LESSON 23: SYNCHRONOUS ALTERNATOR VOLTAGE REGULATION

ET 332b

Ac Motors, Generators and Power Systems

LEARNING OBJECTIVES

After this presentation you will be able to:

- Define voltage regulation of a synchronous machine
- Explain how saturation affects no-load voltage in a synchronous machine
- Compute voltage regulation using an approximate method that accounts for magnetic saturation.

SYNCHRONOUS ALTERNATOR VOLTAGE REGULATION

Defining equation

$$\%VR = \frac{|V_{nl}| - |V_{rated}|}{|V_{rated}|} \cdot 100$$

Where: %VR = percentage voltage regulation
V_{rated} = nameplate voltage rating of machine
V_{nl} = open circuit voltage of machine when supplying rated load at rated voltage

Voltage Regulation related to size of X_s. Lower value is better. Indicates amount of field current change required to maintain rated voltage.

COMPUTING VOLTAGE REGULATION

V_{nl} is not E_{af}. Must include the effects of saturation to get accurate value of %VR.

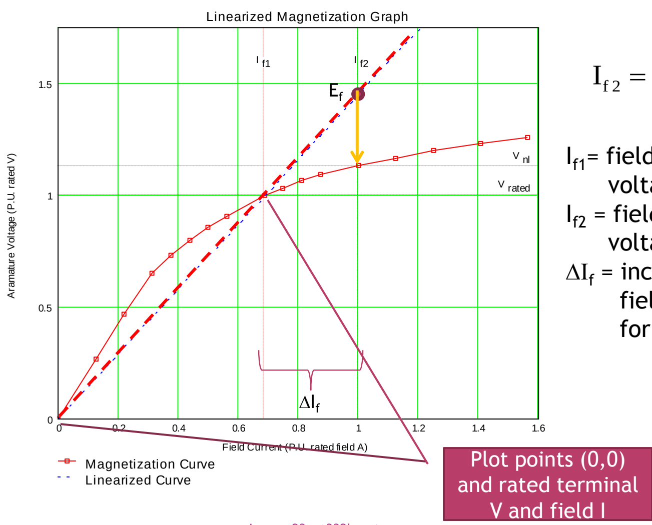
Use an approximate method to find V_{nl}. The hypothetical linearized magnetization curve estimates the value of $V_{nl.}$ This is not equal to the open circuit voltage. We must include the voltage drop due to the synchronous reactance.

<u>Method for finding V_{nl} using approximate method</u>

1.) Compute value of E_{af}
2.) Plot value of E_{af} on graph and intersect with linearized magnetization curve
3.) Project vertical line down to magnetization curve
4.) Project horizontal line from intersection of step 3 to voltage axis and read off value of V_{nl}.

COMPUTING VOLTAGE REGULATION

Magnetization curve plots no-load voltage Vs field current.



$$I_{f2} = I_{f1} + \Delta I_f$$

I_{f1}= field I to produce rated voltage at no-load
I_{f2} = field I to produce rated voltage at rated load.
ΔI_f = incremental increase in field I to compensate for X_s drop

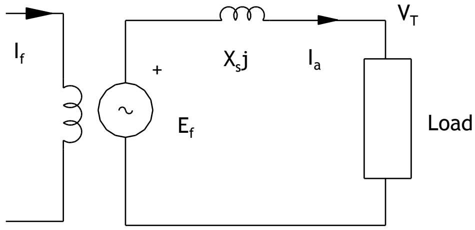
SYNCHRONOUS ALTERNATOR VOLTAGE REGULATION

Example 23-1: A three phase, 2-pole, 60 Hz alternator has a power rating of 6000 kVA at 13.8 kV. The armature is wye connected and has a synchronous reactance of 11.67 ohms/phase. It operates at rated kVA and rated voltage with a power factor of 90% lagging.
Find:
a.) excitation voltage (E_f);
b.) power angle (δ);
c.) no-load voltage assuming no change in field current;
d.) voltage regulation;
e.) no-load voltage if field current is reduced to 85% of its value at rated load

Use the no-load magnetization curve provide on previous slide.

EXAMPLE 23-1 SOLUTION (1)

Per phase model



Compute the value of E_f.

$$\bar{E}_f = \bar{V}_T + \bar{I}_a \bar{X}_s$$

$$\bar{X}_s = 11.67\angle 90^\circ\ \Omega/\text{phase}$$

$$\bar{V}_T = \frac{13{,}800\text{V}}{\sqrt{3}}\angle 0^\circ\ \text{V} \quad \text{Y-Connected}$$

$$S_T = \sqrt{3}\, V_L I_L$$

$$\bar{V}_T = 7967\angle 0^\circ\ \text{V}$$

EXAMPLE 23-1 SOLUTION (2)

Wye Connected, so $\bar{I}_L = \bar{I}_p = \bar{I}_a$

$$|\bar{I}_a| = \frac{S_T}{\sqrt{3}\, V_L}$$

$$|\bar{I}_a| = \frac{6000\ \text{kVA}}{\sqrt{3}\ 13.8\ \text{kV}}$$

$$|\bar{I}_a| = 251.02\text{A}$$

Use power factor to find phase angle on armature current

$$F_p = 0.9\ \text{Lag}$$

$$\theta = \cos^{-1}(F_p)$$

$$\theta = \cos^{-1}(0.9)$$

$$\theta = -25.84^\circ\ (-\text{Lag})$$

$$\bar{I}_a = 251.02\angle -25.85^\circ\ \text{A}$$

EXAMPLE 23-1 SOLUTION (3)

Now compute the value of E_f using the formula given previously

$$\bar{E}_f = 7967\angle 0^\circ + (251.02\angle -25.85^\circ)(11.67\angle 90^\circ\ \Omega)$$

$$\bar{E}_f = 7967\angle 0^\circ + 2929.6\angle 64.2^\circ$$

$$\bar{E}_f = 9612.6\angle 15.92^\circ$$

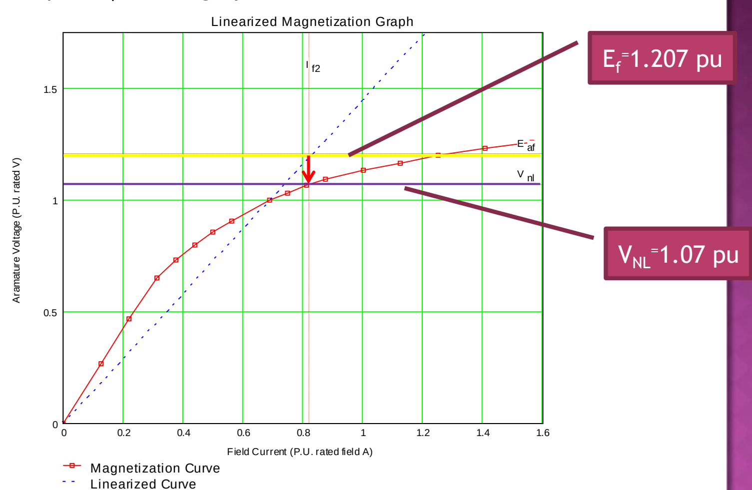
a.) $\boxed{|\bar{E}_f| = 9612.6\text{V}}$ b.) $\boxed{\delta = 15.92^\circ}$

c.) To find no-load voltage, use graph. Voltage axis and current scaled in P.U. based on V_{rated}

$$V_{base} = 7967\text{V} \quad \text{P.U.}|\bar{E}_f| = \frac{|\bar{E}_f|}{V_{base}} = \frac{9612.6\text{V}}{7967\text{V}} = 1.207\ \text{p.u.}$$

EXAMPLE 23-1 SOLUTION (4)

Find V_{nl} using the approximate linearized magnetization curve. Plot the value of p.u. E_f on the graph



EXAMPLE 23-1 SOLUTION (5)

Convert to actual phase voltage by multiplying by V_{base}

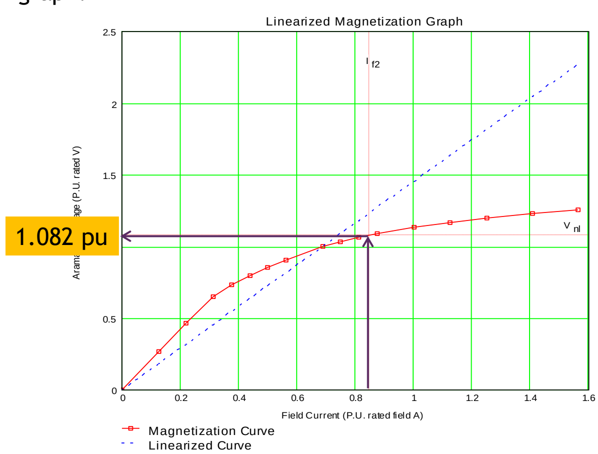
$$V_{nl} = V_{base} \cdot V_{nlpu} = 7967 \cdot 1.07 = 8525\text{ V}$$ Answer

d.) now compute the %VR from rated voltage and the no-load voltage

$$\%VR = \frac{|V_{nl}| - |V_{rated}|}{|V_{rated}|}100\% = \frac{8525 - 7967}{7967}100\% = 7\%$$ Answer

EXAMPLE 23-1 SOLUTION (6)

e.) Now find V_{nl} at 85% rated field I (0.85 pu). Read value from graph.



V_{nlpu}= 1.082 pu V_{nl}=7967(1.082)=8620 V

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END LESSON 23: SYNCHRONOUS ALTERNATOR VOLTAGE REGULATION

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