

2.6 POWER CIRCLE DIAGRAM

Receiving End Power Circle Diagram:

Consider equation in general circuit constants

$$V_s = AV_r + BI_r$$

In phasor diagram except for I_r all other phasors represent voltages. We are interested in studying the power diagram, that too receiving end power diagram. The voltage phasor diagram must be multiplied by suitable value of current. If we multiply equation by V_r/B we get as,

$$\frac{V_s V_r}{B} = \frac{AV_r^2}{B} + V_r I_r$$

We find that the last term in the expression represents the volt-amperes at the receiving end; this is what is required. Since V_r is taken as the reference, the effect of multiplying the equation by V_r/B will be to change the magnitude of all the phasors in Fig. 2.6.1 by $|V_r|/|B|$ and rotate them clockwise through an angle $\angle(0 - \beta^\circ)$ i.e., $-\beta^\circ$. Now when origin is shifted to n and phasor BI_r is to be rotated through $-\beta^\circ$, this phasor will subtend an angle $-\phi_r$ with the horizontal axis. V_r^2/B will subtend an angle $-\beta$ with the horizontal axis. Now with respect to V_r^2/B other phasors AV_r^2/B and $V_s V_r/B$ are drawn as shown in Fig.2.6.1.

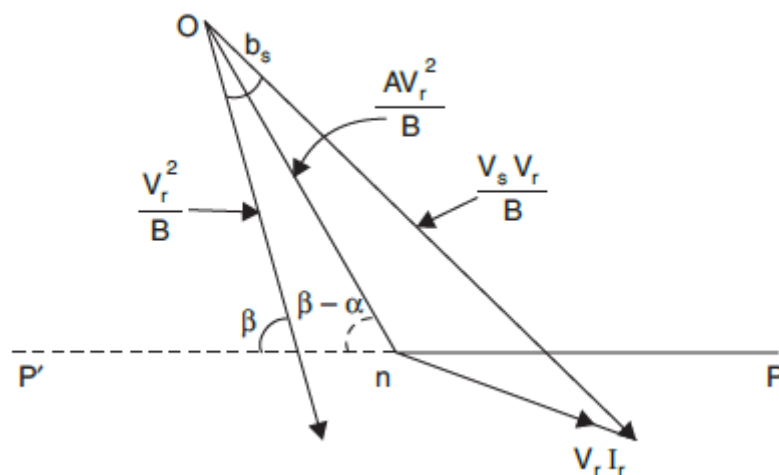


Figure 2.6.1 Phasor diagram

[Source: "Electrical Power Systems" by C.L.Wadhwa Page: 239]

Normally in a 3-phase system, 3-phase power is specified and $L-L$ voltage is given. The power circle diagram that we have obtained we started with phase quantities. We could make use of 3-phase quantities also and in that case the power will be 3-phase power and voltage line to line. The procedure we are going to describe is say on per phase basis.

- (a) Let P be the 3-phase power and V_L the line to line voltage at the receiving end, then

$$P_r = \frac{P}{3} \text{ and } V_r = \frac{V_L}{\sqrt{3}}$$

- (b) Calculate

$$\frac{|A||V_r^2|}{|B|}$$

- (c) Now looking at the relative values of P_r and $A V_r^2 / B$ choose a suitable scale.
- (d) Draw a horizontal line and fix a point n on this line. From this point draw a line subtending an angle ϕ_r as shown in Fig.6.1.2 Then after reducing P_r to scale cut the horizontal line at l by an amount equal to P_r . Draw a vertical line such that it cuts the slanted line (at angle ϕ_r) at m . Thus the operating point m is obtained.
- (e) Now from the point n , draw a line no equal to $A V_r^2 / B$ (reduced to scale) at angle $(\beta - \alpha)$ in the third quadrant.
- (f) Measure the length Om . Convert this to MVA or kVA depending upon the scale chosen. Then

$$Om \times \text{scale} = \frac{|V_s||V_r|}{|B|}$$

The capacity of the phase modifier in all cases will be mm' . The VARs requirements of the load are fixed and are equal to ml . Therefore, the division of VARs in the three situations is as follows:

- (i) When m' is above m . The capacity of the phase modifier is mm' . The VARs transmitted over the line are $m'l$, i.e., in order to have sending end voltage corresponding to this operating point, transmission line has to transmit not only the VARs required by the load but it has to supply VARs to the synchronous phase modifier equal to mm' i.e., the phase modifier takes the lagging VARs from the system which means it is under-excited.

(ii) When m' lies between m and l . In order to meet the VARs requirements of the load mm' is supplied by the phase modifier and $m'l$ have to be transmitted over the line. The phase modifier is over-excited.

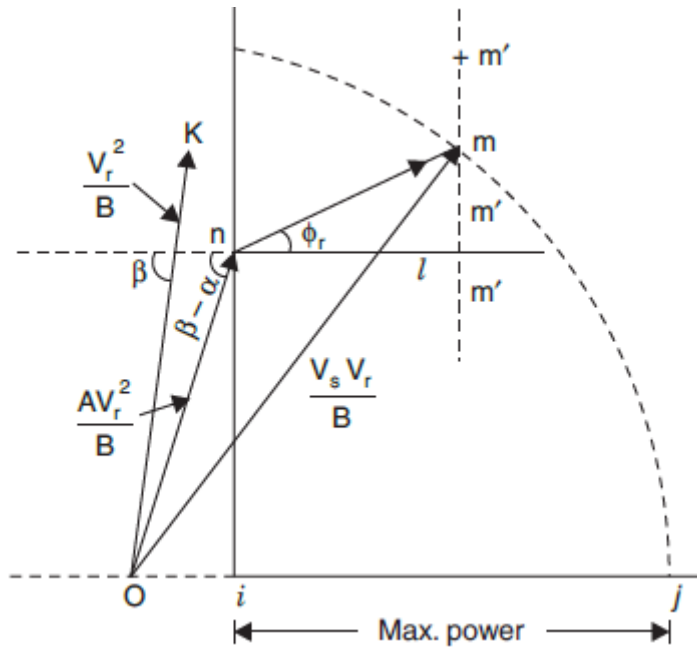


Figure 2.6.2 Power Circle diagram

[Source: "Electrical Power Systems" by C.L.Wadhwa Page: 242]

(iii) When m' lies below the horizontal axis. The capacity of the phase modifier is mm' . Here the phase modifier not only supplied VARs to the load but it supplies lm' VARs to the transmission line also to get this operating point. The phase modifier is over-excited.

The power factor of the load is fixed and is given by $\cos \phi_r$. The power factor of the transmission line at the receiving end will depend upon the position of the operating point m' with respect to the horizontal axis. The power factor angle in all cases is the angle between the line nm' and the horizontal axis. If the point m' lies above the horizontal axis the power factor is lagging and if it lies below the horizontal axis it is leading.

To find out the load angle or torque angle δ_s , draw a horizontal line passing through O and then from O draw a line subtending an angle β . This line corresponds to $|V_r^2|/|B|$. Cut this line to scale equal to $|V_r^2|/|B|$. The angle between Ok and Om' gives the torque angle for regulated systems and for unregulated systems the angle between Ok and Om is the torque angle δ_s .