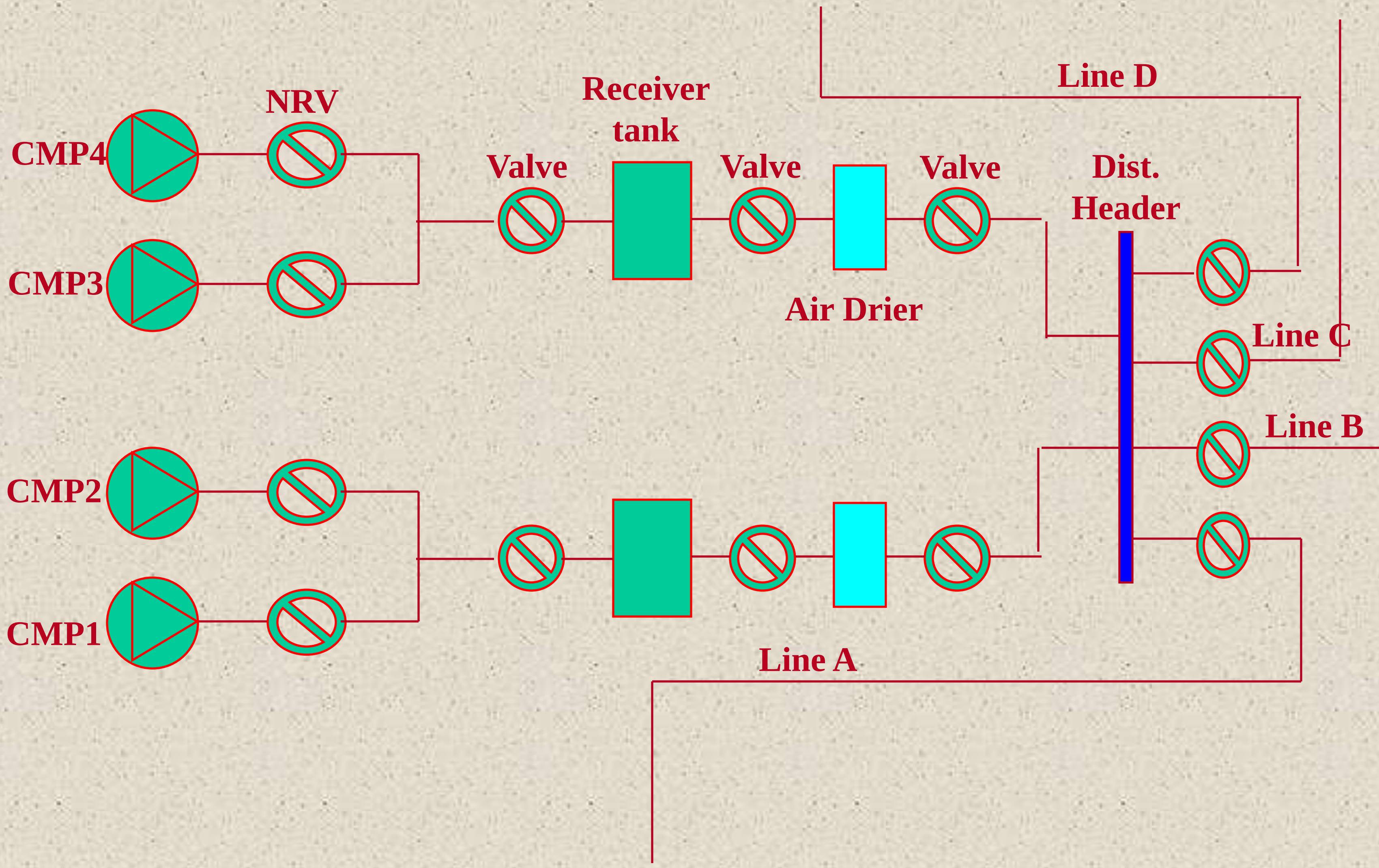
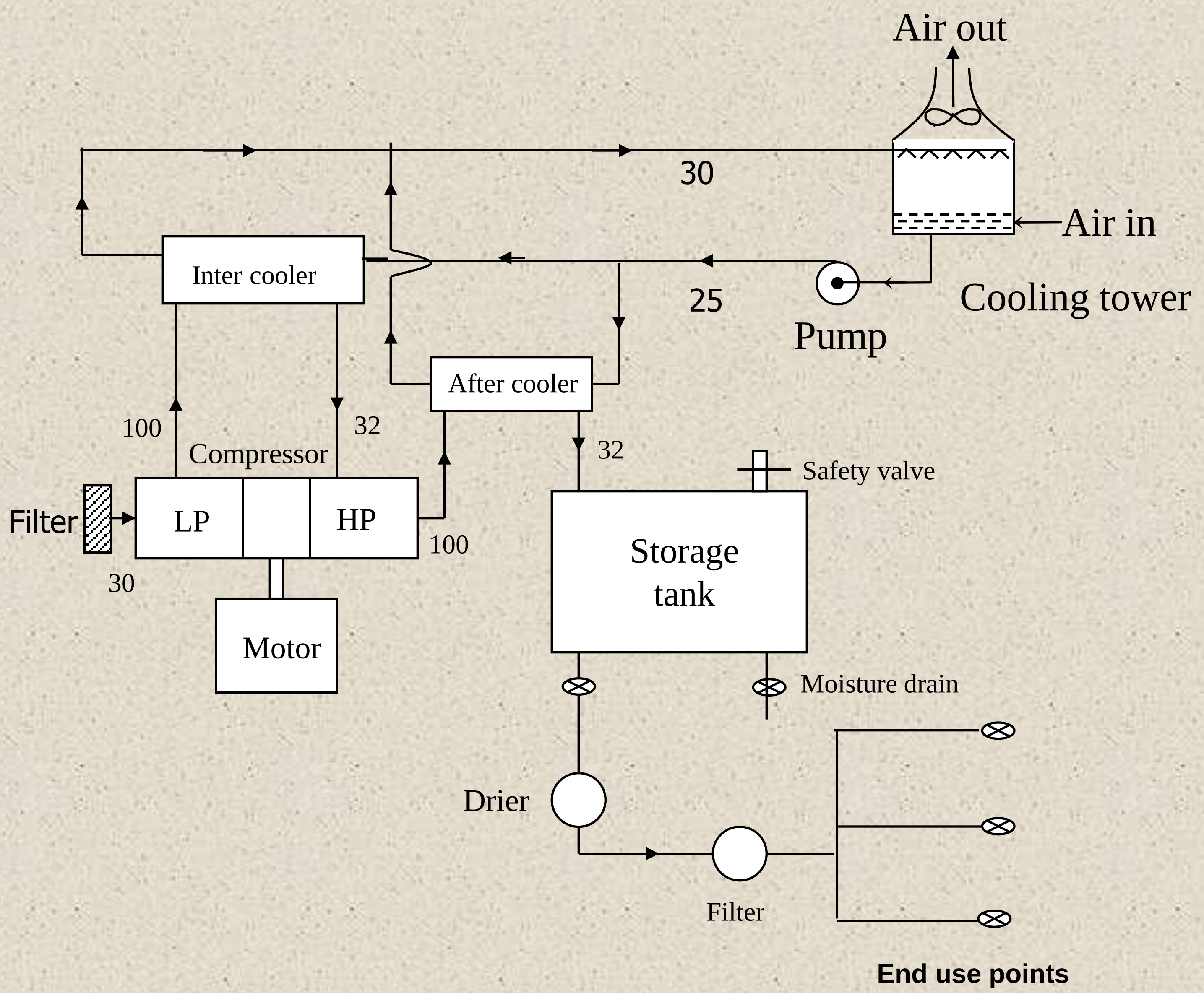
ENERGY CONSERVATION IN PROCESS EQUIPMENTS

Rajashekar P. Mandi, Engineering Officer
Energy Conservation & Development Division, CPRI, Bangalore

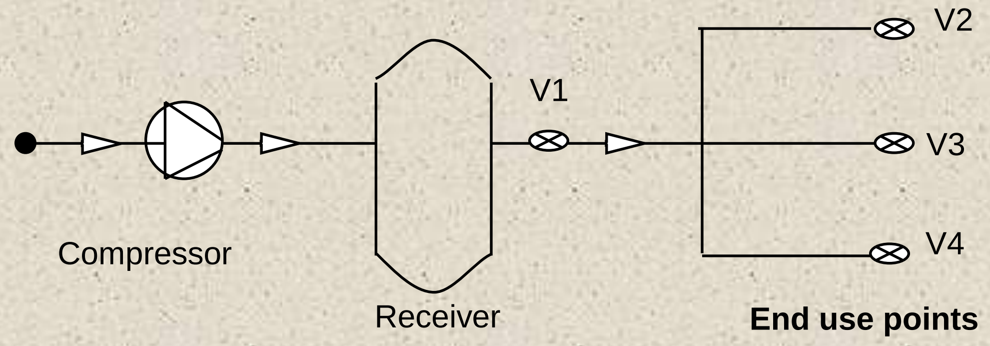
AIR COMPRESSORS



AIR COMPRESSORS



Free air delivery Test (FAD)



- Close the valve V1
- Drain the air receiver
- Switch on air compressor till the receiver pressure reaches to rated pressure
- Record the time taken from zero pressure to rated air pressure
- Capacity of the compressor = $\frac{(P_r - P_o) \times V}{P_a \times t}$ m^3/min.

Where, P_a – Atmospheric pressure, bar (absolute)

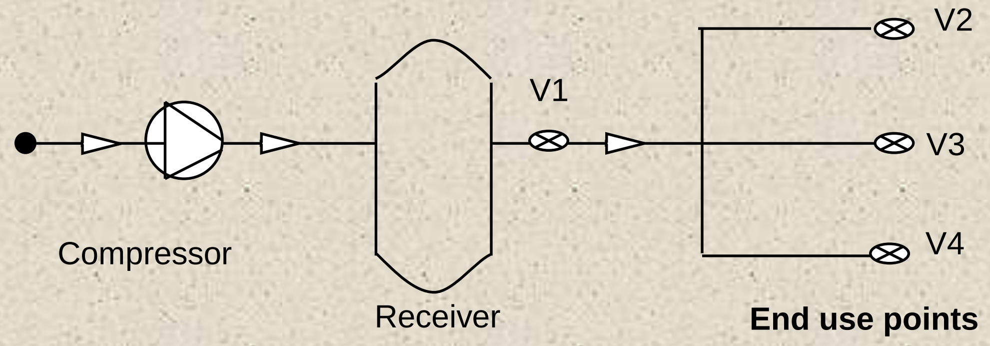
P_r - Rated pressure, bar

P_o – Initial pressure bar

V – Volume of receiver + pipe line before valve V1, m^3

t – Time taken for charging, min.

Air leak Test in Tank & compressor



- Open valve VI and close all the end use valves (V2, V3, V4, etc.)
- Switch ON air compressor and record the loading time (cut –in to cut – out pressure) and unloading time (cut-out to cut-in pressure) of the compressor.

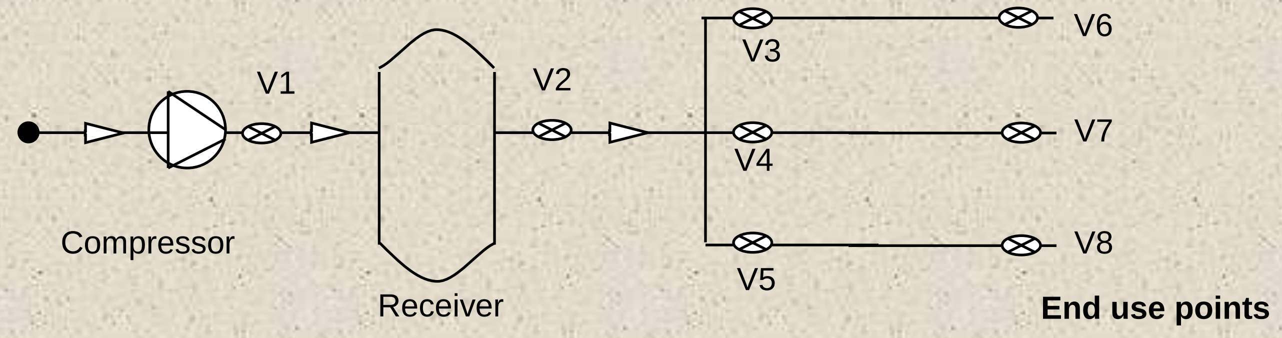
$$\text{Air leakage rate} = \frac{t_{load} \times 100}{t_{load} + t_{unload}} \%$$

Where t_{load} – Average loading time of compressor, min.

t_{unload} – Average unloading time of compressor, min

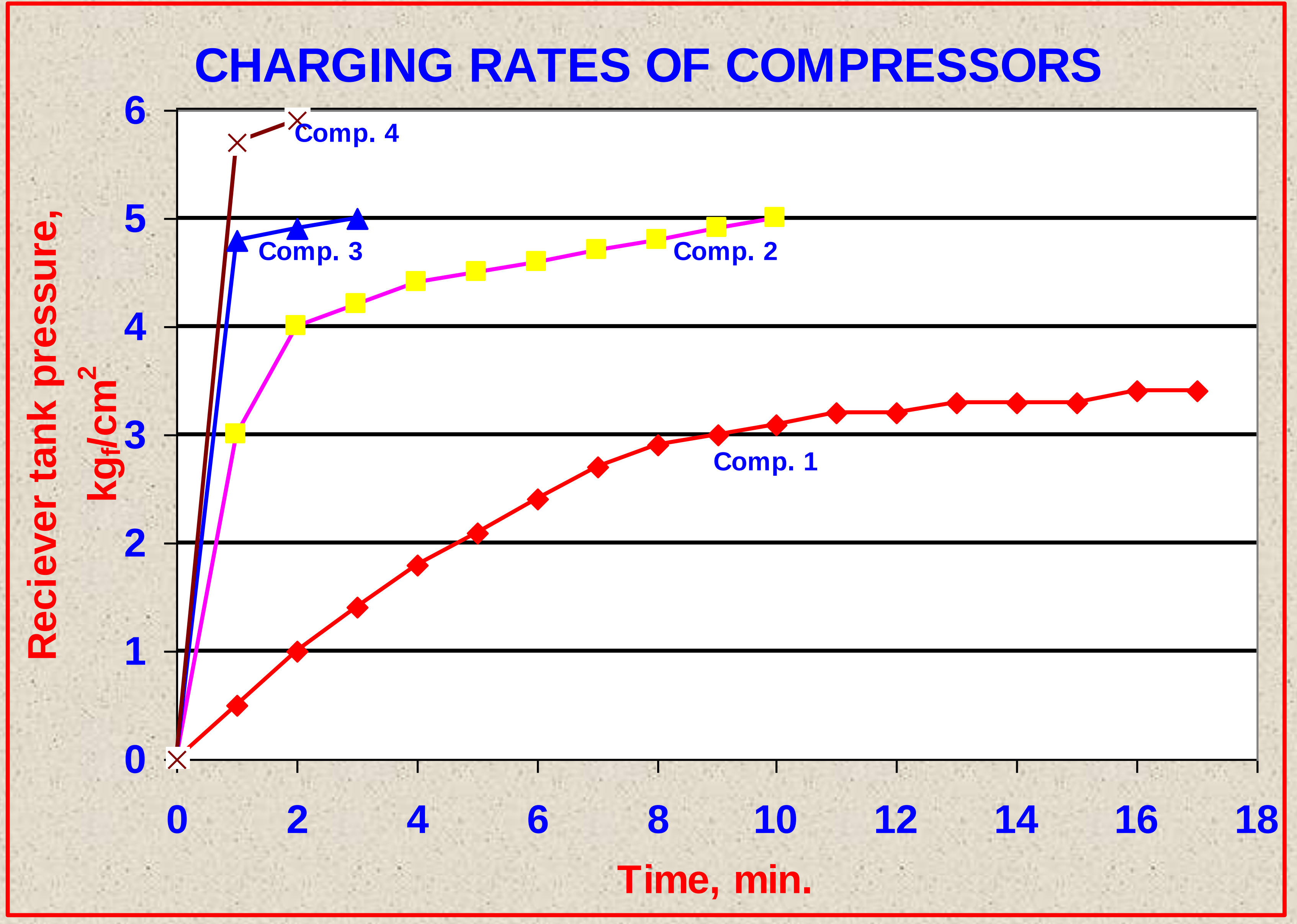
Air leakage rate = Leak in % x Present capacity of compressor in m^3/min.

Air leak Test in Pipe lines

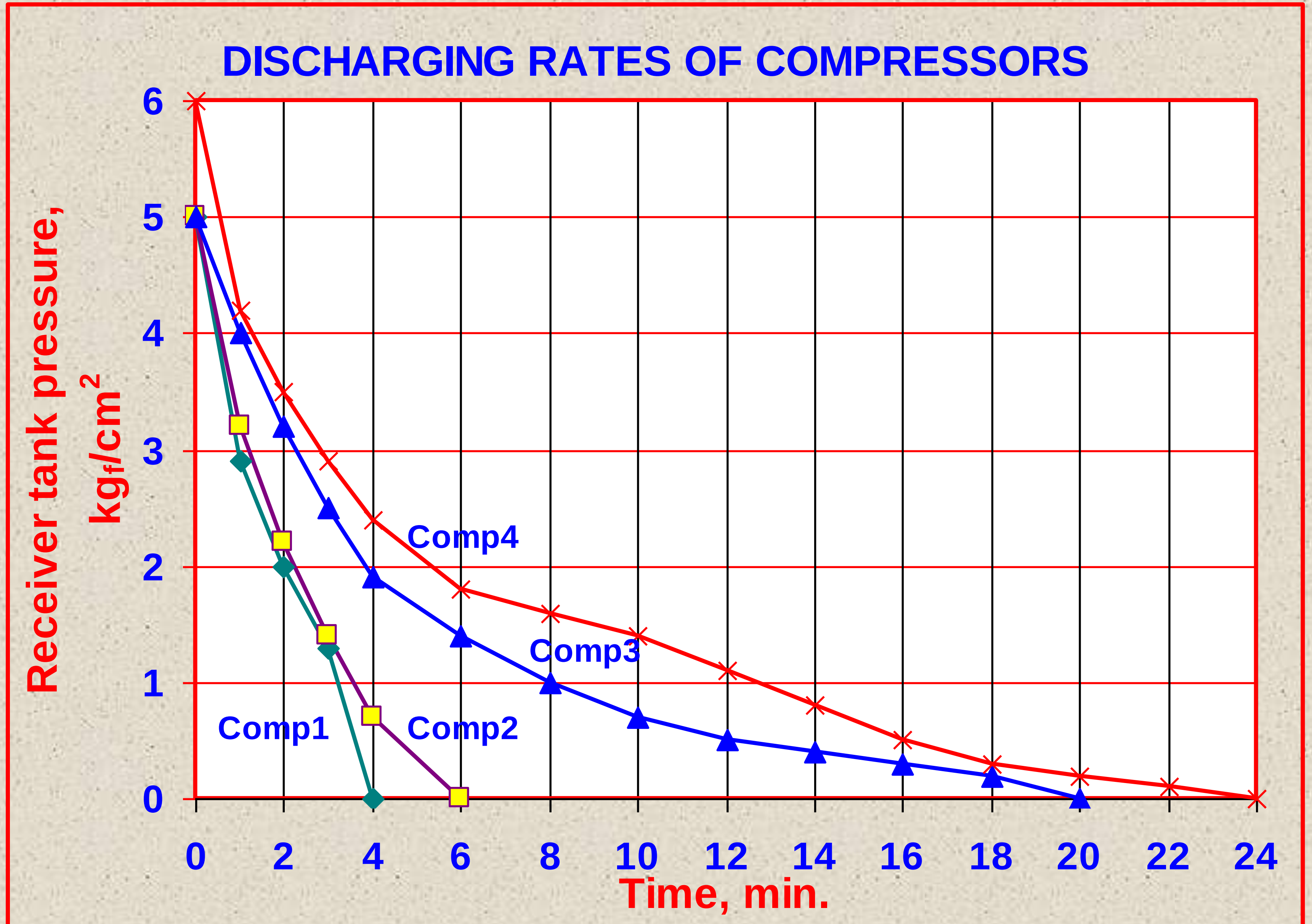


- Open valve V2, Close valve V1, Switch Off compressor and open the end use valves at air compressor side (V3, V4, V5, etc) and close valves at near equipments one by one (V6, V7, V8, etc.)
- Record the pressure drop in receiver tank.

AIR COMPRESSORS



AIR COMPRESSORS



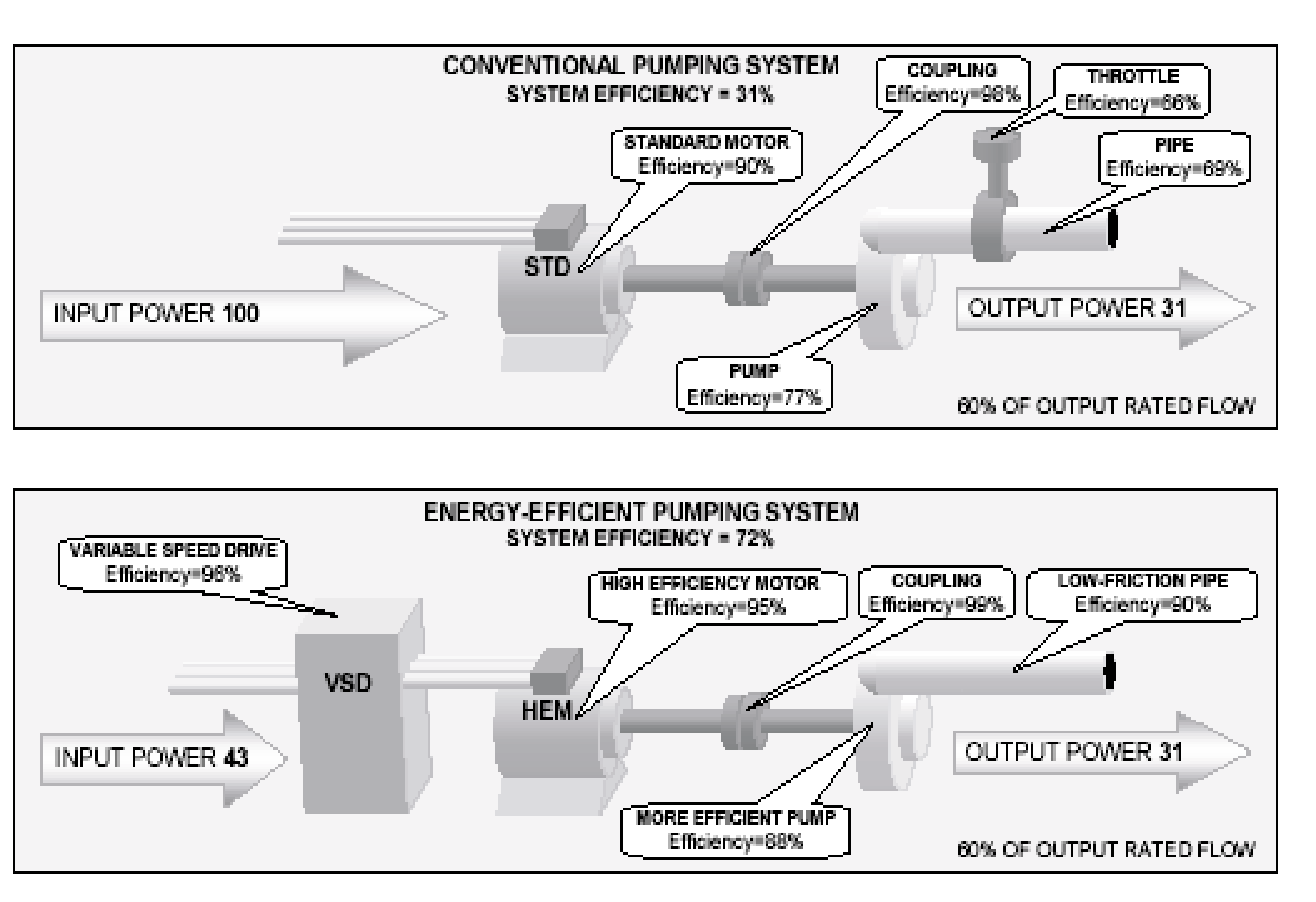
Energy Conservation measures

- Use of Optimum capacity air compressor
- Optimum air pressure based on application. Reducing the air pressure by 1 atm will reduce the energy consumption by about 9 %.
- Optimum capacity of air receiver tank will reduce the frequent ON/OFF of air compressors.
- Use of Variable frequency drives (VFD) or soft starter or intelligent motor controller will saves energy.
- If the compressor loading time is less, the speed of the compressor can be reduced by changing the pulley ratio.

Pumping System

Description	Range	Best practice
Volumetric efficiency of pump	48.0-63.0	85.0
Pressure efficiency of pump	62.0-74.0	95.0
Pump mechanical efficiency	95.0-97.0	99.0
Pump efficiency	28.3-45.2	79.9
Motor efficiency	75.0-82.0	85.0
Circuit efficiency	23.0-39.0	80.0
Re-circulation efficiency	65.0-90.0	100.0
Material utilization efficiency	80.0-90.0	100.0
Circuit pressure efficiency	28.0-43.0	80.0
Overall circuit efficiency	3.2-13.0	54.3
SEC(kWh/ (t of water))	10.1-22.3	6.3
Energy conservation potential	-	76.0

Pumping System



Causes for low efficiency

Volumetric efficiency (pump)

- Leakage through labyrinths,
- Balancing valves and glands;
- Reverse flow from impeller discharge past wearing ring to the suction eye

Pressure efficiency (pump)

- Liquid friction losses through suction elbow/nozzle,
- Impeller surface,
- Entrance/exit valve, etc.

Mechanical efficiency (pump)

- Friction losses in bearings,
- Stuffing box and disk,
- Wearing rings, etc.

Causes for low efficiency

Pump efficiency

- Operation at non-optimal operating point,
- Deterioration in efficiency due to aging of the pump

Pumping circuit efficiency

- High exit losses -exit of water at a pressure higher than the end requirement,
- throttling losses at the end use point

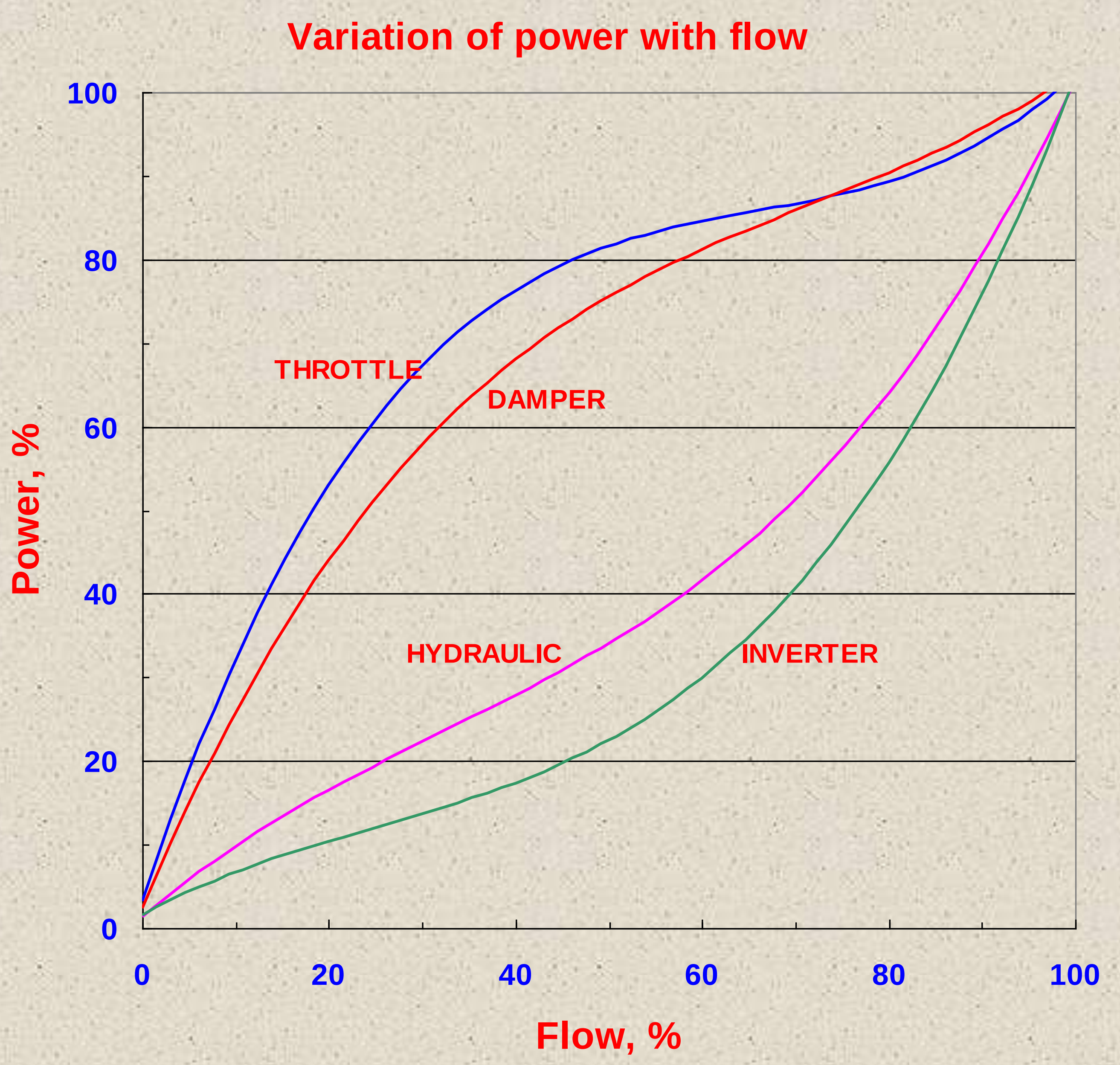
Re-circulation efficiency

- Excessive volumetric capacity in any section is corrected by re-circulation

Material utilization efficiency

- Leakage of water from tanks due to overflow,
- leakage through pipe joints,
- control valves and through breaks in piping and leakage through end use points due to not utilization of water

Flow control



ELECTRO-MECHANICAL CONTROLS

- FLOW RE-CIRCULATION SYSTEMS
- VARIABLE PULLEY SHEAVES
- GEARS
- CHAIN DRIVERS
- MULTI-SPEED MOTORS
- EDDY CURRENT DRIVES
- FLUID COUPLING DRIVES
- MULTIPLE PUMP-MOTOR IN SERIES/PARALLEL

COMMERCIAL CONTROLS

- STAR DELTA STARTERS
- DEL-STAR STARTERS
- PROGRAMMABLE MOTOR CONTROLLERS
- VARIABLE SPEED DRIVES
- VARIABLE FREQUENCY DRIVES

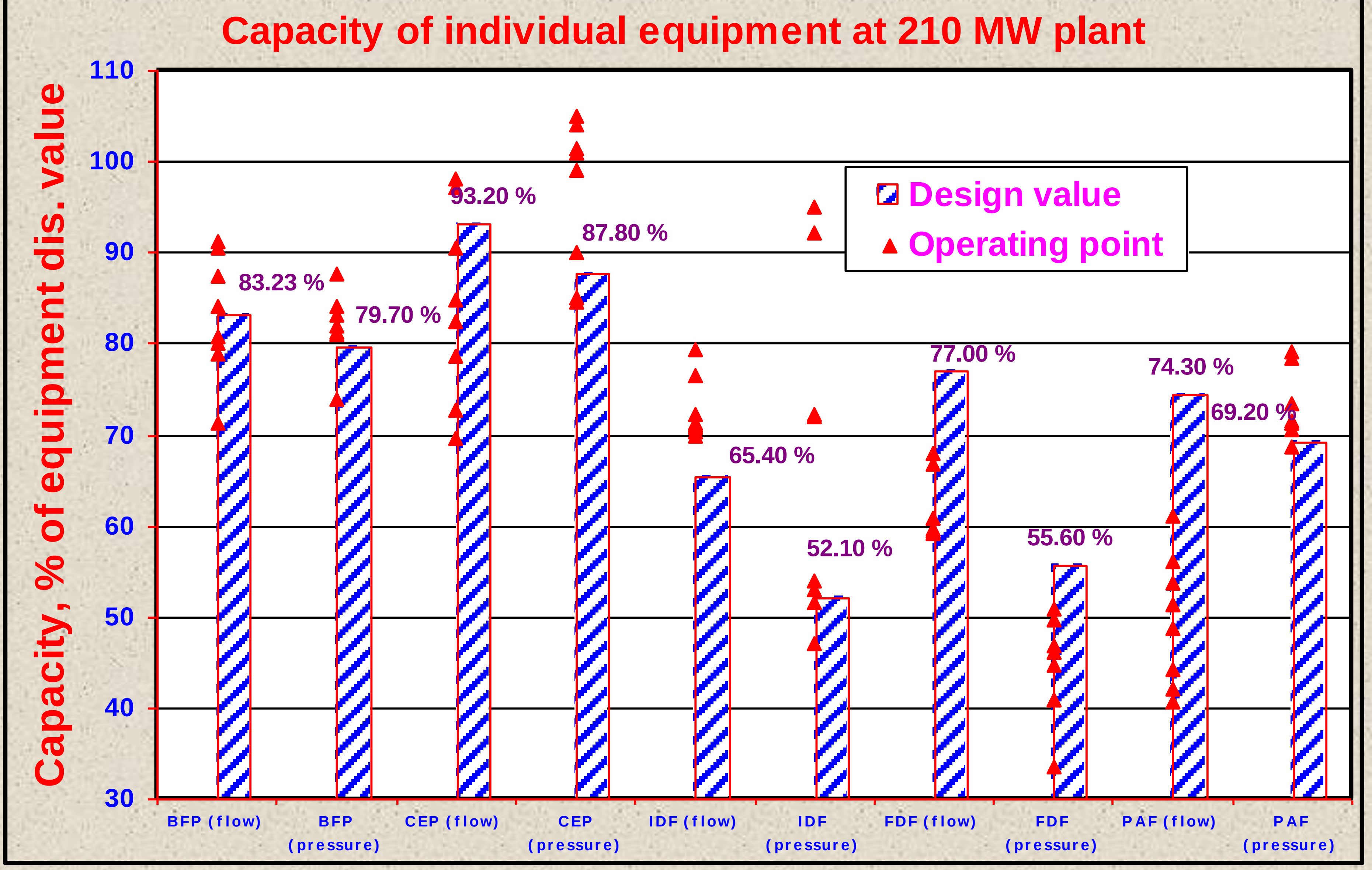
BEST PRACTICES

- ✓ Elimination of redundancy
- ✓ Motor matching
- ✓ Energy efficient motors
- ✓ 3-d design
- ✓ Rapid prototyping
- ✓ Robust designs
- ✓ Concurrent designs
- ✓ Mono-blocks & canned motor-pumps
- ✓ Monitoring schemes

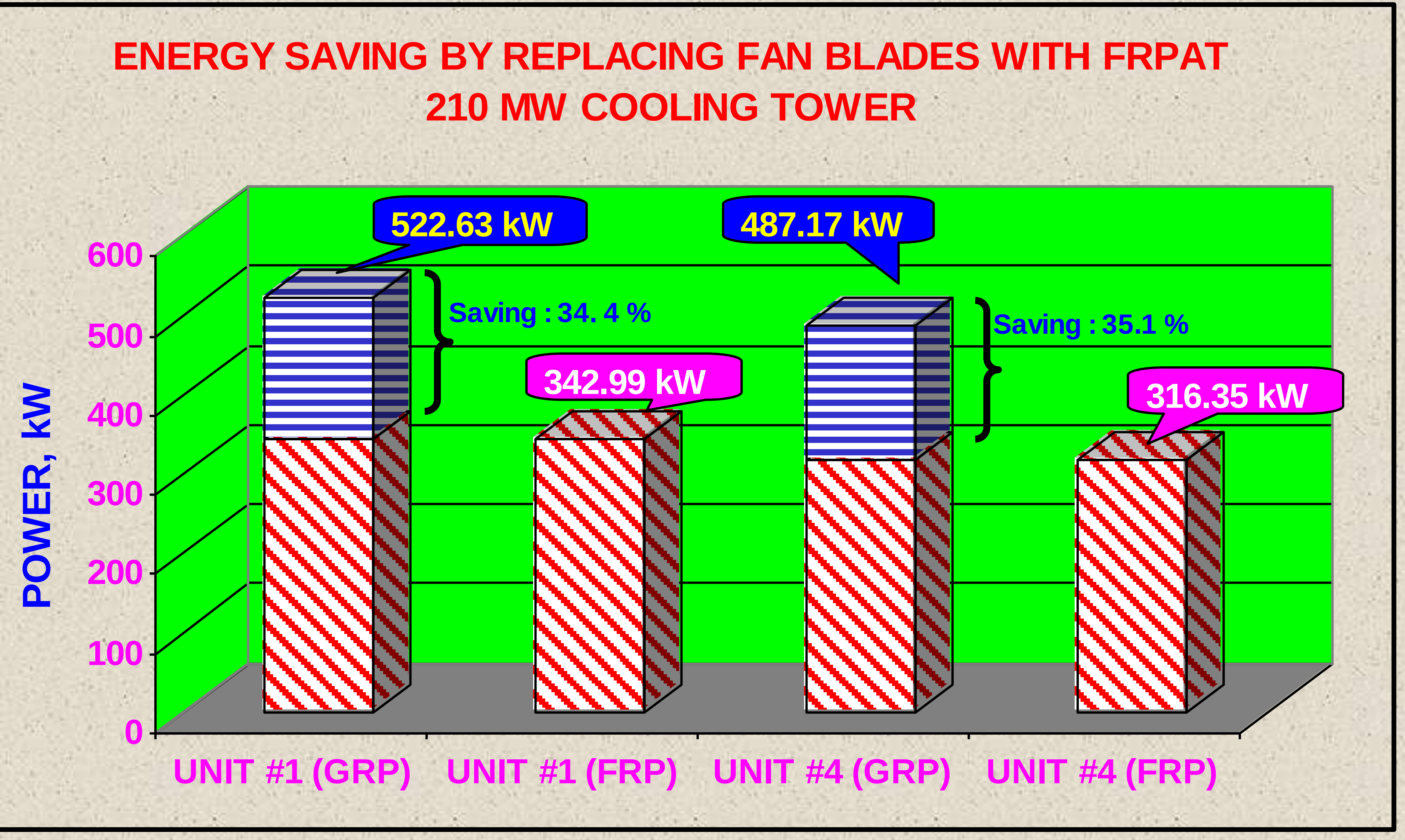
BEST PRACTICES

- ✓ Pre-purchase interactions with manufacturer : Pump fitted to application rather than application fitted to pump
- ✓ Quality planning
- ✓ Life cycle costing : concerns of reliability, safety, environment and energy: Energy is predominant
- ✓ Planning for renovation, modernization and up-gradation

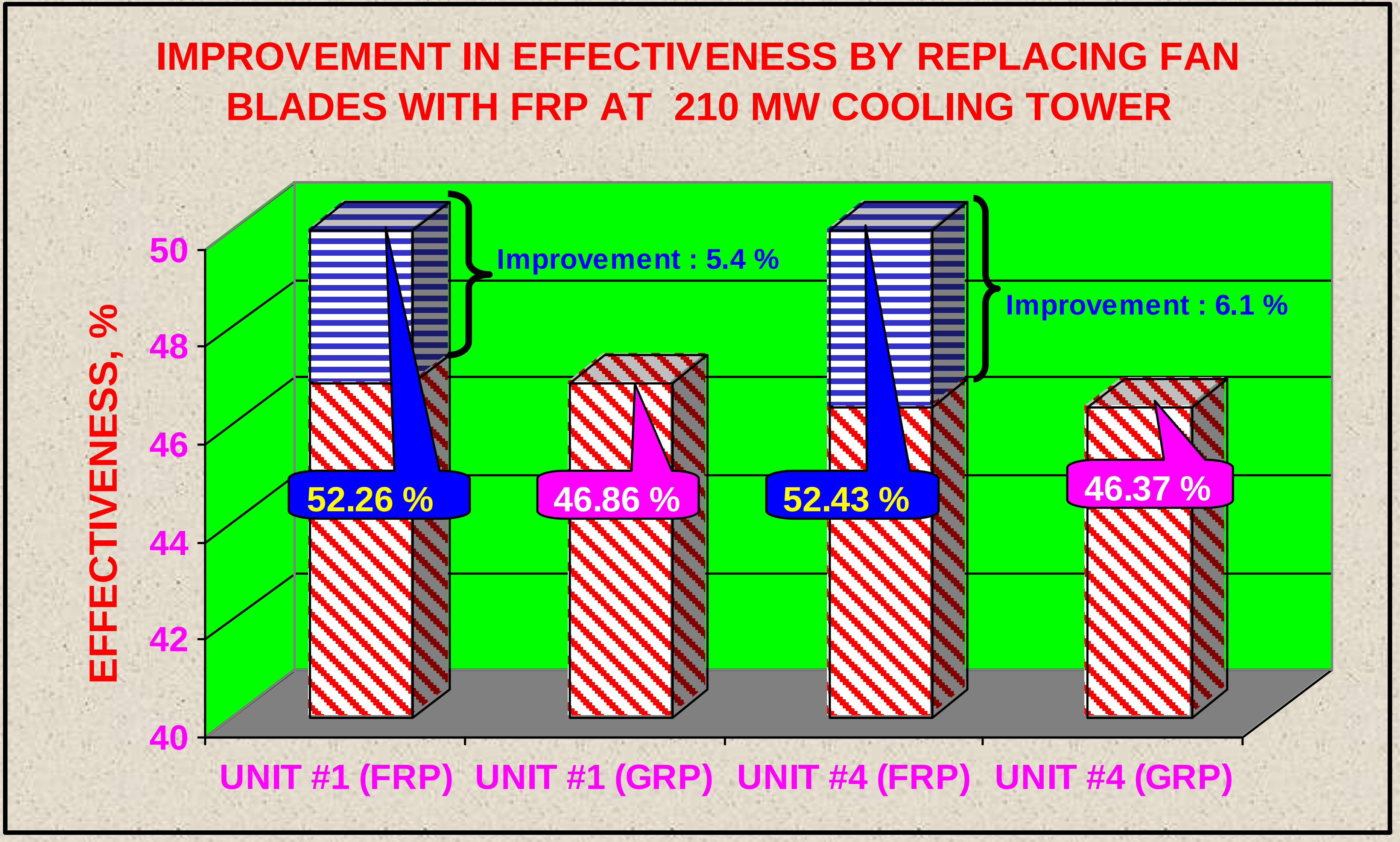
BEST PRACTICES



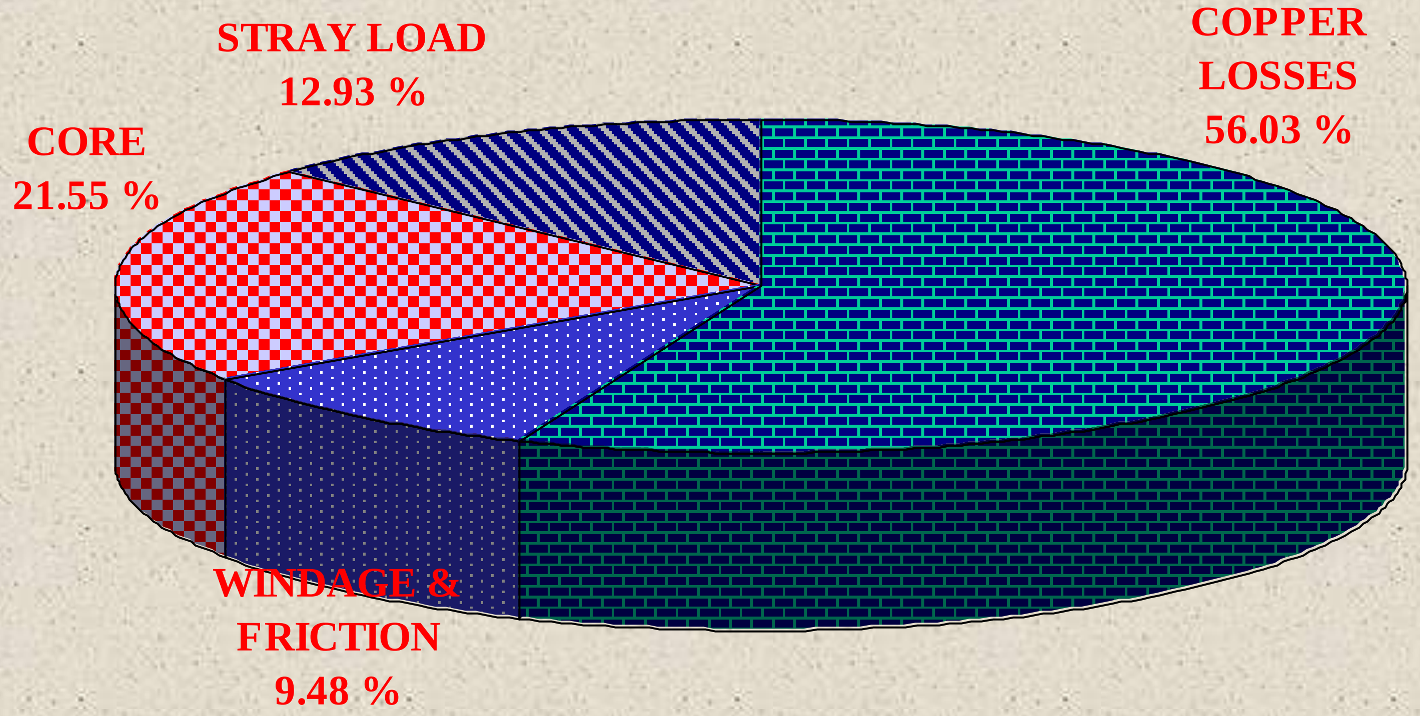
BEST PRACTICES



BEST PRACTICES



LOSSES IN MOTORS



- Copper (I^2R) losses : 3.0 - 9.0 %
- Core losses : 1.0 - 4.0 %
- Windage & friction : 1.0 - 2.4 %
- Stray load losses : 1.8 - 3.2 %

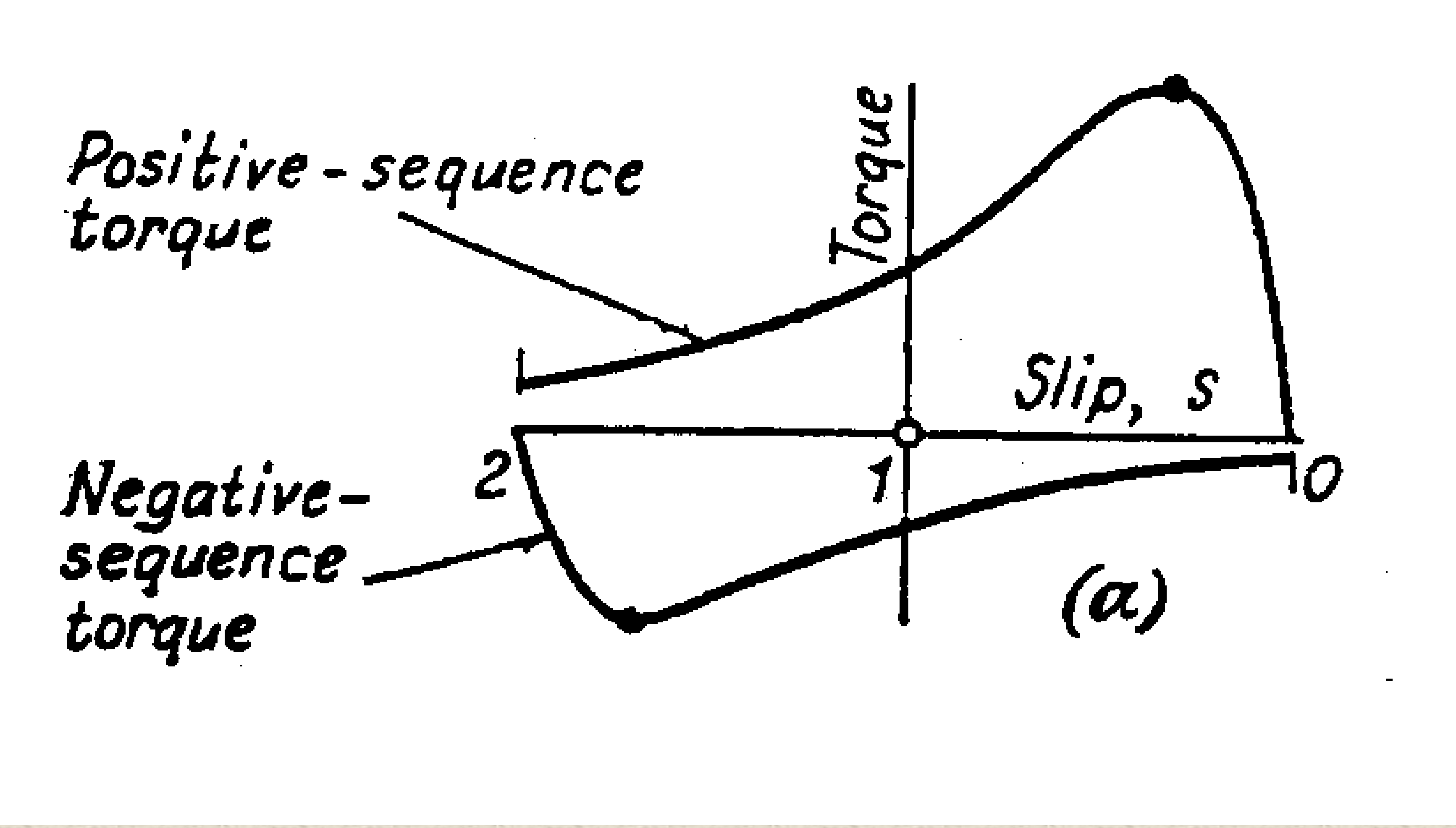
Voltage unbalance

- Load unbalance between 3-phases
- Dissimilar voltage drop in distribution equipment
- Different power factor in 3-phases

Causes

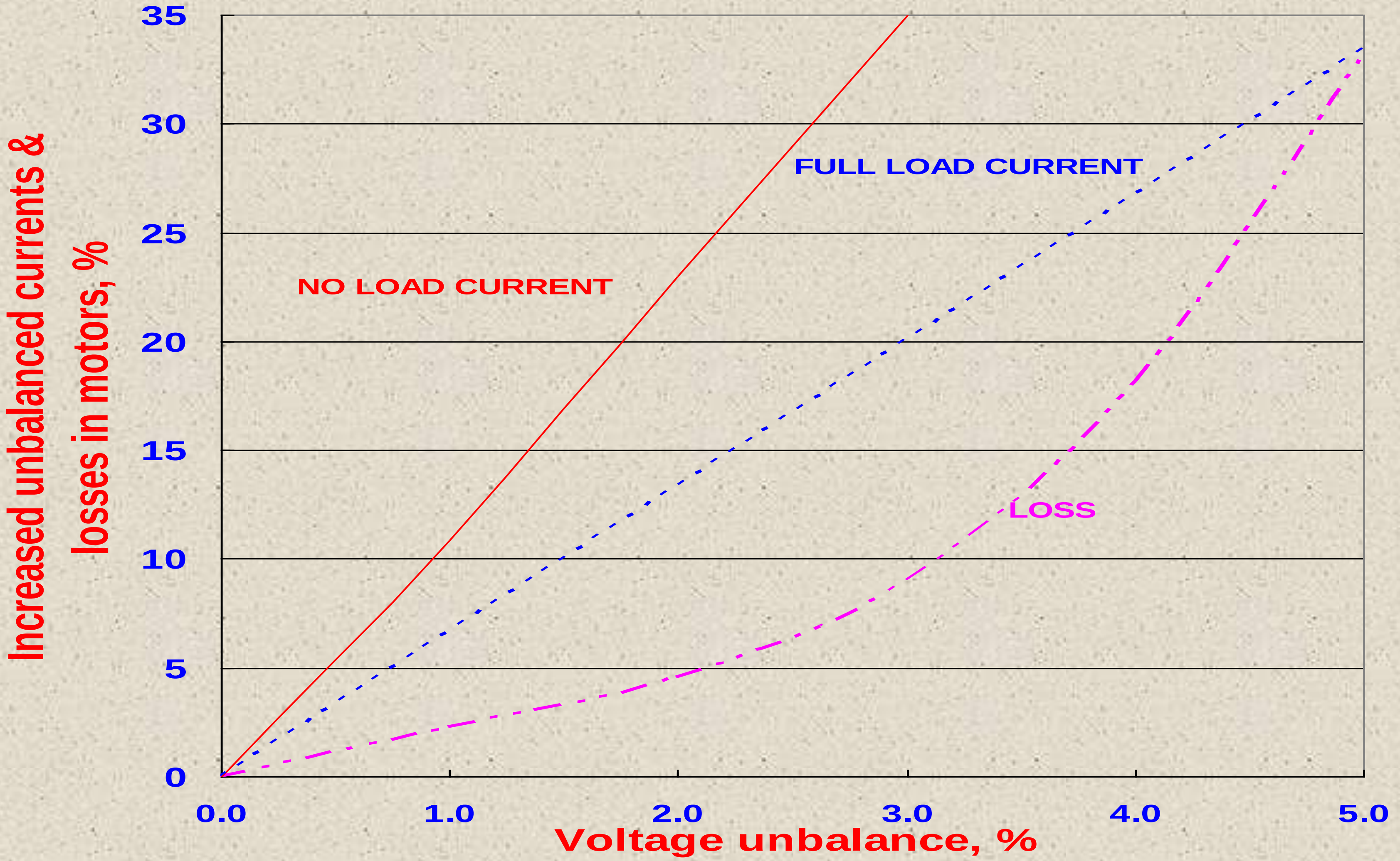
- Negative sequence current in the motor winding
- Heating of motor winding
- Negative sequence torque will reduce the motor capacity

Voltage unbalance

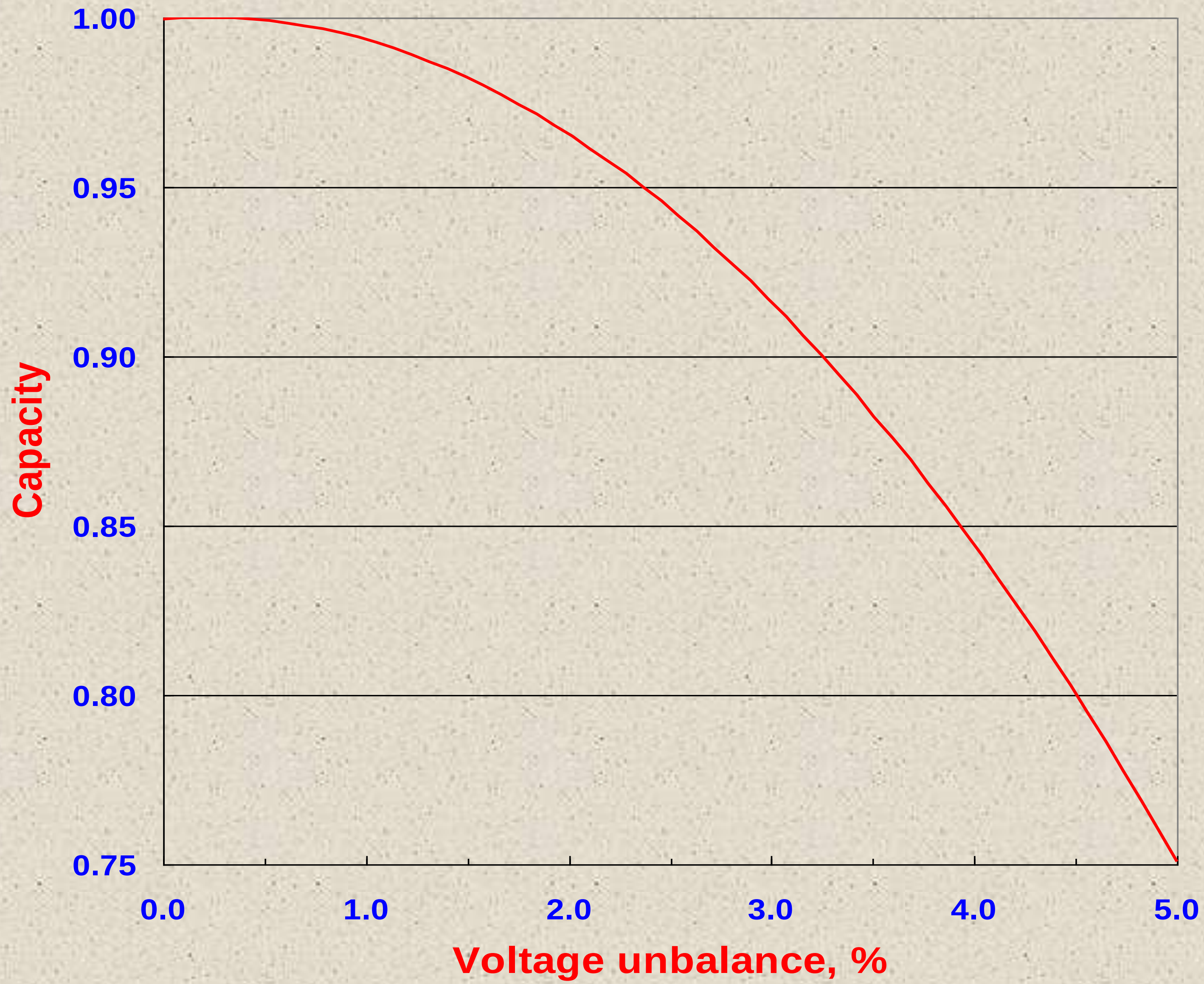


VOLTAGE UNBALANCE

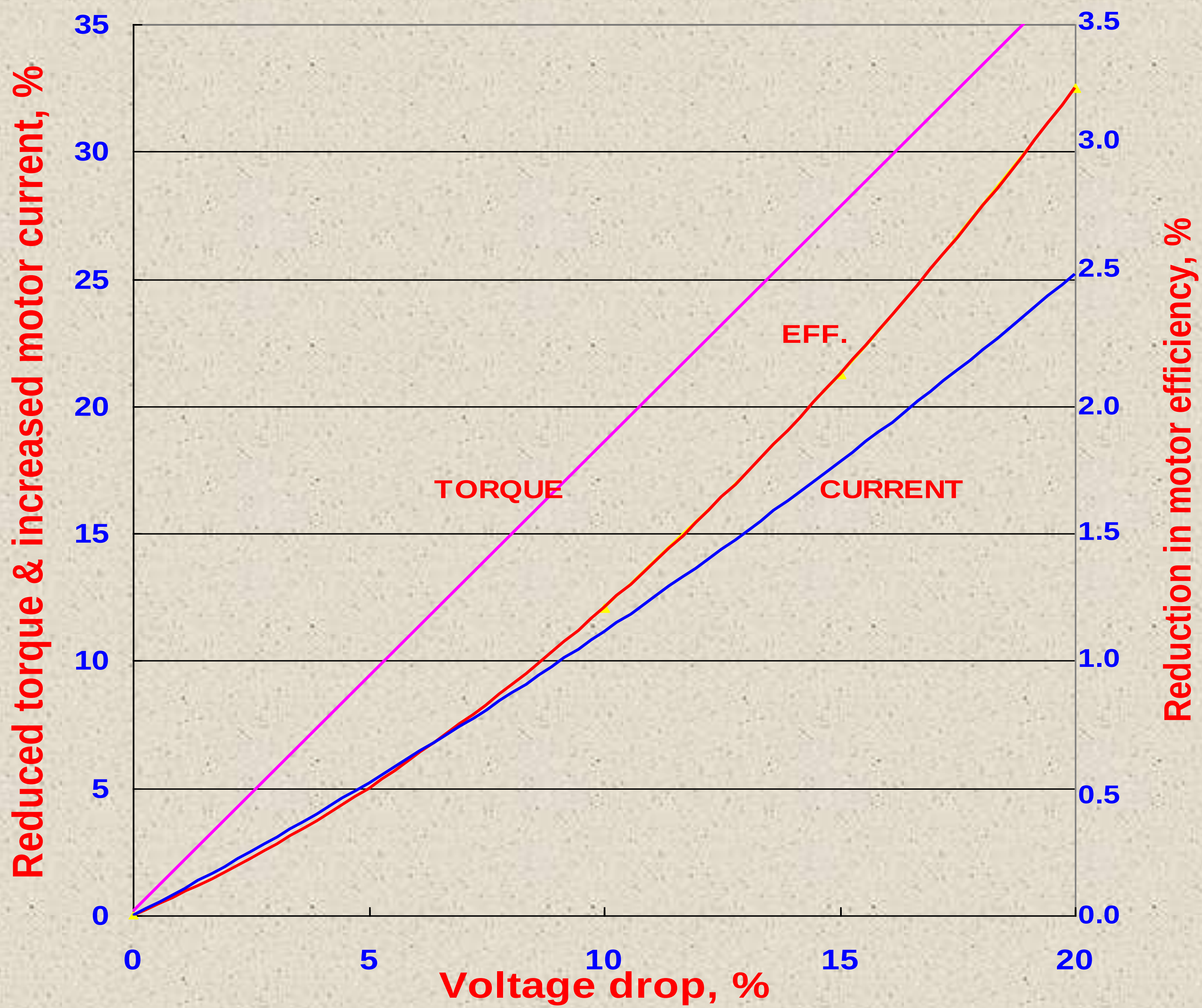
Figure 1: Variation of motor current and losses with voltage unbalance at motor terminals.



VOLTAGE UNBALANCE



VOLTAGE VARIATION



VOLTAGE VARIATION

- ☞ **10 % voltage drop reduces**
  - ➢ **torque by 19 %**
  - ➢ **increases current by 11 %**
- ☞ **Remedies :**
  - ➢ **On-load tap changers**
  - ➢ **Regulating transformers**
  - ➢ **Voltage stabilizers**

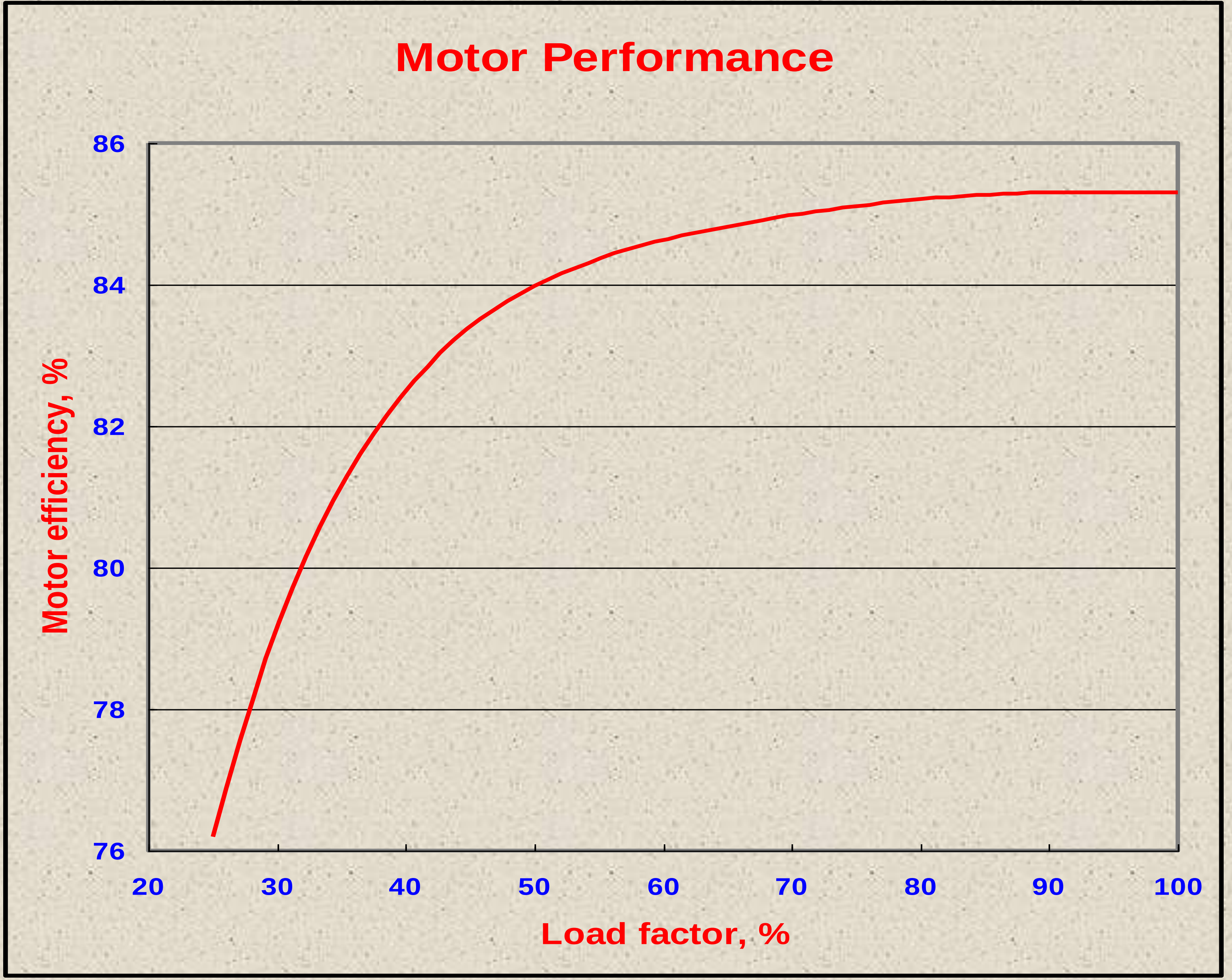
HARMONICS

- **Harmonic currents will increase I^2R losses in windings**
- **5^{th}, 11^{th}, 17^{th}, 23^{rd},……… harmonics will develop reverse torque on the rotor.**
- **Harmonic voltages increase the core losses and heat the core.**
- **Remedies :**
  - **Use of harmonic filters for suppressing the harmonics**

STARTING CHARACTERISTICS

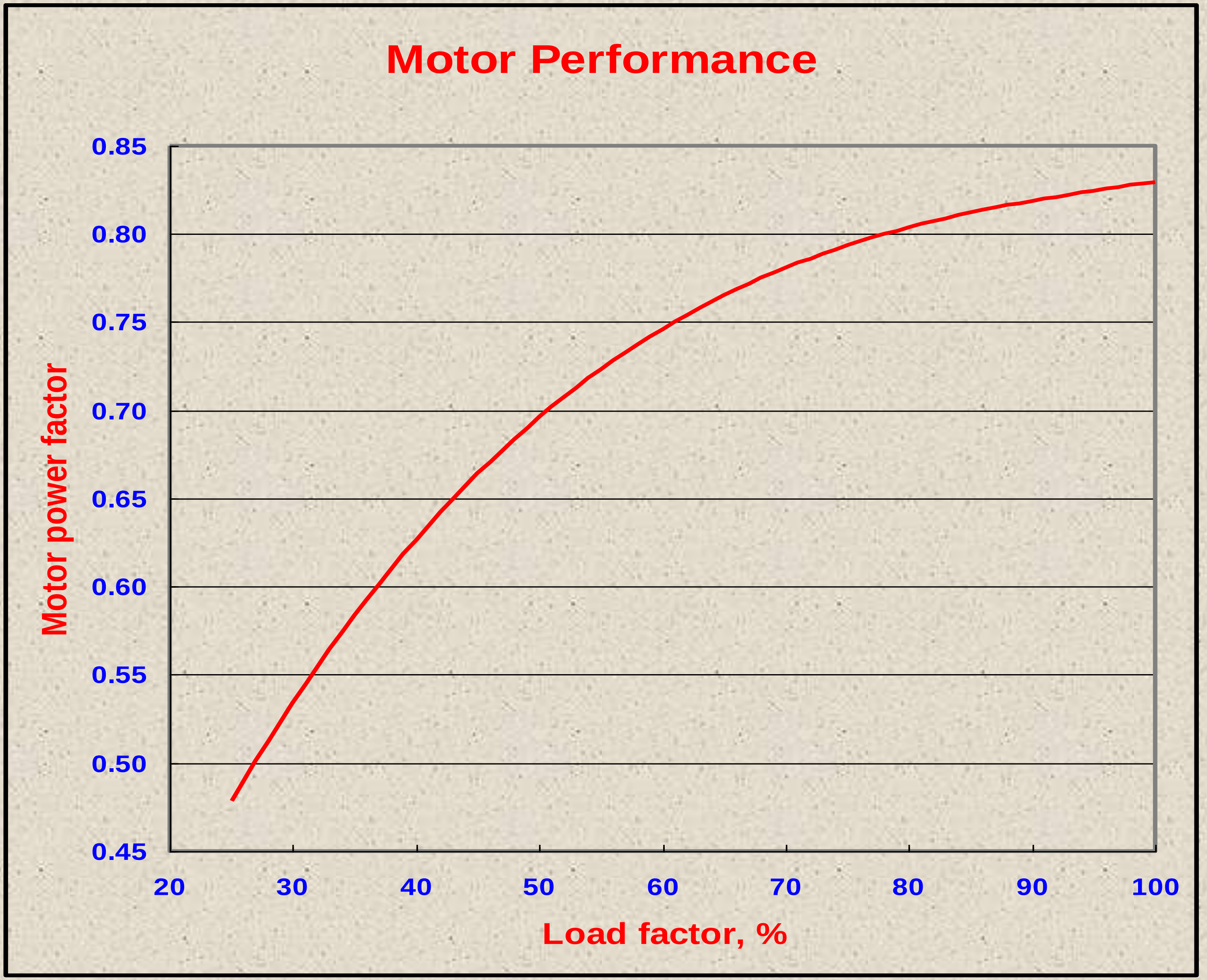
- **Direct-on-line (DOL)**
  - **5-6 times of FL current**
- **Star-delta**
  - **2-3 times of FL current**
- **DELSTAR**
  - **Initially starts with star connection and then delta mode**
  - **Sense the load on the motor, for below 50 % load, converts the mode from delta to star automatically and vice-a-versa.**
- **Auto transformer**
- **Soft starter**
  - **Economically feasible where no. of switchings are more**

LOAD FACTOR



Motor Performance
86
84
82
80
78
76
Motor efficiency, %
20
30
40
50
60
70
80
90
100
Load factor, %

POWER FACTOR



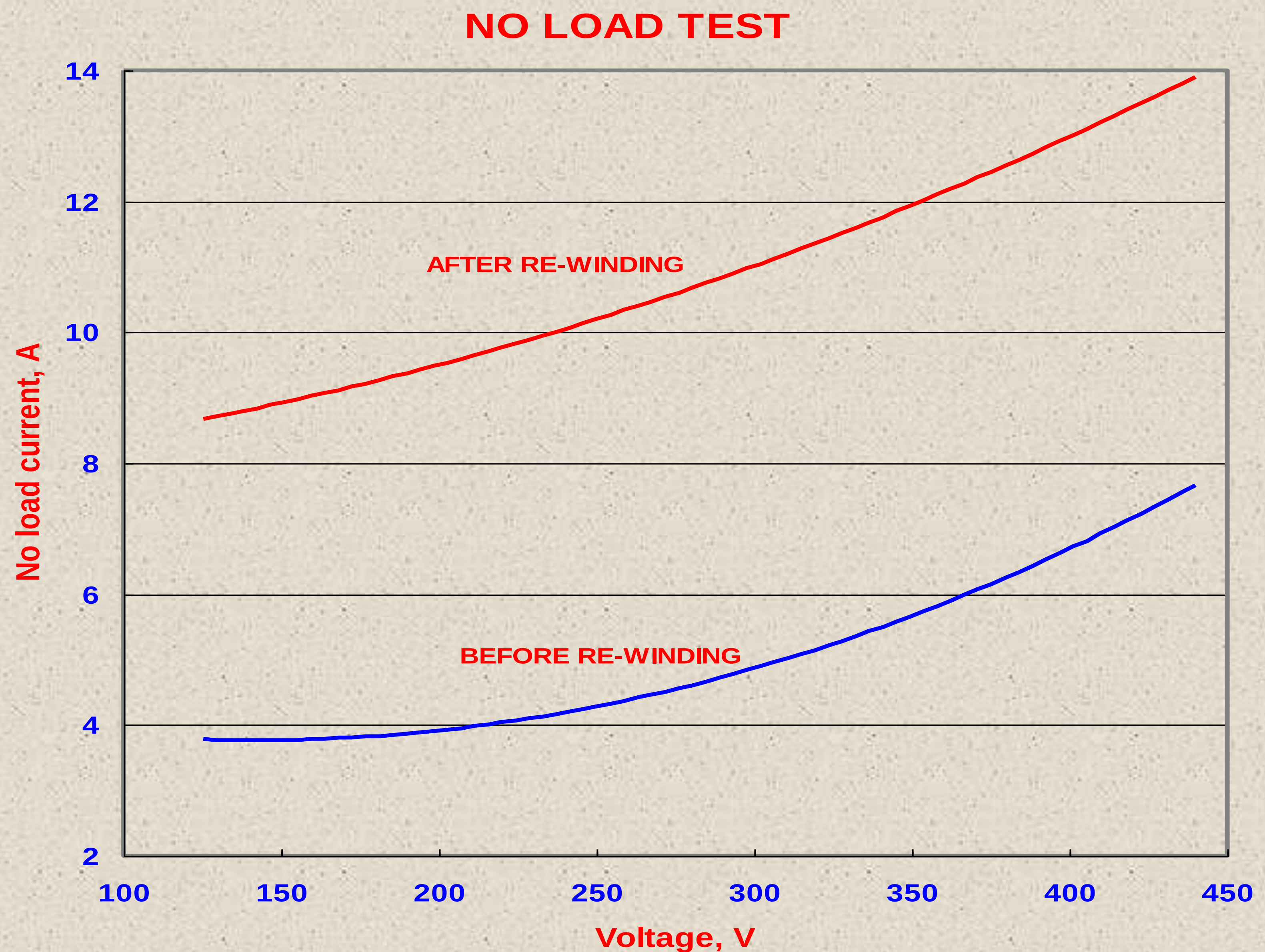
Load factor

Particulars	Present motor	Replaced motor
Motor rating, hp	40	25
Motor load factor, %	60	96
Motor efficiency, %	85	91
Motor input, kW	20.89	19.52
Units consumed/day(a),kWh	417.8	390.4
Power factor	0.79	0.86
Demand KVA	26.44	16.79
Savings due to demand, Rs.(thousands)/month(b)	--	0.4825
Savings due to energy, Rs. (thousands)/month(c)	--	0.9125
Total savings Rs. (thousands)/month	--	1.395
Re-sale value old motor, Rs (thousands)	8.0	--
Total investment for new motor, Rs. (lakhs)	--	0.34
Net investment, Rs. (lakhs)	--	0.26
Pay back period, months	--	23
Life time gain (d) Rs. (lakhs)	--	1.263

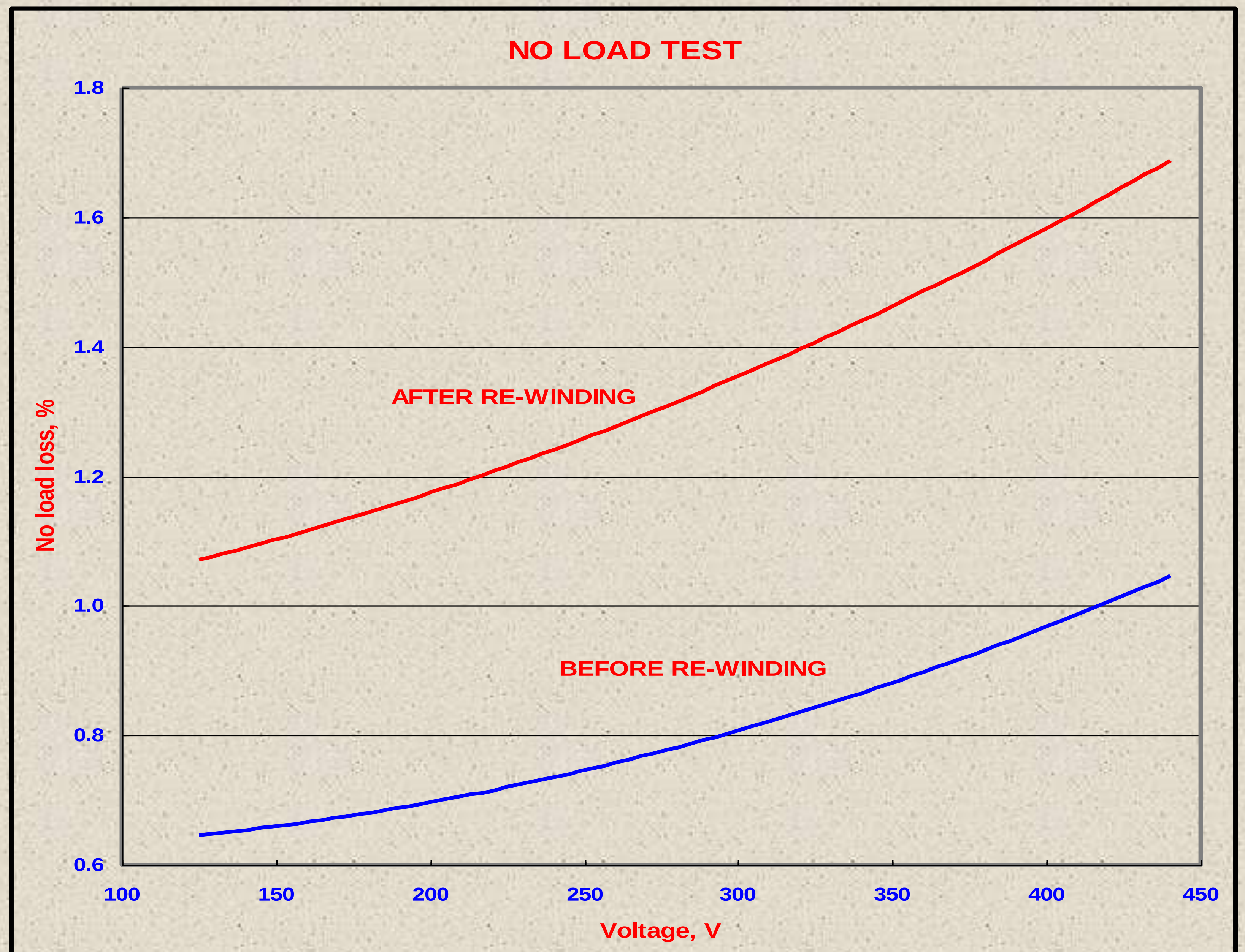
Speed

- In a bakery multi-speed (two winding) motor of 72/36 rpm was installed.
- Efficiency was below 85 %.
- Variable speed drive with single winding improves the efficiency to 89 - 91 %.
- At higher speed the motor efficiency will be more.
- Star-delta
  - 2-3 times of FL current
- DELSTAR
  - Initially starts with star connection and then delta mode
  - Sense the load on the motor, for below 50 % load, converts the mode from delta to star automatically and vice-a-versa.
- Auto transformer
- Soft starter
  - Economically feasible where no. of switchings are more

REWINDING OF MOTOR

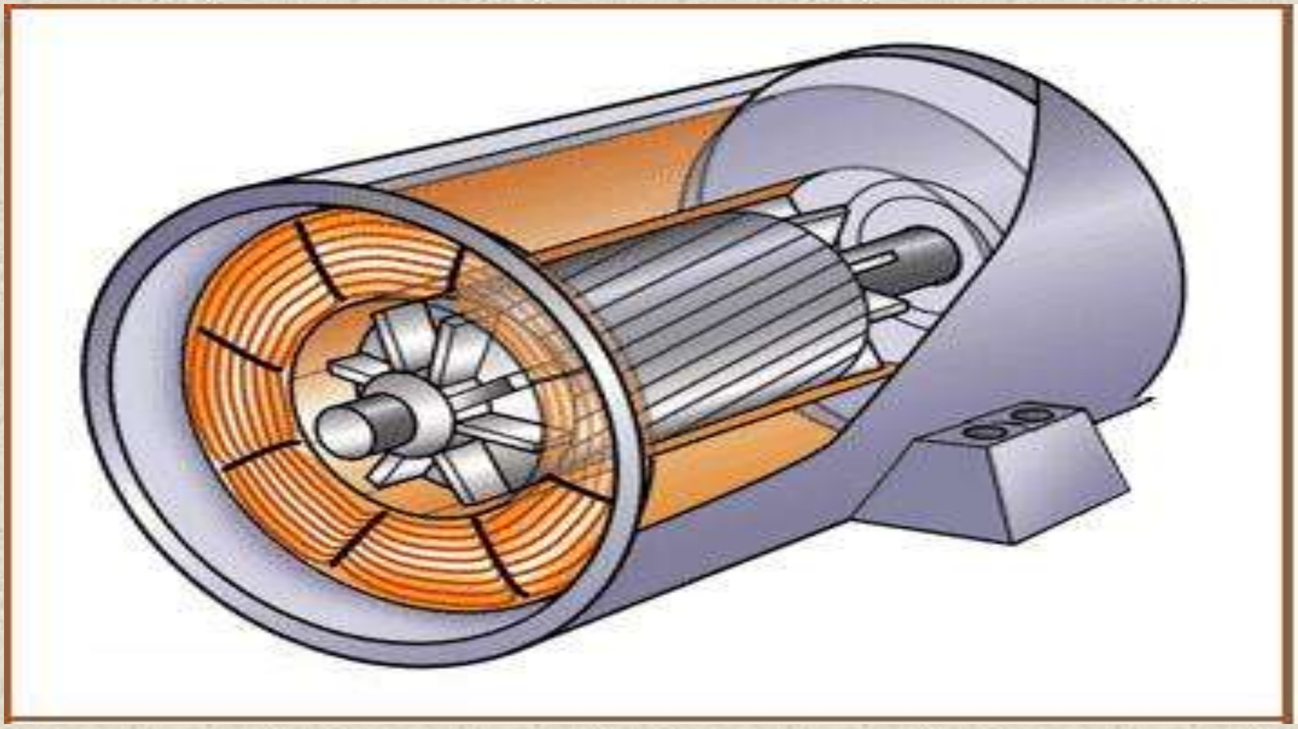


REWINDING OF MOTOR

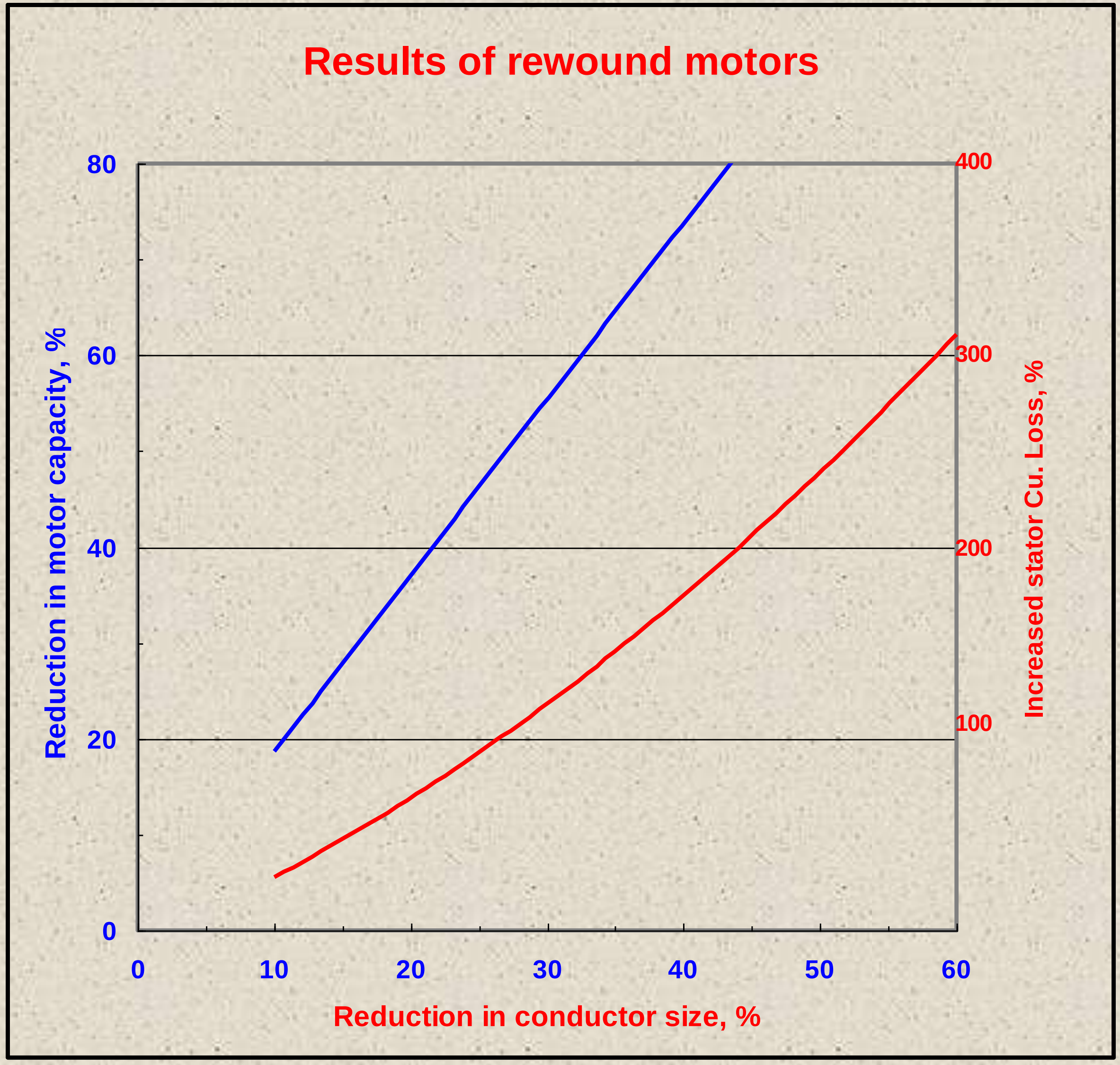


REWINDING OF MOTOR

- Reduced inter insulation of laminations will increase the eddy current loss.
- Higher winding temperature.
- Increased no load current and energy loss.



REWINDING OF MOTOR



Reduced conductor size

increase winding losses

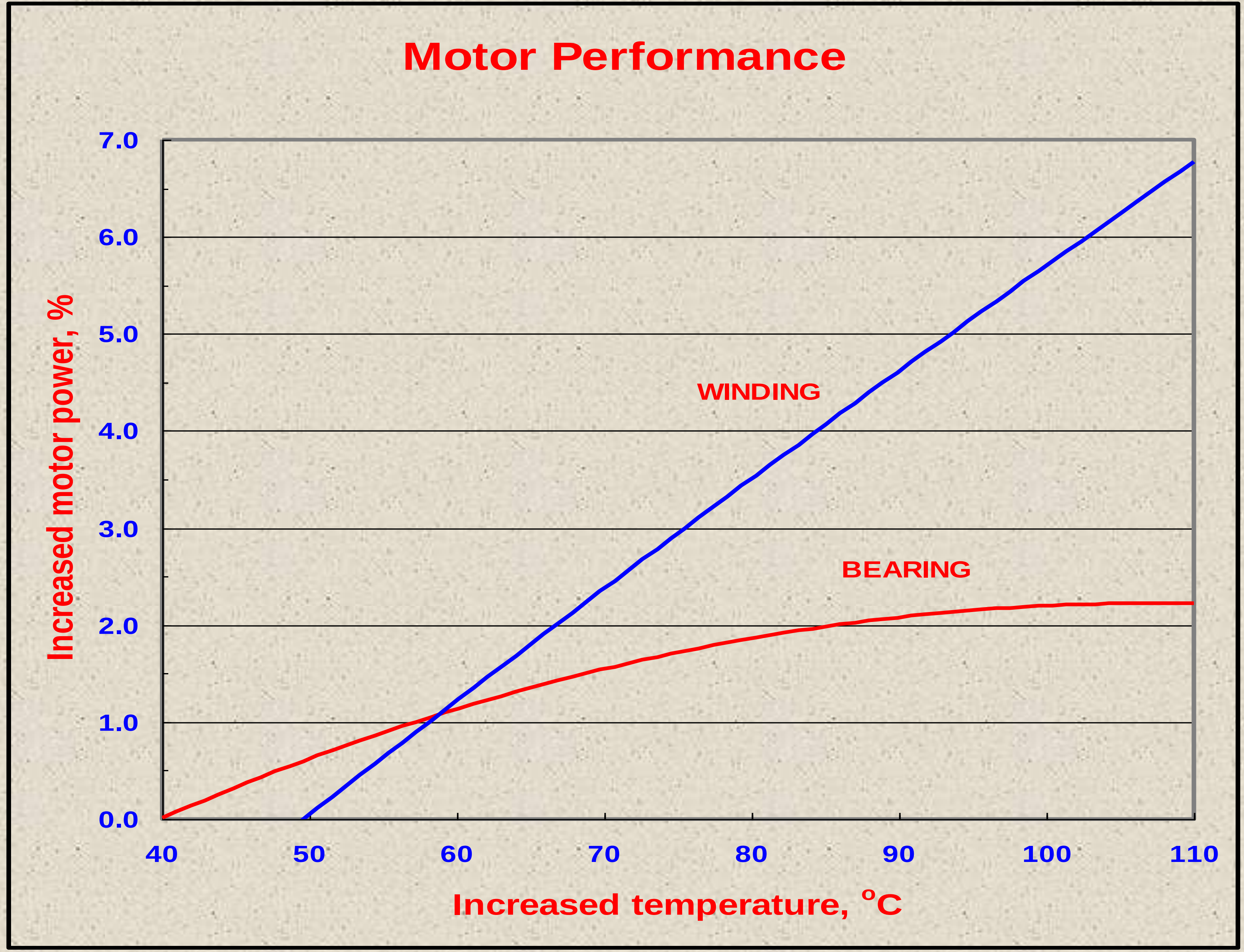
reduce the motor capacity

MAINTENANCE AND OVERHAULING

- **Dust particles inside the motor will reduce heat removal and increase the winding temp.**
- **Increased winding and bearing temp. will increase motor losses.**

Particular	Before overhaul Wind. temp., °C	After overhaul Wind.temp., °C	Saving in losses due to reduced motor wind.temp., MWh/month
BFP B	72.11	67.63	1.10
BFP C	73.24	65.16	1.99
ID Fan A	73.24	59.80	0.76
ID Fan B	70.14	74.7	0.30
FD Fan A	63.92	60.80	0.09
FD Fan B	66.65	59.14	0.22
PA Fan A	71.02	67.71	0.33
PA Fan B	72.79	66.56	0.60
Mill A	61.57	47.20	0.80

MAINTENANCE & OVERHAULING



ENERGY EFFICIENT MOTOR

Reduction in volume	Losses	Percentage	Factors decreasing losses
Copper losses	55 - 60	Factor increasing losses of copper	a. Changing winding configuration using more copper. b. Thicker wire. c. Thinner laminations. d. Use of copper bars in rotor. e. Longer core to increase active material.
Core losses	20 - 25	Use of carbon steel	Use of silicon steel
Stray load losses	11 - 14	Increasing the air gap length	Decreasing the air gap length
Friction & Windage losses	6 - 10	Use of bigger cooling fan, ordinary bearings	Use of efficient cooling fan, better bearings

ENERGY EFFICIENT MOTOR

Particulars	Standard motor	Energy efficient motor
Motor rating, hp	25	25
Motor efficiency, %	88	92
Motor input, kW[a]	18.92	18.10
Units consumed, kWh/month[b]	5676	5430
Power factor	0.86	0.87
Demand, kVA	22.0	20.8
Savings due to demand, Rs/month [c]	-	246
Savings due to energy, Rs/month [d]	-	738
Total savings, Rs (thousands)/month	-	984
The difference in cost, Rs.	-	10,000
Pay back period, months	-	12
Life time gain[e], Rs (lakhs)	-	1.65

TRANSFORMERS

Sl. No.	Type/grade, mm	Thicknes s	Core loss at flux density of 1.7 T, W/kg
01	M4	0.27	1.22
02	MOH	0.30	1.01
03	ZH 100	0.27	0.96
04	ZDKH	0.23	0.84
05	METAL GLASS	0.025	0.31

- **Use of low loss metal glass cores reduce the iron loss by about 75 % with an extra cost of 1.6 to 2 times**

TRANSFORMERS

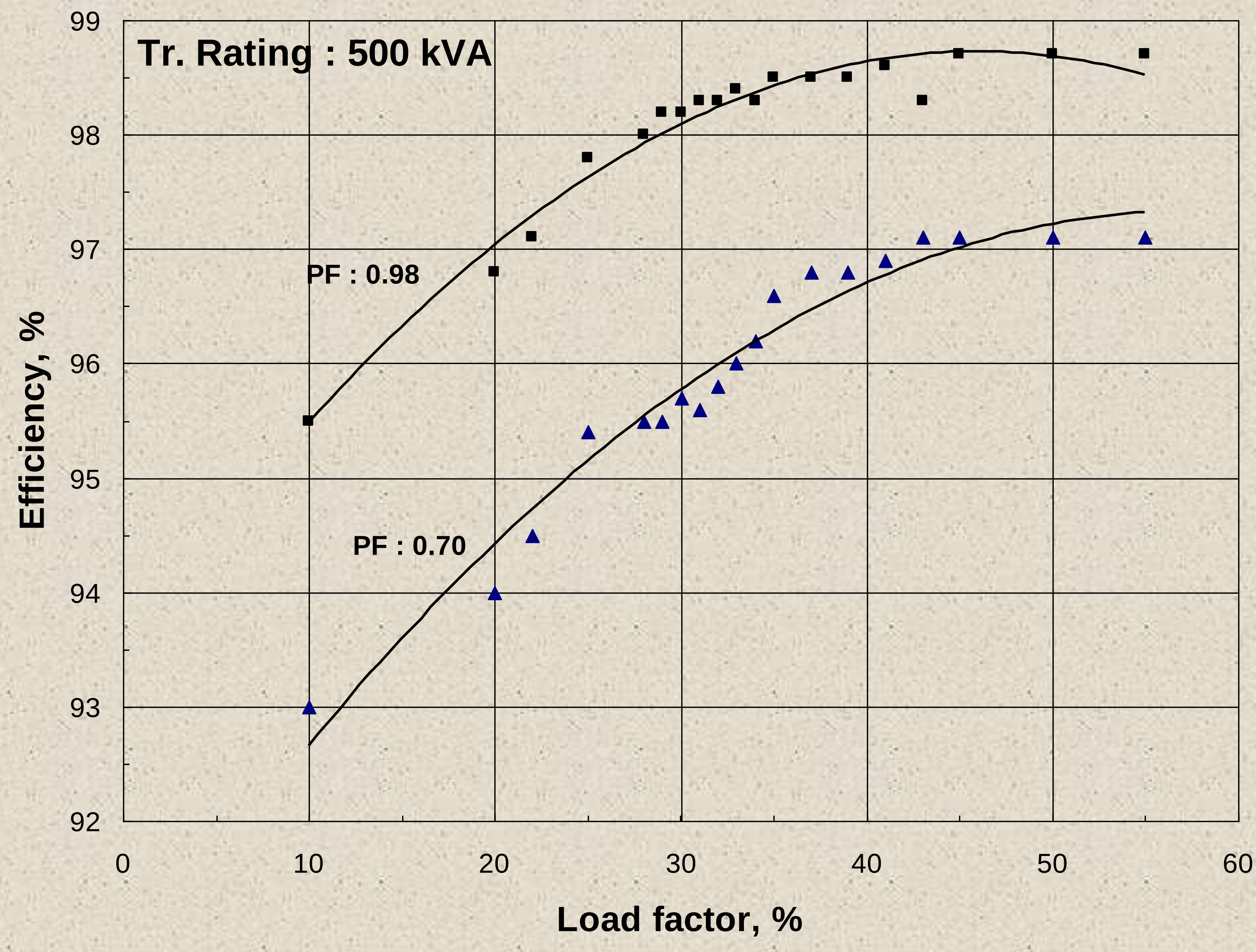
Iron losses

Rating (kVA)	No Load Loss (W)		Load Loss (W)		Efficiency (%)		Impedance (%)	
	AMIT	SiFe-IT	AMIT	SiFe-IT	AM IT	SiFe-IT	AMIT	SiFe-IT
250	160	570	3200	4000	98.7	98.2	4.50	4.50
500	250	900	4800	6550	99.0	98.53	4.50	4.50
630	260	1000	5200	8000	99.1	98.54	4.75	4.75
750	365	1250	6050	9000	99.2	98.65	4.75	4.75
1000	450	1500	7650	11800	99.2	98.68	5.00	500

TRANSFORMERS

- ☞ **Poor factor at Tr. Secondary increases Tr. Losses**
- ☞ **Load unbalance on secondary increases Tr. losses**

TRANSFORMERS



TRANSFORMERS

Transformer	Peak (0730 – 1430h)		Non-Peak (1530 – 2230h)		All day efficie-ncy, %	New load factor		Energy saving MWh/month
	kVA	LF, %	kVA	LF, %		Peak	Non-peak	
F6	259.74	25.97	178.53	17.85	95.69			
F7	105.09	10.51	48.75	4.88	85.82	36.48	22.73	5.160
F2	249.04	24.90	278.03	27.80	96.46			
F1	264.26	26.43	85.71	8.57	94.37	51.33	36.37	5.206
F5	330.42	33.04	51.15	5.11	92.66	-	-	-
CCH	235.19	23.52	86.68	8.67	93.46			
PCB	317.87	31.79	141.96	14.20	95.78	55.31	22.87	5.208
F71 SS1 TR1.	245.53	24.55	113.25	11.33	94.73			
F71 SS1 TR 2.	169.18	16.92	39.55	3.95	91.65	61.58	24.01	10.435
F71 SS1 TR3	200.13	20.01	87.28	8.73	93.58			

TRANSFORMERS

Harmonics

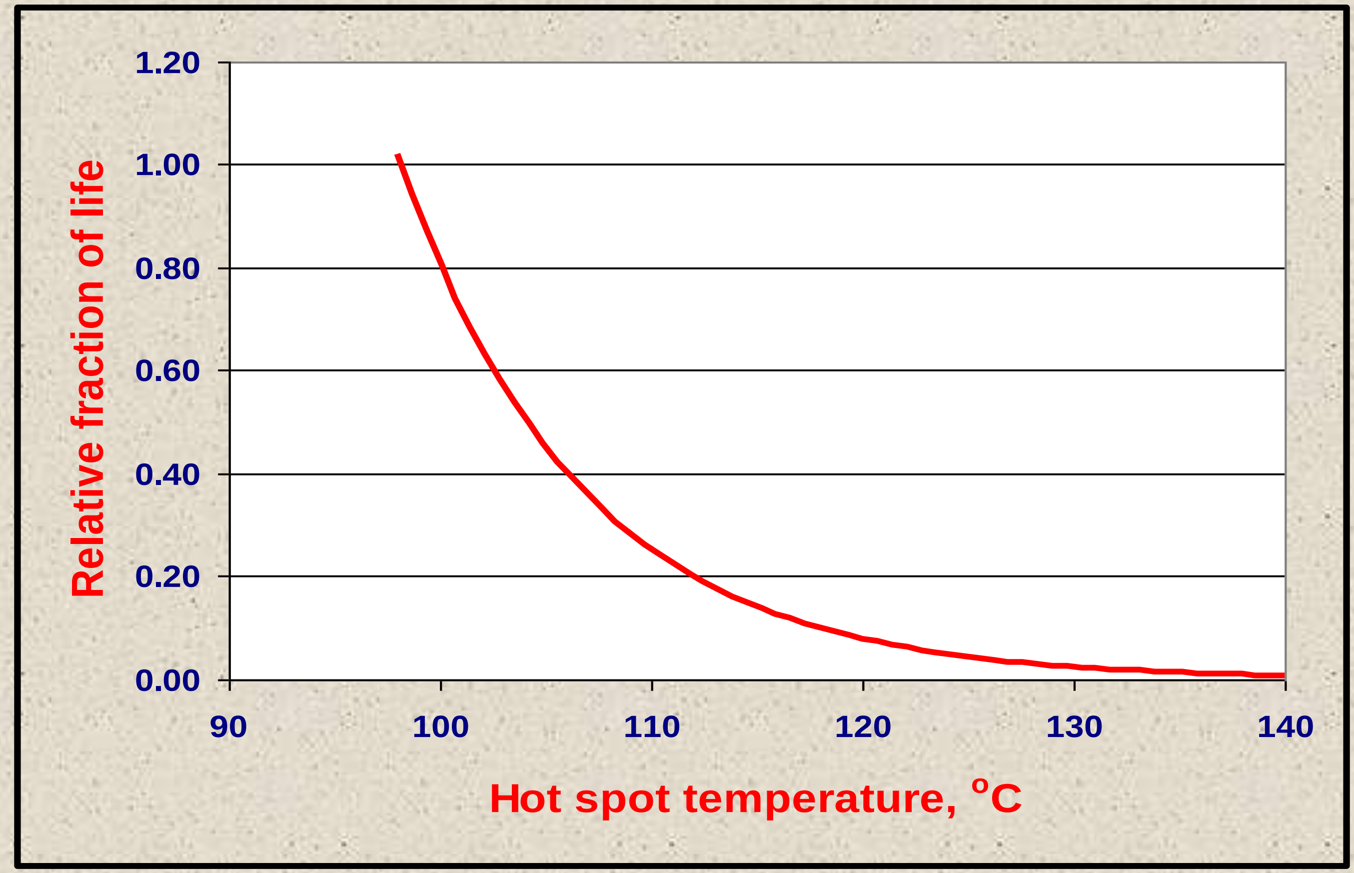
- Harmonic currents increase the copper loss
- Harmonic voltage increase core loss.
- Harmonic voltages increase the dielectric stresses, reactance between inductance of the transformer windings.

TRANSFORMERS

Oil quality

- Increased oil temp. increases the winding temp. which increase the winding losses and reduce the life of transformer
- For better efficiency, the transformer oil must have high dielectric strength, low dissipation factor, lower acidity, lower sludge content, etc.

TRANSFORMERS



- Hot spot temp. rise is higher than rise of the top oil temp. i.e., 10 % more
- Transformer insulation deterioration increases exponentially with temp. i.e., for every rise in 6 oC, the deterioration rate doubles.

THANK YOU

Email:rajashekarmandi@yahoo.com & mandi@cpri.in