ENERGY EFFICIENCY IN MOTORS AND PUMPS

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At NCR Chamber of Commerce

Gurgaon, May5,2007

WHY ENERGY CONSERVATION?

- ENERGY SECURITY- NATIONAL POLICY
- DEPLETING OIL- MAY LAST 50 YRS
- INCREASING DEMAND
- PROVIDE QUALITY OF LIFE
- SUSTAINABLE DEVELOPMENT
- ENVIRONMENT ISSUES
- POSTPONE ZERO AVAILABILITY DATE OF ENERGY SOURCES
- FOR FUTURE GENERATION

MAJOR SECTORS

- DOMESTIC & COMMERCIAL PREMISES
- INDUSTRY
- AGRICULTURE & IRRIGATION
- TRACTION & TRANSPORTATION
- TRANSMISSION SYSTEMS
- DEFENCE & SECURITY
- UTILITIES- WATER ,GAS, PHONES
- STANDBY/ DECENTRALIZED POWER

ELECTRICITY USED FOR…

- MOTION (MOTORS CONSUME 70%)
- LIGHTING
- HVAC (HEATING, VENT. AIR COND.)
- PROCESSES
- POWER MANAGEMENT
- IT EQUIPMENT

ENERGY AUDIT

NEW NEED

MASUREMENTS- ELECTRICAL

- **VOLTAGE**
- **CURRENT**
- **FREQUENCY**
- **POWER**
- **ENERGY**
- **WAVEFORM, HARMINICS, THD**
- **(USE CLAMP ON METERS, POWER ANALYSERS)**

DATA

- CREDIBILITY
- ACCURACY
- DEFINITION OF DATA CRUCIAL
- WHAT DATA AVAILABLE? ARE THERY RELIABLE
- NEW INSTRUMENTS TO BE INSTALLED WITHOUT DISTURBING THE PROCESS
- INSTRUMENTATION & PERSONNEL REQUIRED

TYPICAL DATA REQUIRED

- PROCESS FLOWSHEETS WITH POINTS OF INSTRUMENTATION
- HISTORICAL ENERGY USE & PRODUCTION DATA
- NAME PLATE DATA OF ENERGY USING EQUIPMENT
- DIMENTIONAL DATA
- PRODUCTION DATA
- EQUIP. OPERATING PROFILE
- FUEL & ELEC. COSTS
- GUSSTIMATES OF INCOMPLETE INFO.

Energy Audit Instruments

 	**Electrical Measuring Instruments:** These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kvar, Amps and Volts. In addition some of these instruments also measure harmonics. These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.
	**Combustion analyzer:** This instrument has in-built chemical cells which measure various gases such as CO_2, CO, NO_X, SO_X etc
	**Fuel Efficiency Monitor:** This measures Oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.
	**Fyrite:** A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. Percentage Oxygen or CO_2 can be read from the scale.
	Contact thermometer:

Energy Audit Instruments

	**Contact thermometer:** These are thermocouples which measures for example flue gas, hot air, hot water temperatures by insertion of probe into the stream. For surface temperature a leaf type probe is used with the same instrument.
	**Infrared Pyrometer:** This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. Can be useful for measuring hot jobs in furnaces, surface temperatures etc.
	**Pitot Tube and manometer:** Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.
	**Ultrasonic flow meter:** This a non contact flow measuring device using Doppler effect principle. There is a transmitter and receiver which are positioned on opposite sides of the pipe. The meter directly gives the flow. Water and other fluid flows can be easily measured with this meter.

TO RECALL

- **EA CAN TAKE SEVERAL FORMS- SUPERFICIAL INSPECTION TO DEEP ENGG. STUDIES**
- **CAREFUL PLANNING & ATTN. TO DETAIL ESSENTIAL**
- **BASE AUDIT ON MEASURED DATA AND NOT CONJECTURES**
- **THOROUGH EVALUATION OF ENERGY USE IN A PLANT PROVIDES MASTERPLAN FOR ENERGY CONSERVATION**
- **RESULTS WILL JUSTIFY THE EFFORTS**

SUMMARY TABLE

PROJECT PRIORITY	SAVING METHODS	POTENTIAL ENERGY SAVING/YR	COST	PAY BACK (Yr)
1				
2				
3				

EVALUATION OF ESO

- REVIEW EACH ESO- QTTY OF SAVING POTENTIAL
- USE MOST ATTRACTIVE CHOICE FOR DETAILED EVALUATION
- CITE ENERGY SAVING AND ECONOMIC FACTORS SEPERATELY

REPORT

- QUALITY OF FINAL REPORT CRITICAL
- IT IS A *SALES DOCUMENT*
- TO SELL MANAGEMENT THE IDEA OF INVESTING IN SAVING
- MUST BE CONCISE, DIRECT & CONVINCING
- EXECUTIVE SUMMARY ESSENTIAL

EFFORT ON REPORT

- SUBSTANTIAL TIME & EFFORT TO BE DEVOTED TO PREPARE AN EXCELLENT REPORT
- ENGINEERS SPEND MORE TIME IN TESTING/ CALCULATION AND LESS ON REPORT

ON REPORT

- **EFFORT PUT TO CREATE A FIRST CLASS DOCUMENTATION MAY SPELL DIFERNCE BETWEEN A REPORT THAT _PRODUCES RESULTS_ AND ONE THAT _GATHERS DUST ON A SHELF_**

DOMESTIC

- LOADS- LIGHTING, FANS, PUMPS, REFRIGERATORS,KITCHEN APPLIANCES,WASHING MACHINES,WATER HEATERS, TV/ENTERTAINMENT, COMPUTERS, AC, ROOM HEATERS, INVERTORS
- ENERGY GUZZLERS- HEATERS, AC

SAVING OPTIONS

- SOLAR HEATER/COOKER
- CFL, ELECTRONIC CHOKE,LED
- EFFICIENT MOTORS IN GADGETS
- VFD

STANDBY POWER

- BOON OR BANE!
- THANKS TO UTILITIES- THIS INDUSTRY IS FLOURISHING
- POWER TO CHARGE BATTERIES
- SQUARE WAVES- AFFECTING GADGETS
- BATTERIES NEED REPLACEMENT REGULARLY

COMMERCIAL & OFFICE COMPLEXES

- Bulk of Electricity on LT side consumed by them
- LOADS-
  - HVAC,
  - PUMPS,
  - LIGHTING,
  - SUBSTATION,
  - IT EQUIP.,
  - STANDBY POWER

SCOPE OF SAVING

- SUBSTATION- EFF.TRANSF & LOAD MANAGEMENT
- PUMPING- ENERGY EFF. EQUIP , MATCH CAPACITY
- LIGHTING- CFL, ELEX BALLAST, USE OF NATURAL LIGHT, SOLAR ARCH.
- IT- LOW POWER PCs, MONITORS, PRINTERS

HVAC

- TEMP. CONTROL
- INTELLIGENT BUILDINGS
- SOLAR HEATING
- SWITCH OFF AC

STANDBY POWER

- LOAD (DEMAND SIDE) MANAGEMENT
- SOLAR PV- EXPENSIVE
- OTHER RENEWABLES

RURAL SECTOR-AGRICULTURE/IRRIGATION

- SOCIAL SECOR
- BULK OF POPULATION RESIDE
- POLITICISED-NON TECHNICAL
- SUBSIDISED- NO INSENTIVE TO SAVE
- POOR POWER QUALITY
- USE EFFICIENT PUMPSETS
- DECENTRALISED POWER/ RENEWABLES
- VISION PURA

INDUSTRY

- BULK OF POWER USED BY INDUSTRY, MAINLY FOR MOTORS
- ENERGY SAVING DEPENDS ON INDUSTRY
- MOTION AND HEATING ARE MAIN FUNCTIONS
- ENERGY EFFICIENT MOTORS, VFDs, LOAD PATTERN STUDY
- COGENERATION, RENEWABLE, BANKING

TRANSPORT

- **ALL ELECTRIC TRAINS**
- **HYBRID VEHICLES**
- **METROS, PUBLIC TRANSPORT**
- **MASS RAPID TRANSIT**
- **AIR-RAIL- ROAD COORDINATION**
- **BIO FUELS**
- **ANIMAL (CARTS) AND HUMAN ENERGY (Bicycles)**

TRANSMISSION- TARRIFF

- 40% LOSS, THEFT
- MONITORING OF ENRGY FLOW
- ENCOURAGE BULK CONSUMERS
- PREPAID METERS
- METERING / BILLING AUTOMATION
- USE OF IT

LABELLING

- EFFICIENCY LABELLING
- NEW STANDARDS
- TESTING
- ENERGY CONSUMPTION INFO

DEFENCE/ SECURITY

- **DEFENCE IS A MAJOR OIL GUZZLER**
- **STUDY VARIED ACTIVITIES**
- **RENEWABLES**

EFFICIENCY

- **SAVING POSSIBLE IN**
  - **MINING**
  - **POWER GENERATION, TRANSMISSION, DISTRIBUTION AND UTILISATION**
  - **PUMPING WATER**
  - **INDUCTION PRODUCTION/PROCESSES**
  - **HAULAGE**
  - **MASS TRANSPORT**
  - **BUILDING DESIGN, CONSTRUCTION**
  - **HVAC,**
  - **LIGHTING, DOMESTIC APPLIANCES**

Future tasks

- **EDUCATION, TRAINING, PUBLICITY**
- **ENERGY AUDIT , ENERGY SAVING SOLUTIONS, IMPLEMENTATION, VERIFICATION**
- **R&D, NEW TECHNOLOGIES**
- **SEMINARS/ CONFERENCES**
- **INDUSTRY-UTILITY LINKAGE**
- **ADVISE GOVT. POLICIES**
- **INERNATIONAL LINKAGES**
- **COGEN. WASTE MANAG. RENEWABLE**
- **EFFICIENCY LABELLING**

TO CONCLUDE

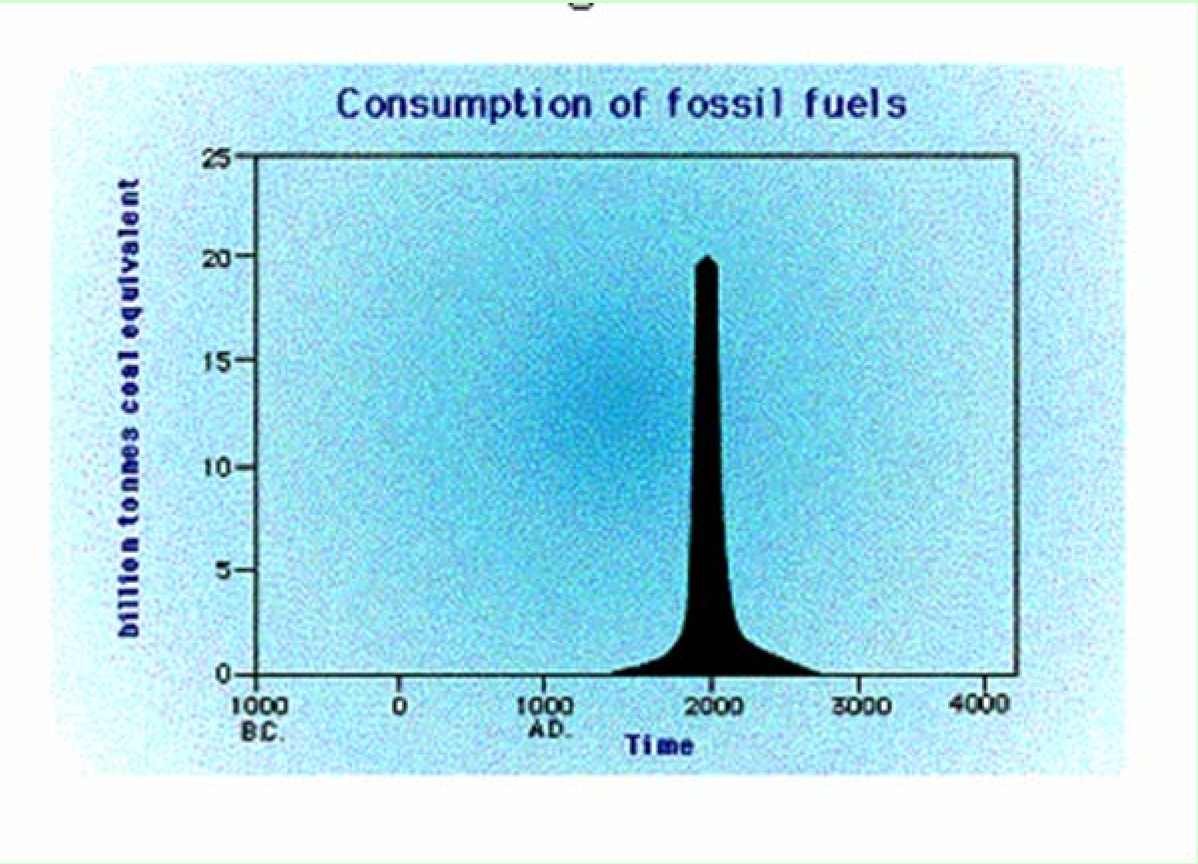
- MUCH SCOPE TO SAVE ENERGY
- ENERGY AUDIT CENTRAL
- STUDY CONSUMPTION PATTERN
- INVESTMENT AND PAY BACK VITAL
- POLICY SHOULD ENCOURAGE SAVING AND **NOT** CONSUMPTION

TO DISCUSS FURTHER….

Energy Conservation and its importance

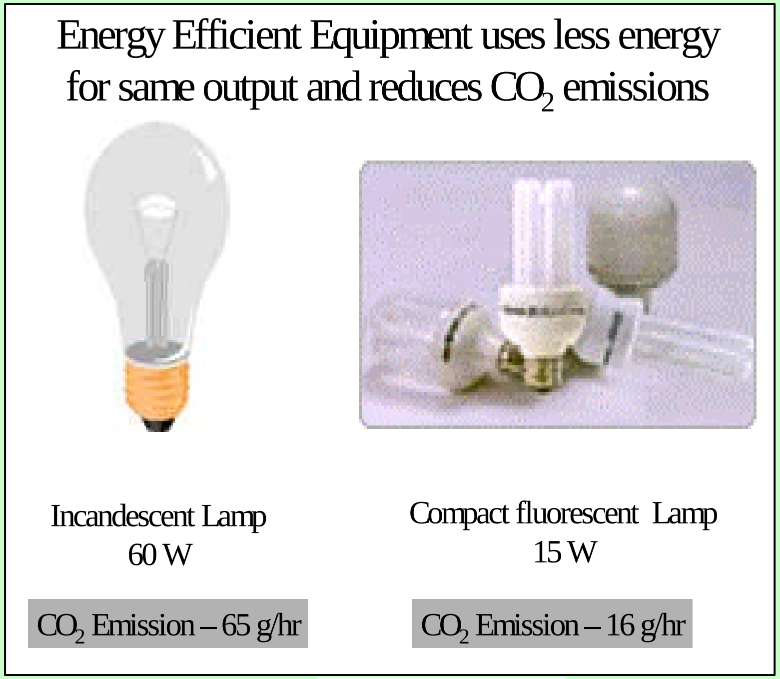
60% of resources consumed so far

85% of raw energy comes from non-renewable sources and hence not available for future generation



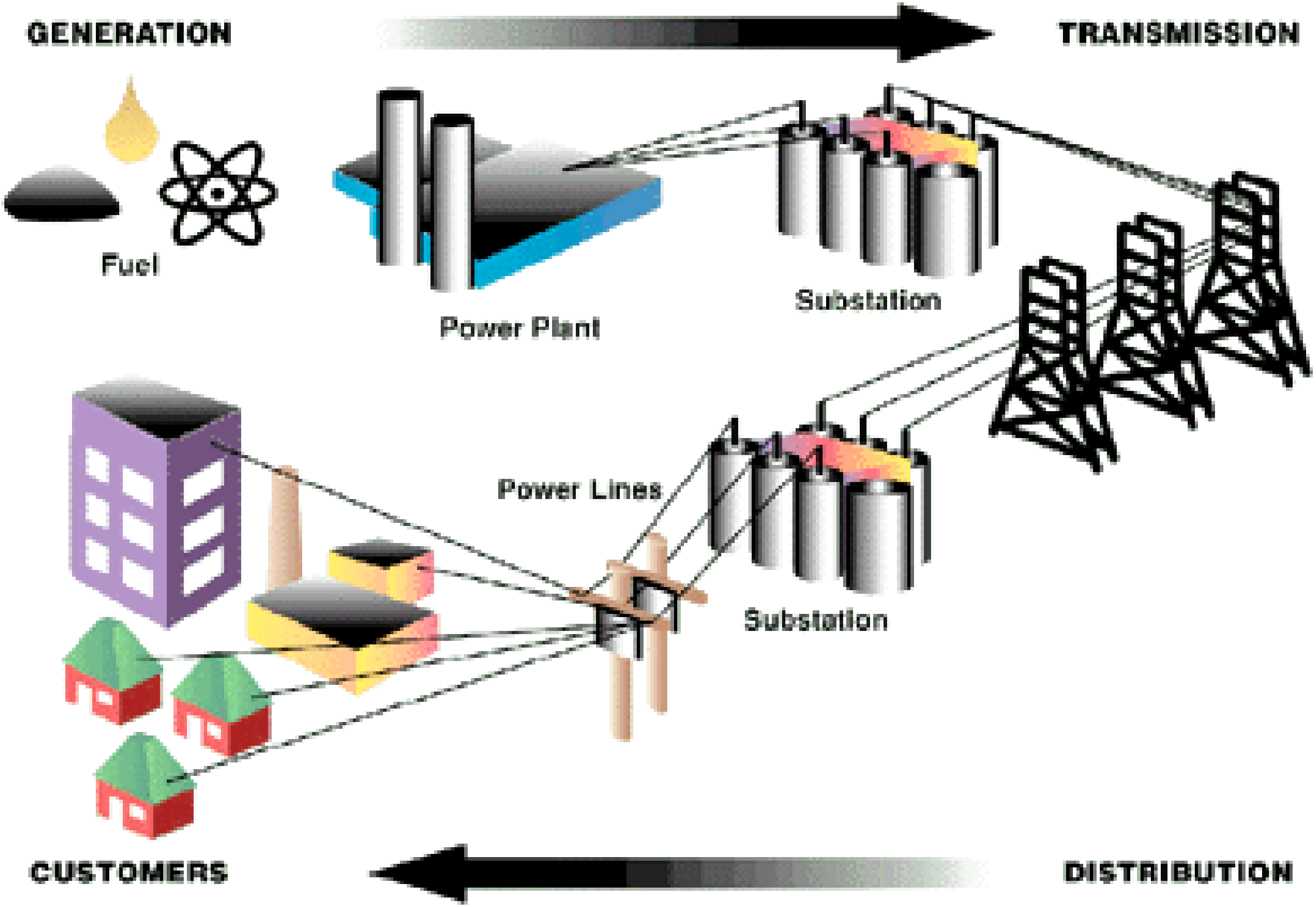
What is Energy Conservation?

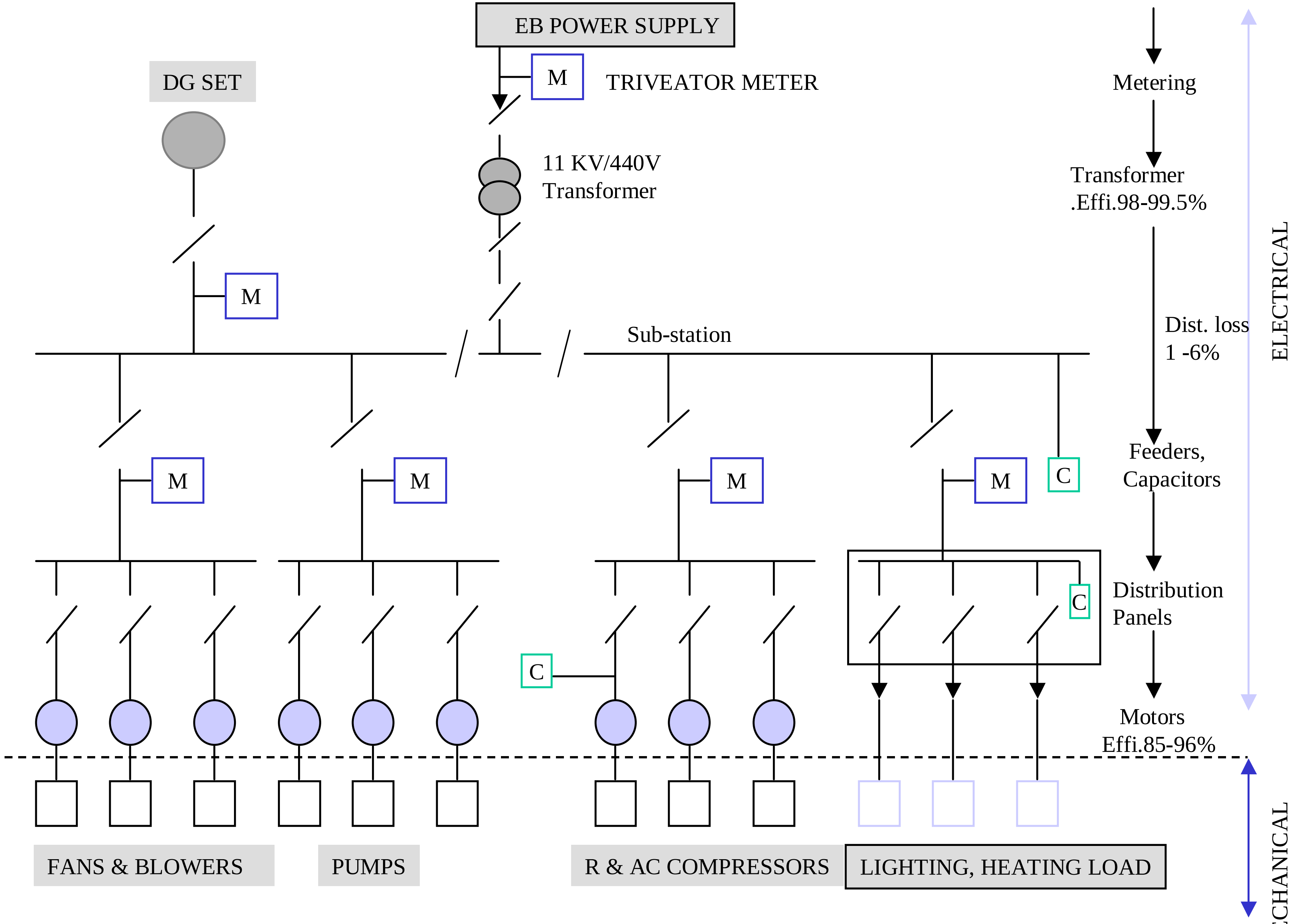
- Energy conservation is achieved when growth of energy consumption is reduced, measured in physical terms
- Energy efficiency is achieved when energy intensity in a specific product, process or area of production or consumption is reduced without affecting output, consumption or comfort levels



Energy Audit Instruments

 Tachometer	 Stroboscope	**Speed Measurements:** In any audit exercise speed measurements are critical as thay may change with frequency, belt slip and loading. A simple tachometer is a contact type instrument which can be used where direct access is possible. More sophisticated and safer ones are non contact instruments such as stroboscopes.
		**Leak Detectors:** Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible with human abilities**.**
		**Lux meters:** Illumination levels are measured with a lux meter. It consists of a photo cell which senses the light output, converts to electrical impulses which are calibrated as lux.


GENERATION
TRANSMISSION
Fuel
Power Plant
Substation
Power Lines
Substation
CUSTOMERS
DISTRIBUTION



Electrical Distribution System –Single Line Diagram

ELECTRICAL MOTORS

- ✓ **INDUCTION MOTORS ARE THE MOST COMMONLY USED PRIME MOVER FOR VARIOUS EQUIPMENT IN INDUSTRIAL APPLICATIONS**

ELECTRICAL MOTORS

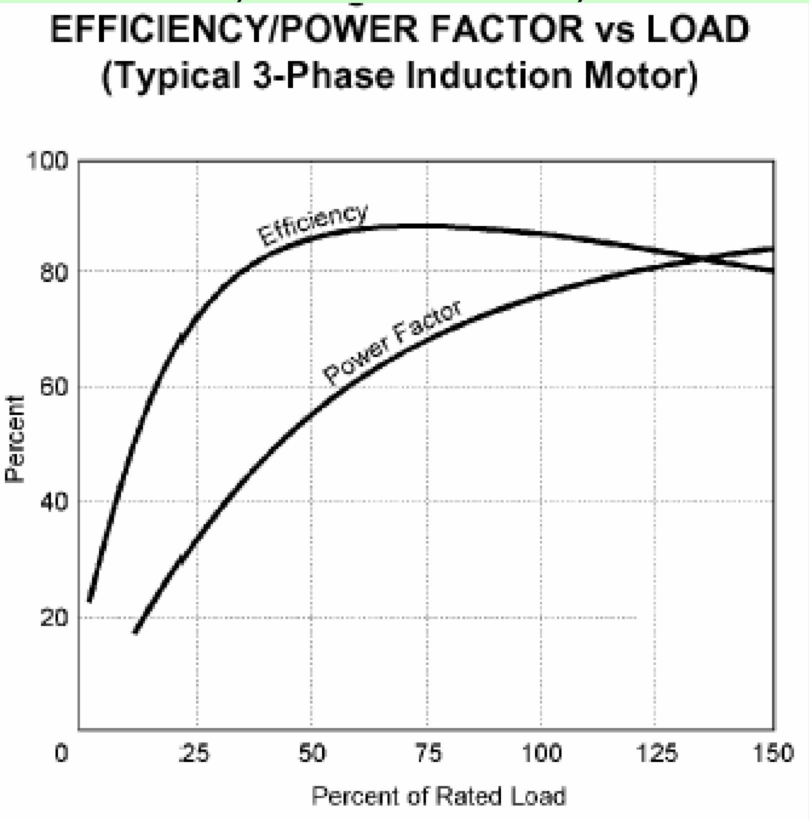
- TWO IMPORTANT ATTRIBUTES RELATING TO EFFICIENCY OF ELECTRICITY USE BY A.C. INDUCTION MOTORS ARE EFFICIENCY (η) AND POWER FACTOR (PF)
- HIGH VALUE FOR η AND A PF CLOSE TO UNITY ARE DESIRED FOR EFFICIENT OVERALL OPERATION IN A PLANT

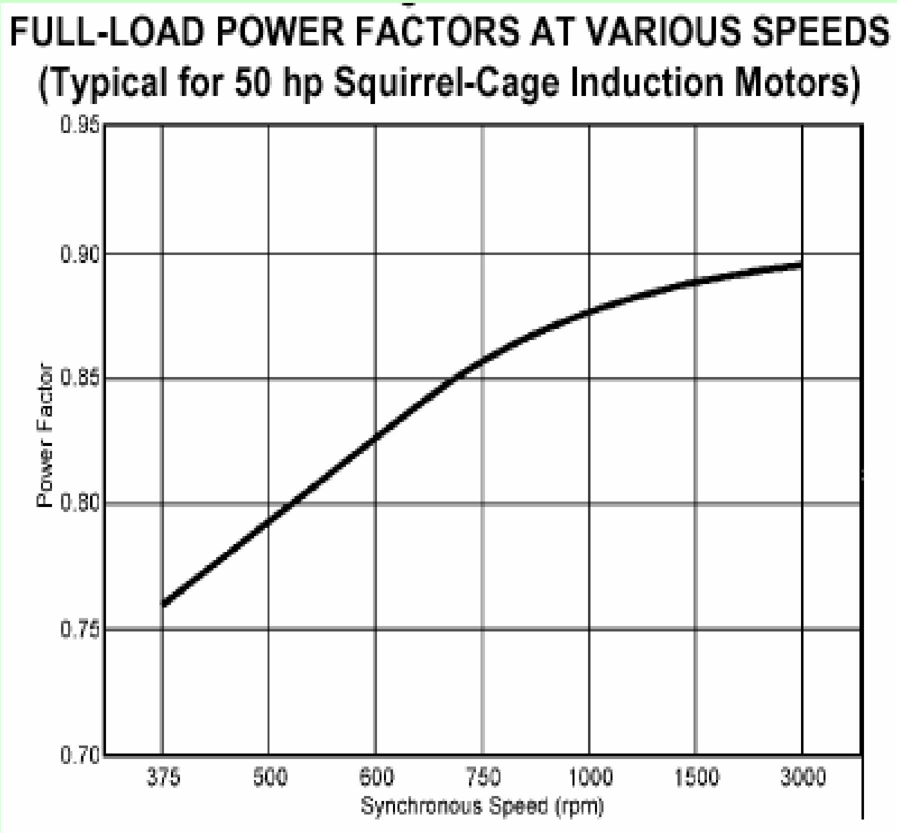
- **SQUIRREL CAGE MOTORS ARE NORMALLY MORE EFFICIENT THAN SLIP-RING MOTORS, AND HIGHER-SPEED MOTORS ARE NORMALLY MORE EFFICIENT THAN LOWER-SPEED MOTORS**
- **EFFICIENCY IS FUNCTION OF MOTOR TEMPERATURE. TOTALLY-ENCLOSED, FAN-COOLED (TEFC) MOTORS ARE MORE EFFICIENT THAN SCREEN-PROTECTED, DRIP-PROOF (SPDP) MOTORS**
- **MOTOR EFFICIENCY INCREASES WITH THE RATED CAPACITY.**

POWER FACTOR

$$\text{Power Factor} = \text{Cos}\phi = \frac{\text{kW}}{\text{kVA}}$$

AS THE LOAD ON THE MOTOR IS REDUCED, THE MAGNITUDE OF THE ACTIVE CURRENT REDUCES. HOWEVER, THERE IS NOT A CORRESPONDING REDUCTION IN THE MAGNETIZING CURRENT, WITH THE RESULT THAT THE MOTOR POWER FACTOR REDUCES, OR GETS WORSE, WITH A REDUCTION IN APPLIED LOAD.





MOTOR EFFICIENCY

$$Efficiency = \frac{Output}{Input} \times 100 = \frac{Input - Losses}{Input} \times 100$$

$$= \frac{746 \times HP\,Output}{Watts\,Input} \times 100$$

ELECTRIC MOTORS HAVE A RELATIVELY HIGH EFFICIENCY. A TYPICAL VALUE FOR AN 11 KW STANDARD MOTOR IS AROUND 90 PER CENT AND, FOR 100 KW, UP TO 94 PER CENT. DUE TO THE LAWS OF GROWTH, THE EFFICIENCY LEVELS MOTORS ARE HIGHER THAN FOR SMALLER ONES

FIELD TESTS FOR DETERMINING MOTOR EFFICIENCY

REFERENCE STANDARDS

THE FOLLOWING STANDARDS ARE WIDELY USED FOR EFFICIENCY

TESTING OF MOTORS AT MANUFACTURERS' TEST FACILITIES AND LABORATORIES

- IEC 600 34-2: 1996 ROTATING ELECTRICAL MACHINES- PART-2
- IEC 600 34-2: PROPOSED DRAFT DOCUMENT DATED AUGUST 2003

- **IEEE STANDARD 112-1996: IEEE TEST PROCEDURE FOR POLY PHASE INDUCTION MOTORS AND GENERATORS**
- **IS 4889: 1968 (REAFFIRMED 1996): METHODS OF DETERMINATION OF EFFICIENCY OF ROTATING ELECTRICAL MACHINES**
- **IS 4029: 1967 (FIFTH REPRINT 1984): GUIDE FOR TESTING THREE PHASE INDUCTION MOTORS**
- **IS 325: 1996: THREE PHASE INDUCTION MOTORS-SPECIFICATION**

EFFICIENCY TESTING OF A MOTOR

Essential Tests

1. **NO LOAD TEST**
2. **WINDING RESISTANCE MEASUREMENT**
3. **AMBIENT TEMPERATURE MEASUREMENT**
4. **ELECTRICAL INPUT MEASUREMENTS AT ACTUAL LOAD, IF THE MOTOR IS CONNECTED TO LOAD**
5. **OPERATING SPEED MEASUREMENT, IF THE MOTOR IS CONNECTED TO LOAD**

NON-ESSENTIAL TESTS

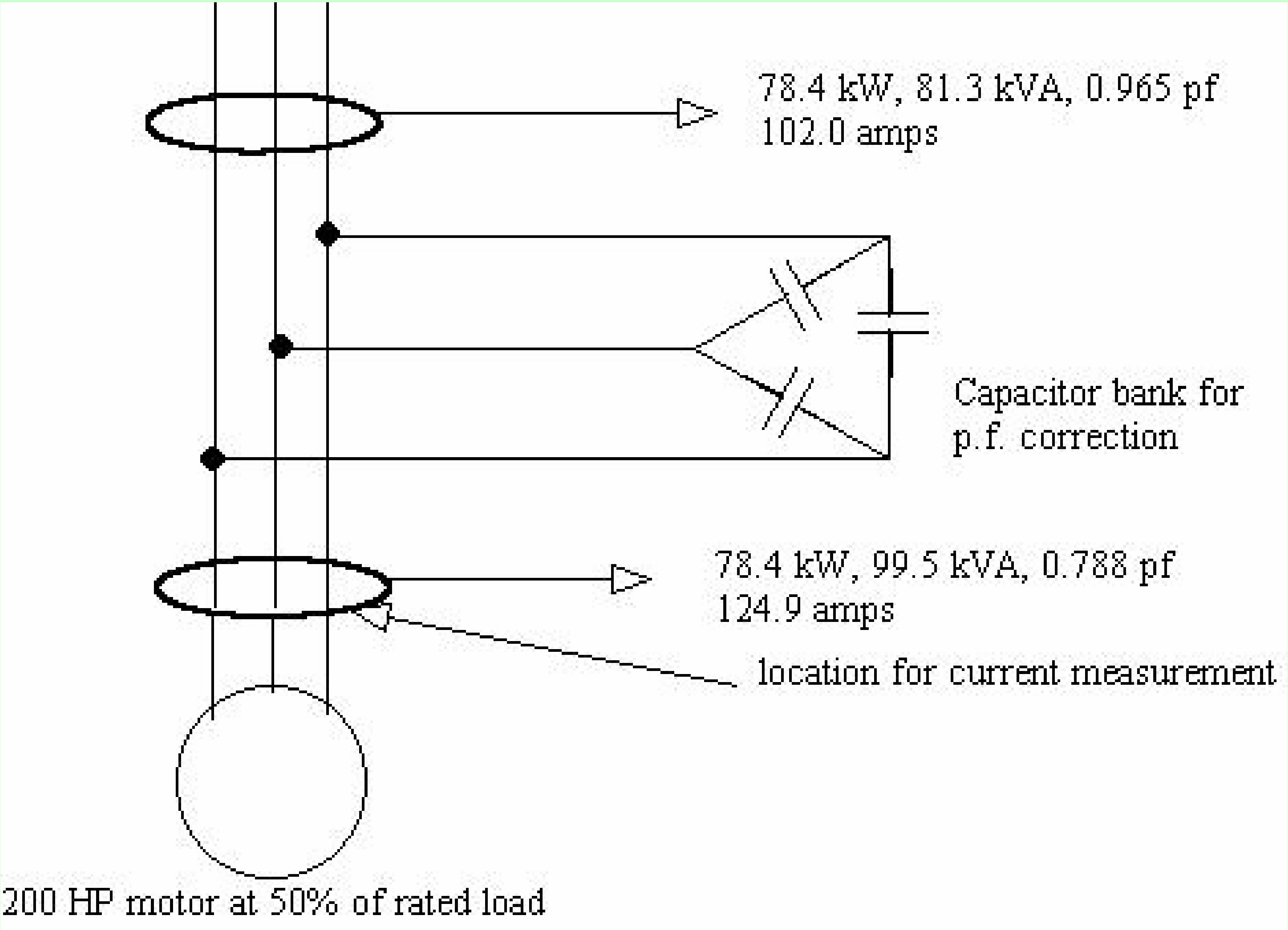
1. FRICTION & WINDAGE LOSS MEASUREMENT

ESTIMATION OF TOTAL LOSSES

1. STATOR COPPER LOSSES
2. ROTOR COPPER LOSSES
3. IRON LOSSES
4. FRICTION AND WINDAGE LOSSES
5. STRAY LOSSES

- ESTIMATION OF MOTOR EFFICIENCY FROM TOTAL LOSSES AND OUTPUT/INPUT POWER

Location of current measurement

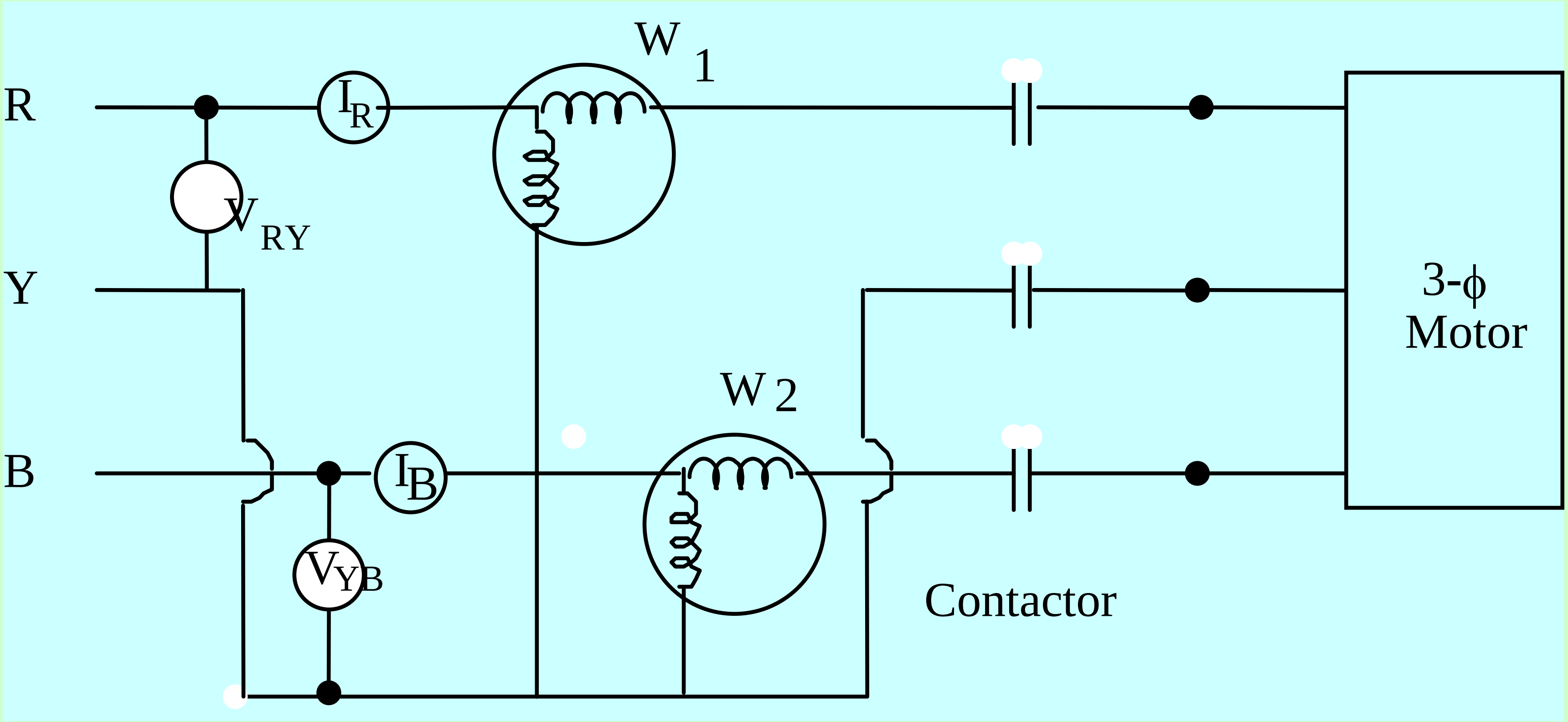


NO LOAD TEST

- **THE MOTOR IS RUN AT RATED VOLTAGE AND FREQUENCY WITHOUT ANY SHAFT LOAD**
- **INPUT POWER, CURRENT, FREQUENCY AND VOLTAGE ARE NOTED**
- **THE NO LOAD P.F. IS QUITE LOW AND HENCE LOW PF WATT METERS ARE REQUIRED**

F&W and core losses = No load power (watts) – (No load current)^2 $\times$ Stator resistance

- **TO SEPARATE CORE AND F & W LOSSES, TEST IS REPEATED AT VARIABLE VOLTAGES**
- **IT IS WORTHWHILE PLOTTING NO-LOAD INPUT KW VERSUS VOLTAGE; THE INTERCEPT IS F & W KW LOSS COMPONENT**
- **FROM THE INPUT POWER, STATOR I^2R LOSSES UNDER NO LOAD ARE SUBTRACTED TO GIVE THE SUM OF FRICTION AND WINDAGE (F&W) AND CORE LOSSES**



Two wattmeter method

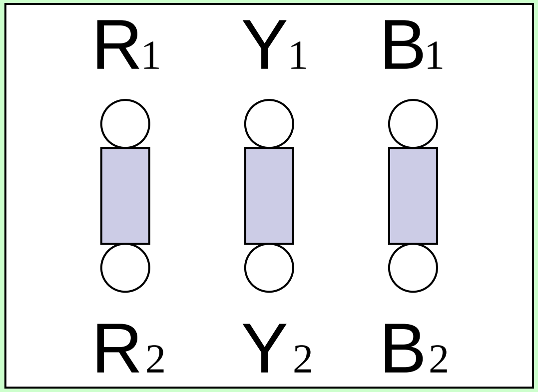
ESTIMATION OF FRICTION & WINDAGE LOSSES

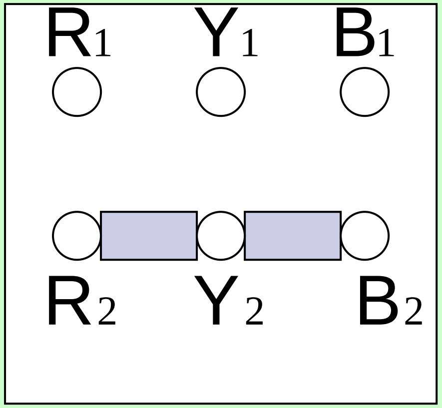
(NON ESSENTIAL TEST)

HOWEVER, IF IT IS REQUIRED TO KNOW HOW MUCH IS THE FRICTION AND WINDAGE LOSSES, THE NO LOAD TEST IS REPEATED AT VARIABLE VOLTAGES. IN CASE VARIABLE VOLTAGE SOURCE IS NOT AVAILABLE, FOR DELTA CONNECTED MOTORS, TWO READINGS CAN BE TAKEN; ONE WITH STATOR IN 'DELTA' AND THE OTHER WITH STATOR IN 'STAR'.

WHEN STATOR IS CONNECTED IN 'STAR' EXTERNALLY AS SHOWN ABOVE,

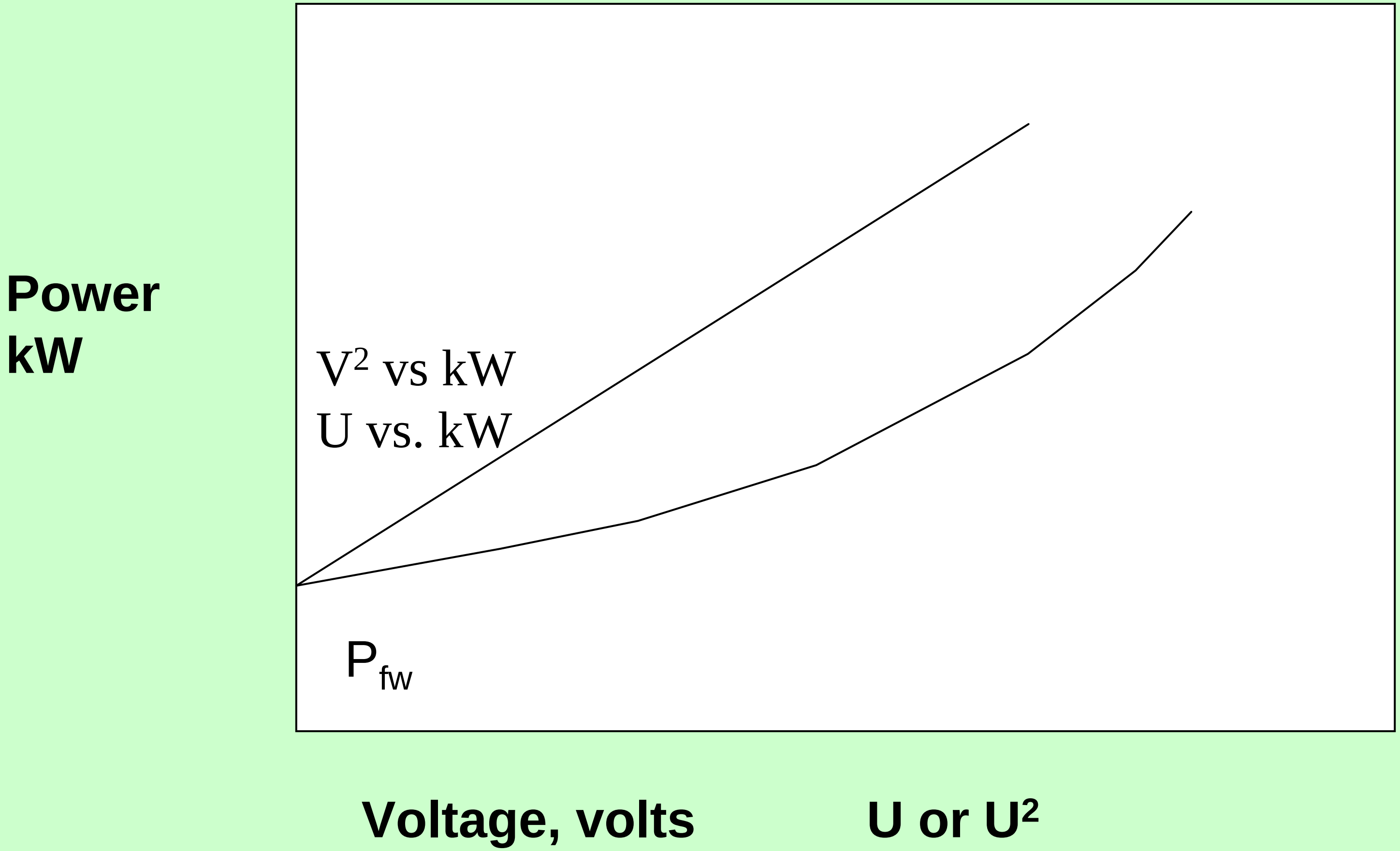
PHASE VOLTAGE = LINE VOLTAGE ÷ √3





SAMPLE PLOT. OF POWER VS. VOLTAGE^2 & VOLTAGE

VALUES OF POWER VS. VOLTAGE^2 IS PLOTTED



Alternatively, if variable voltage testing is not possible, assuming friction & windage losses as follows is also reasonably correct,

For Drip proof motors, friction & windage losses ≈ 0.8 to 1.0% of motor rated output

For TEFC motors, friction & windage losses ≈ 1 to 1.5% of motor rated output

2 pole motors have higher friction & windage losses compared to 4 pole motors.

Stator and Rotor I^2R Losses

THE STATOR WINDING RESISTANCE IS DIRECTLY MEASURED BY A BRIDGE OR VOLT AMP METHOD. THE RESISTANCE MUST BE CORRECTED TO THE OPERATING TEMPERATURE. FOR MODERN MOTORS, THE OPERATING TEMPERATURE IS LIKELY TO BE IN THE RANGE OF 100^0C TO 120^0C AND NECESSARY CORRECTION SHOULD BE MADE. CORRECTION TO 75^0C MAY BE INACCURATE. THE CORRECTION FACTOR IS GIVEN AS FOLLOWS

$$\frac{R_2}{R_1} = \frac{235 + t_2}{235 + t_1}$$

WHERE, T_1 = AMBIENT TEMPERATURE, ^{O}C & T_2 =- OPERATING TEMPERATURE, ^{O}C.

THE ROTOR RESISTANCE CAN BE DETERMINED FROM LOCKED ROTOR TEST AT REDUCED FREQUENCY, BUT ROTOR I^2R LOSSES ARE MEASURED FROM MEASUREMENT OF ROTOR SLIP.

ROTOR I^2R LOSSES = SLIP × (STATOR INPUT – STATOR I^2R LOSSES – CORE LOSS)

ACCURATE MEASUREMENT OF SLIP IS POSSIBLE BY STROBOSCOPE OR NON-CONTACT TYPE TACHOMETER. SLIP ALSO MUST BE CORRECTED TO OPERATING TEMPERATURE

REFERENCE TEMPERATURE FOR INSULATION CLASSES

Thermal class of insulation	Reference temperature, ^{o}C
A	75
B	95
F	115
H	130

WHILE ESTIMATING MOTOR EFFICIENCY AT ACTUAL LOAD, THE WINDING RESISTANCE IS MEASURED IMMEDIATELY AFTER STOPPING THE MOTOR. HENCE TEMPERATURE CORRECTION IS NOT REQUIRED IN THIS CASE

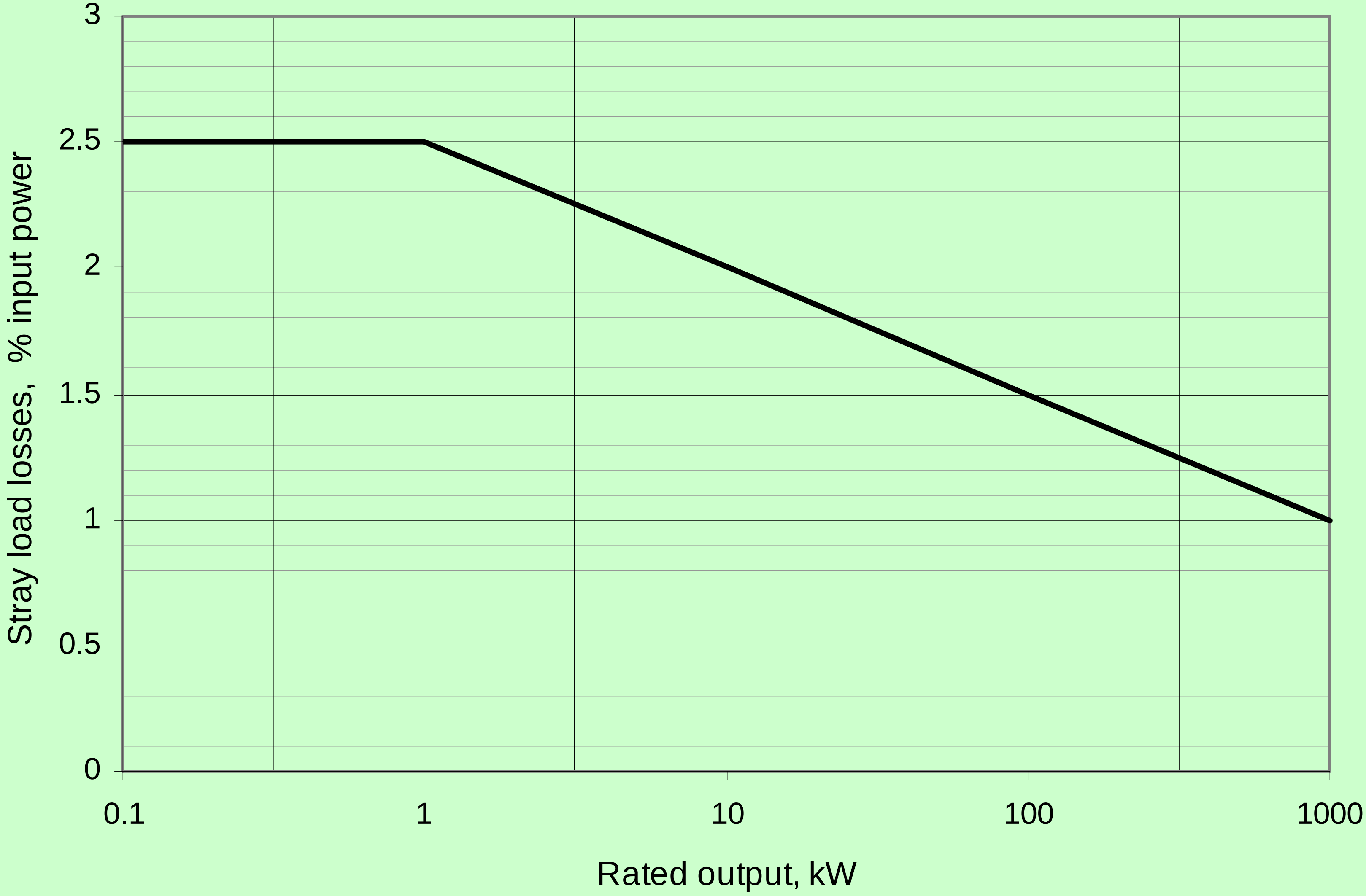
STRAY LOAD LOSSES

- **THESE LOSSES ARE DIFFICULT TO MEASURE WITH ANY ACCURACY. IEEE STANDARD 112 GIVES A COMPLICATED METHOD, WHICH IS RARELY USED ON SHOP FLOOR. IS AND IEC STANDARDS TAKE A FIXED VALUE AS 0.5 % OF OUTPUT. THE ACTUAL VALUE OF STRAY LOSSES IS LIKELY TO BE MORE. IEEE – 112 SPECIFIES VALUES FROM 0.9 % TO 1.8 %**

Motor Loading vs. Stray Losses - IEEE	
Motor Rating	**Stray Losses**
1 – 125 HP	1.8 %
125 – 500 HP	1.5 %
501 – 2499 HP	1.2 %
2500 and above	0.9 %

- These losses are difficult to measure with any accuracy. IEEE Standard 112 gives a complicated method, which is rarely used on shop floor. IS and IEC standards take a fixed value as 0.5 % of output. The actual value of stray losses is likely to be more. IEEE – 112 specifies values from 0.9 % to 1.8 %

Stray loss



3
2.5
2
1.5
1
0.5
0
0.1
1
10
100
1000
Stray load losses, % input power
Rated output, kW

Motor losses

The % losses indicated are for ***3000 rpm motor***s, and ***1500 rpm motors in brackets***.

Core Loss : approx 18% *(22%)* of total loss at full load

Stator and Rotor Resistance (I^2R) Loss: approx 42% (*56*%) of total loss at full Load

Friction and Windage Loss approx 30% (*11*%) of total loss at full load

Stray Load Loss : approx 10%(*11%)* of total loss at full load

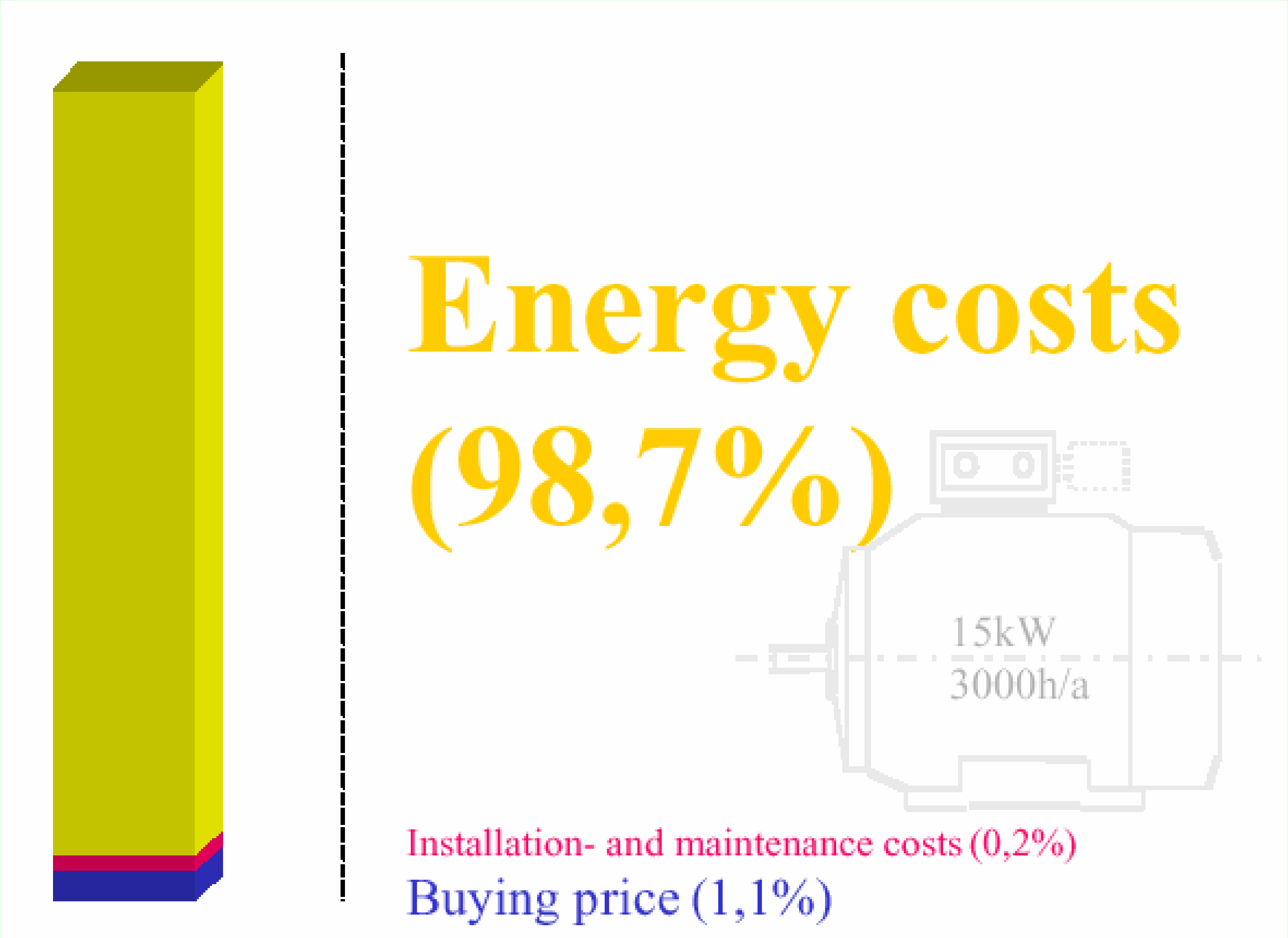
Range of losses in Induction motors

Range	Energy Loss at Full Load (%)
1 - 10 HP	14.0 - 35
10 - 50 HP	9.0 - 15
50 - 200 HP	6.0 - 12
200 - 1500 HP	4.0 - 07
1500 - HP & ABOVE	2.3 - 04

Motor Selection

- Reliability
  - seeking reliability will grossly oversize equipment, leading to sub-optimal energy performance. Good knowledge of process parameters and a better understanding of the plant power system can aid in reducing over sizing with no loss of reliability
- Inventory
  - large industries use standard equipment, which can be easily serviced or replaced, thereby reducing the stock of spare parts that must be maintained and minimizing shut-down time. This practice affects the choice of motors that might provide better energy performance in specific applications. Shorter lead times for securing individual motors from suppliers would help reduce the need for this practice
- Price
  - Many users are first-cost sensitive, leading to the purchase of less expensive motors that may be more costly on a lifecycle basis because of lower efficiency

Life cycle cost of a motor



ENERGY CONSERVATION IN MOTORS

ENERGY SAVING IN MOTORS

- HOUSE KEEPING-CONDITION MONITORING
- INSTALLATION
  - MATCH MOTOR WITH LOAD
  - SUITABLE DRIVE MECHANISM

CONTD…

- VOLTAGE OR ENERGY CONTROLLER
  - VARIAC
  - STAR-DELTA
  - AC CONTROLLER

CONTD..

- VARIABLE FREQUENCY DRIVES (VFDs)
- PAM OR POLE CHANGING (2 SPEED)
- RIGHT CONTROLLER IN VARIABLE SPEED DRIVES TO CAUSE MIN. LOSS

HOW TO CHOOSE MOTOR

- SUPPLY
- APPLICATION
- NATURE OF LOAD TORQUE
- SPEED RANGE

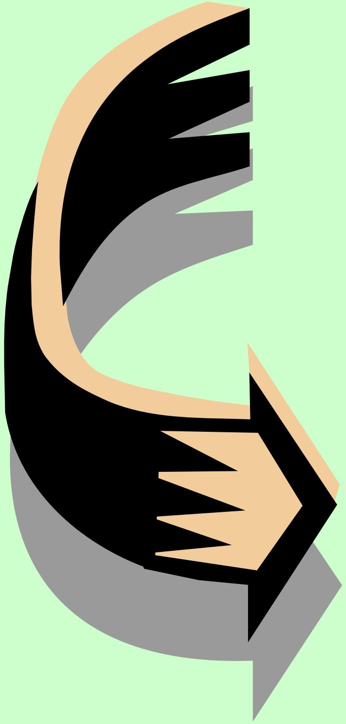
POWER RATING

- CONTINUOUS LOAD CARRIED
- CURRENT
- HEATING
- COOLING USED

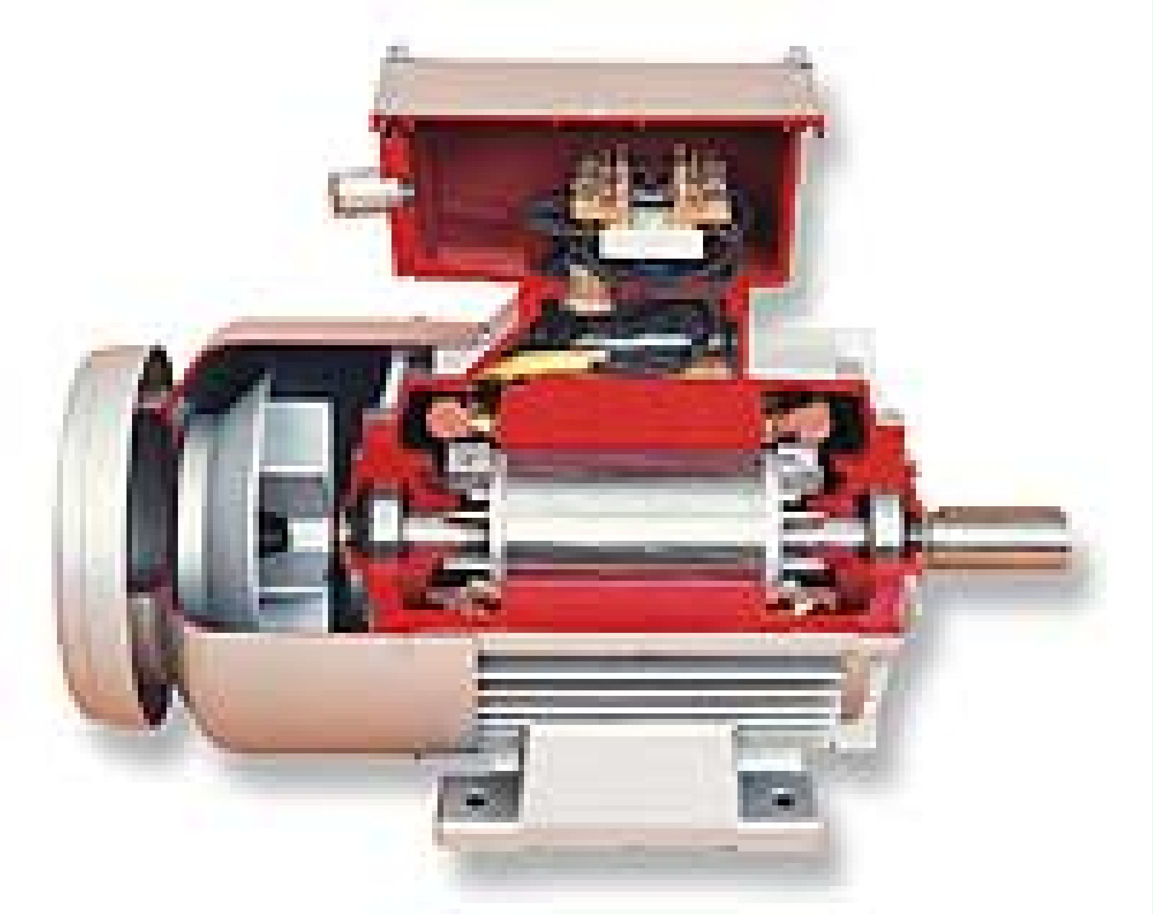
REPLACEMENT Vs REPAIR

- REWOUND MOTOR IS NOT NECESSARILY BETTER THAN NEW MOTOR

MINIMIZING MOTOR LOSSES IN OPERATION



Energy Efficient Motors



ENERGY EFFICIENT MOTORS

- IMPROVEMENTS INCLUDE THE USE OF LOWER-LOSS SILICON STEEL, A LONGER CORE (TO INCREASE ACTIVE MATERIAL), THICKER WIRES (TO REDUCE RESISTANCE), THINNER LAMINATIONS, SMALLER AIR GAP BETWEEN STATOR AND ROTOR, COPPER INSTEAD OF ALUMINUM BARS IN THE ROTOR, SUPERIOR BEARINGS AND A SMALLER FAN, ETC
- LOWER OPERATING TEMPERATURES AND NOISE LEVELS, GREATER ABILITY TO ACCELERATE HIGHER-INERTIA LOADS, AND ARE LESS AFFECTED BY SUPPLY VOLTAGE FLUCTUATIONS

E^2 MOTORS…

- **STATOR AND ROTOR I^2R LOSSES**
  - **SUITABLE SELECTION OF COPPER CONDUCTOR SIZE**
  - **DECREASING THE MAGNETIZING COMPONENT OF CURRENT BY LOWERING THE OPERATING FLUX DENSITY AND POSSIBLE SHORTENING OF AIR GAP**
  - **ROTOR I^2R LOSSES DEPENDS ON ROTOR CONDUCTORS AND THE ROTOR SLIP**
  - **STARTING PERFORMANCE TEND TO LIMIT THE AMOUNT BY WHICH ROTOR I^2R LOSSES CAN BE REDUCED TO FAVOR EFFICIENCY (AS STARTING TORQUE IS PROPORTIONAL TO ROTOR RESISTANCE)**
  - **OPERATION CLOSER TO SYNCHRONOUS SPEED REDUCE ROTOR I^2R LOSSES**

ENERGY EFFICIENT MOTORS

- **CORE LOSSES**
  - **DUE TO HYSTERISIS EFFECT AND EDDY CURRENT**
  - **HYSTERISIS LOSSES – REDUCED BY REDUCING FLUX DENSITY**
    - **REDUCED BY UTILIZING LOW-LOSS GRADE OF SILICON STEEL LAMINATIONS AND BY SUITABLE INCREASE IN THE CORE LENGTH OF STATOR AND ROTOR**
  - **EDDY CURRENT LOSSES GENERATED BY CIRCULATING CURRENT WITHIN THE CORE STEEL LAMINATIONS**
    - **REDUCED BY USING THINNER LAMINATIONS**

- FRICTION AND WINDAGE LOSSES
  - RESULTS FROM BEARING FRICTION, WINDAGE AND CIRCULATING AIR THROUGH THE MOTOR (INDEPENDENT OF LOAD)
  - USE OF SMALLER FAN
- STRAY LOAD-LOSSES
  - CAUSED BY LEAKAGE FLUX INDUCED BY LOAD CURRENTS IN THE LAMINATIONS (IMPERFECTIONS RELATED TO SLOTTING AND SATURATION EFFECTS RESULTS IN HIGH FREQ. CURRENTS IN ROTOR BARS)
  - REDUCED BY CAREFUL SELECTION OF SLOT NUMBERS, TOOTH/SLOT GEOMETRY AND AIR GAP

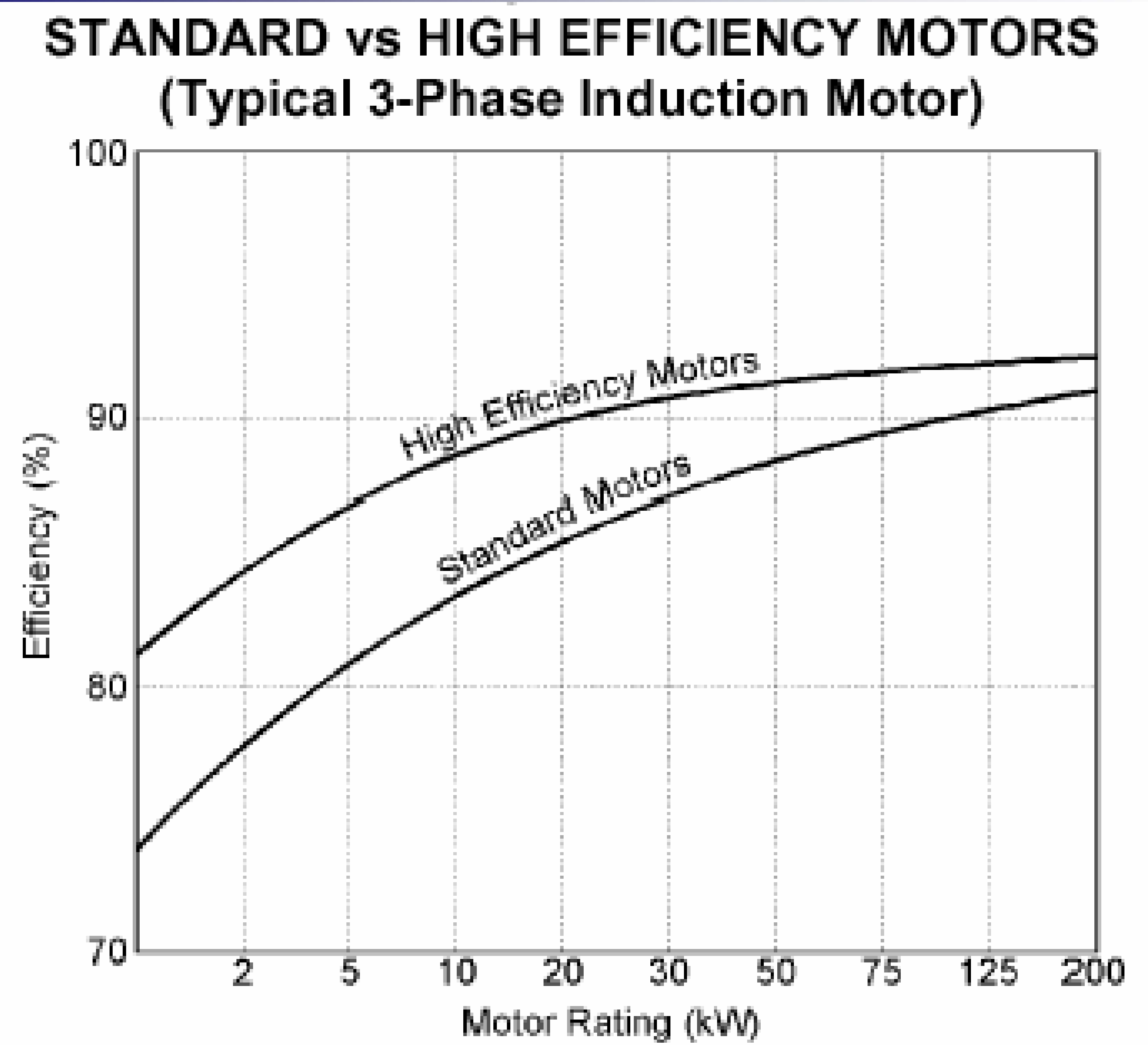
ENERGY EFFICIENT MOTORS (LIMITATIONS)

- THE COSTS OF ENERGY-EFFICIENT MOTORS ARE HIGHER THAN THOSE OF STANDARD MOTORS
- ECONOMICALLY ILL-SUITED CASES TO ENERGY-EFFICIENT MOTORS
- HIGHLY INTERMITTENT DUTY OR SPECIAL TORQUE APPLICATIONS SUCH AS HOISTS AND CRANES, TRACTION DRIVES, PUNCH PRESSES, MACHINE TOOLS, AND CENTRIFUGES

- **ENERGY, EFFICIENT DESIGNS OF MULTI-SPEED MOTORS ARE GENERALLY NOT AVAILABLE**
- **ENERGY-EFFICIENT MOTORS NOT AVAILABLE FOR MANY SPECIAL APPLICATIONS, E.G. FOR FLAME-PROOF OPERATION IN OIL-FIELD OR FIRE PUMPS OR FOR VERY LOW SPEED APPLICATIONS (BELOW 750 RPM)**
- **MOST ENERGY-EFFICIENT MOTORS PRODUCED TODAY ARE DESIGNED ONLY FOR CONTINUOUS DUTY CYCLE OPERATION**

Design changes

Watt Loss Area and Efficiency Improvement	
Watts Loss Area	**Efficiency Improvement**
1. Iron	Use of thinner gauge, lower loss core steel reduces eddy current losses. Longer core adds more steel to the design, which reduces losses due to lower operating flux densities.
2. Stator I^2R	Use of more copper and larger conductors increases cross sectional area of stator windings. This lowers resistance (R) of the windings and reduces losses due to current flow (I).
3. Rotor I^2R	Use of larger rotor conductor bars increases size of cross section, lowering conductor resistance (R) and losses due to current flow (I).
4. Friction & Windage	Use of low loss fan design reduces losses due to air movement.
5. Stray Load Loss	Use of optimised design and strict quality control procedures minimizes stray load losses.



STANDARD vs HIGH EFFICIENCY MOTORS
(Typical 3-Phase Induction Motor)
100
90
80
70
Efficiency (%)
High Efficiency Motors
Standard Motors
2
5
10
20
30
50
75
125
200
Motor Rating (kW)

TECHNICAL ASPECTS OF ENERGY EFFICIENT MOTORS

- ENERGY-EFFICIENT MOTORS LAST LONGER, AND MAY REQUIRE LESS MAINTENANCE. AT LOWER TEMPERATURES, BEARING GREASE LASTS LONGER; REQUIRED TIME BETWEEN RE-GREASING INCREASES. LOWER TEMPERATURES TRANSLATE TO LONG LASTING INSULATION. GENERALLY, MOTOR LIFE DOUBLES FOR EACH 10°C REDUCTION IN OPERATING TEMPERATURE.
- ELECTRICAL POWER PROBLEMS, ESPECIALLY POOR INCOMING POWER QUALITY CAN AFFECT THE OPERATION OF ENERGY-EFFICIENT MOTORS.

- **SPEED CONTROL IS CRUCIAL IN SOME APPLICATIONS. IN POLYPHASE INDUCTION MOTORS, SLIP IS A MEASURE OF MOTOR WINDING LOSSES. THE LOWER THE SLIP, THE HIGHER THE EFFICIENCY. LESS SLIPPAGE IN ENERGY EFFICIENT MOTORS RESULTS IN SPEEDS ABOUT 1% FASTER THAN IN STANDARD COUNTERPARTS.**
- **STARTING TORQUE FOR EFFICIENT MOTORS MAY BE LOWER THAN FOR STANDARD MOTORS. FACILITY MANAGERS SHOULD BE CAREFUL WHEN APPLYING EFFICIENT MOTORS TO HIGH TORQUE APPLICATIONS.**

Maintain Good Power Quality

Maintain Voltage Levels

ALTHOUGH MOTORS ARE DESIGNED TO OPERATE WITHIN 10% OF NAMEPLATE VOLTAGE, LARGE VARIATIONS SIGNIFICANTLY REDUCE EFFICIENCY, POWER FACTOR, AND SERVICE LIFE

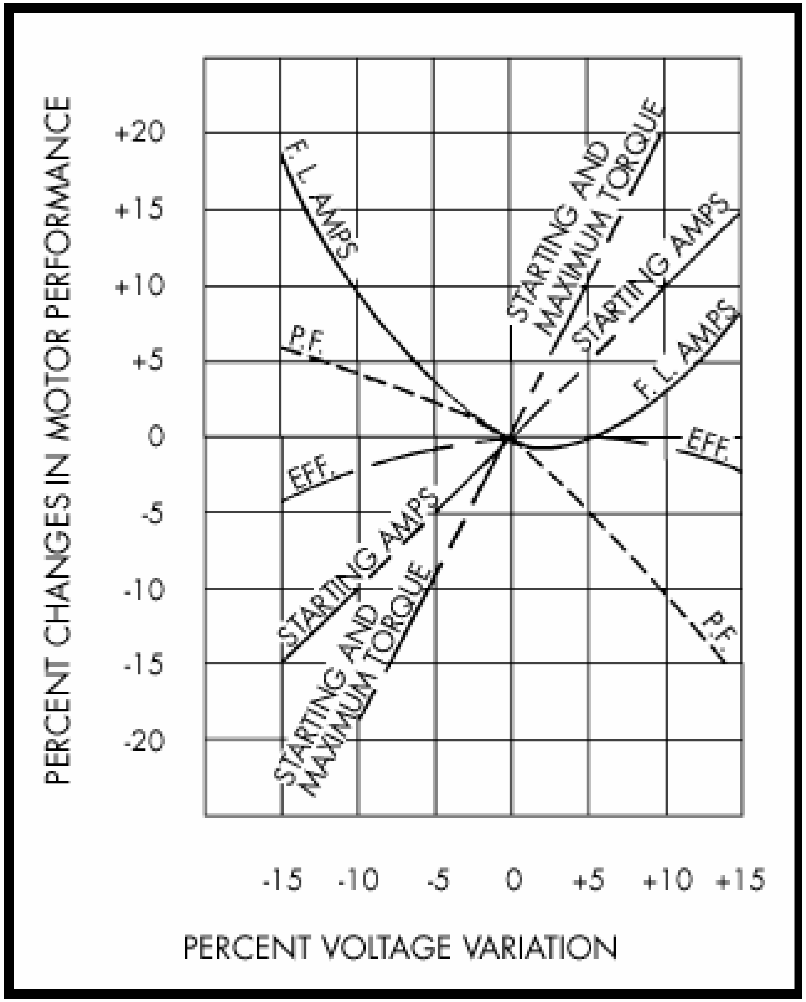


Figure 1
Voltage Variation Effect on Motor Performance

MAINTAIN GOOD POWER QUALITY

MINIMIZE PHASE UNBALANCE

PHASE BALANCE SHOULD BE WITHIN 1% TO AVOID DERATING OF THE MOTOR. SEVERAL FACTORS CAN AFFECT VOLTAGE BALANCE: SINGLE-PHASE LOADS ON ANY ONE PHASE, DIFFERENT CABLE SIZING, OR FAULTY CIRCUITS. AN UNBALANCED SYSTEM INCREASES DISTRIBUTION SYSTEM LOSSES AND REDUCES MOTOR EFFICIENCY.

COMMON CAUSES OF VOLTAGE UNBALANCE

- 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.

MAINTAIN HIGH POWER FACTOR

- **LOW POWER FACTOR REDUCES THE EFFICIENCY OF THE ELECTRICAL DISTRIBUTION SYSTEM BOTH WITHIN AND OUTSIDE OF YOUR FACILITY. LOW POWER FACTOR RESULTS WHEN INDUCTION MOTORS ARE OPERATED AT LESS THAN FULL LOAD. MANY UTILITIES CHARGE A PENALTY IF POWER FACTOR DIPS BELOW 95%. INSTALLING SINGLE CAPACITORS OR BANKS OF CAPACITORS EITHER AT THE MOTOR OR THE MOTOR CONTROL CENTERS ADDRESSES THIS PROBLEM**

POWER FACTOR

- **PF CAPACITOR IMPROVES POWER FACTOR FROM THE POINT OF INSTALLATION BACK TO THE GENERATING SIDE. IT MEANS THAT, IF A PF CAPACITOR IS INSTALLED AT THE STARTER TERMINALS OF THE MOTOR, IT WON'T IMPROVE THE OPERATING PF OF THE MOTOR, BUT THE PF FROM STARTER TERMINALS TO THE POWER GENERATING SIDE WILL IMPROVE, I.E., THE BENEFITS OF PF WOULD BE ONLY ON UPSTREAM SIDE.**

Maintain High Power Factor

- IN GENERAL, THE CAPACITOR SELECTED SHOULD NOT EXCEED 90 % OF THE NO-LOAD KVAR OF THE MOTOR (HIGHER CAPACITIES COULD RESULT IN OVER-VOLTAGES AND MOTOR BURN-OUTS)
- REQUIRED CAPACITIVE KVAR INCREASES WITH DECREASE IN SPEED OF THE MOTOR, AS THE MAGNETIZING CURRENT REQUIREMENT OF A LOW SPEED MOTOR IS MORE IN COMPARISON TO THE HIGH SPEED MOTOR FOR THE SAME HP OF THE MOTOR

CAPACITOR…

- **SINCE A REDUCTION IN LINE CURRENT, AND ASSOCIATED ENERGY EFFICIENCY GAINS, ARE REFLECTED BACKWARDS FROM THE POINT OF APPLICATION OF THE CAPACITOR, THE MAXIMUM IMPROVEMENT IN OVERALL SYSTEM EFFICIENCY IS ACHIEVED WHEN THE CAPACITOR IS CONNECTED ACROSS THE MOTOR TERMINALS, AS COMPARED TO SOMEWHERE FURTHER UPSTREAM IN THE PLANT’S ELECTRICAL SYSTEM.**

- USE ADJUSTABLE SPEED DRIVES (ASDS) OR TWO-SPEED MOTORS WHERE APPROPRIATE
  - **WHEN LOADS VARY, ASDS OR TWO-SPEED MOTORS CAN REDUCE ELECTRICAL ENERGY CONSUMPTION IN CENTRIFUGAL PUMPING AND FAN APPLICATIONS—OFTEN BY 50% OR MORE.**

CONSIDER LOAD SHEDDING

- USE CONTROLS TO TURN OFF IDLING MOTORS. THE MAXIMUM NUMBER OF ON/OFF CYCLES PER HOUR AND THE MAXIMUM AMOUNT OF TIME OFF BETWEEN CYCLES IS AFFECTED BY MOTOR SIZE, TYPE OF LOAD (VARIABLE OR FIXED), AND MOTOR SPEED. USE OF SOFT STARTERS PROVE HELPFUL IN INCREASING THE NUMBER OF STARTS AND STOPS PER HOUR.

MATCH MOTOR OPERATING SPEEDS

- **THE ENERGY CONSUMPTION OF CENTRIFUGAL PUMPS AND FANS IS EXTREMELY SENSITIVE TO OPERATING SPEED. FOR EXAMPLE, INCREASING OPERATING SPEED BY 2% CAN INCREASE THE POWER REQUIRED TO DRIVE THE SYSTEM BY 8%. TO MAINTAIN SYSTEM EFFICIENCY, IT IS CRITICAL TO MATCH FULL-LOAD SPEEDS WHEN REPLACING PUMP AND FAN MOTORS.**

SIZE MOTORS FOR EFFICIENCY

- SIZE MOTORS TO RUN PRIMARILY IN THE 65% TO 100% LOAD RANGE.
- CONSIDER REPLACING MOTORS RUNNING AT LESS THAN 40% LOAD WITH PROPERLY SIZED MOTORS.
- YOU CAN ADDRESS APPLICATIONS WITH OCCASIONAL HIGH PEAK LOADS BY A VARIETY OF DESIGN STRATEGIES INCLUDING ASDS FOR PUMPS AND FANS, RESERVOIRS FOR FLUIDS, AND FLY WHEELS FOR MECHANICAL EQUIPMENT.

OPERATING A MOTOR IN STAR INSTEAD OF DELTA

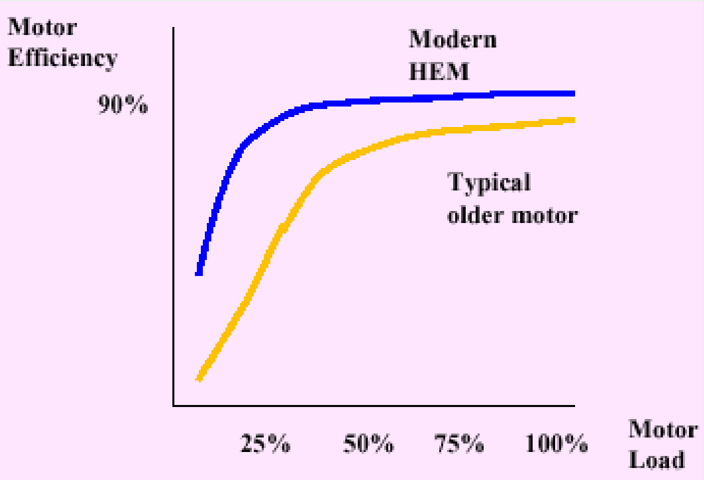
- **FOR MOTORS, WHICH CONSISTENTLY OPERATE AT LOADS BELOW 40 % OF RATED CAPACITY, AN INEXPENSIVE AND EFFECTIVE MEASURE MIGHT BE TO OPERATE IN STAR MODE**
- **OPERATING IN THE STAR MODE LEADS TO A VOLTAGE REDUCTION BY A FACTOR OF '$\sqrt{3}$'**

OPERATE IN STAR…

- **THIS WILL REDUCE THE MAGNETIZING CURRENT, AND WILL ALSO REDUCE THE TORQUE CAPACITY OF THE MOTOR**
- ***IF YOU OPERATE AT LIGHT LOADS, THERE WILL BE NO PROBLEM,*** **HOWEVER IF YOU OPERATE AT HIGH LOADS, THE SLIP OF THE MOTOR WILL BE INCREASED DRAMATICALLY AND IT MAY STALL RESULTING IN THE ROTOR AND STATOR OVER HEATING CAUSING A MOTOR FAILURE**

Effect of over sizing

Why are motors often oversized?
Original design requires 7kW
Engineer adds in 10% for contingency - 7.7kW
Selects next standard size motor - 11kW
Over rating = 57%



Operating a high capacity motor for lower loads results in reduced efficiency, power factor and also increases the energy consumption.

To meet 7.5 kW load if the motor selected is 7.5 /11 /15 kW then the variations in energy consumption is as shown in Table below: -

Parameter	Case 1	Case 2	Case 3
Motor Load	7.5 kw at F.L.	10 kw at 3/4 load	15 kw at ½ load
Required load	7.5	7.5	7.5
Motor EFF (%)	88	84	79
Motor input kw	8.5	9.0	9.5
Unit consumed kwh	42500	45000	47500
% increase	--	5.8	11.76

Optimize Transmission Efficiency

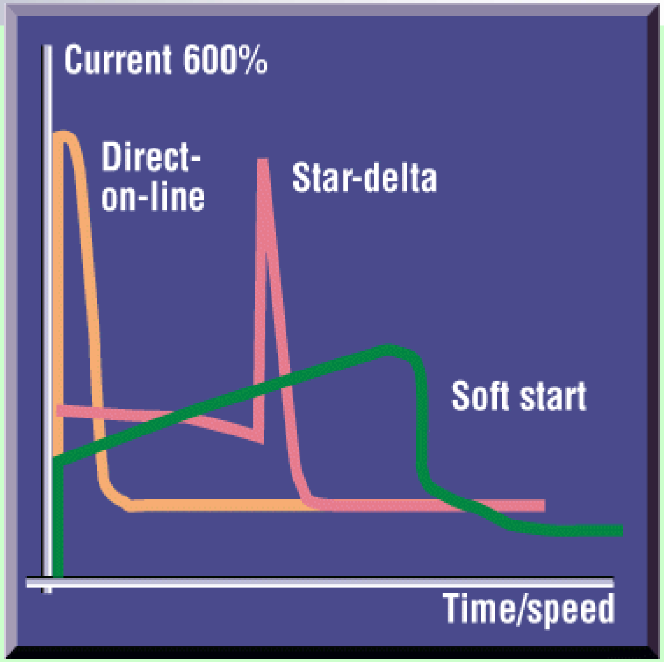
TRANSMISSION EQUIPMENT INCLUDING SHAFTS, BELTS, CHAINS, AND GEARS SHOULD BE PROPERLY INSTALLED AND MAINTAINED. WHEN POSSIBLE, USE FLAT BELTS IN PLACE OF V-BELTS. HELICAL GEARS ARE MORE EFFICIENT THAN WORM GEARS; USE WORM GEARS ONLY WITH MOTORS UNDER 10 HP. AS FAR AS POSSIBLE IT IS BETTER TO HAVE A DIRECT DRIVE THUS AVOIDING LOSSES IN TRANSMISSION SYSTEM.

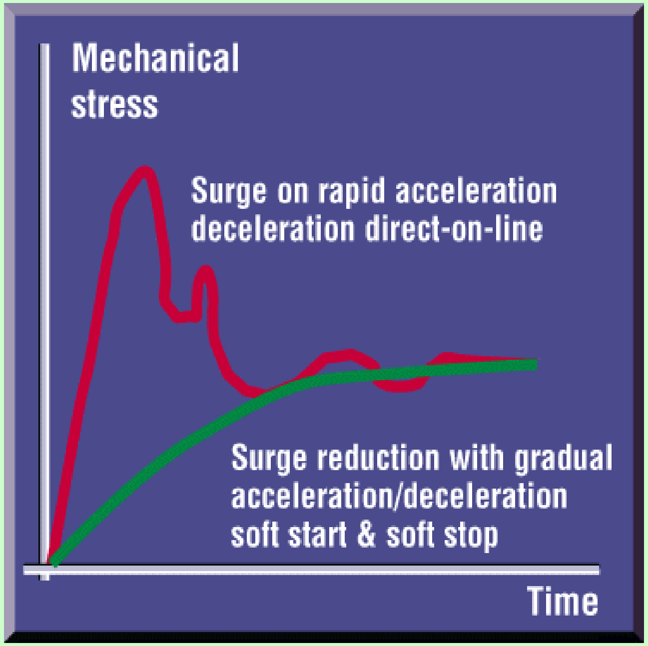
Standard Motor	→	HEM Motor	→	+1% to 3%
Worm Gearbox	→	Helical Gearbox	→	+8% to 10%
“V” belt drive	→	Flat belt drive	→	+5% to 6%

Efficiency gain = 14% to 19%

SOFT STARTER

- SOFT STARTER PROVIDES A RELIABLE AND ECONOMICAL SOLUTION TO STARTING PROBLEMS BY DELIVERING A CONTROLLED RELEASE OF POWER TO THE MOTOR, THEREBY PROVIDING SMOOTH, STEPLESS ACCELERATION AND DECELERATION. MOTOR LIFE WILL BE EXTENDED AS DAMAGE TO WINDINGS AND BEARINGS IS REDUCED.
- ADVANTAGES OF SOFT START
- \- LESS MECHANICAL STRESS
- \- IMPROVED POWER FACTOR
- \- LOWER MAXIMUM DEMAND
- \- LESS MECHANICAL MAINTENANCE





Speed Control of Motors

- TRADITIONALLY, DC MOTORS ARE USED FOR VARIABLE SPEED APPLICATIONS
  - WIDE RANGE OF OUTPUT SPEEDS CAN BE OBTAINED
  - RESTRICTED TO A FEW LOW SPEED, LOW-TO-MEDIUM POWER APPLICATIONS LIKE MACHINE TOOLS AND ROLLING MILLS BECAUSE OF PROBLEMS WITH MECHANICAL COMMUTATION AT LARGE SIZES
  - RESTRICTED FOR USE ONLY IN CLEAN, NON-HAZARDOUS AREAS BECAUSE OF THE RISK OF SPARKING AT THE BRUSHES
  - DC MOTORS ARE ALSO EXPENSIVE RELATIVE TO AC motors

SPEED CONTROL OF MOTORS

- **BOTH AC SYNCHRONOUS AND INDUCTION MOTORS ARE SUITABLE FOR VARIABLE SPEED CONTROL**
  - **INDUCTION MOTORS ARE MORE POPULAR, BECAUSE OF THEIR RUGGEDNESS AND LOWER MAINTENANCE REQUIREMENTS, THEY ARE INEXPENSIVE (HALF OR LESS OF THE COST OF A DC MOTOR) AND ALSO PROVIDE A HIGH POWER TO WEIGHT RATIO (ABOUT TWICE THAT OF A DC MOTOR)**

Motor Speed Control Systems

- **Multi-speed motors**
  - Motors can be wound such that two speeds, in the ratio of 2:1, can be obtained
  - Motors can also be wound with two separate windings, each giving 2 operating speeds, for a total of four speeds
  - limited speed control (two or four fixed speeds instead of continuously variable speed)
  - lower efficiency than single-speed motors

MOTOR SPEED CONTROL SYSTEMS

- ADJUSTABLE FREQUENCY AC DRIVES
  - COMMONLY CALLED INVERTERS
  - DESIGNED TO OPERATE STANDARD INDUCTION MOTORS
  - COVERTS THE 50 HZ INCOMING POWER TO A VARIABLE FREQUENCY AND VARIABLE VOLTAGE. THE VARIABLE FREQUENCY IS THE ACTUAL REQUIREMENT, WHICH WILL CONTROL THE MOTOR SPEED
  - THREE MAJOR TYPES OF INVERTERS
    - CURRENT SOURCE INVERTERS (CSI), VOLTAGE SOURCE INVERTERS (VSI), AND PULSE WIDTH MODULATED INVERTERS (PWM)

Motor Speed Control Systems

- **Direct Current Drives (DC)**
  - **consists of a DC motor and a controller**
  - **speed of the motor is directly proportional to the applied voltage**
  - **controller is a phase controlled bridge rectifier with logic circuits to control the DC voltage delivered to the motor armature**
- **Wound Rotor AC Motor Drives (Slip Ring Induction Motors)**
  - **controller places variable resistors in series with the rotor windings**
  - **torque performance of motor controlled by using these variable resistors**
  - **Wound rotor motors are most common in the range of 300 HP and above ratings**

TYPE OF LOADS

- **THE CHARACTERISTICS OF THE LOAD ARE PARTICULARLY IMPORTANT**
  - **LOAD REFERS ESSENTIALLY TO THE TORQUE OUTPUT AND CORRESPONDING SPEED REQUIRED**
  - **<u>CONSTANT TORQUE LOADS</u> - THE OUTPUT POWER REQUIREMENT MAY VARY WITH THE SPEED OF OPERATION BUT THE TORQUE DOES NOT VARY**
    - **CONVEYORS, ROTARY KILNS, AND CONSTANT-DISPLACEMENT PUMPS**

LOADS….

- VARIABLE TORQUE LOADS - THE TORQUE REQUIRED VARIES WITH THE SPEED OF OPERATION
  - CENTRIFUGAL PUMPS AND FANS (TORQUE VARIES AS THE SQUARE OF THE SPEED)
- CONSTANT POWER LOADS - THE TORQUE REQUIREMENTS TYPICALLY CHANGE INVERSELY WITH SPEED
  - MACHINE TOOLS

APPLICATION OF VARIABLE SPEED DRIVES

LOADS IDEAL FOR VSD APPLICATION: VARIABLE TORQUE (CENTRIFUGAL PUMPS, FANS ETC.)

AT THESE LOADS, TORQUE INCREASES WITH SQUARE OF SPEED AND IS USUALLY ASSOCIATED WITH CENTRIFUGAL FAN AND PUMP LOADS, WHERE, IN THEORY, THE HORSEPOWER REQUIREMENT VARIES AS THE CUBE OF THE SPEED CHANGE. THESE APPLICATIONS USUALLY HAVE THE GREATEST OPPORTUNITIES FOR ENERGY SAVINGS AS WELL AS IMPROVED CONTROL.

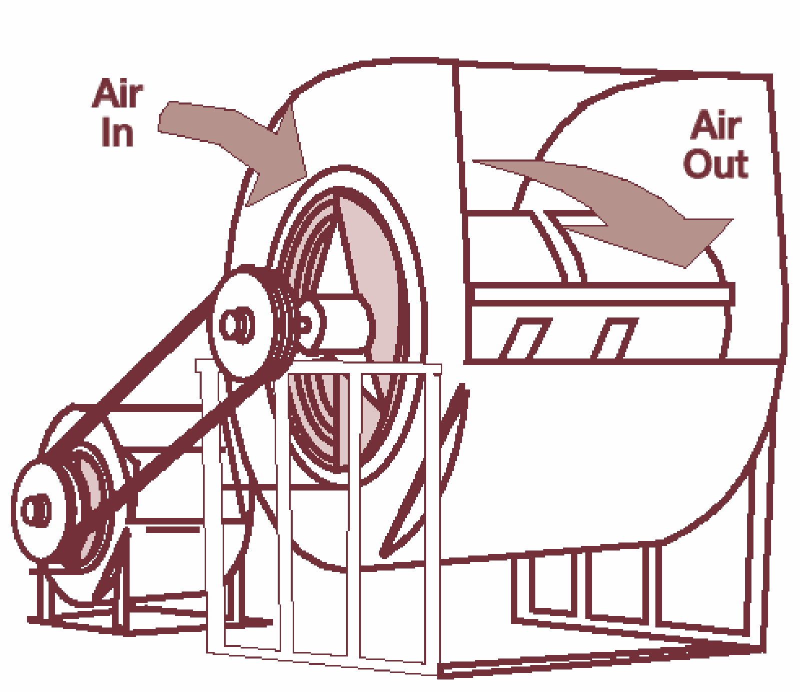
APPLICATION OF VARIABLE SPEED DRIVES

LOADS REQUIRING CAREFUL VSD APPLICATION: CONSTANT TORQUE LOADS (POSITIVE DISPLACEMENT AIR COMPRESSORS, CONVEYORS, CRUSHERS ETC)

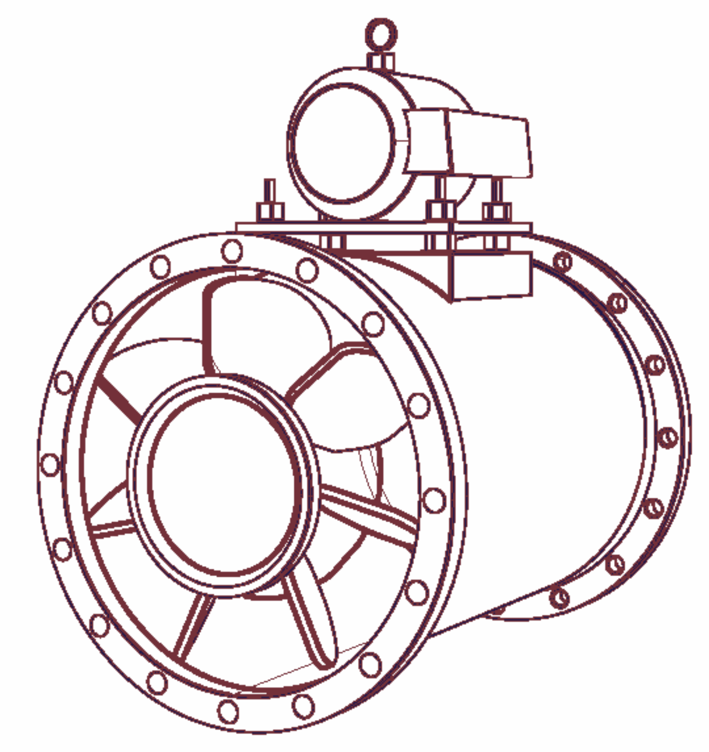
CONSTANT-TORQUE LOADS REQUIRE THE SAME TORQUE REGARDLESS OF SPEED. ALTHOUGH CONSTANT-TORQUE LOADS ARE SUITABLE FOR ASDS, OPERATION OF THESE LOADS AT LOW RPM WILL BE LIMITED, AND THE ASD MUST BE CAREFULLY SIZED TO ENSURE ADEQUATE STARTING TORQUE. POWER IS PROPORTIONAL TO SPEED.

Fans and Blowers

Fan types

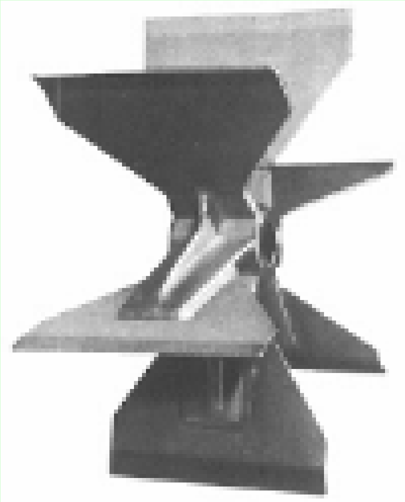


Centrifugal fan

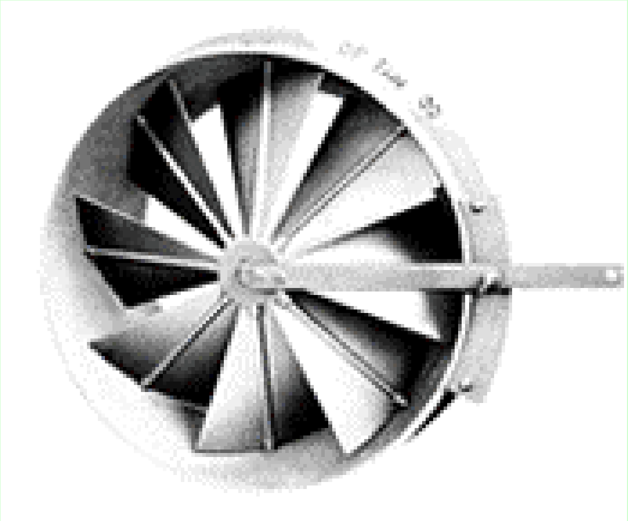


Axial fan

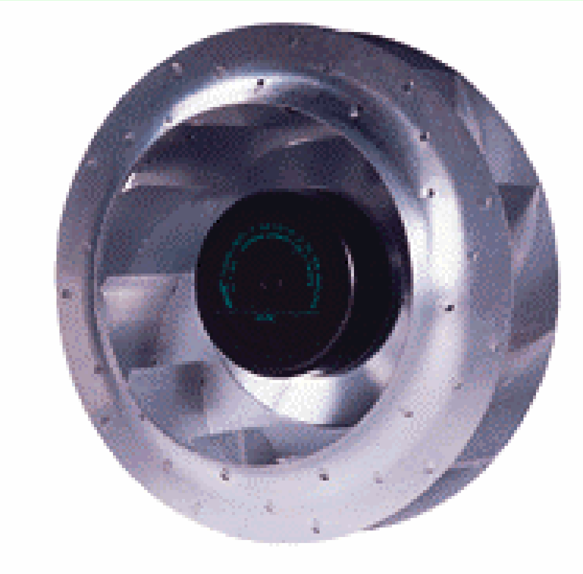
Centrifugal Fan: Types



Paddle Blade
(Radial blade)



Forward Curved
(Multi vane)

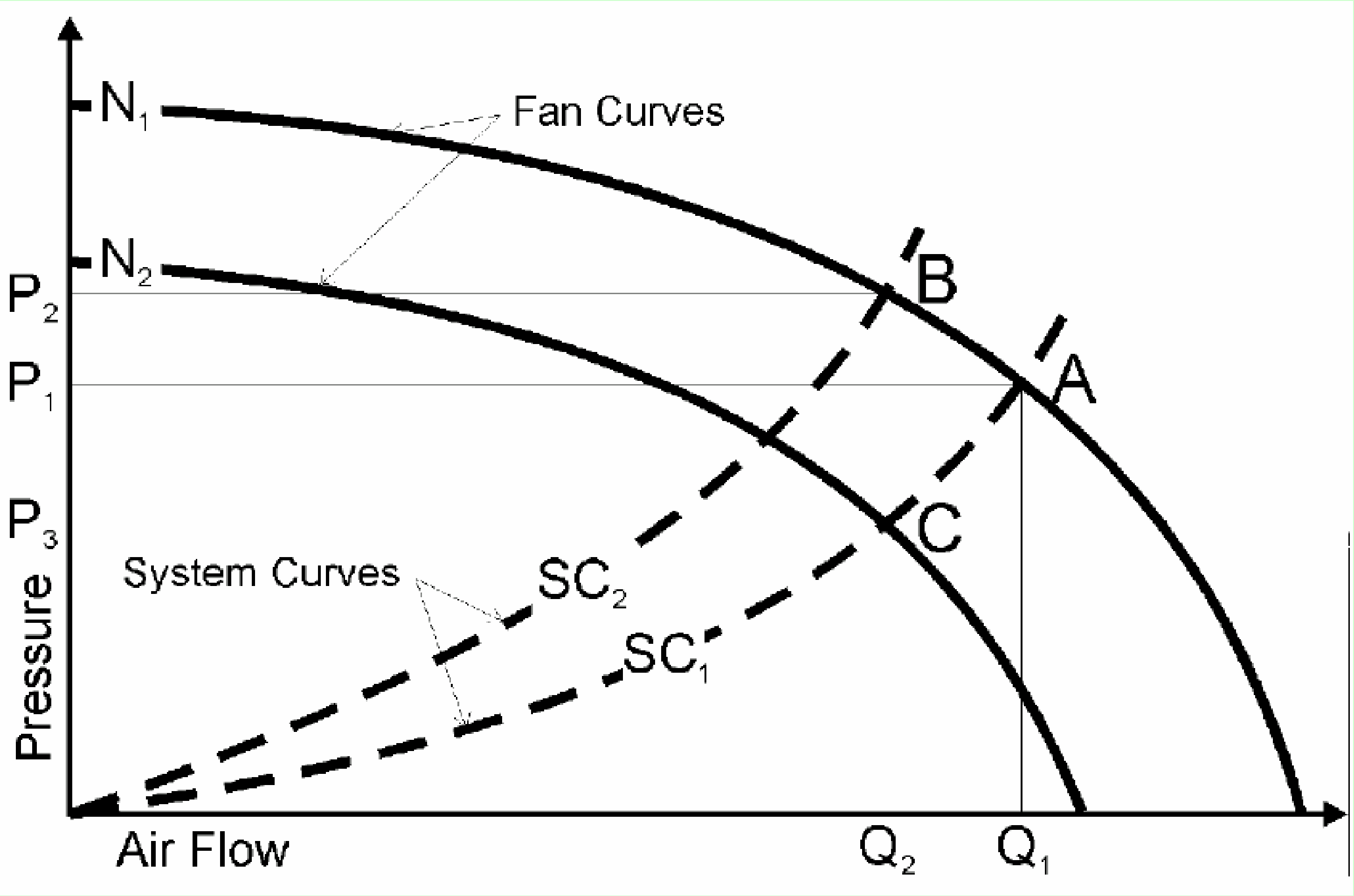


Backward Curved

Fan Types and Efficiencies

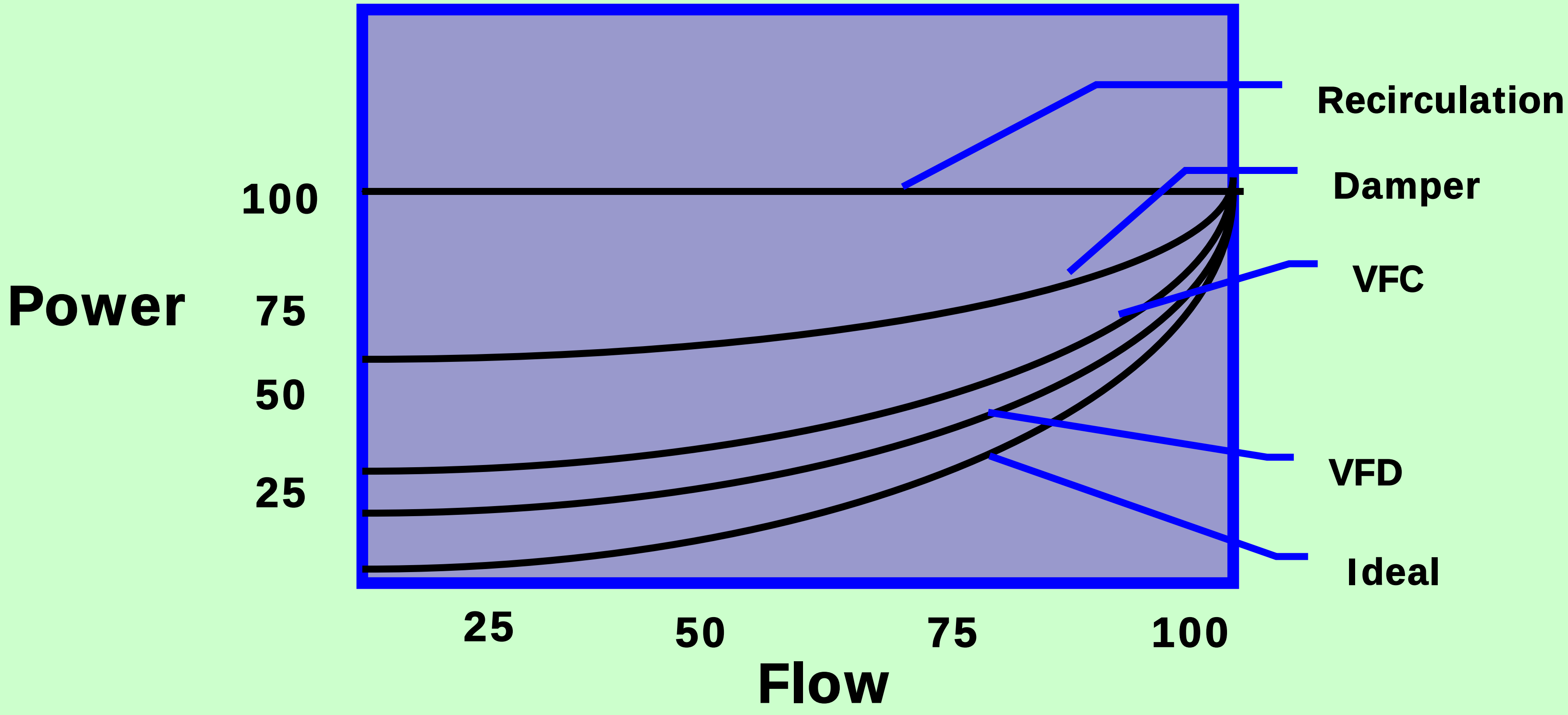
Centrifugal Fans	**Peak Efficiency Range**
Airfoil, backwardly curved/inclined	79-83
Modified radial	72-79
Redial	69-75
Pressure blower	58-68
Forwardly curved	60-65
Axial fan	
vanaxial	78-85
Tubeaxial	67-72
Propeller	45-50

System curve

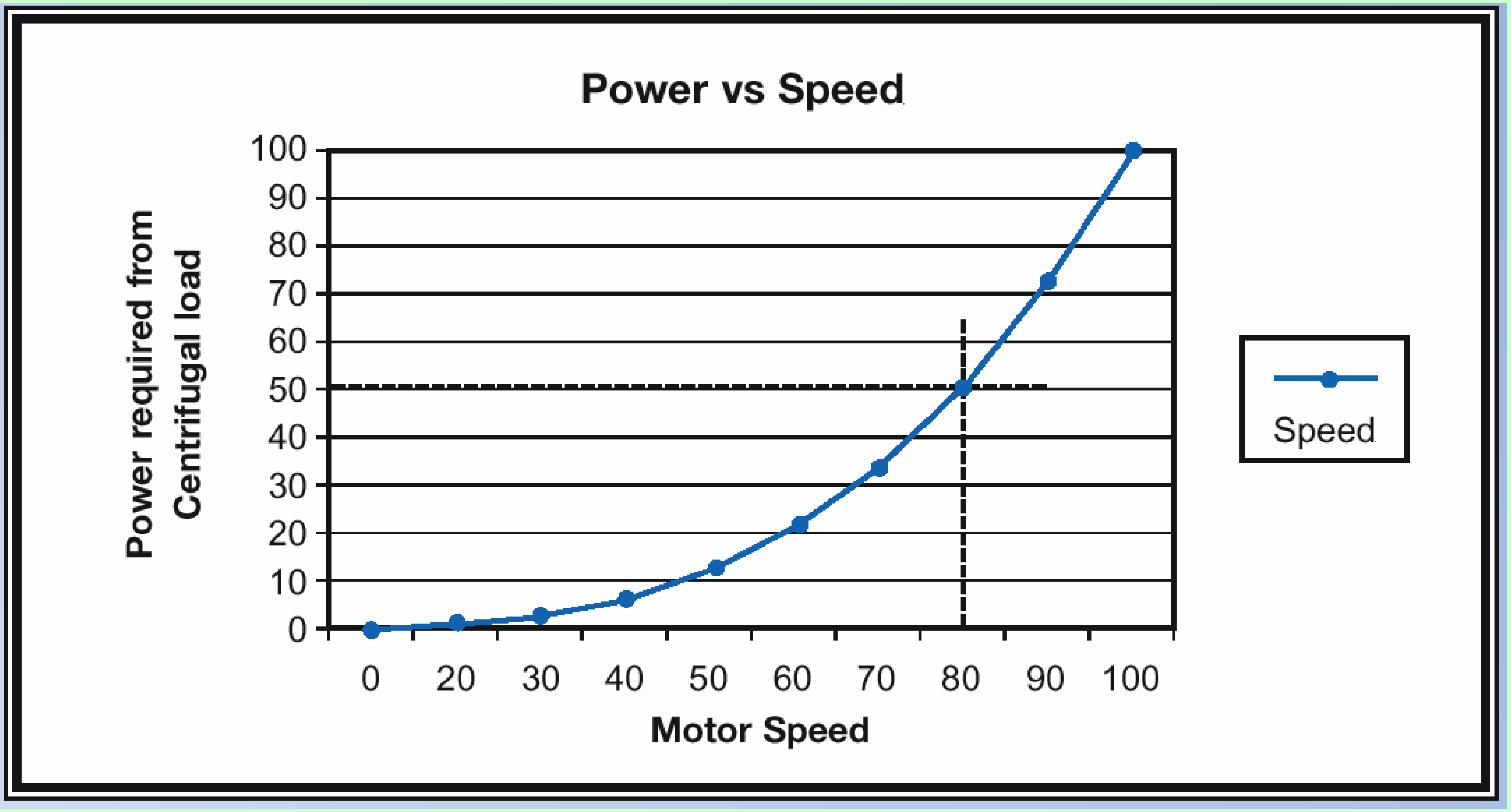


Flow control

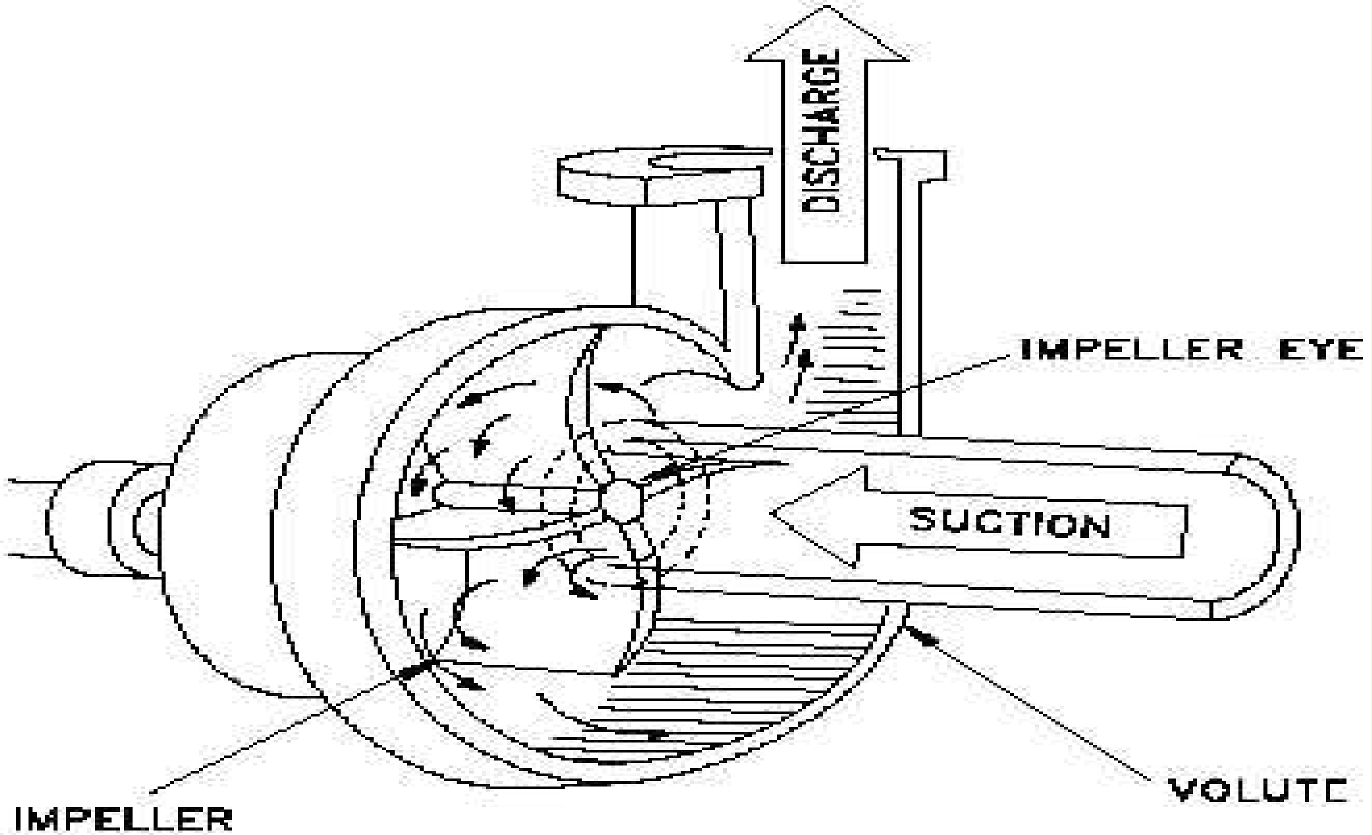
- Damper - Most Popular
- Variable Speed Drive



Impact of speed reduction



Pumps and Pumping Systems

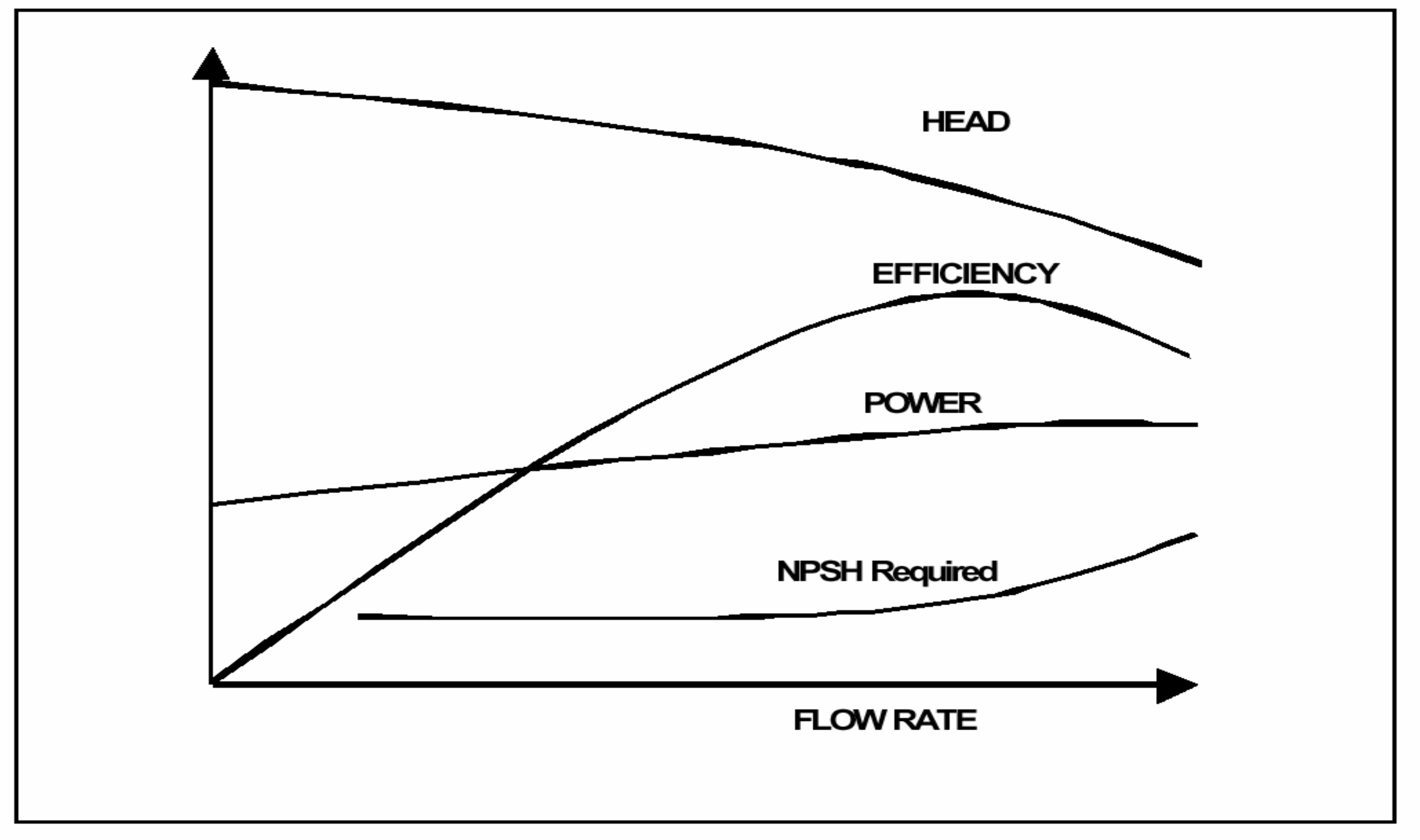


Centrifugal pump

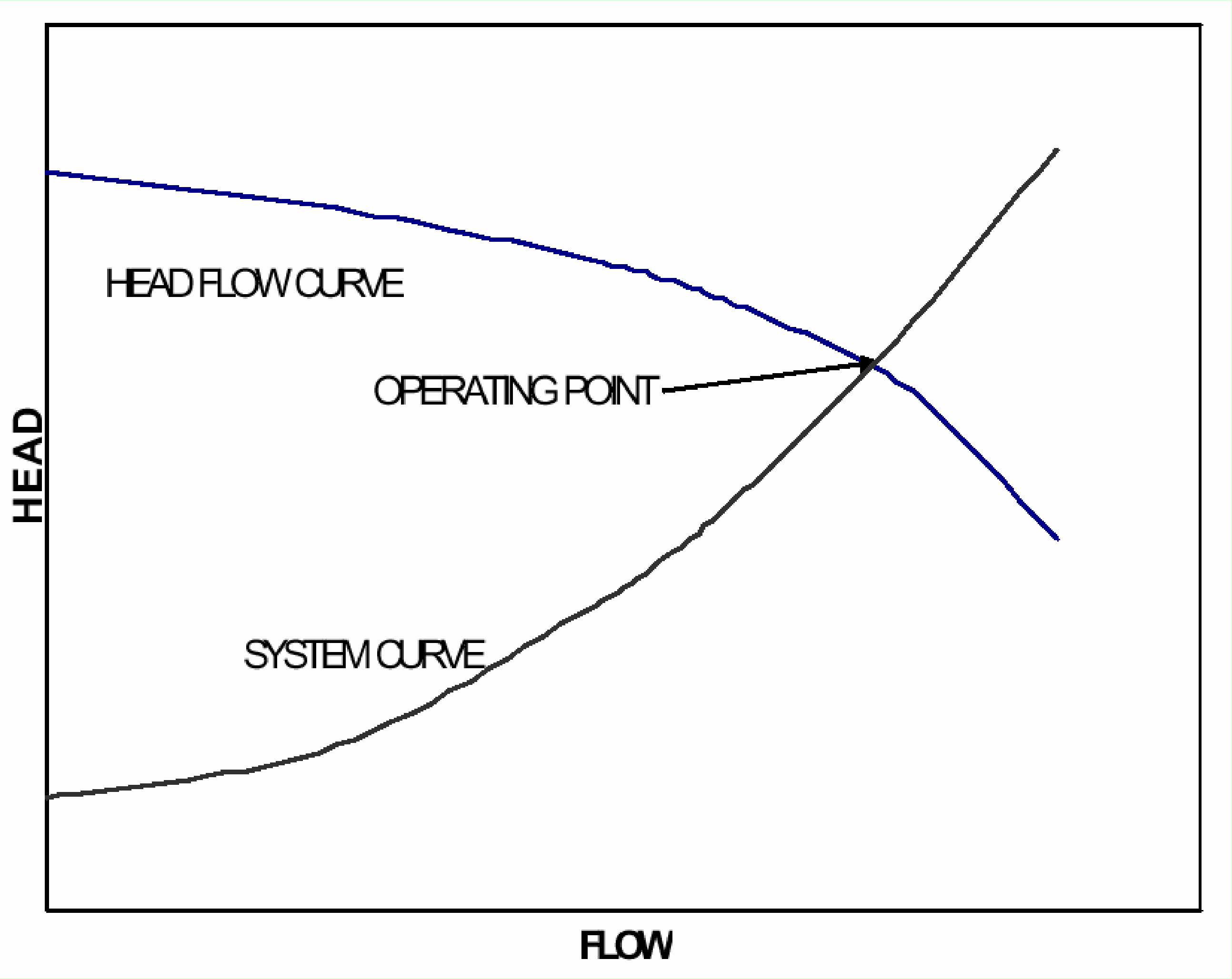
Pump Types

- Dynamic type
  - centrifugal and special effect pumps
- Displacement type
  - rotary or reciprocating pumps
- Centrifugal pump is generally the most economical followed by rotary and reciprocating pumps
- Although, positive displacement pumps are generally more efficient than centrifugal pumps, the benefit of higher efficiency tends to be offset by increased maintenance costs
- centrifugal pumps account for the majority of electricity used by pumps

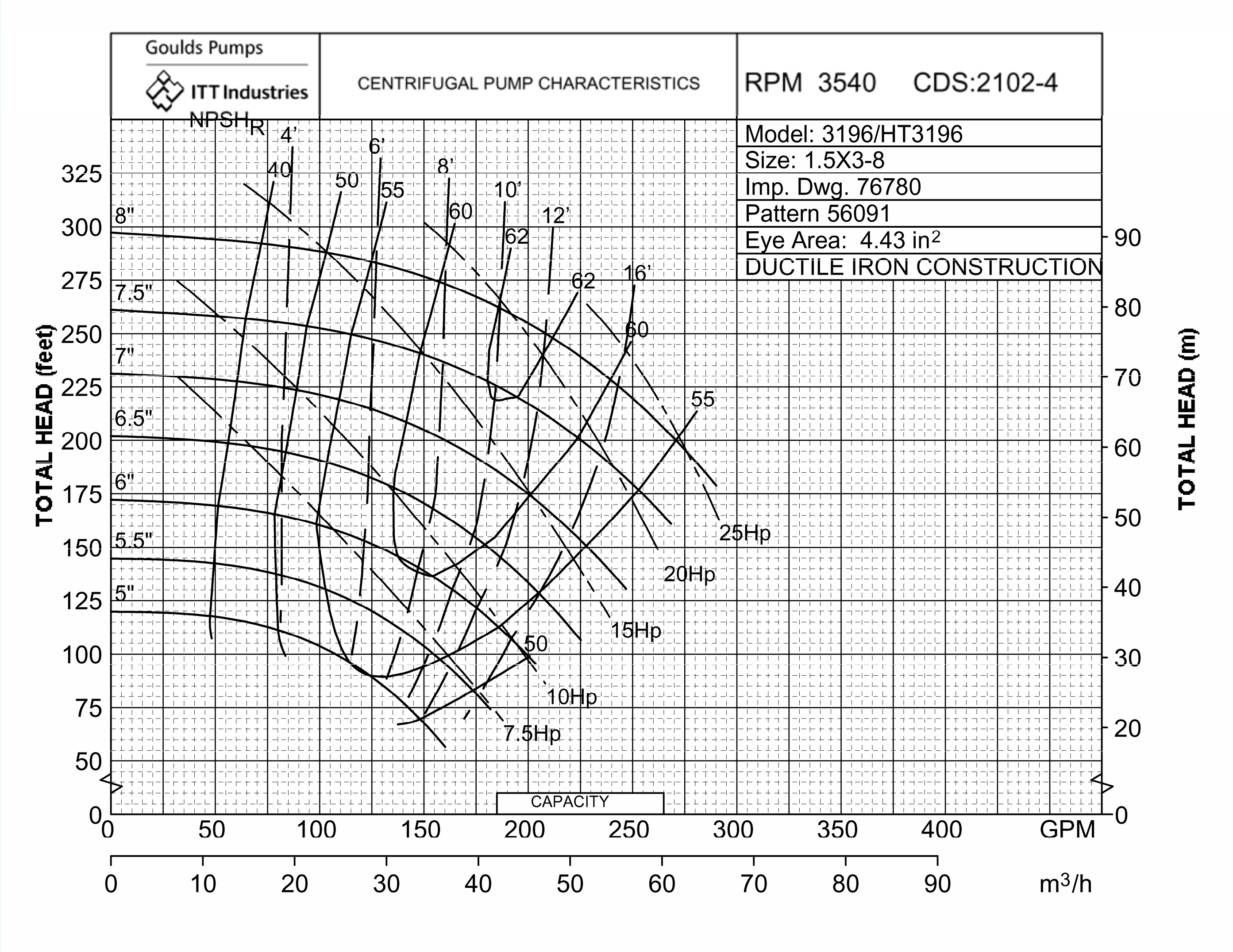
Pump Performance Curve



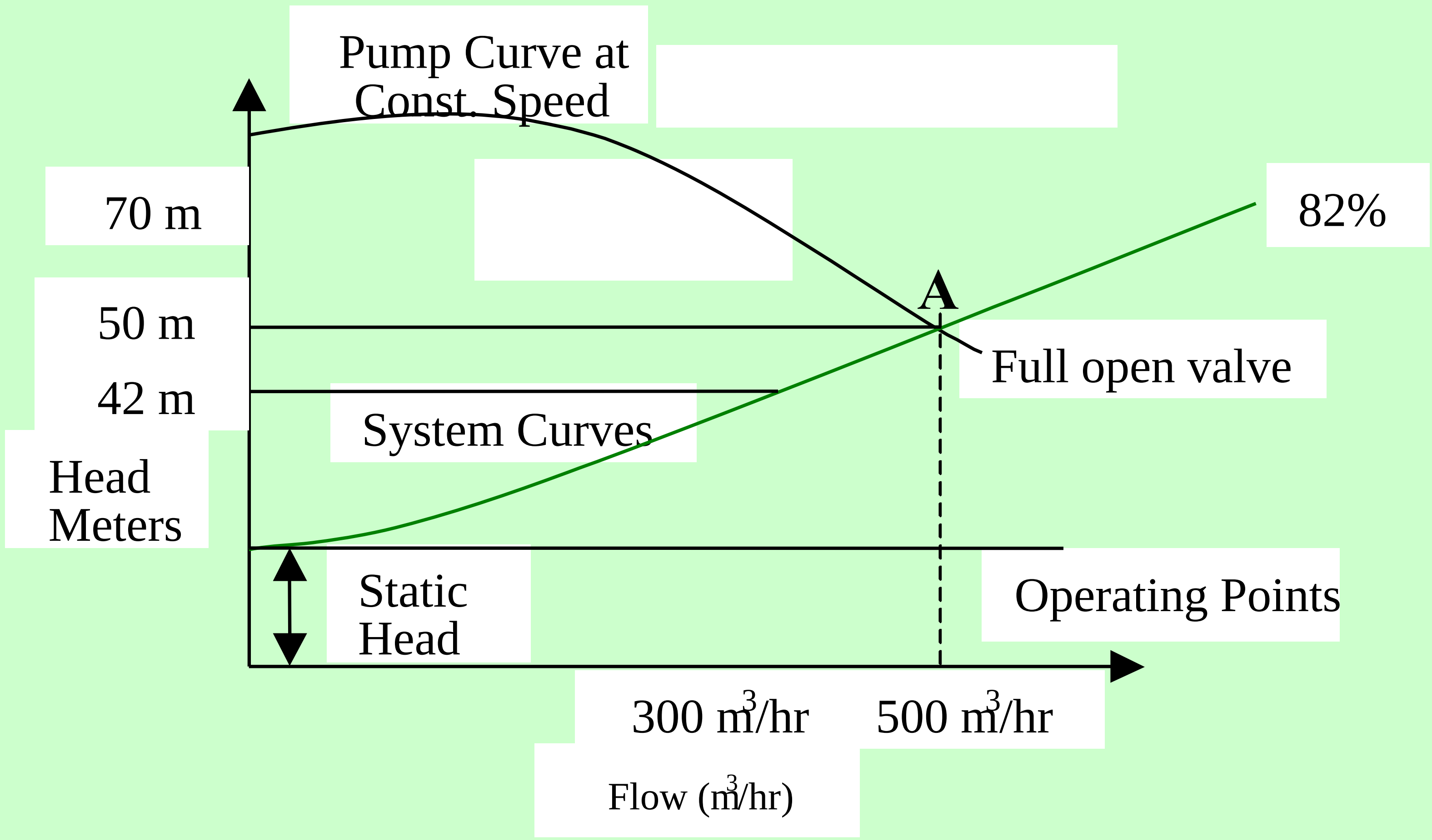
Pump operating point



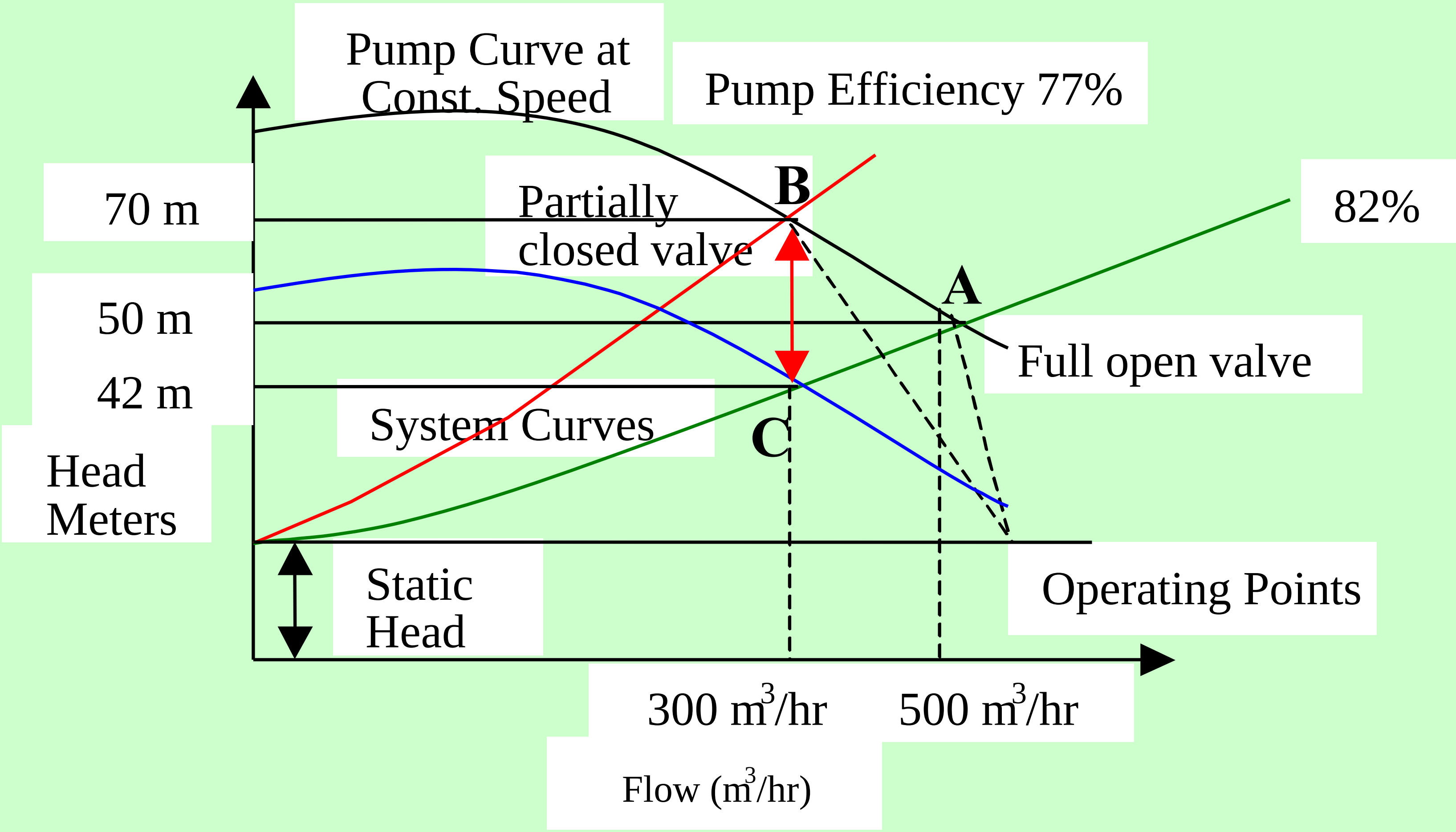
Typical pump characteristic curves



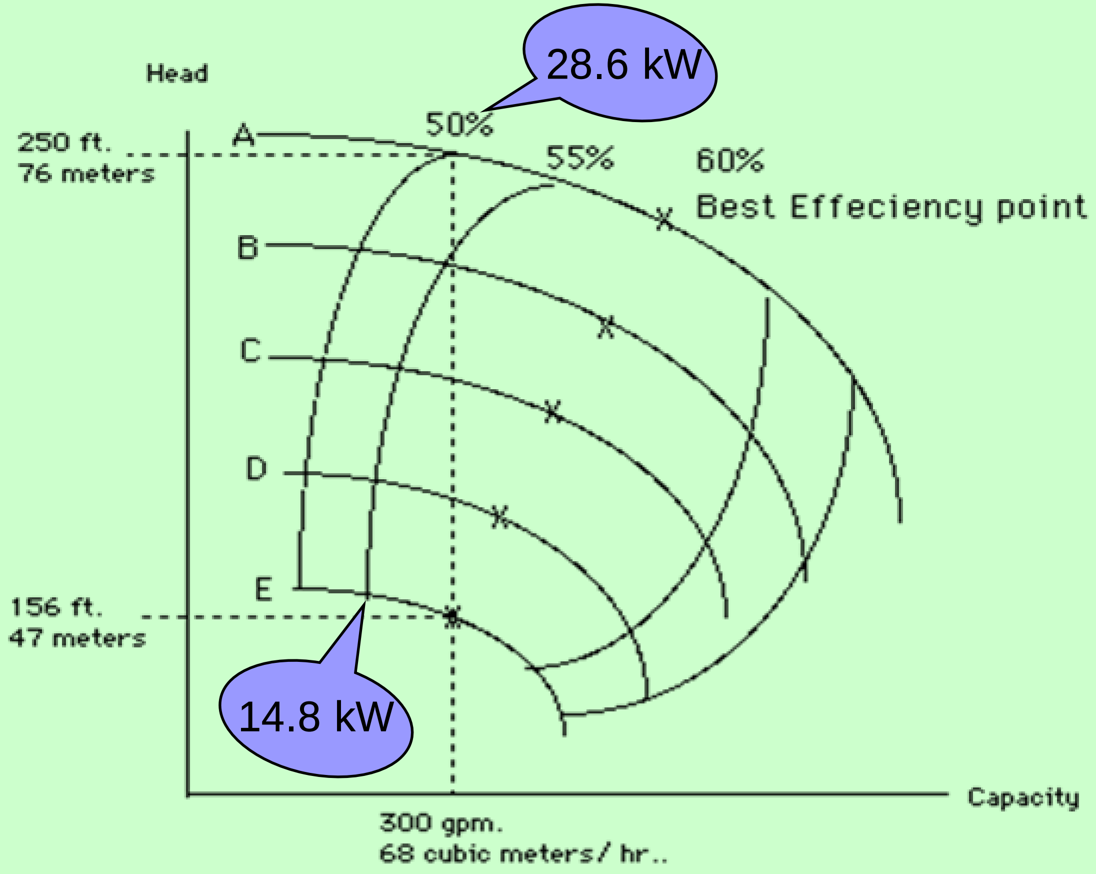
Effect of Throttling



Effect of Throttling



Efficiency Curves



ENERGY CONSERVATION OPPORTUNITIES IN PUMPING SYSTEMS

- **OPERATE PUMPS NEAR BEST EFFICIENCY POINT.**
- **MODIFY PUMPING SYSTEM AND PUMPS LOSSES TO MINIMIZE THROTTLING.**
- **ADAPT TO WIDE LOAD VARIATION WITH VARIABLE SPEED DRIVES OR SEQUENCED CONTROL OF MULTIPLE UNITS.**
- **USE BOOSTER PUMPS FOR SMALL LOADS REQUIRING HIGHER PRESSURES.**
- **AVOID COOLING WATER RE-CIRCULATION IN DG SETS, AIR COMPRESSORS, REFRIGERATION SYSTEMS, COOLING TOWERS FEED WATER PUMPS, CONDENSER PUMPS AND PROCESS PUMPS.**

THANK YOU…………

HOPE YOU FOUND THE LECTURES USEFUL

- CREATE AND SAVE ENERGY
- USE RENEWABLES
- LEAVE ENERGY SOURCES TO FUTURE GENERATIONS
- MAKE TECHNOLOGY SUSTAINABLE