are the same as the pressure developed by one fan while the total air flow is the sum of the air flow rates for the individual fans

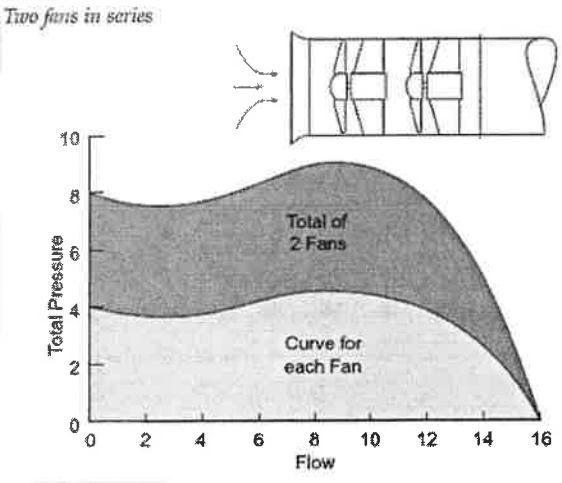
Fan Systems

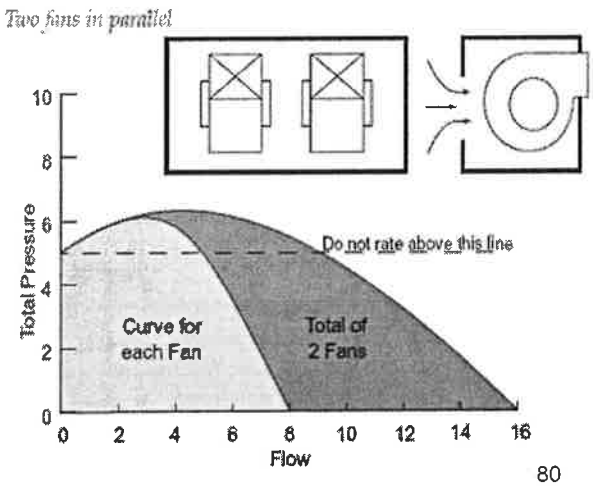
Fans in Series

- Air flow rate is the same
- Total pressure is the sum of Fan 1 and Fan 2

Fans in Parallel

- Air flow rate is proportional to the no. of installed fans
- System pressure is the same





Fan Power

- Power consumed by fans is related to the product of the volume flow and pressure developed

$$\text{Fan impeller power} \propto \frac{\text{Air flow rate x Pressure developed}}{\text{Efficiency}}$$

In SI units:

$$\text{Fan impeller power (kW)} = \frac{\text{Flow rate (m}^3\text{/s) x Pressure developed (N/m}^2\text{ or Pa)}}{1000 \text{ x Efficiency}}$$

In Imperial units:

$$\text{Fan brake horsepower} = \frac{\text{Flow rate (cfm) x Pressure difference (in. water)}}{6350 \text{ x Efficiency}}$$

Fan Affinity Laws

	Change in Speed (RPM)	Change in impeller diameter (D)
Flow (CFM)	$CFM_2 = CFM_1\left(\frac{RPM_2}{RPM_1}\right)$	$CFM_2 = CFM_1\left(\frac{D_2}{D_1}\right)^3$
Pressure (P)	$P_2 = P_1\left(\frac{RPM_2}{RPM_1}\right)^2$	$P_2 = P_1\left(\frac{D_2}{D_1}\right)^2$
Power (HP)	$HP_2 = HP_1\left(\frac{RPM_2}{RPM_1}\right)^3$	$HP_2 = HP_1\left(\frac{D_2}{D_1}\right)^5$

Fan Systems

Example:

A fan delivers 5 m^3/s @ 1400 rpm and consumes 20 kW. Calculate the new air flow rate and power consumption if the fan speed is reduced to 1200 rpm.

$CFM_2/CFM_1=RPM_2/RPM_1$

$CFM_2=(1200/1400)*5 = 4.3\ m^3/s$

$HP_2/HP_1=(RPM2/RPM1)^3$

$HP_2=(1200/1400)^3*20 = 12.6$ kW

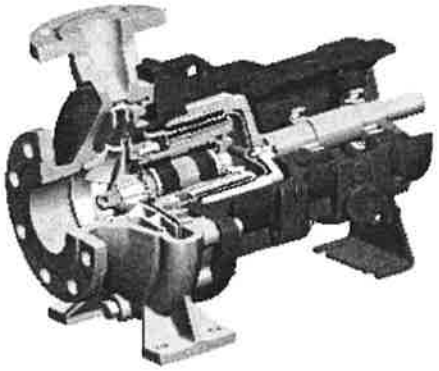
Types of Fan System Losses

1. Friction losses – due to fluid viscous effects and from fluid mechanics
2. Dynamic losses- due to change in flow direction caused by fittings such as elbows, bends and tees and changes in area OR velocity caused by fittings like diverging sections, contracting sections, openings and dampers etc
3. Fan discharge and inlet losses
4. Filter losses
5. Coil losses

Pumping Systems

Various pumping systems are used in buildings:

- Chilled Water
- Condenser Water
- Cold Water
- Hot Water



Pump Systems Characteristics

- Pumps are related based on flow rate and pressure head
- Pressure developed by pumps are used to overcome resistances in the system
- Pressure losses are proportional to square of flow rate

Pump Systems Characteristics

Example

A cooling water pump is used to remove heat from a heat exchanger by circulating 4000 CMH of water through a cooling tower.

The pressure across the pump discharge and suction is measured to be 0.4 bar and 2.5 bar, when the pump is switched-off and on respectively. Plot the curve and estimate the total system pressure if the water flow is reduced to 3500 CMH.

$$\frac{P_2}{P_1} = \left(\frac{cfm_2}{cfm_1}\right)^2$$

$$\frac{P_2}{2.5} = \left(\frac{3500}{4000}\right)^2$$

$$P_2 = 1.9 \text{ bar}$$

Losses in Pumping Systems

1. Friction losses

- Pipes size
- Pipe length
- Pipe material

2. Dynamic losses

- Change in flow rate
- Change in flow direction
- Obstruction

Pumps Configuration

Pump in Series

- Fluid flow rate will remain the same
- Total pressure developed will be the sum of the pressure developed by the individual pumps

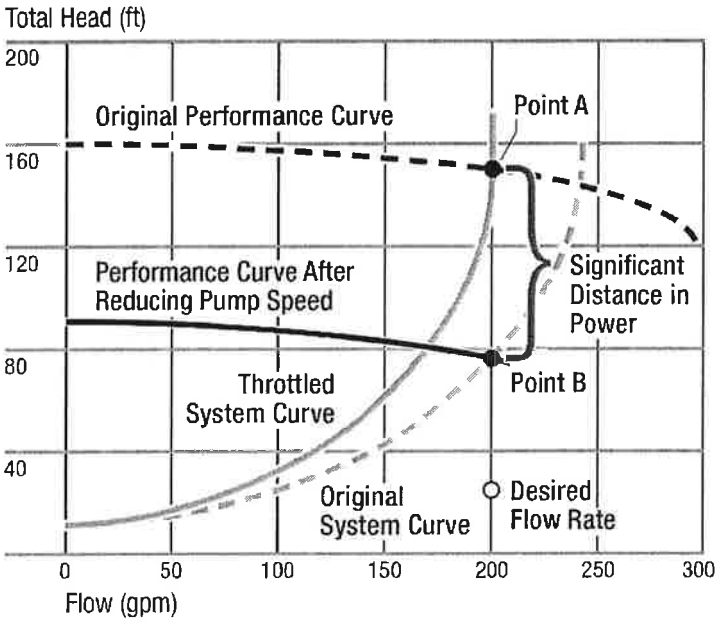
Pump in Parallel

- System pressure will remain same
- Fluid flow rate will be proportional to the number of pumps

Pump Affinity Laws

	Change in Speed (RPM)	Change in impeller diameter (D)
Flow (CFM)	$CFM_2 = CFM_1\left(\frac{RPM_2}{RPM_1}\right)$	$CFM_2 = CFM_1\left(\frac{D_2}{D_1}\right)$
Pressure (P)	$P_2 = P_1\left(\frac{RPM_2}{RPM_1}\right)^2$	$P_2 = P_1\left(\frac{D_2}{D_1}\right)^2$
Power (HP)	$HP_2 = HP_1\left(\frac{RPM_2}{RPM_1}\right)^3$	$HP_2 = HP_1\left(\frac{D_2}{D_1}\right)^3$

Effect of Speed reduction on the power used by pump



Pump Affinity Laws

Example

A pump delivers 120 l/s at 1400 rpm and consumed 55kW. If the pump speed is reduced to 1120 rpm, calculate the new flow rate and power consumption.

$$cfm_2 = cfm_1 \left(\frac{RPM_2}{RPM_1}\right) \qquad \frac{P_2}{120} = \frac{1120}{1400} \qquad P_2 = 96\ l/s$$

$$HP_2 = HP_1 \left(\frac{RPM_2}{RPM_1}\right)^3 \qquad \frac{HP_2}{55} = \left(\frac{1120}{1400}\right)^3 \qquad HP_2 = 28\ kW$$

Pump Power

$$\text{Pump power} \propto \frac{\text{Liquid flow rate x Pressure difference}}{\text{Efficiency}}$$

$$\text{Pump impeller power (kW)} = \frac{\text{Flow rate } (m^3/s) \text{ x Pressure difference } (N/m^2)}{1000 \text{ x Efficiency}}$$

$$\text{Pump brake horsepower} = \frac{\text{Flow rate (Usgpm) x Pressure difference (ft. water)}}{3960 \text{ x Efficiency}}$$

Q & A

Building vertical transportation systems

Introduction

- Energy efficient transportation systems for buildings.

- Lifts and escalators (vertical transportation) consumption is likely to be around 5% - 15% of total energy costs, depending on the layout and use of the building.

LIFTS SYSTEM

The following issues should be taken into account when designing energy efficient vertical transportation systems:

- Aim to group lifts together in order to group their controls as this may help minimise the number of journeys and, hence, reduce energy consumption.
- Locate lifts as appropriate and locate stairs before lifts. If passengers pass a well signposted staircase on the way to the lift, the demand for the lift may be less.
- Select the lift control strategy to minimise the number of journeys as this may reduce energy consumption.
- Select lift speeds that are appropriate to the task, e.g. slower speeds for goods lifts.
- Select an energy efficient drive for the lift and consider regeneration systems where the electricity can be used on-sit.

Energy consumption of lifts is affected by:

- rated speed
- rated capacity
- travel distance
- duty cycle (i.e. starts per hour, average run distance, load variation, direction when loaded, idle time etc.)
- drive system
- method of drive and speed control
- system losses (e.g. machinery inefficiencies, controller power consumption)

Measured average power consumption of passenger lift motors is shown in Table 11.6(5).

LIFTS SYSTEM

Energy efficiency improvement

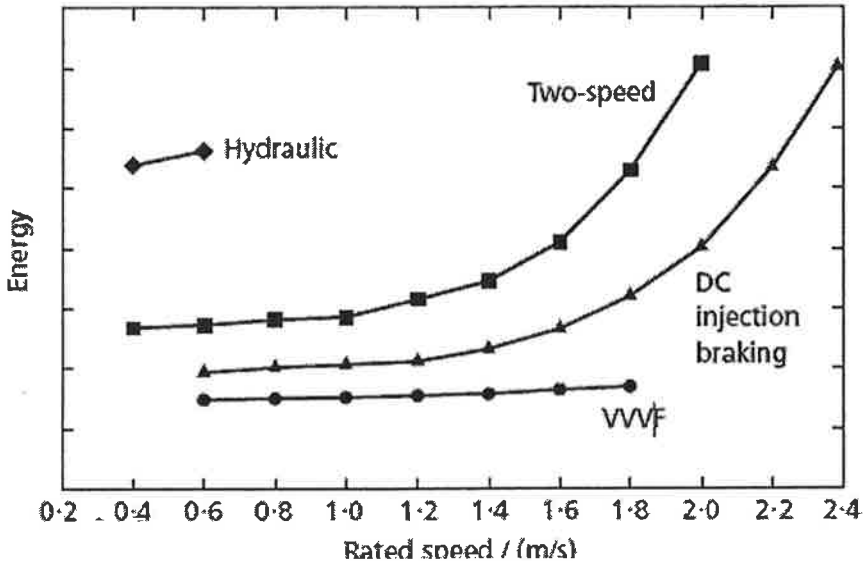
- LED lighting in the lift car
- Motor drives are normally of the variable voltage, variable frequency (VVVF) type
- Regenerative drives have high levels of energy efficiency and recover energy from the out-of-balance condition by regeneration of power back into the mains electricity supply

Points should be considered when designing energy efficient vertical transportation systems:

- Group lifts together in order to minimise the number of journeys by collecting passengers to travel together.
- Locate lifts in the most appropriate positions and locate stairs before lifts. If passengers pass a well sign posted staircase on the way to the lift, the demand for the lift may be less.
- Review the traffic patterns and consider the suitability of the lift traffic controls to the demand. Select the lift control strategy to minimise the number of journeys.

- Where possible, designers should aim to minimise transportation requirements through good building layout during the concept design stage.
- The number and type of lifts installed in a building is determined by the traffic requirements of the building occupants.
- Energy cannot sensibly be saved by reducing the number of lifts installed, as this action may not provide a sufficient transportation facility in the building.
- Counterbalancing ratios down to 40% are used and when employed with modern drive technology lead to the installation of smaller motors.
- Control systems, such as 'hall call allocation' ('destination control') can reduce energy use by optimising the use of the lifts. Destination control uses a keypad where passengers register their destinations before entering the lift car. The system directs the passenger to an individual car, rather than all the passengers boarding the next car to arrive.
- Increased energy efficiency can often involve higher initial capital cost; this may be recovered through energy savings and, therefore, each application warrants a full cost analysis.

Energy consumption of various types of lift drive



Other considerations

- Select lift speeds that are appropriate to the task, e.g. slower speeds for goods lifts.
- Select an energy efficient drive for the lift and consider regeneration systems where the energy can be used on site.
- In some multiple lift installations, it may be advantageous to omit the parking feature, whereby idle lifts are directed to specific floors.
- Consider the possibility of shutting-down some lifts at the end of the working day, when they are idle. This avoids more lifts being in service than are required and eliminates the controller standby consumption.
- Consider reducing car lighting and ventilation, when passengers are not being carried.

Regenerative lift systems

Drive type	Speed / m·s^{-1}	Number of passengers									
		8		10		13		16		21	
		Motor rating / kW	Average power / kW	Motor rating / kW	Average power / kW	Motor rating / kW	Average power / kW	Motor rating / kW	Average power / kW	Motor rating / kW	Average power / kW
Geared variable voltage	1.0	10	2.4	10	2.4	12.4	10	12	2.9	15	3.6
	1.6	15	3.6	15	3.6	15	13.6	17.6	4.2	22	5.3
Geared variable frequency	1.0	15.5	1.0	17.5	1.3	19.5	11.6	11	1.8	15	2.4
	1.6	19.5	1.6	11	1.8	13	12.2	18.5	3.0	22	3.6
Gearless static direct drive	2.5	—	—	—	—	—	13.8	—	4.2	—	5.2
	4.0	—	—	—	—	—	16.7	—	7.6	—	8.6

Regenerative lift systems

- Lifts need to dissipate energy from the system, either as waste heat into banks of resistors, or by regeneration.
- Whether the energy can be regenerated and the mechanism for achieving it depends on the type of drive.
- Regenerating lift systems return the energy back to the supply through the meter.

Escalators and moving walks

- Most escalators, and moving walks operate continuously and require constant speed, but widely varying torque.
- Their motors generally run at the same speed whether they are fully or partially loaded. Factors affecting escalator energy consumption are:
  - rise
  - mechanical design
  - number of passengers
  - speed
  - step width
  - direction of travel
  - whether passengers walk or remain stationary.

Factors should be considered in designing

- Stop some units, when convenient, after peak periods (tidal flow).
- Stop some units, when convenient, after normal working hours.
- Use automatic start-up switches, or programme multiple escalators, to ensure they only operate when there is a demand.
- Use variable speed escalators and moving walks.
- High efficiency motors and 'soft start' are now in common use on passenger conveyors, escalators and baggage handling systems.

Examples of energy consumption for escalators

Rise / m	Hours run / h	Passengers per hour	Daily energy consumption / kW·h	
			Up	Down
3	8	1000	30.0	27.6
		5000	34.9	22.7
	10	1000	37.2	34.8
		5000	42.1	29.9
	12	1000	44.4	42.0
		5000	49.3	37.1
6	8	1000	43.2	40.8
		5000	48.1	35.9
	10	1000	53.7	51.3
		5000	58.6	46.4
	12	1000	64.2	62.8
		5000	69.1	56.9

UNINTERRUPTIBLE POWER SUPPLY (UPS)

Two major contributors to UPS inefficiency:

a. the inherent losses of the UPS modules themselves

b. how the system is implemented (i.e. right-sizing, redundancy).

Oftentimes, when specifying UPS systems, the only efficiency value considered is the best case value published by manufacturers.

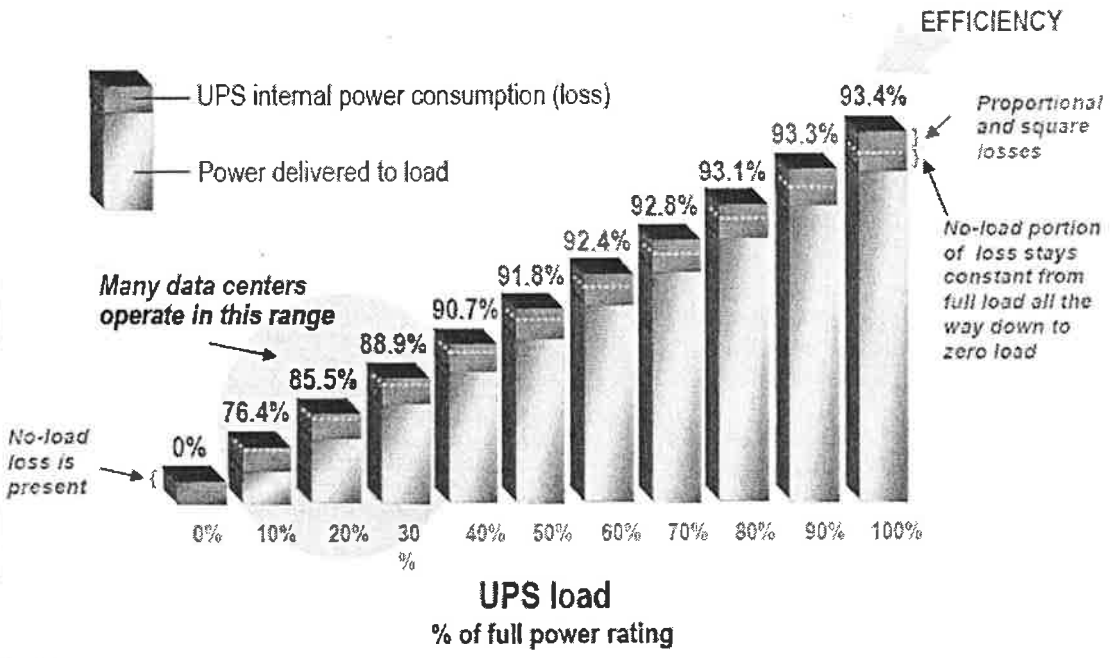
Three factors to improve the efficiency of large UPS:

a. **Technology** - Switching technology: IGBTs replace SCRs

b. **Topology** - Double conversion on-line and Delta conversion on-line (higher efficiency)

c. **Modularity** - Allows users to size the UPS system as closely to the load as practicable

Loading vs efficiency



Type of Losses in UPS

Three types of UPS losses:

a. no-load losses
b. proportional losses
c. square-law losses.

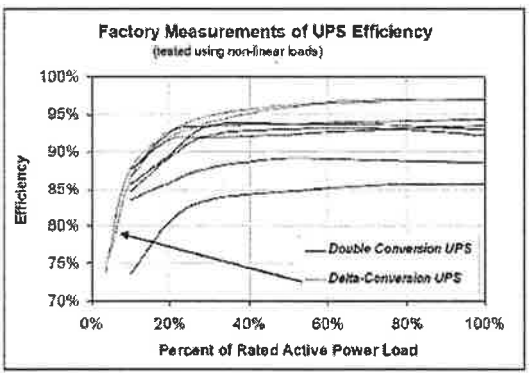
- **No-load losses** - at 0% load, all the input power is used by the UPS, hence the name "no-load" losses. These losses are independent of load and are attributed to powering such things as transformers, capacitors, logic boards, and communication cards. No-load losses can represent over 40% of all UPS losses and are by far the largest opportunity for improving UPS efficiency.

- **Proportional losses** - as more load is added to a UPS, a larger amount of power must be "processed" by various components in its power path. For example, the switching losses from transistors, and the resistance losses from capacitors and inductors, all add to proportional losses.

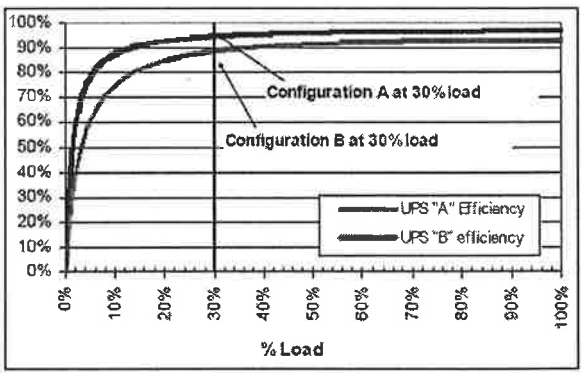
- **Square-law losses** - as more load is added to a UPS, the electrical current running through its components increases. This causes losses in the UPS with the square of the current sometimes referred to as "I-squared R" losses. The power losses dissipated in the form of heat are proportional to the square of the current. Square-law losses become significant (1-4%) at higher UPS loads.

UPS Efficiency

Factory measurement of UPS efficiency



Efficiency curves for delta conversion UPS "A" and double conversion UPS "B"



Common mistakes made in specifying UPS systems

Reason	Flaw
Published UPS efficiencies are almost always quoted at 100% load under the most favorable conditions leading to nearly identical efficiencies between different UPSs.	Quoted efficiencies should only be considered when the UPS will be loaded greater than 80% on day one. Otherwise, the efficiency at the lower load should be used for UPS specification. Furthermore, manufacturers often exclude input filters that decrease quoted efficiencies by 0.5-1%.
When a UPS is loaded above 80%, the electrical cost of UPS losses represents a small percentage compared to the cost of powering the IT load.	Although this is true, the actual dollar savings between one UPS and another can nevertheless be quite large.
The published efficiencies for the UPSs being compared are used to calculate electrical losses for all load scenarios resulting in similar costs.	Although efficiency appears constant above 30% load, it does drop slightly and drops significantly below a 20-30% load level. Furthermore, a small difference in efficiency translates into a larger than expected energy cost difference.
Cost calculations are performed on an annual basis resulting in minor costs.	Seemingly small annual costs are off by a factor of 10. Cost calculations should assume the life of the data center which is typically 10 years.

METERING AND MONITORING
Metering Coverage

1. In tenanted areas, it is likely that regulatory criteria will determine the requirements for sub-metering for billing purposes. In addition, for energy purposes metering should be provided for electricity for areas above 500m2, together with heating and cooling provision where appropriate.

2. At least 90% of each service by end-use; or so that at least 90% of the estimated annual energy consumption of each fuel can be assigned to the relevant end-use function.

3. All major items of equipment.

Metering Coverage

4. The output to individual contribution and performance can be monitored, which will aid the process of optimising performance.

5. District heating and cooling distribution.

6. Electric humidifiers, above about 10kW.

7. Dedicated lighting distribution boards and lighting controllers.

8. Particular usages that might need to be subtracted so that consumption in other areas can be evaluated in relation to relevant benchmarks.

9. For areas above 1000m2, automatic reading and data collection.

Coverage for particular buildings and systems

- Data processing and ICT systems, such as data centres, main and secondary equipment rooms, including loads supported by UPS systems;
- Small power systems, specifically in areas where particular attention is merited to monitor the pattern of usage to help control energy consumption;
- Specialist lighting where the function is beyond general illumination and is of relatively higher power density, such as in retail and display areas;
- Lighting management systems, logging of the dimming levels and the running hours to allow calculation of consumed energy related to the installed load;
- External lighting, particularly for car parks and floodlighting;
- All catering installations.

Coverage for particular buildings and systems

It is worth considering sub-metering of separate sections of a catering facility or large items of equipment with high energy usage

- Other process loads related to the business function;
- All significant load centres, switchgear and distribution boards;
- Other identifiable services or functions with the potential for high energy usage without management intervention.

Metering types

- The type of metering should be selected to suit the most appropriate usage of the data, and this will often require a mixture of manual reading meters and automatic meters.

- Automatic meters can have three main types of output data: pulsed output, typically 0–10V; analogue output, typically 4–20mA; or a communications output that can be used with open protocol systems.

The facilities should be planned so that output data is in a form that can be connected to a BMS, or to another collection system. This information can then be used for the automatic monitoring and targeting of energy data.

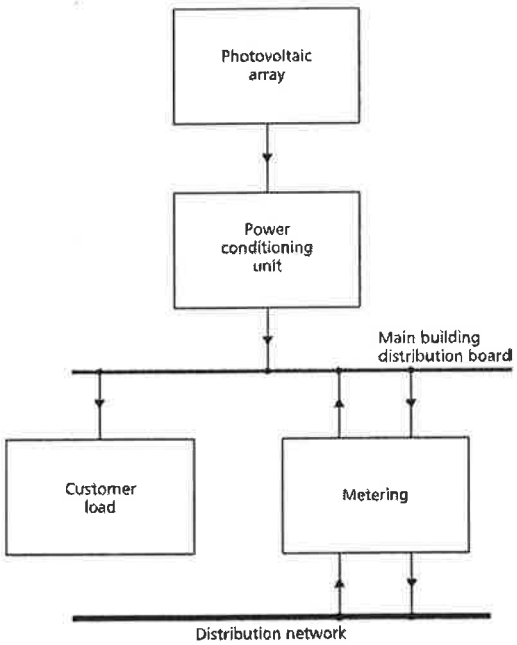


RENEWABLE ELECTRICITY GENERATION

The main renewable technologies for electricity generation for buildings – Photovoltaics system

- Consideration with location - information on the average accumulated radiation over a period of time is required to determine the potential viability of PV generation.
- A PV or solar cell is a large area semiconductor that uses the 'photovoltaic effect' to absorb the energy of the sun and cause current to flow between two oppositely charged semiconductor layers.
- Cell efficiencies are about 13–17% for monocrystalline cells, and about 12–15% for polycrystalline cells, with module efficiencies a little lower.
- The semiconductor technologies are continually changing and this is a major area of research, particularly related to new thin film devices.

Block diagram of a grid-connected PV system



Photovoltaics (PVs) System consideration

- The inverters will operate at their rated power for just a few hours each year. For most of the time, they will be operating at part-load, so it is important for the inverter to maintain good efficiency levels for low loads.
- Inverters should not be oversized; should have minimal losses; and should be switched off during hours of darkness.
- The majority of inverters used for PVs generally have an efficiency of about 90%, for an inverter with about 1kW rating, and this efficiency is maintained even down to loads of about 10% of the inverter rating.
- Higher rated inverters can have an efficiency of up to 96–97%.
- The lengths of d.c. and a.c. cabling should be kept short to limit distribution losses.

Other losses and consideration

- A system might have losses of about 15–20% for these aspects.
- There will be additional losses external to the array due to the inverter, transformer (if required) and distribution cabling.

Note the figures for losses for an example application :

- Multiplier to account for losses from cables: 0.98
- Efficiency of inverter: 0.85