2.6 POWER CIRCLE DIAGRAM

Receiving End Power Circle Diagram:

Consider equation in general circuit constants

Vs = AVr + BIr

In phasor diagram except for *Ir* 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 *Vr*/*B* we get as,

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

We find that the last term in the expression represents the volt-amperes at the receiving end; this is what is required. Since *Vr* is taken as the reference, the effect of multiplying the equation by *Vr*/*B* will be to change the magnitude of all the phasors in Fig. 2.6.1 by |*Vr*|/|*B*| and rotate them clockwise through an angle ∠(0 – β°) *i.e.*, – β°.Now when origin is shifted to *n* and phasor *BIr* is to be rotated through – β°, this phasor will subtend an angle – φ*r* with the horizontal axis. *Vr* 2/*B* will subtend an angle – β with the horizontal axis. Now with respect to *Vr* 2/*B* other phasors *AVr* 2/*B* and *VsVr*/*B* are drawn as shown in Fig.2.6.1.

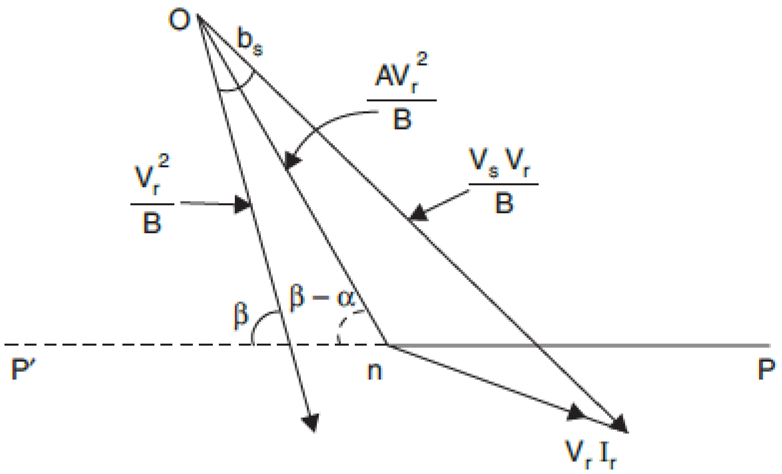

Figure 2.6.1 Phasor diagram

[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 *VL* 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 $A\,V_r^2 / \text{B}$ 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 *Pr* to scale cut the horizontal line at *l* by an amount equal to *Pr*. 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 $A\,V_r^2 / \text{B}$ (reduced to scale) at angle (β – α) 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.

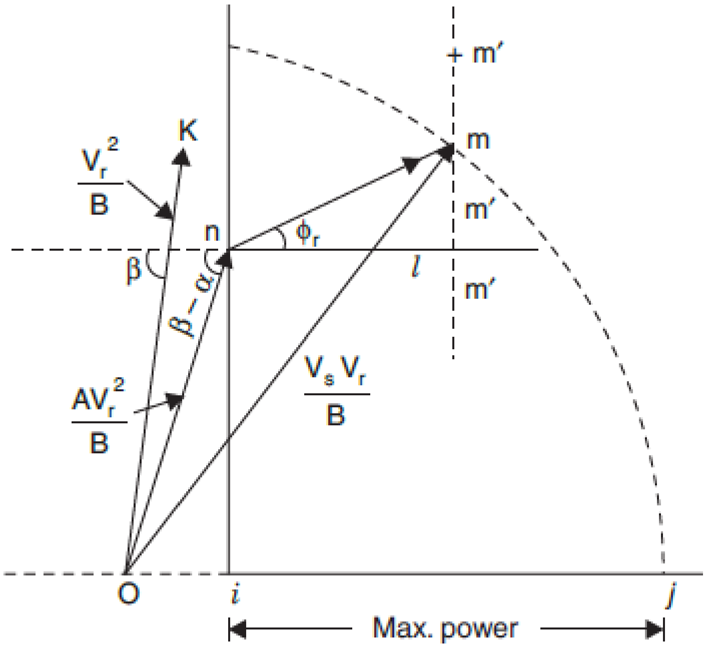

Figure 2.6.2 Power Circle diagram

[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 φ*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 $|Vr^2|/|B|$. Cut this line to scale equal to $|Vr^2|/|B|$. 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*.