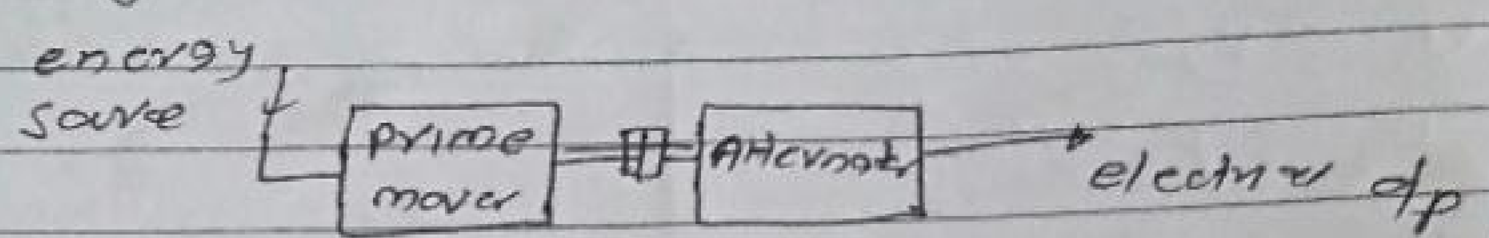
Types of Generating System

→ Conversion of energy available in different form into electrical energy is known as generation of electrical energy.



Depending upon form of energy converted into electrical generating system are classified into different Types

1) Steam Power plant
2) Hydroelectric power plant
3) Diesel power plant
4) Nuclear Power plant

Comparision:

Item	Steam	Hydroelectric	Diesel	Nuclear
(1) Site	place where adequate supply of water and ~~coal earth trans-~~ portation facilities	water source with ~~large reservoirs~~ can be made by constructing dam.	→ At any place	→ Away from thickly ~~populated area~~ to avoid radio interference
(2) Initial cost	less than hydro & nuclear	very high	less compared to other	high on building of nuclear reactor
(3) Running cost	High than hydro & nuclear	No	highest among all	except hydro, minimum
(4) cost of fuel transportation	Maximum because of coal	Nil	Higher than nuclear	minimum
(5) cleanliness	least clean	most simple & clean	more clean than ~~steam & nuclear~~	~~lessmore~~ clean than hydro diesel
(6) limit of source	limited reserve	Non	limited	sufficient qty because small fuel produce large qty.

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1.2 Load curve

The curve showing variation of the electrical load w.r.to time is known as load curve. The load are plotted/ recorded hourly monthly or annually

↳ If this curve is plotted over a period of 24 hours, it is known as daily load curve.

↳ If its plotted for a week, month or a year then its named as weekly, monthly or yearly load curve respectively.

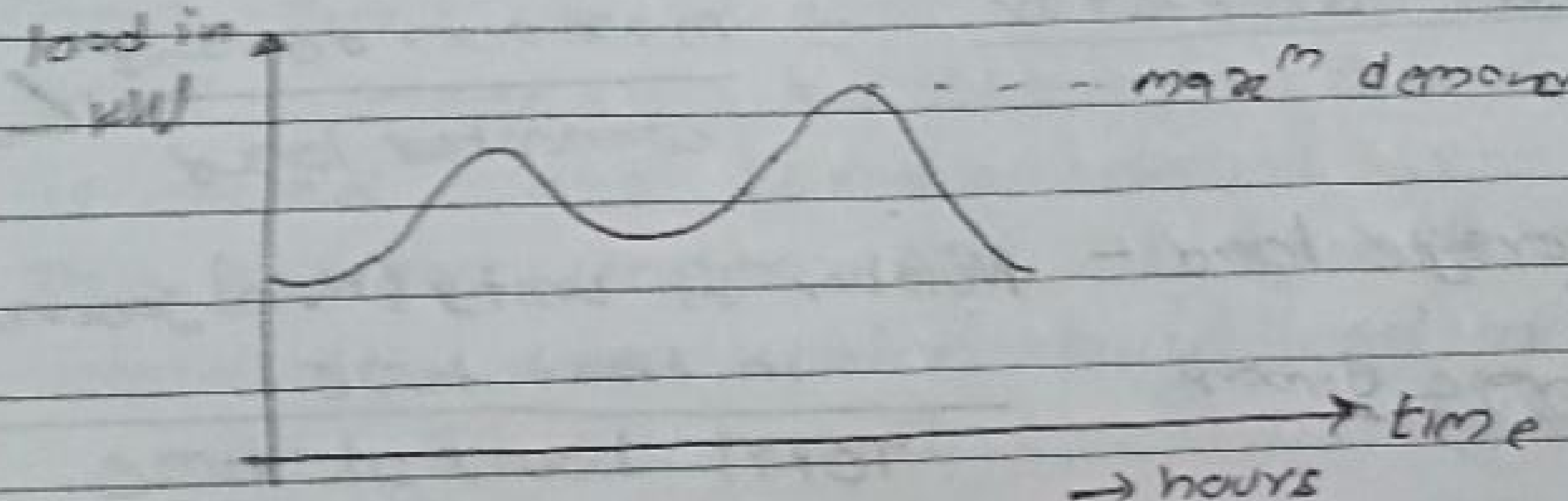

fig: daily load curve

* The area under daily load curve gives the number of unit generated in that day.
* The area under daily load curve divided by total number of hours gives average load.

$$\text{Average Load} = \frac{\text{Area under daily load curve (kWh)}}{24 \text{ hours}}$$

Importance

↳ load curve helps in selecting the size and number of generating units

↳ load curve helps in preparing operation schedule of station

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(7) Unit generated Per Annum

$$L.f = \frac{\text{Average load}}{\text{Maximum demand}}$$

⇒ ~~Average load = Maximum Demand * L.f~~

∴ unit generated/annum = Avg load in(kW) * Hour in a year

= Max demand (in kW) * LF * 8760

(9) Load duration Curve: An arrangement of load level in descending order of magnitude is called load duration curve.

↳ The area under LDC is equal to load curve. obviously, area under daily load duration curve (in kW) will gives unit generated on that day.

Eg Consider daily load curve data of power system

Time	Load in MW
6:00 Am to 8:00 Am	8
8:00 Am to 1:00 noon	20
1:00 noon to 2:00 noon	5
12:30 noon to 6:00 pm	30
6.00 pm to 6 Am	8

Soln: Arrangement of load

Load	Hour in a day	Time in percent
30	4	$\frac{4}{24} * 100 = 16.67\%$
20	4+5	$\frac{9}{24} * 100\% = 37.5\%$
8	2+4+5+12=23	$\frac{23}{24} * 100 = 95.83\%$
5	4+5+2+12+1=24	$\frac{24}{24} * 100 = 100\%$

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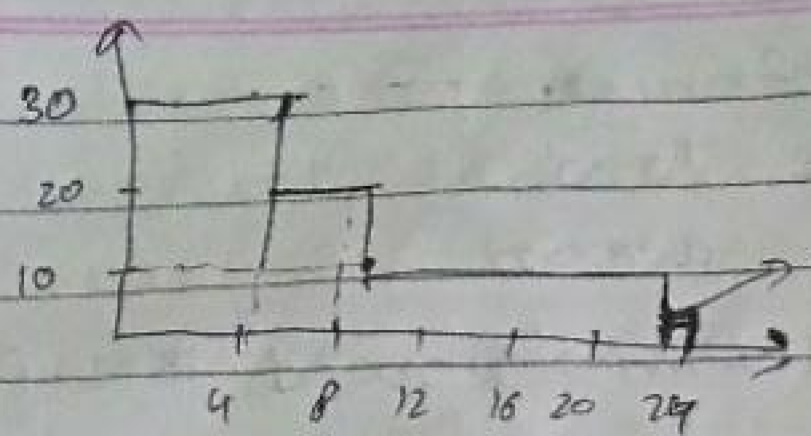

Q. A generating station supplies the following loads 15000 kW, 12000 kW, 8500 kW, 6000 kW and 450 kW. The station has a maximum demand of 22000 kW. The annual load factor for the station is 48%. Calculate (1) The number of units supplied annually (2) diversity factor (3) demand factor

soln:

Yearly Load factor = $\dfrac{\text{Yearly Avg. load}}{\text{maximum demand}}$

$\therefore$ yearly Avg. load $= 0.48 * 22000$

$= 10560$ kW

Also,

Yearly Avg load = $\dfrac{\text{No. of units (kWh) generation in a year}}{8760 \text{ hour}}$

(1) ⇒ No. of units supplied in a year = year Avg load * 8760

$= 10560 * 8760$

$= 925 * 10^5$ kWh

(2) diversity factor = $\dfrac{\text{Sum of individual max. demand}}{\text{maximum demand}}$

Ans 52.4%.

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(i) Demand factor = $\frac{\text{Max}^m \text{ demand}}{\text{connected load}}$

$= \frac{22000}{41950}$

1.9

$= 0.524$

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4 Plant Capacity factor: It is the ratio of actual energy produced to the maximum possible energy that could have been producing during a given period i.e

plant capacity factor = $\frac{\text{Actual energy produced}}{\text{Max. energy that could have been produced}}$

Due to reserve max energy that could have been produced is greater.

$= \frac{\text{Average demand} * T}{\text{Plant capacity} * T}$

$= \frac{\text{Average demand}}{\text{plant capacity}}$

If T = 1 years

Annual plant capacity factor = $\frac{\text{Annual kwh o/p}}{\text{Plant capacity} * 8760}$

plant capacity factor = $E/(C*t)$

where E = Energy produced (kwh) in a given period

C = Capacity of plant in kw

t = Total no. of hours in given period

5) Plant use factor: It is ratio of kwh generated to the product of plant capacity and the number of hours for which the plant was in operation i.e

plant use factor = $\frac{\text{Station o/p in kwh}}{\text{Plant capacity} * \text{Hour in use}}$

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(6) A power station is to supply four regions of loads whose peak values are 10000 kW, 5000 kW, 8000 kW and 7000 kW. The diversity factor of the load at the station is 1.5 and the average annual load factor is 60%. Calculate the maximum demand on the station and annual energy supplied from the station.

Soln:

$$\text{Diversity factor} = \frac{\text{Sum of max}^m \text{ demand}}{\text{max}^m \text{ demand}}$$

$$1.5 = \frac{10\,000 + 5000 + 8000 + 7000}{\text{max}^m \text{ demand}}$$

$\therefore$ Maximum Demand = 20,000 kW

Annual L.f = 60%

$$\text{L.f} = \frac{\text{Avg load}}{\text{max}^m \text{ demand}}$$

$$0.6 = \frac{\text{Annual Avg load}}{20\,000}$$

Annual Avg load = 12 000 kW × 8760

= 105.12×10^6

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Significance of load factor and diversity factor

Load factor and diversity factor play an important role in the cost of the supply of electrical energy. Higher the value of load factor and diversity, lower will be the overall cost per unit generated.

The capital cost of power station depends upon the capacity of power station. lower the maximum demand of the power station, the lower is the capacity required and lower is capital cost of plant. With the given number of consumers the higher the diversity factor of their loads the smaller will be the capacity of plant required and consequently the fixed charges due to capital investment will be much reduced.

Similarly, high load factor means more average load or more number of units generated for a given maximum demand and therefore overall cost per unit of electrical energy generated is reduced due to distribution of standing charges which are proportional to maximum demand and independent of numbers of units generated.

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~~Selection~~ Types of loads
load may be resistive (electric lamp) inductive (e.g induction motor) capacitive or combination of them. The various types of loads on power system are

① Domestic load

② Commercial load

③ Industrial load

④ Municipal load

⑤ Irrigation load

⑥ Traction load

Selection of Generating Units
while making the selection of number and sizes of the generating units the following points should be kept in view

i) The number and sizes of the units should be so selected that they approximately fit the annual load curve of the station.

ii) The units should be preferably of different capacities to meet the load requirement.

iii) The capacity of the plant should be made 15% to 20% more than the maximum demand to meet the future load requirement.

iv) There should be a spare generating unit so that repairs and overhauling of the working units can be carried out.

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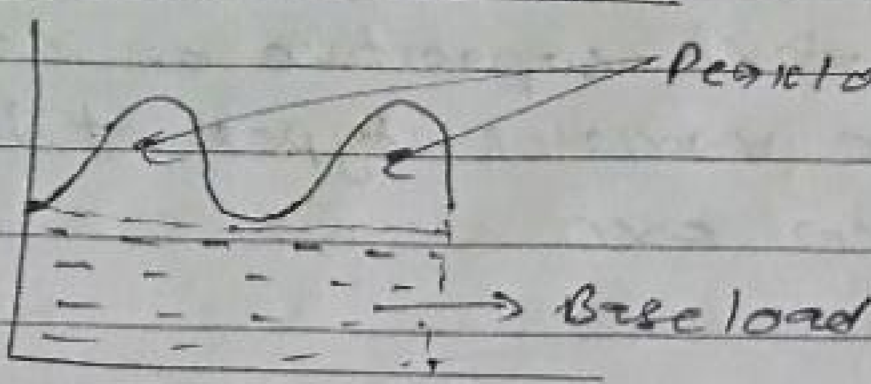
Peakload and Base load



Base load: Those load which are almost used a whole day on the station is known as baseload.

Peak load: The various peak demands of load over and above the base load of the station is called peakload.

Q The daily demands of three consumers are given below:

Time	consumer 1	consumer 2	consumer 3
12 midnight to 8 A.M	No load	200W	No load
8 A.M to 2 P.M	600W	No load	200W
2 P.M to 4 P.M	200W	1000W	1200W
4 P.M to 10 PM	800W	No load	No load
10 PM to midnight	No load	200W.	200W

Plot the load curve and find

i. Maximum demand of the individual consumers

ii. Load factor of the individual consumer

iii. Diversity factor

iv. Load factor of the station.

Soln,

1. Maximum demand of consumer 1 = 800W

" 2 = 1000W

3 = 1200W

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ii) Load factor of consumer 1 = $\frac{\text{Avg energy} * T}{\text{Max demand} * T}$

$$= \frac{600 * 6 + 200 * 2 + 800 * 6 + 0 * 10}{800 * 24}$$

$$= 0.458$$

" " " " 2 $= \frac{200 * 8 + 1000 * 2 + 200 * 2 + 0 * 12}{1000 * 24}$

$$= 0.167$$

" " " 3 $= \frac{200 * 6 + 1200 * 2 + 200 * 2}{1200 * 24}$

$$= 0.138$$

iii) Diversity factor = $\frac{\text{sum of individual max}^m \text{ demand}}{\text{Max demand}}$

$$= \frac{800 + 1000 + 1200}{2400}$$

$$= 1.25$$

iv) Load factor at station = $\frac{\text{Average energy}}{\text{Max. demand energy}}$

= (energy consumed at station 1 + " " " 2 + " " " 3) / (Max demand * 24)

$$= \frac{(600 * 6) + (200 * 2) + (800 * 6) + (200 * 8 + 1000 * 2 + 200 * 2) + (200 * 6 + 1200 * 2 + 200 * 2)}{(200 + 1000 + 1200) * 24}$$

$= \cdot 29.1\ \%$

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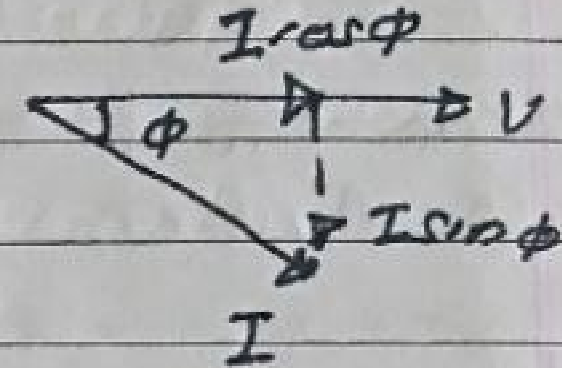
Power factor and it's Improvement

- The cosine of angle between V and I i.e $\cos\phi$

for inductive ckt I lags V and the Power factor is lagging.

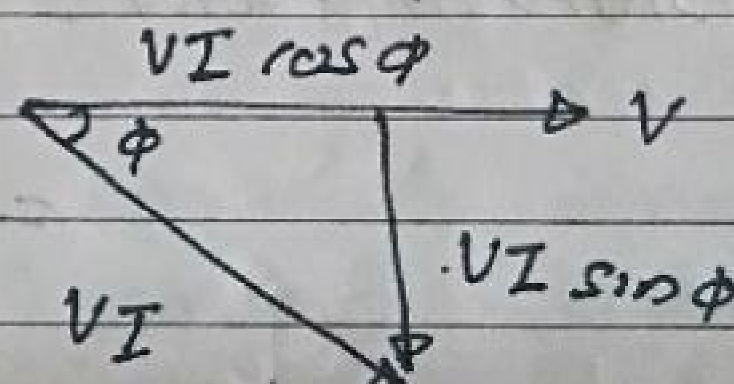
for capacitive circuit I lead V and the power factor is leading

usually circuit is inductive so for inductive circuit



$I\cos\phi$ = Active component and is phase with V

$I\sin\phi$ = Reactive component and is 90° out of phase with V.



we know

$$(VI)^2 = (VI\cos\phi)^2 + (VI\sin\phi)^2$$

$$(KVA)^2 = (KW)^2 + (KVAR)^2$$

$$\text{Power factor} = \frac{KW}{KVA} = \frac{\text{Active Power}}{\text{Apparent Power}}$$

$$KVAR = KVA\sin\phi$$

$$= \frac{KW}{\cos\phi}\sin\phi$$

$$= KW\tan\phi$$

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Illustration of p.f

Power factor (P.F) = $\cos\phi$

we have $P = V I_L \cos\phi$

$$I_L = \frac{P}{V \cos\phi} \quad \text{--- (1)}$$

from eqn 1) $I_L \propto \frac{1}{\cos\phi}$

i.e more current is drawn at low power factor than it does at high power factor.

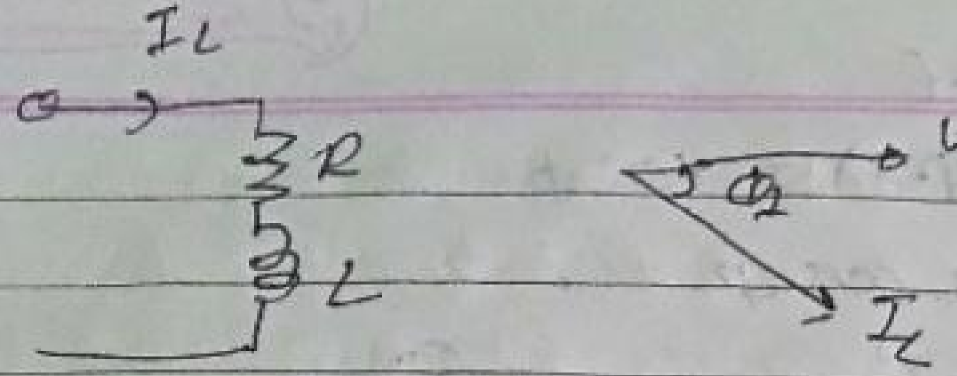
Disadvantage of low p.f

- when power factor decreases, the load current increases, which increase the rating of the machine.
- The size of conductor increases
- Higher amount of current leads to higher copper loss in the system thus efficiency of the system is reduced
  i.e $P_{loss} = I^2 R$
- Higher current produces larger voltage drop in cable and cause poor voltage regulation.

Improvement of Power factor

The low power factor is mainly due to the fact most of the power load are inductive therefore lagging current. In order to improve the power factor some device taking leading current should be connected in parallel with load.

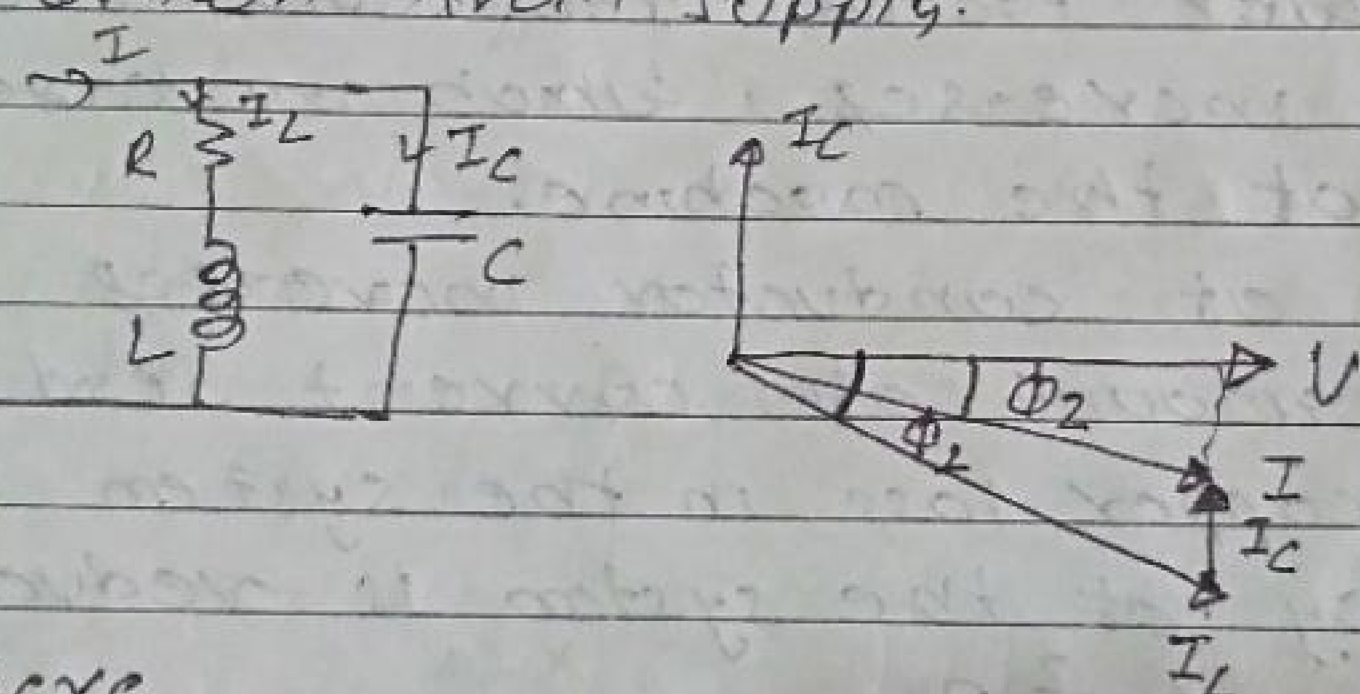
12+10



ϕ_1 = phase angle by which current I_L lags behind voltage

$\cos\phi_1$ = original power factor.

Let a capacitor is placed in parallel with load, it will draw leading current I_c from the supply. Hence total current I is drawn from supply. Hence total current I is drawn from supply.



here

$\phi_2 < \phi_1$ $\qquad [I = I_L + I_C]$

$\therefore \cos\phi_2 > \cos\phi_1$

$\boxed{\text{p.f of ckt 2 > p.f of ckt 1}}$

Now

Before placement of capacitor $P = V I_L \cos\phi_1$

After placement of capacitor $P = V I \cos\phi_2$

Vertical component of current before the capacitor placement $= I_L \sin\phi_1$

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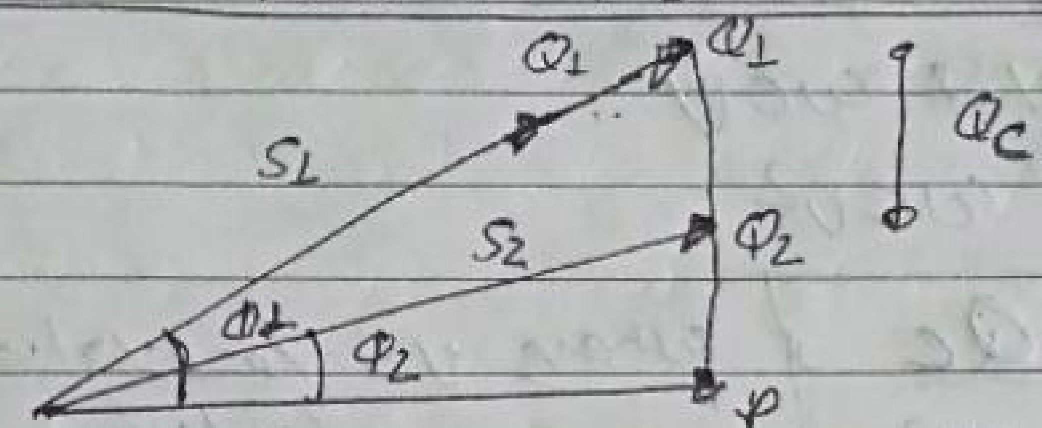
After capacitor placement vertical component of capacitor $= I_L \sin\phi_1 - I \sin\phi_2$

$$\Rightarrow I_C = \frac{V}{X_C} \text{ or } \frac{V}{1/\omega C} \Rightarrow \boxed{C = \frac{I_C}{\omega V}}$$

Calculation of rating of capacitor to improve Power factor



P = Active Power drawn from supply
Q_1 = Reactive Power taken by load
Q_2 = Reactive Power taken from supply
Q_C = leading reactive power drawn by capacitor from the supply

from power diagram

$$\tan\phi_1 = \frac{Q_1}{P}$$

$$\therefore Q_1 = P\tan\phi_1 \quad \text{--- (1)}$$

Similarly

$$Q_2 = P\tan\phi_2 \quad \text{--- (2)}$$

Now

$$Q_C = Q_1 - Q_2$$

$$\boxed{Q_C = P\tan\phi_1 - P\tan\phi_2 \text{ VAR}}$$

This equation gives VAR rating of capacitor to improve p.f from $\cos\phi_1$ to $\cos\phi_2$ i.e

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The value of capacitor can be found as

$$Q_C = V I_C \sin 90$$
$$= V I_C$$

$$I_C = \frac{V}{X_C} = \frac{V}{\frac{1}{\omega C}} = \omega C V$$

$$Q_C = I_C * V$$
$$= V * \omega C V$$
$$= \omega C V^2$$

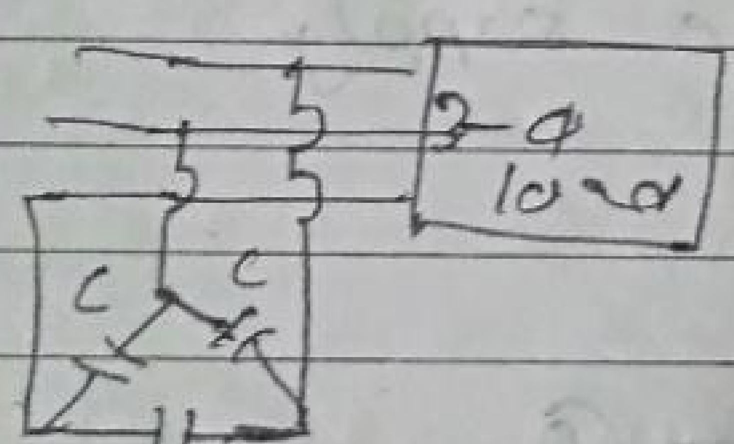
$$\boxed{\therefore C = \frac{Q_C}{\omega V_L^2}}$$ where, V = rms value of supply. (or line)

$V_L = \sqrt{3} V_{ph}$

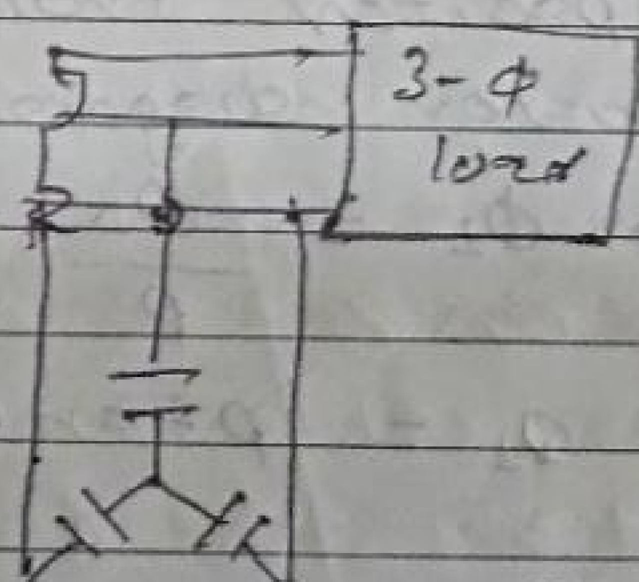
Power factor Improvement Equipment

1) static capacitor

$V_L = 400$
$V_p = \frac{400}{\sqrt{3}}$

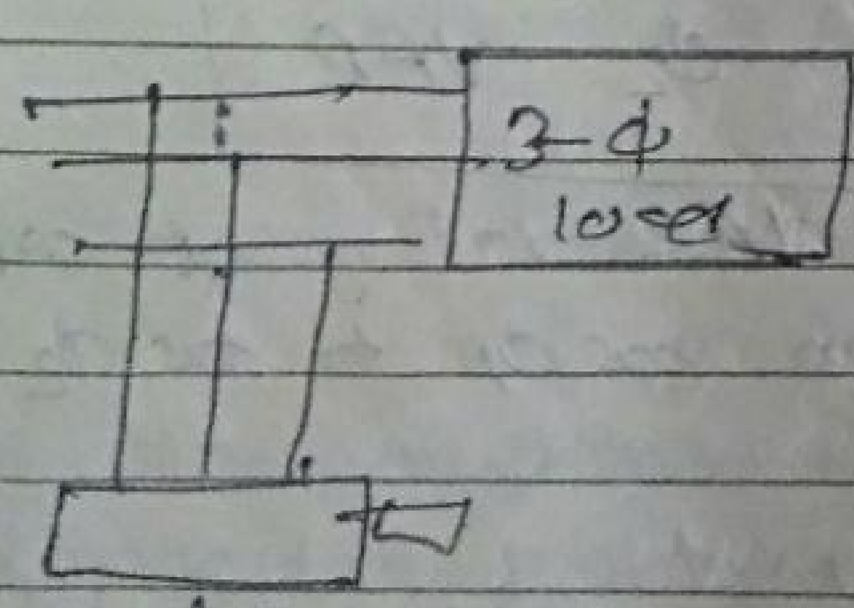


KVAR = $6\pi f C V_L^2 * 10^{-9}$ KVAR



$= 2\pi f C V^2 * 10^{-9}$ KVAR

② Synchronous condenser



when sync motor operates at No-load and is over-excited, it's called sync condenser. It provide leading current.
In sync motor a separate DC source is used for excitation of field winding. Therefore input supply only provide current to energize stator.

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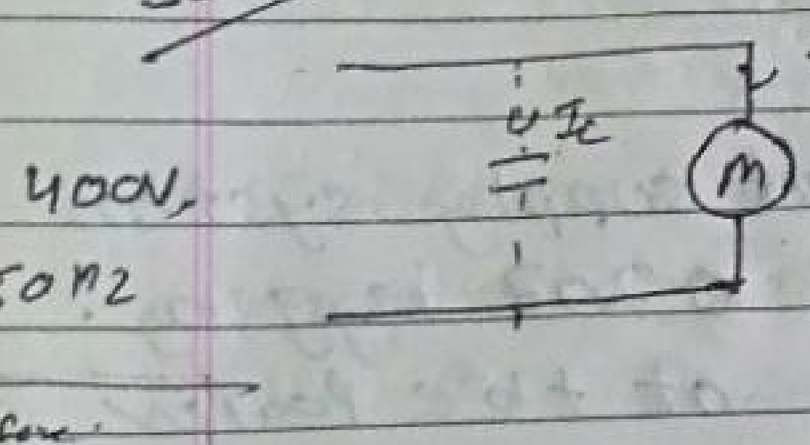
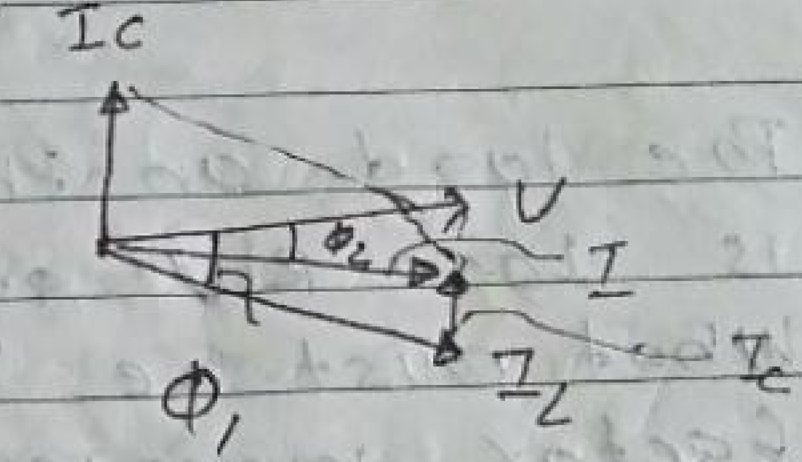
(3) Phase Advancers: simple AC excitor which is connected on the main shaft of motor and operates with motor's circuit for power factor improvement. It is used to improve p.f of industrial ~~motor~~ induction motor.

(Q) A single phase motor connected to 400V 50 Hz supply and it draws 31.7 A current with p.f 0.707 lagging. Calculate the capacitance required in parallel with motor to raise power factor 0.9 and VAR delivered by capacitor.

Soln.





Active component of $I_M = I_L \cos\phi_L$

$= 31.7 * 0.707$

$= 22.19A$

Active component of $I = I \cos\phi$

$= I * 0.9$

But, $I * 0.9 = 22.19$

$\therefore I = \frac{22.19}{0.9} = 24.65A$

Reactive component of $I_L = I_L \sin\phi_L$

$= 31.7 * 0.714$

$= 22.6A$

Reactive component of $I = I \sin\phi$

$= 24.65\sqrt{1-0.9^2}$

$= 10.75A$

But I_C = Reactive comp of I_L - Reactive comp. of I

$= I_L - I_C$

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$= 22.6 - 10.75$
$= 11.85\ A$

$I_c = \frac{V}{X_C} = V * 2\pi f C$

or, $11.85 = 400 * 2\pi .50 * C$
$\therefore C = 94.3 * 10^{-6}\ F$

$Q_c = V \cdot I_c$

(Q) The load on the mains of supply system is 1000 KW at a p.f of 0.707 lagging. What must be KVA rating of the power factor improvement equipment which takes leading current at a p.f of 0.1 in order to raise the p.f of entire system to 0.95?

Soln:
Load $P = 1000$ KW
$\cos\phi_1 = 0.707 \Rightarrow \phi_1 = 45^\circ$ (lagging)
$\cos\phi_2 = 0.95 \quad \phi_2 = 18.195$ (lagging)
Required rating of p.f improvement equipment
$= P(\tan\phi_1 - \tan\phi_2)$
$= 1000(\tan 45 - \tan 18.195)$
$= 1000(1 - 0.32868)$
$= 671.32$ KVAR
Phase angle of pf improvement eqpt
$\phi = \cos^{-1} 0.1 = 84.26^\circ$ (leading)
$= \frac{\text{Reactive KVAR supplied by eqpt}}{\sin\phi}$ KVA
$= \frac{671.32}{\sin 84.26} = 674.7$ KVA

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Q) An industrial load of 4000 kW is supplied at 11 kV, the power factor being 0.8 lagging. A synchronous motor is required to meet an additional load of 1,500 hp (1103.25 kW) and the same time to raise the resultant power factor to 0.95 lagging. Determine the kVA capacity of the motor and power factor at which it must operate. Take the efficiency of the motor as 80%.

Soln: $P_1 = 4000$ kW

$\cos\phi_1 = 0.8$ lagging $\Rightarrow \phi_1 = 36.87°$ (lagging)

$P_2 = \frac{1103.25}{0.8} = 1379.06$ kW

Total load on the system including additional load supplied by the synchronous motor

$P = P_1 + P_2 = 4000 + 1379.06 = 5379.06$ kW

Improved p.f $\cos\phi_2 = 0.95$ (lagging)

$\phi_2 = 18.195°$ (lagging)

Reactive kVA supplied by sync. motor

= Reactive kVA drawn by industrial load − Reactive kVA drawn by combined load

$= 4000 \tan 36.87 - 5379.06 \tan 18.195$

$= 1232$ kVAR (leading)

kVA rating of motor $= \sqrt{P_2^2 + (\text{kVAR supplied by motor})^2}$

$= \sqrt{(1379.06)^2 + (1232)^2}$

$= 1849$ kVA

Power factor of sync. motor $= \frac{1379.06}{1849}$

$= 0.7458$ (leads)

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(3) A 400V, 50 Hz, 3-phase line delivers 2000 kW at 0.8 p.f lagging. It is desired to raise the line power factor to unity by installing shunt capacitors. Calculate the capacitance of each unit if they are connected in
(i) star (ii) Delta

Soln:

$P = 200$ kW $\quad \phi_1 = \cos^{-1}(0.8) = 36.87$

$\phi_2 = \tan^{-1}(1) = 0$

$\therefore Q_C = KVAR_1 - KVAR_2$

$= P(\tan\phi_1 - \tan\phi_2)$

$= 200(\tan 36.87 - \tan 0)$

$= 150$

for star,

$Q_C = 2\pi f C V_L^2 * 10^{-9}$; μf

$150 * 10^9 = 2\pi * 50 * (400)^2 * C$

$\therefore C = 2984$ μf

for delta

$Q_C = 6\pi f C V^2 * 10^{-9}$

$C = \dfrac{150 * 10^9}{6\pi * 50 * (400)^2} = 995$ μf

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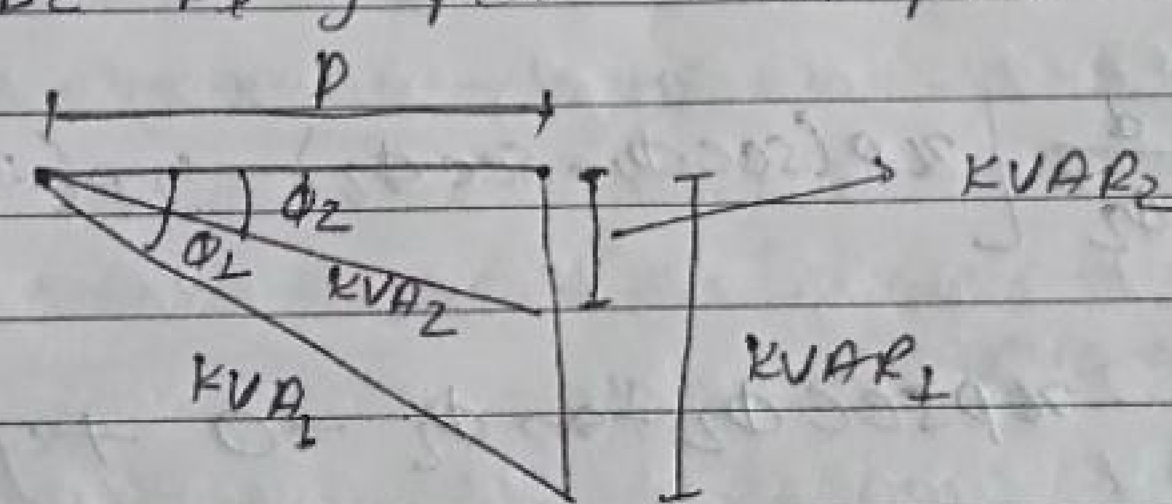
Most Economical power factor

Improvement in power factor will result in reduction in maximum demand. The limit of the power factor at which the net saving (saving in annual maximum demand charges less annual expenditure incurred on power factor correcting equipment) is maximum is known as economical limit of power factor correcting.

Let,

P = Peak load kW at a P.f of $\cos\phi_1$ and charged at a rate of Rs x per KVA of maximum demand per annum.

Let, expenditure incurred on P.f correcting equipment be Rs y per KVAR per annum.



KVA max. demand at $\cos\phi_1$, $KVA_1 = \frac{P}{\cos\phi_1}$

$= P\sec\phi_1$

KVA max. demand at $\cos\phi_2$, $KVA_2 = \frac{P}{\cos\phi_2}$

$= P\sec\phi_2$

Annual saving in maximum demand charge

$= Rs\ x\ (KVA_1 - KVA_2)$

$= Rs\ x\ (P\sec\phi_1 - P\sec\phi_2)$

Reactive power at $\cos\phi_1$, $KVAR_1 = P\tan\phi_1$

Reactive power at $\cos\phi_2$, $KVAR_2 = P\tan\phi_2$

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Leading kVAR taken by p.f correcting equipment = $P(\tan\phi_1 - \tan\phi_2)$

Annual cost of p.f correcting equipment
$= Rs\ P.y(\tan\phi_1 - \tan\phi_2)$

So,

Net annual saving = eq^n (1) − eq^n (2)

$= xP(\sec\phi_1 - \sec\phi_2) - yP(\tan\phi_1 - \tan\phi_2)$

Here
ϕ_2 is only variable

So, annual saving is max^m if $\frac{dS}{d\phi_2} = 0$

or, $\frac{d}{d\phi_2}\left[xP(\sec\phi_1 - \sec\phi_2) - yP(\tan\phi_1 - \tan\phi_2)\right] = 0$

$0 - xP\sec\phi_2\tan\phi_2 - 0 + yP\sec^2\phi_2 = 0$

or $xP\sec\phi_2\tan\phi_2 = yP\sec^2\phi_2$

$\tan\phi_2 = \frac{y}{x}\sec\phi_2$

$\sin\phi_2 = \frac{y}{x}$

∴ most economical p.f $\cos\phi_2 = \sqrt{1-\sin^2\phi_2}$

$= \sqrt{1-\left(\frac{y}{x}\right)^2}$

Hence, most economical p.f depend upon the relative cost of supply of p.f correcting equipment but is independent of original p.f $\cos\phi_1$.

(6) A consumer takes load of 600 kW at a lagging power factor of 0.7 for 3000 hours a year. The tariff is Rs 260 per kVA of maximum demand annually and 8 paisa per kWh. The annual cost of phase advancing plant is Rs 26 per kVAR. Determine the annual saving if the pf of the load is improved (i) to 0.9 lagging, (ii) most economical p.f

Soln:

(x) maximum demand charge = 260 per kVA / annum
charges = 8 paisa per kwh.

(y) Annual cost of phase advancing unit = Rs 26 per kVAR / annum

Let, for most economical p.f (it improved to most economical p.f)

$$\cos\phi_2 = \sqrt{1-\left(\frac{y}{x}\right)^2}$$

$$= \sqrt{1-\left(\frac{26}{260}\right)^2}$$

$= 0.995$ lagging

Capacity of phase advancing plant $= kW(\tan\phi_1 - \tan\phi_2)$
$= 600[\tan\cos^{-1}0.7 - \tan\cos^{-1}0.995)$
$= 552$ kVAR

Annual saving in demand charge

$$= Rs\ x\left(\frac{P}{\cos\phi_1} - \frac{P}{\cos\phi_2}\right)$$

$$= 260\left(\frac{600}{0.7} - \frac{600}{0.995}\right)$$

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$= Rs \_\_\_$ — (1)

Annual expenditure on phase advancing plant

$= Rs\ 9\,(kVAR_1 - kVAR_2)$

$= 26 \times 552$

$= \_\_\_$ — (2)

Net saving in annual cost = (1) − (2)

kWh charges will be same as there will be no change in energy consumption.

(5) A factory to be set up is to have a fixed load of 760 kW at 0.8 p.f. The electricity board offers to supply energy at the following alternate rate

1) LV supply at Rs 32/ kVA max demand/Annum + 20 paisa / kWh

2) HV supply at Rs 30/ kVA max demand/ Annum + 20 paisa/ kWh.

The H.V switchgear costs Rs 60/ kVA and switchgear losses at full load amount of 5%. Interest depreciation charge for the switch gear are 12% of the capital cost. If the factory is to work for 48 hours/ week, determine most economical tariff.

Soln:

~~kVA demand~~ $= \cancel{\frac{760}{0.8}} = \cancel{950\ kVA}$. max demand in kVA $= \frac{760}{0.8} = 950$

$\boxed{\text{(1) for H.V supply}}$

As losses = 5%. so capacity of H.V stch $= \frac{950}{0.95}$

$= 1000\ kVA.$

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Given,

H.V supply at Rs 30/kVA Max Demand / Annum + 20 paise / 1 kwh.

Cost on capital investment on HV eqpt = Rs 60/kVA

$= 60 \times 1000$

$= Rs\ 60000.$

Annual interest & Depreciation = Rs $60{,}000 \times \frac{12}{100}$

$= Rs\ 7200$ # ——

So, ~~for H.V supply,~~

~~Annual charge at M.D~~ → working hour per Annum $= 52 \times 48$

$= 2496$ hours

Annual charge due to max kVA Demand = Rs 30 × ____

Annual charge due to kwh consumption = Rs $0.20 \times \frac{760}{0.95} \times 2496$

=

∴ Total annual cost = Annual Interest & dep charge + Annual charge on max Demand

+ annual energy charge

= ____

~~For LV supply~~

No loss as no eqpt is connected

Annual charge on Maximum kVA demand = Rs 32 × ____

Annual charge on kwh consumption = Rs $0.2 \times \frac{760}{1} \times 2496$

=

Total annual cost = ___ + ___ =

Per unit modelling

Per unit System: The equipment of power system like generator motor transmission line may have large rating numerical figures, voltage in kV power in MW current in KA etc. If the actual rating are used in calculating, the calculation becomes bulky and complex. So the value are expressed in term of per unit or percentage value for voltage current impedance and power.

Per unit is the ratio of actual value of that quantity to the base value of same quantity.

i.e per unit value = $\frac{\text{Actual value}}{\text{Base value}}$

Selection of Base value

① In a power system base value of power and voltage are first selected by the user. These base value are called as standard base values.

② The base value of current and impedance are calculated from the base value of power and voltage and called as derived base value.

Let, for $3-\phi$

Base value of power = S_B

Base value of voltage = V_B

Then, Base current $(I_B) = \frac{S_B}{\sqrt{3} V_B}$

Base impedance $Z_B = \frac{\text{Base voltage (phase)}}{\text{Base current (phase)}}$

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$$= \frac{V_B/\sqrt{3}}{I_B}$$

$$= \frac{V_B}{\sqrt{3}} * \frac{S_B}{\sqrt{3}V_B}$$

$$= \frac{V_B^2}{S_B}$$

for 1-ϕ

Base power $= S_B$

Base voltage $= V_{B\,ph}$

then $I_B = \frac{S_B}{V_{B\,ph}}$

$$Z_B = \frac{V_{B\,ph}}{I_B}$$

$$= \frac{V_{B\,ph}^2}{S_B}$$

NOTE: Base power is always constant while base voltage changes according to transformer.

Changes of Base ~~Power~~

Let,

Old base power $= S_B^{old}$

" " Voltage $= V_B^{old}$

Then,

Old base current $= I_B^{old} = \frac{S_B^{old}}{\sqrt{3}\, V_B^{old}}$

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Old base impedance $(Z_B^{old}) = \frac{(V_B^{old})^2}{S_B^{old}}$

Actual impedance $= Z(\Omega)$

$\therefore$ Old base per unit impedance, $Z_{pu}^{old} = \frac{\text{Actual Imp}}{\text{Base Imp}}$

$$= \frac{Z}{\frac{(V_B^{old})^2}{S_B^{old}}}$$

$$\therefore Z_{pu}^{old} = Z * \frac{S_B^{old}}{(V_B^{old})^2} \quad \text{---} (1)$$

Now,

Again,

New Base power $= S_B^{New}$

" " Voltage $= V_B^{New}$

" " Impedance $Z_B^{New} = \frac{(V_B^{New})^2}{S_B^{New}}$

$\therefore$ New per unit impedance $(Z_{pu}^{New}) = \frac{Z}{\frac{(V_B^{New})^2}{S_B^{New}}}$

$$\therefore Z_{pu}^{New} = Z * \frac{S_B^{New}}{(V_B^{New})^2} \quad \text{---} (2)$$

Dividing eqn (2) and (1), we get

$$\boxed{\therefore Z_{pu}^{New} = Z_{pu}^{old} * \left(\frac{V_B^{old}}{V_B^{New}}\right)^2 * \left(\frac{S_B^{New}}{S_B^{old}}\right)}$$

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Advantages of per unit system

1. It makes calculation easier and interpretation will also be easier.
2. All values falls into a narrow ranges so any error can be detected easily.
3. There will be no difference in per unit values considering single phase or three phase system.
4. Manufactures usually specifies their equipment in per unit values according to their own rating.
5. Per unit impedance of a transformer referred to the primary side is same as that of a secondary side.

proof:

Let us consider a single phase transformer

Let Base voltage at primary side $= V_1$

" current " " " $= I_1$

" Impedance " " " $= Z_{B1} = \frac{V_1}{I_1}$

Actual impedance of primary side $= Z_1 \,\Omega$

$\therefore$ p.u impedance of primary side

$$Z_1^{pu} = \frac{Z_1}{V_1/I_1} = Z_1 \times \frac{I_1}{V_1} \quad \text{--- (1)}$$

Similarly

p.u impedance of secondary side

$$Z_2^{pu} = \frac{Z_2}{V_2/I_2} = Z_2 \times \frac{I_2}{V_2} \quad \text{--- (2)}$$

for a lossless transformer

$$V_1 I_1 = V_2 I_2$$

$$I_1 = \frac{V_2 I_2}{V_1} \quad \text{--- (3)}$$

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for a transformer primary side impedance can be referred to the secondary side and viceversa as

$$Z_1 = Z_2 \times \left(\frac{V_1}{V_2}\right)^2 \quad \text{--- (4)} \quad \left[Z_{01} = \frac{Z_2}{k^2}\right]$$

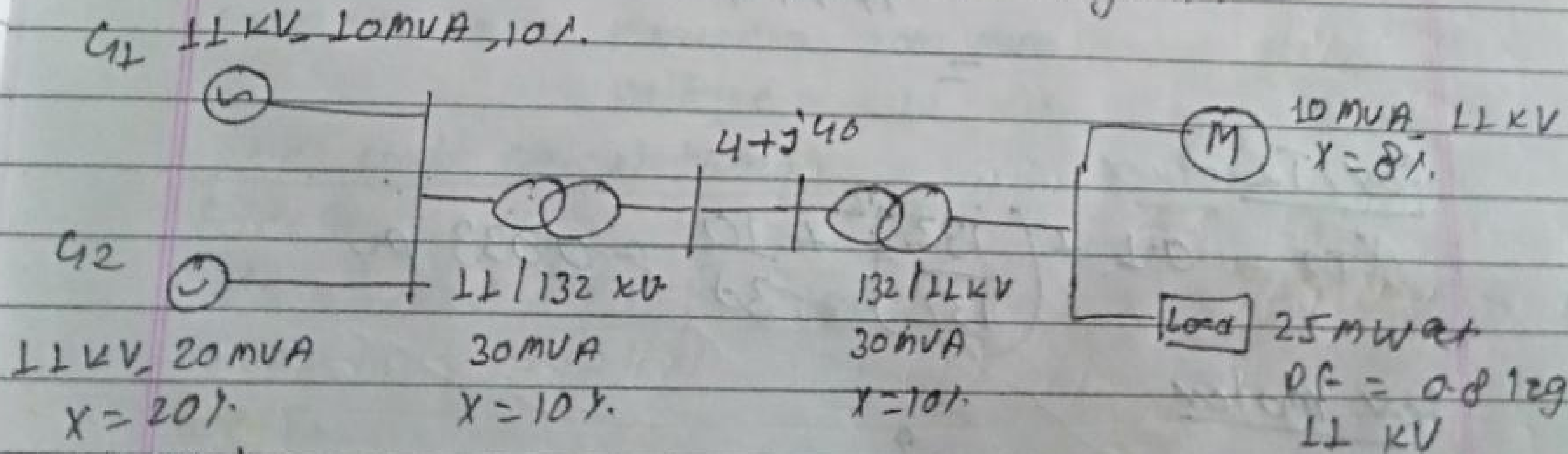
Substuting eqn (3) & (4), in (I)

$$Z_1^{pu} = Z_2 \times \left(\frac{V_1}{V_2}\right)^2 \times \frac{V_2 I_2 / V_1}{V_1} \quad \text{from eq}^n \text{ (3).}$$

$$= Z_2 \times \frac{I_2}{V_2} = Z_2^{pu}$$

$$\boxed{\therefore Z_1^{pu} = Z_2^{pu}}$$

Q) Determine per unit values for the given figure. Also draw the impedence diagram



Soln:

Let common base power (S_B^{New}) = 10MVA

New common base voltage V_B^{New} = 11KV

per unit calculation

$$X_{G1} = 0.1 \times \left(\frac{11}{11}\right)^2 \times \left(\frac{10}{10}\right) = 0.1 \text{ p.u}$$

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