Efficiency of T/F :-

Efficiency $\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \text{losses}} = \frac{P_{out}}{P_{out} + P_{cu} + P_c}$

B_{max} remains practically constant from no load to full load condition.

Full load condition is the condition when the coils are carrying the rated current.

(*) Core loss P_c is practically constant/fixed.

(*) Depending on the loading condition the copper loss P_{cu} will vary.

$P_{cu} = |I_2'|^2 (R_{eq})$ at any current I_2'

During SC test the wattmeter reads Cu loss at full load current $= (P_{cu})_{fl}$

During OC test the wattmeter reads core loss at rated voltage and it will be constant/fixed

Now if the T/F is loaded in such that it carries K times of the rated current then

$$K = \frac{\text{Actual current}}{\text{Full load current}}$$

Cu loss will be $= K^2 (P_{cu})_{fl}$

K is known as the degree of loading on the T/F where

$$\boxed{0 \leq K \leq 1}$$

Therefore at K degree of loading

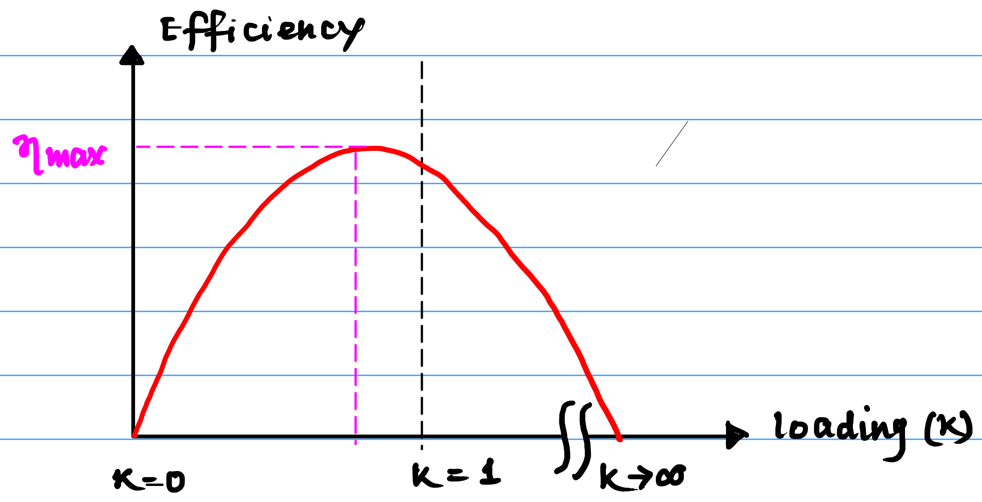
$$\eta_K = \frac{(P_{out})_K}{(P_{out})_K + P_c + (P_{cu})_K}$$

$\cos\theta$ = power factor of the load

$$= \frac{K S \cos\theta}{K S \cos\theta + P_c + K^2 (P_{cu})_{fl}}$$

When $K = 0$ then $\eta_K = 0$

When $K \to \infty$ (Theoretically) $\eta_K \to 0$



We will keep power factor of the Load $\cos\theta$ constant, we will vary the degree of Loading K

$$\eta_K = \frac{KS\cos\theta}{KS\cos\theta + P_c + K^2 (P_{cu})_{fl}}$$

$$\frac{d\eta_K}{dK} = 0$$

$$= \frac{S\cos\theta}{S\cos\theta + \frac{P_c}{K} + K(P_{cu})_{fl}}$$

Now η_K will be max. when the denominator is minimum

$$\frac{d}{dK}\left[S\cos\theta + \frac{P_c}{K} + K(P_{cu})_{fl}\right]_{K=K_m} = 0$$

$$\Rightarrow \quad -\frac{P_c}{K_m} + (P_{cu})_{fl} = 0 \qquad \Rightarrow \quad K_m^2 (P_{cu})_{fl} = P_c$$

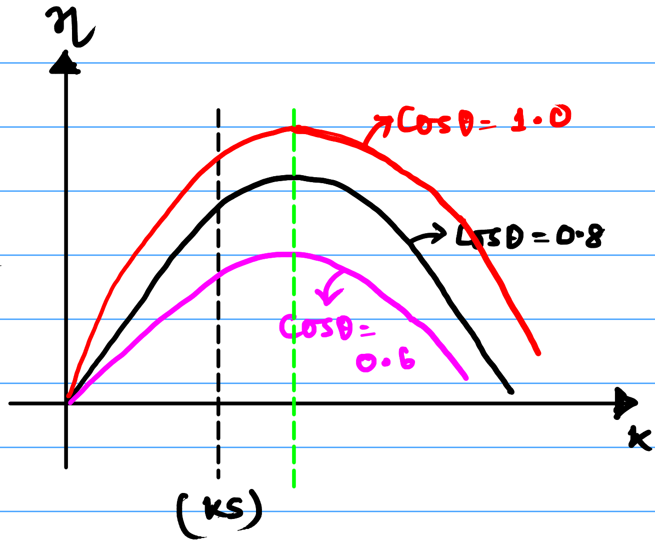
$$\Rightarrow \quad \boxed{K_m = \sqrt{\frac{P_c}{(P_{cu})_{fl}}}}$$

η_K will be max. when variable loss is equal to the fixed Loss.

S = Rated kVA of T/F

$$\boxed{(\eta_K)_{max} = \frac{K_m S\cos\theta}{K_m S\cos\theta + 2P_c}}$$

We will keep k fixed
i.e (kS) also will be fixed
Now we want to see the effect of variation of power factor.



$$\eta = \frac{kS\cos\theta}{kS\cos\theta + k^2 (P_{cu})_{fl} + P_c}$$

You can find out $\frac{d\eta}{d\theta} = 0$

η is maximum when $\cos\theta = 1$

Example:-

T/F rating ⇒ 10 kVA, 2500/250 V (50 Hz)

OC Test :- 250 V, 0.8 A, 50 W

SC Test : 60 V, 4 A, 80 W

Q. Calculate efficiency at 25% of full load @ 0.8 pf

Q. Load kVA at which max efficiency occurs.

Soln. $(P_{cu})_{fl} = 80$ kW $\quad (P_c) = 50$ W $\quad K = 0.25$

$$\eta_{0.25} = \frac{K S \cos\theta}{K S \cos\theta + P_c + K^2 (P_{cu})_{fl}} \times 100$$

$$= \frac{0.25 \times 10 \times 10^3 \times 0.8}{0.25 \times 10 \times 10^3 \times 0.8 + 50 + (0.25)^2 \times 80} \times 100$$

$$= ?$$

$$K_m = \sqrt{\frac{P_c}{(P_{cu})_{fl}}} = \sqrt{\frac{50}{80}} = ?$$

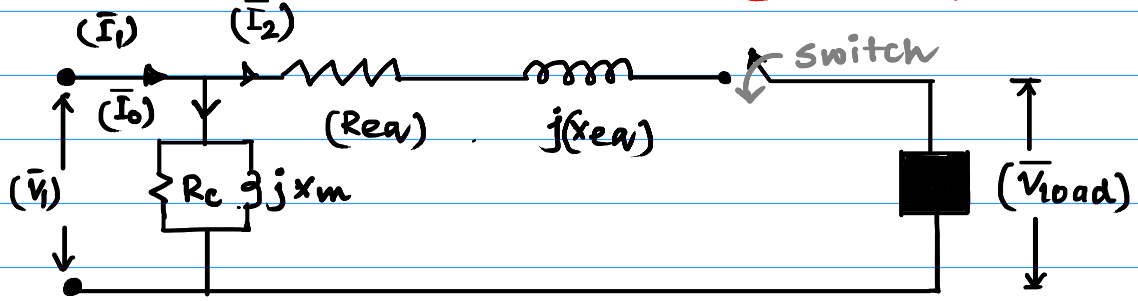
$$I_{HV} = K_m (I_{fl}) = K_m (I_{fl})_{HV} =$$

$$\text{Load kVA} = I_{HV} V_{HV} = ?$$

Voltage regulation :-

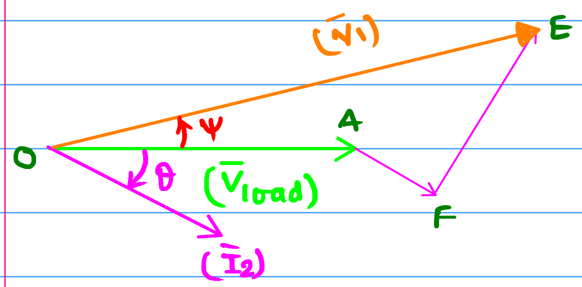
Voltage Regulation is a measure of how the terminal load voltage varies from no load to full load condition.

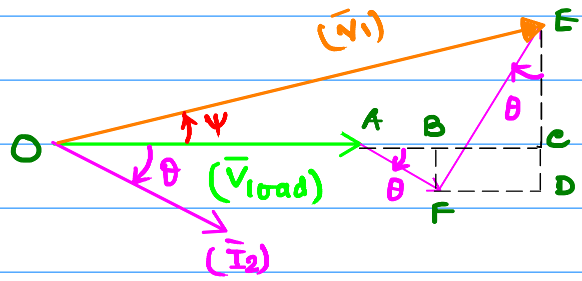
(say 230V/115V, 1 kVA)



As a consumer our requirement is to maintain 115V at load terminal at any loading

$$\% \text{ Reg} = \frac{|(\bar{V}_{load})^{NL}| - |(\bar{V}_{load})^{FL}|}{|(\bar{V}_{load})^{FL}|} \times 100$$





$|(\bar{V}_{load})^{NL}| = OE \approx OC$ as ψ is very small as the resistance and leakage reactance of a T/F is low.

$$\left|(\bar{V}_{load})^{FL}\right| = OA$$

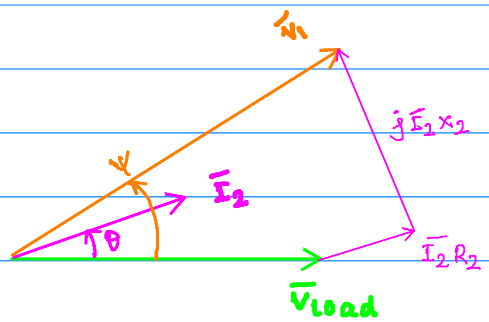
Therefore $\% \; Reg = \dfrac{OC - OA}{OA} \times 100$

$$OC = OA + AB + BC$$
$$= OA + AB + FD$$
$$= OA + I_2 (R_{eq}) \cos\theta + I_2 (X_{eq}) \sin\theta$$

$$\boxed{OC - OA = I_2 (R_{eq}) \cos\theta + I_2 (X_{eq}) \sin\theta}$$

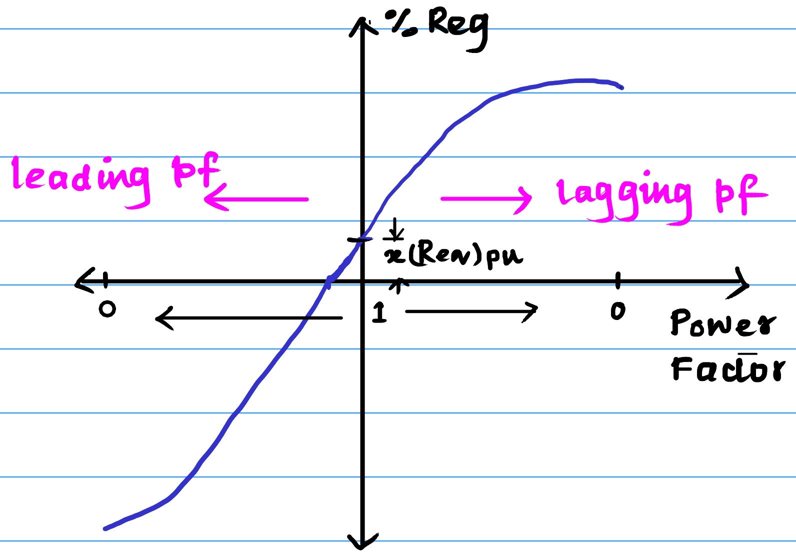
$$\% \text{ Voltage Regulation} = \frac{(I_2)\left[(R_{eq}) \cos\theta + (X_{eq}) \sin\theta\right]}{(V_{load})^{FL}} \times 100$$

[Approximate]



$$\% \text{ voltage Regulation} = \frac{I_2\left[R_{eq} \cos\theta - X_{eq} \sin\theta\right]}{(V_{load}^{FL})}$$

[Approximate]



Maximum Voltage Regulation

$$VR = \frac{I_2 (R_{eq} \cos\theta + X_{eq} \sin\theta)}{(V_{load\,FL})}$$

$$\frac{d(VR)}{d\theta} = \frac{I_2 (-R_{eq} \sin\theta + X_{eq} \cos\theta)}{(V_{load\,FL})}$$

$$\frac{d(VR)}{d\theta} = 0 \quad \Rightarrow \quad -R_{eq} \sin\theta + X_{eq} \cos\theta = 0$$

$$\Rightarrow \quad \boxed{\tan\theta = \frac{X_{eq}}{R_{eq}}}$$

$$\boxed{\cos\theta = \frac{R_{eq}}{\sqrt{(R_{eq})^2 + (X_{eq})^2}}}$$

Zero Voltage Regulation:-

Zero voltage Regulation is possible only for leading load.

For leading load the voltage Regulation is

$$VR = \frac{I_2[R_{eq}\cos\theta - X_{eq}\sin\theta]}{(V_{load}^{FL})}$$

$$VR = 0 \Rightarrow R_{eq}\cos\theta = X_{eq}\sin\theta$$

$$\Rightarrow \boxed{\tan\theta = \frac{R_{eq}}{X_{eq}}}$$

$$\boxed{\cos\theta = \frac{X_{eq}}{\sqrt{(R_{eq})^2 + (X_{eq})^2}}}$$

Example :-

T/F rating ⇒ 10 kVA, 2500/250 V (50 Hz)

OC Test :- 250 V, 0.8 A, 50 W

SC Test : 60 V, 4 A, 80 W

& Calculate approximate voltage regulation under rated load for 0.8 pf (lag & lead).

& Calculate the power factor at zero voltage regulation

Sol^n

$$Z_{eq} = \frac{V_{sc}}{I_{sc}} = \frac{60}{4} = 15\,\Omega$$

$$R_{eq} = \frac{P_{sc}}{(I_{sc})^2} = \frac{80}{16} = 5\,\Omega \qquad X_{eq} = \sqrt{(15)^2 - (5)^2} = 14.1421\,\Omega$$

$$\text{Approx. } VR(\%) = \frac{I(R_{eq}\cos\theta \pm X_{eq}\sin\theta)}{(V_{load}^{FL})}$$

for (lag pf)

$$= \frac{4 \times (5 \times 0.8 + 14.1421 \times 0.6)}{2500} = ?$$

for (lead pf)

$$= \frac{4 \times (5 \times 0.8 - 14.1421 \times 0.6)}{2500} = ?$$

Zero regulation is possible for leading pf

$$\tan\theta = \frac{R_{eq}}{X_{eq}} = ? \qquad \cos\theta = ? \text{ (lead)}$$