Example 5.11.3 A single phase a.c Generator supplies the following Load;

(i) Lighting Load of 20 kW at unity power factor.

(ii) Induction Motor Load of 100 kW at pf 0.707 lagging.

(iii) Synchronous Motor Load of 50 kW at pf 0.9 leading

Calculate the total kW and kVA delivered by the Generator and the power factor at which it works

Solution: Using the suffixes 1, 2 and 3 to indicate the different Loads we have

$$kVA_1 = \frac{kW_1}{\cos\phi_1} = \frac{20}{1} = 20 \text{ KVA}$$

$$kVA_2 = \frac{kW_2}{\cos\phi_2} = \frac{100}{0.707} = 141.4\text{KVA}$$

$$kVA_3 = \frac{kW_3}{\cos\phi_3} = \frac{50}{0.9} = 55.6\text{KVA}$$

There Loads are represented In Fig 5.11.3 the three kVA are not in phase In order to find the total kVA. We resolve each kVA into rectangular-components kW and kVA as shown in Fig 5.11.3 The total kW and kVAR may then be combined to obtained it obtain total kVA.

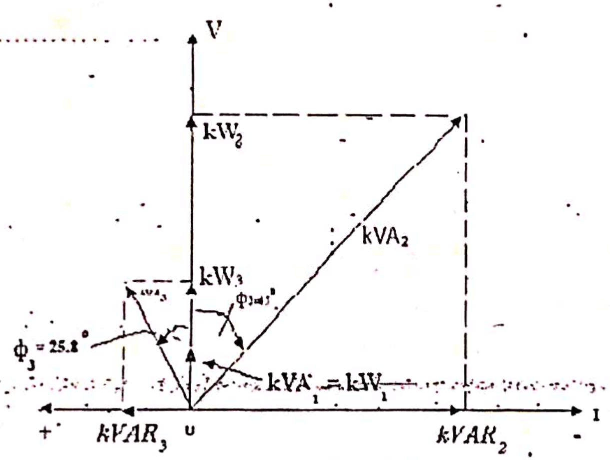

Fig. 5.11.3

$$kVAR_1 = kVA_1 \sin\phi_1 = 20 \times 0 = 0$$

$$kVAR_2 = kVA_2 \sin\phi_2 = -141.4 \times 0.707 = -100 \text{ kVAR}$$

$$kVAR_3 = kVA_3 \sin\phi_3 = +55.6 \times 0.436 = +24.3 \text{ kVAR}$$

Note that $kVAR_2$ and $kVAR_3$ are in opposite direction: $kVAR_2$ being a lagging while $kVAR_3$ being a leading kVAR.

Total kVA = 20 + 100 + 50 = 170 kW

Total kVAR = 0-100 + 24.3 = - 75.7 kVAR

Total kVA = $\sqrt{(KW)^2 + (KVAR)^2} = \sqrt{(170)^2 + (75.7)^2} = 186$KVA

$$\text{Power factor} = \frac{\text{Total KW}}{\text{Total KVA}} = 0.914 \text{ lagging}$$

The power factor must be lagging since the resultant kVAR is lagging.

12 **Example 5.11.4** A synchronous ~~the~~ Motor (Synchronous condensor) improves the power factor of a Load of 300 kW from 0.7 lagging to 0.9 lagging. Simultaneously the Motor carries a Load of 80 kW Find (i) the leading kVAR taken by the Motor (ii) kVA rating of the Motor and (iii) Power factor at which the Motor operates.

Solution:

Load, P_1 = 300KW; Motor Load P_2 = 80KW

P.F of Load $\cos\phi_1$ = 0.7 Lag

P.F of Load (Combined Load) $\cos\phi_2$ = 0.9 Lag

Combined Load P = $P_1 + P_2$ = 300+80 = 380KW

$\phi_1 = \cos^{-1}(0.7) = 45.57^0$; $\phi_2 = \cos^{-1}(0.9) = 25.84^0$

(i) Leading KVAR taken by the Motor

CE = DE-DC

= AB-DC[∴ DE = AB] → combined load

= $(P_1 \tan\phi_1) - (P \tan\phi_1)$

= $(300 \times \tan(45.57^0)) - (380 \times \tan(25.84^0))$

= 121.986 KVAR

(ii) KVA rating of the Motor BC = $\sqrt{(BE)^2 + (CE)^2}$

= $\sqrt{(P_2)^2 + (CE)^2}$

= $\sqrt{(80)^2 + (121.986)^2}$

= 145.878KVA

(iii) P.F of Motor, $\cos\phi_m$ = $\frac{\text{Motor KW}}{\text{Motor KVA}} = \frac{80}{145.878}$

= 0.548Leading

Example 5.11.5 A 3- phase , 50 Hz 400 V Motor develops 200 H.P (149.2 kW) the power factor being 0.75 lagging and efficiency 90% A bank of capacitors is connected in delta across the supply terminals and power factor raised to 0.95 lagging . Each of the capacitance units is built of 4 similar 100 V capacitors; determine the capacitance of each capacitor.

Solution:

Original P.F $\cos\phi_1$ = 0.75 Lagging

Final P.F $\cos\phi_2$ = 0.95 Lagging

Motor input, P $= \frac{\text{Output}}{\eta} = \frac{149.2 \times 10^3}{0.9}$

= 165.77KW

$\phi_1 = \cos^{-1}(0.75)$ = 41.41^0

$\tan\phi_1 = 0.8819$

$\phi_2 = \cos^{-1}(0.95) = 18.19^0$

$\tan\phi_2 = 0.3286$

Leading KVAR taken by condenser bank

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

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

$= 165.77\ (0.8819 - 0.3286)$

= 91.72KVAR

Leading KVAR taken by each of three sets

$= \frac{91.72}{3}$

= 30.57KVAR ....(i)

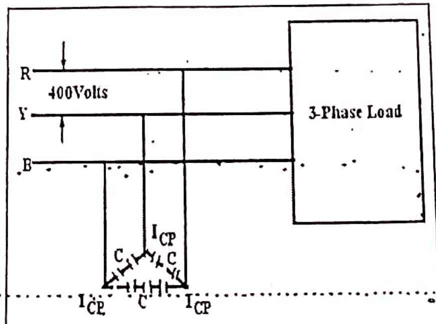

Fig 5.11.4

Fig 5.11.4 shows the delta connected condenser bank let c farad be capacitance of 4 capacitors in each phase

Phase current of capacitor is

$I_{CP} = \frac{V_{ph}}{X_c} = 2\pi fc\ V_{ph}$

$I_{CP} = 2\pi c \times 50 \times 400$

I_{CP} = 1,25,663.7.0 C amperes

KVAR /Phase $= \frac{V_{ph} \times I_{cp}}{1000}$ = 50265.48C.........(ii)

Equating (i) and (ii)

30.57 = 50265.48C

C = 608.17×10^{-6} farad

C = 608.17μF

Since it is combined capacitance of four equal capacitors joined in series

∴ Capacitance of each capacitor = 4x608.17μF

= 2432.68μF

Example 5.11.6 An Educational institute takes a Load of 400 kW at 0.80 p.f lagging for 2300 hours per annum the tariff is Rs 150 / kVA plus 50 paise / kWh consumed. If the p.f is improved to 0.95 lagging by means of capacitors costing Rs 520 / kVAR and having a power loss of 50 Watts power / kVA, calculate the annul. saving effected by their use Allow 10% per annum for Interest and depreciation.

Solution:

Load P_1 = 400KW

$\cos\phi_1$ = 0.8 lagging

$\phi_1 = \cos^{-1}(0.8) = 36.86^0$; $\tan\phi_1 = 0.075$

$\cos\phi_2$ = 0.95 lagging

$\phi_2 = \cos^{-1}(0.95) = 18.19^0$

$\tan\phi_2$ = 0.3286

Let the leading KVAR taken by the capacitor is 'x'

∴Capacitor loss $= \frac{50x}{1000} = 0.05x$ KW

Total power, $P_2 = (400 + 0.05x)$ KW

Leading KVAR taken by the Capacitor is

$x = P_1\tan\phi_1 - P_2\tan\phi_2$

$x = [(400 \times 0.075) - ((400+0.05x)(0.3286)]$

$x = (300) - [(131.44) + 0.01643x]$

$1.01643x = 168.56$

$x = \frac{168.56}{1.01643} = 165.835$ *KVAR*

Annual cost before P.F. Correction

Max KVA demand = $\frac{400}{0.8}$ = 500KVA.

Max KVA demand charges = Rs.150x500 = Rs. 75000

Units consumed/year = (400 x 2300) = 9, 20,000 KWh

Energy charges/year = Rs. (0.5 x 9, 20,000) = Rs. 4, 60,000

Total annual cost = Rs. (75,000 + 4, 60,000)= Rs. 5, 35,000

Annual cost after P.F. correction

Max KVA demand = $\frac{400}{0.95}$ = 421.052KVA

Max KVA demand charges = Rs.150 x 421.0520 = Rs. 63,157.8

Units consumed/year = (400 x 2300) = 9, 20,000KWh

Energy charges/year = Rs. (0.5 x 9, 20,000) = Rs. 4, 60,000

Capital cost of capacitors = Rs. 520 x 168.56 = 87,651.2

Annual interest and depreciation = 0.1 x 87651.2 = 8,765.12

Annual Energy loss in capacitor = 0.05x x 2300

= 0.05x168.56 x 2300 = 19,384.4KWh

Annual cost of lossess occurring in capacitors

= Rs. 0.5 x 19,384.4. = Rs. 9,692.2

∴ Total annual cost = Rs. (63,157.8 + 4, 60,000+8767.12+9692.2)

= Rs. 5, 41,615.12

Annual saving = Rs. (5, 41,615.12 – 5, 35,000) = Rs. 6,615.12

Example 5.11.7 An Industrial Load operates at 0.75 p.f lagging and has a monthly demand of 750 kVA the monthly power rate is Rs 8.50 per kVA. To improve the power factor 200 kVAR. Capacitors are installed, in which there is negligible power loss. The installed cost of equipment is Rs 20,000 and fixed charges are estimated at 10% per year .Calculate the annual saving effected by the use of capacitors.

Solution:

Monthly Demand = 750KVA

Cosϕ = 0.75

ϕ = $\cos^{-1}(0.75)$

ϕ = 41.409^0

Sinϕ = 0.6614

KW component of MD = (250 x 0.75); since [KVA x cosϕ]

KW = 562.5

KVAR component of Max Demand = (750 x 0.6614)

= 496.05 KVAR

Leading KVAR taken by the capacitor is 200 KVAR

Net KVAR after improvement = (496.05 – 200)

= 296.05 KVAR

KVA after P.F. improvement = $\sqrt{(562.5)^2 + (296.05)^2}$ = 635.65

Reduction in KVA = 750 - 635.65 = 114.35

Monthly saving on KVA charges = Rs.(8.5 x 114.35) = Rs.971.975

Yearly saving on KVA charges = Rs. (971.975 x 12) = Rs. 11663.7

Fixed charges/year = Rs.(0.1 x 20,000) = Rs. 2,000

Net annural savings = Rs. (11663.7 – 2000) = Rs. 9663.07

Example 5.11.8. A Factory Load consists of the following.

(i). An induction Motor of 100 H.P with 0.75 p.f. lagging and efficiency 80%

(ii) A synchronous Motor of 50 H.P with 0.9 leading and efficiency 90%

(iii)Lighting Load of 100 kW at unity p.f

Find the annual electrical charges if the tariff is Rs 100 per kVA of maximum demand per annum plus 50paise per kWR, assuming the Load to be steady for 2000 hours in a year.

Solution:

Input power to induction Motor = $\frac{100 \times 735.5}{80}$

= 919.37KW

Lagging KAVR taken by induction Motor

= 919.375 x tan ($\cos^{-1}(0.75)$)

= 81.0812KVAR

Input power to synchronous Motor = $\frac{50 \times 735.5}{90}$

= 408.33KW

Leading KVAR taken by synchronous Motor

= 408.33 x tan ($\cos^{-1}(0.9)$)

= 19.789KVAR

Since lighting Load works at unity power factor its lagging KVAR is 0 .

∴Total Lagging KVAR	=	(81.0812 – 19.789)
	=	61.2922KVAR
Total active power	=	91.9375 + 40.8611
	=	132.7986KW
Total KVA	=	$\sqrt{(132.7986)^2 + (61.2922)^2}$
	=	146.26KVA
Annual KVA demand charges	=	Rs. 100 x 146.26
	=	Rs. 14,626.07
Energy consumed/year	=	132.7986 x 2000
	=	2,65,597.2 KWh
Annual energy charges	=	Rs. 0.5 x 2, 65,597.2
	=	Rs. 1, 32,798.6
Total annual bill	=	KVA demand charges + Energy charges
	=	14,626.07 + 1, 32,798.6
	=	Rs. 1,47,424.67

13 **Example 5.11.9** A supply system feeds the following Loads (i) a lighting Load (purely resistive). of 1500 kW (ii) a Load of 400 kW at a p.f of 0.8 lagging (iii) a Load of 800 kW at a p.f of 0.8 leading (iv) a Load of 1500 kW at a p.f 0.6 lagging (v) a synchronous Motor driving a 540 kW D.C Generator and having an overall efficiency of 90%. Calculate the power factor of synchronous Motor so that the station power factor may become unity.

Solution:

The lighting Load works at unity power factor and

∴ it's lagging KVAR is 0

The lagging KVAR are taken by the Loads 2nd and 4th

Whereas Loads 3rd and 5th take the leading KVAR for station power factor to be unity and total lagging KVAR must be neutralized by the total leading KVAR

∴ Total lagging KVAR taken by Load 2nd and 4th

= $[(400 \tan(\cos^{-1}(0.8))] + [(1500 \times \tan(\cos^{-1}(0.6))]$

= 2300KVAR

Leading KVAR taken by Load = $[800 \times \tan(\cos^{-1}(0.6))]$

= 600 KVAR

Leading KVAR taken by synchronous Motor

= 2300 – 600

= 1700KVAR

Motor input = out/(= 540/0.9 = 600 KW

If Ø is the phase angle of synchronous Motor then tanØ

$$\tan\phi = \frac{KVAR}{KW} = \frac{1700}{600} = 2.833$$

$Ø = \tan^{-1}(2.833)$

$= 70.55^0$ $\cos\phi = \cos(70.55) = 0.332$

In order that station power factor may become unity the synchronous Motor should operated at a power factor 0.332 leading.

Example 5.11.10 A factory which has a maximum demand of 175 kW at a power factor of 0.75 lagging is charged at Rs 100 per kVA per annum. If the phase advancing equipment costs Rs 100 per kVAR, find the most economical power factor at which the factor should operate. Interest and depreciation total 10% of the capital investment on the phase advancing equipment.

Solution:

Power factor of the factory cos ϕ_1	=	0.75 lagging.
Maximum Demand charges, x	=	Rs 100/KVA/annum.
Expenditure on pahse advancing plant y	=	Rs 100x0.1
	=	Rs 10/KVAR/annum

Most economical power factor at which factory should operate

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

$$= \sqrt{1 - \left(\frac{10}{100}\right)^2}$$

$\cos\phi_2 = 0.9486$ lagging

Example 5.11.11 A factory has an average demand of 50kW and an annual Load factor of 0.6 The power factor is 0.75 lagging The tariff is Rs 150 per kVA of maximum demand per annum plus 50 paise per kWh If loss free capacitors costing Rs 600 per kVAR are to be utilized find the value of power factor at which maximum saving will result The interest and depreciation together amount to 10% also determine the annual saving effected by improving the p.f to this value. Power factor is improved to 0.96 lagging by installing phase advancing equipment.