**EE331 Fall 2019 HW 8**
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(1)
First we encapsulate values that are given in python dictionaries.

```
import numpy
import matplotlib.pyplot as pyplot
import pint
unit = pint.UnitRegistry()

terminal = {
    'power': 120 * unit.kW,
    'voltageRated': 266 * unit.V
}

stator = {
    'currentRated': 180 * unit.A,
    'impedance': (0.05 + 1.5j) * unit.ohms
}

field = {}
```

We are assuming the motor is running at its rated voltage. With this assumption, we get the current through the stator.

```
stator['current'] = (terminal['power']/3/terminal['voltageRated']).to('A')
print(f"\(I_s = {stator['current']:.2fLx}\)")
```

$I_s = 150.38\,\mathrm{A}$
Since we know the rated current, we can find out the max imaginary stator current.

```
stator['currentMaxImaginary'] = numpy.sqrt(stator['currentRated']**2 - stator['current']**2)
print(f"\(\max{{(I_m(I_s))}} = {stator['currentMaxImaginary']:.2fLx}\)")
```

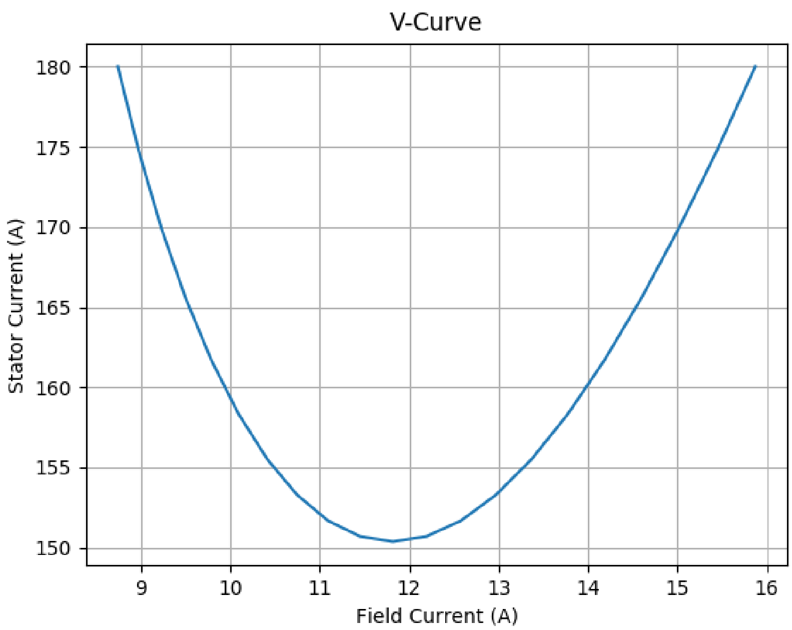
$\max\left(I_m(I_s)\right) = 98.93\,\mathrm{A}$
We will use the max imaginary current to establish a range for our v-curve.

```
imaginaryRange = 1j*stator['currentMaxImaginary'] * numpy.linspace(-1, 1, 21, endpoint=True)
stator['currents'] = stator['current'] + imaginaryRange
```

Now we can calculate the field current, $I_f$, for each stator current in our `stator['currents']` array.

```
field['voltages'] = (stator['currents']*stator['impedance'] + terminal['voltageRated']).to('V')
field['currents'] = (abs(field['voltages']) / (30*unit.ohms)).to('A') #Given in problem statement
```

Finally, we plot stator currents vs field currents.

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(2)

**(a) Find $P_{max}$ at $E_f = 19.5\text{kV}$**

Assuming $R_s, R_{sys} \ll X_{sys} \ll X_s$:

$$X_T = X_s + X_{sys} = 0.80\,\Omega$$

And, given:

$$V_{bus} = 13.00\,\text{kV}$$

$$E_f = 19.50\,\text{kV}$$

The maximum output power of the generator is obtained when $\delta = 90°$.

$$P_{e,max} = \frac{3E_f V_{bus}}{X_T} \sin 90° = \boxed{950.63\,\text{MW}}$$

**(b)**

$$\delta = \sin^{-1} \frac{700\text{MW}}{P_{e,max}} = \boxed{47.42°}$$

**(c)**

We apply the current $\delta$ to the field voltage at $\delta = 90°$ to get $E_f$.

$$E_f = 19.50\angle 47.42°\text{kV}$$

Now, to get the stator current, $I_s$,

$$E_f = I_s \cdot X_T + V_{bus}$$

$$\rightarrow I_s = \frac{E_f - V_{bus}}{X_T} = 17.95\angle -0.77°\text{kA}$$

Finally, we get the terminal voltage, $V_t$.

$$V_t = I_s \cdot X_{sys} + V_{bus}$$

$$V_t = \boxed{14.79\angle -0.09°\text{kV}}$$

**(d)**

$$S_t = (796.66 + 9.44\text{i})\,\text{MVA}$$
$$Q_t = \boxed{9.44\,\text{MVAR}}$$

**(e)**

$$\delta = \sin^{-1}\frac{200\text{MW}}{P_{e,max}} = \boxed{12.15°}$$

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(3)

**(a) Calculate Motor Slip**

$$s = \frac{\omega_2}{\omega_1} = \frac{\omega_1 - p_p\omega_r}{\omega_1}$$
$$\omega_1 = 376.99\,\text{rad}\,\text{s}^{-1}$$
$$\omega_r = 91.63\,\text{rad}\,\text{s}^{-1}$$
$$s = \frac{\omega_1 - p_p\omega_r}{\omega_1} = \boxed{0.03}$$

**(b)** $I_1$, $I_2$

$$Z_{eq} = R_1 + jX_1 + (\frac{R_2'}{s} + jX_2')||jX_m = (1.88 + 0.75\text{i})\,\Omega$$
$$I_1 = \frac{V_1}{Z_{eq}} = \boxed{131.13\angle - 21.76°\,\text{A}}$$
$$E_1 = 251.15\angle - 5.01°\,\text{V}$$
$$I_2' = \frac{E_1}{R_2'/s + jX_2'} = \boxed{126.20\angle - 10.78°\,\text{A}}$$

**(c) Motor Efficiency**

$$P_1 = \Re(3V_1I_1^*) = 97.18\,\text{kW}$$
$$P_{es} = \Re(3E_1I_2'^*) = 94.60\,\text{kW}$$
$$P_m = (1 - s)P_{es} = 91.97\,\text{kW}$$
$$\eta = \frac{P_m}{P_1} = \boxed{0.95}$$

**(d)**

Assuming no mechanical loss, $P_e = P_m$

$$T_e = \frac{P_e}{\omega_r} = \boxed{1.00\,\text{kW}\,\text{s}\,\text{rad}^{-1}}$$

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(4)

$$Z_{eq} = R_1 + jX_1 + (\frac{R_2'}{s} + jX_2')||jX_m + Z_{th} = (0.14 + 0.51\text{i})\,\Omega$$
$$I_1 = \frac{V_{src}}{Z_{eq}} = \boxed{526.48\angle - 74.24°\,\text{A}}$$

$$V_t = V_{src} - I_1 Z_{th} = \boxed{215.59\angle 1.21^\circ\,\mathrm{V}}$$

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(5)

**(a) Slip**

$$\omega_1 = 376.99\,\mathrm{rad\,s^{-1}}$$
$$\omega_r = 193.73\,\mathrm{rad\,s^{-1}}$$
$$\omega_2 = -397.94\,\mathrm{rad\,s^{-1}}$$
$$s = \boxed{-1.06}$$