ECE 111: Homework 15

Week #15 - ECE 331 Energy Conversion. Due 8am, Tuesday May 3rd

Please submit as a Word or pdf file to BlackBoard or email to Jacob_Glower@yahoo.com with header ECE 111 HW#15

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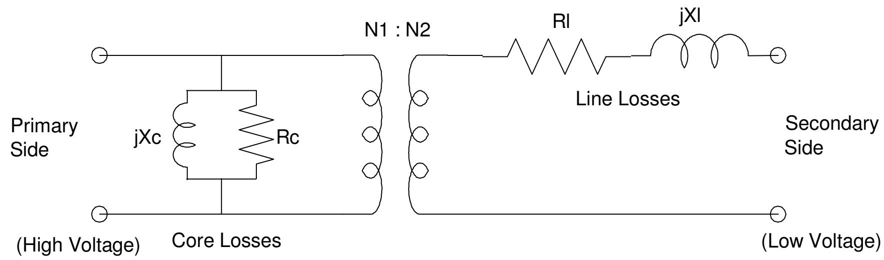
1) Determine the circuit model for a 9.6kV : 240V transformer is tested with the following test results:



Transformer Model

	V	Power	pf
Open-Circuit Test	V1 = 9.6kV	105 W	0.03
Short-Circuit Test	V2 = 24V	22 W	0.95

Open-Circuit Test (Rc & jXc)

$$P = V \cdot I \cdot pf$$

$$105W = 9600V \cdot I \cdot 0.03$$

$$I = 0.3646A$$

$$pf = \cos(\theta)$$

$$\theta = 88.2809^0$$

$$Z = \left(\frac{V}{I}\right)\angle\theta = \left(\frac{V}{I}\right) \cdot \exp(j\theta)$$

$$Z = 789.94 + j26320$$

This is the series model. To find the parallel model, use 1/Z

$$\frac{1}{Z} = 1.1393 \cdot 10^{-6} - j3.7960 \cdot 10^{-5}$$

This is the parallel R and X

$$R_c = \left(\frac{1}{1.1393 \cdot 10^{-6}}\right) = 877.71k\Omega$$

$$jX_c = \left(\frac{1}{-j3.7960 \cdot 10^{-5}}\right) = j26.343k\Omega$$

In Matlab

```
>> V = 9600;
>> P = 105;
>> I = 105/(9600*0.03)

I =     0.3646

>> Z = (V/I) * exp(j*acos(0.03))

Z =   7.8994e+002 +2.6320e+004i

>> 1/Z

ans =   1.1393e-006 -3.7960e-005i

>> Rc = 1 / real(1/Z)

Rc =   8.7771e+005

>> jXc = 1 / ( j*imag(1/Z) )

jXc =         0 +2.6343e+004i
```

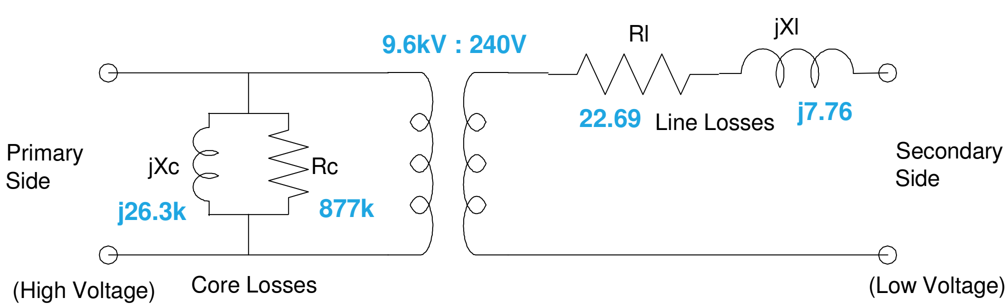
Open-Circuit Test (RL and jXL)

Same procedure but stop at Z

```
>> P = 22;
>> V = 24;
>> pf = 0.95;
>> I = P / (V*pf)

I =  0.9649

>> Z = (V/I) * exp(j*acos(pf))

Z = 23.6291 + 7.7665i
```

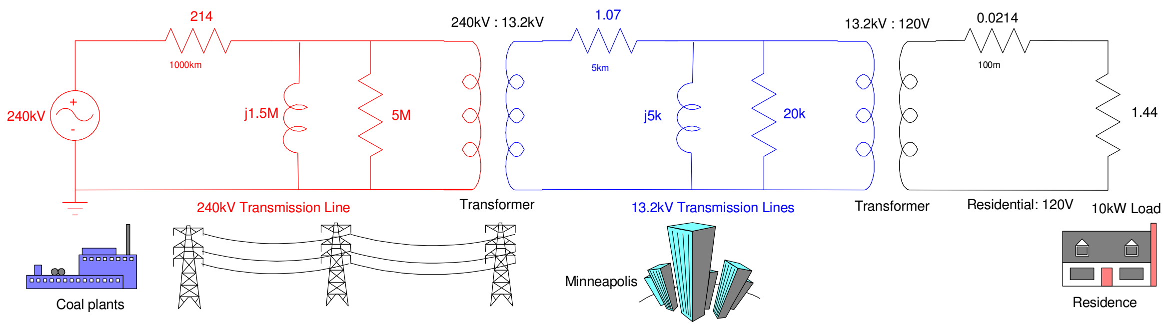
R_L = 22.629 Ohms

jX_L = j7.7665 Ohms



For the utility grid on the back of the page....

2) Convert the voltages and impeances to the 120V node (right side)



240kV section (red)

```
>> V0 = 120;
>> R01 = 214 * (120/240000)^2
R01 =  5.3500e-005

>> R1 = 1.5e6 * (120/240000)^2
R1 =     0.3750

>> X1 = 5e6 * (120/240000)^2
X1 =     1.2500
```

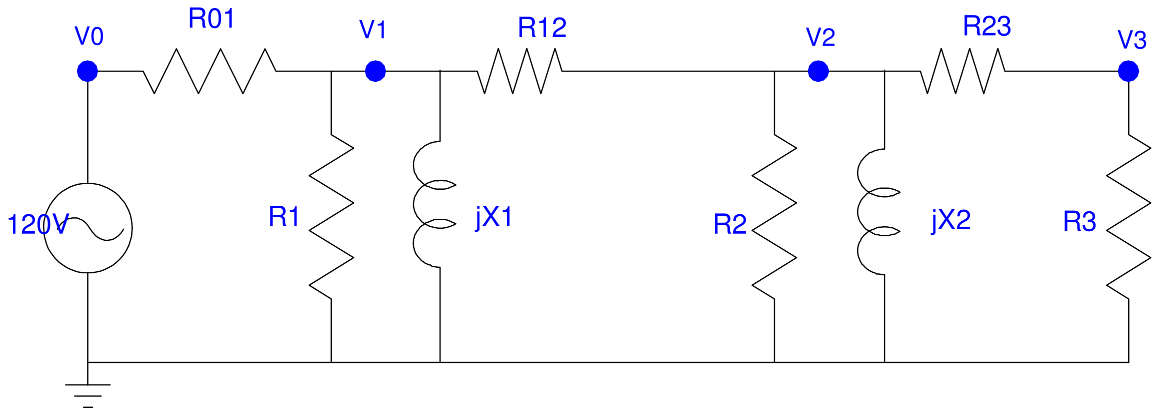
13.2kV section (blue)

```
>> R12 = 1.07 * (120/13200)^2
R12 =  8.8430e-005

>> R2 = 20e3 * (120/13200)^2
R2 =     1.6529

>> X2 = 5e3 * (120/13200)^2
X2 =     0.4132
```

120V section (black)

```
>> R23 = 0.0214;
>> R3 = 1.44;
```

3) Determine the voltages at each node



Write the voltage node equations

$$V_0 = 120$$

$$\left(\frac{V_1 - V_0}{R_{01}}\right) + \left(\frac{V_1}{R_1}\right) + \left(\frac{V_1}{jX_1}\right) + \left(\frac{V_1 - V_2}{R_{12}}\right) = 0$$

$$\left(\frac{V_2 - V_1}{R_{12}}\right) + \left(\frac{V_2}{R_2}\right) + \left(\frac{V_2}{jX_2}\right) + \left(\frac{V_2 - V_3}{R_{23}}\right) = 0$$

$$\left(\frac{V_3 - V_2}{R_{23}}\right) + \left(\frac{V_3}{R_3}\right) = 0$$

Group terms

$$V_0 = 120$$

$$\left(\frac{-1}{R_{01}}\right) V_0 + \left(\frac{1}{R_{01}} + \frac{1}{R_1} + \frac{1}{jX_1} + \frac{1}{R_{12}}\right) V_1 + \left(\frac{-1}{R_{12}}\right) V_2 = 0$$

$$\left(\frac{-1}{R_{12}}\right) V_1 + \left(\frac{1}{R_{12}} + \frac{1}{R_2} + \frac{1}{jX_2} + \frac{1}{R_{23}}\right) V_2 + \left(\frac{-1}{R_{23}}\right) V_3 = 0$$

$$\left(\frac{-1}{R_{23}}\right) V_2 + \left(\frac{1}{R_{23}} + \frac{1}{R_3}\right) V_3 = 0$$

Place in matrix form

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ \left(\frac{-1}{R_{01}}\right) & \left(\frac{1}{R_{01}}+\frac{1}{R_1}+\frac{1}{jX_1}+\frac{1}{R_{12}}\right) & \left(\frac{-1}{R_{12}}\right) & 0 \\ 0 & \left(\frac{-1}{R_{12}}\right) & \left(\frac{1}{R_{12}}+\frac{1}{R_2}+\frac{1}{jX_2}+\frac{1}{R_{23}}\right) & \left(\frac{-1}{R_{23}}\right) \\ 0 & 0 & \left(\frac{-1}{R_{23}}\right) & \left(\frac{1}{R_{23}}+\frac{1}{R_3}\right) \end{bmatrix} \begin{bmatrix} V_0 \\ V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 120 \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

Solve using Matlab

```
>> a1 = [1,0,0,0];
>> a2 = [-1/R01, 1/R01+1/R1+1/(j*X1)+1/R12, -1/R12, 0];
>> a3 = [0,-1/R12, 1/R12+1/R2+1/(j*X2)+1/R23,-1/R23];
>> a4 = [0,0,-1/R23,1/R23+1/R3];
>> A = [a1;a2;a3;a4]

  1.0e+004 *

   0.0001                  0                  0                  0
  -1.8692             3.0003 - 0.0001i  -1.1308                  0
        0            -1.1308             1.1356 - 0.0002i  -0.0047
        0                  0            -0.0047             0.0047


>> B = [120;0;0;0]

   120
     0
     0
     0

>> V = inv(A)*B
```

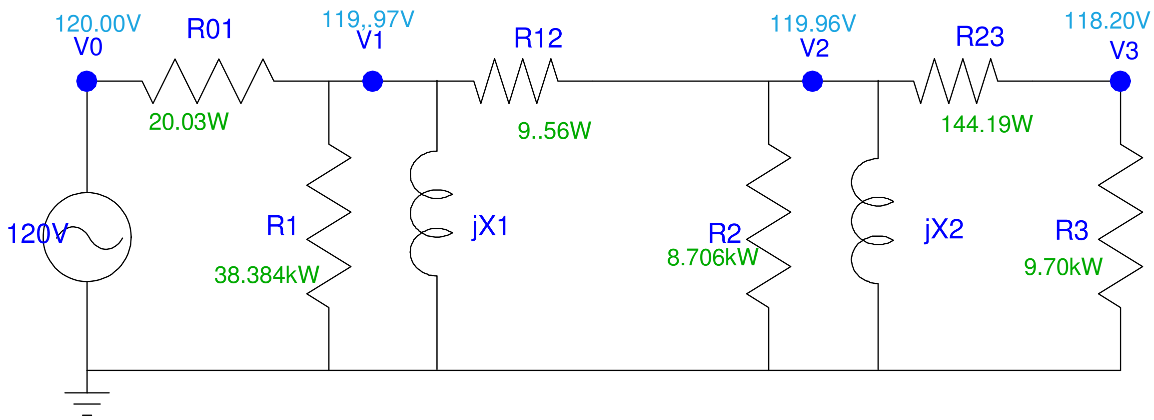
V0   120.00 – 000.00i
V1   119.97 + 000.02i
V2   119.96 + 000.05i
V3   118.20 + 000.05i

```
>> abs(V)

V0  120.0000
V1  119.9746
V2  119.9609
V3  118.2043
```

4) Determine the efficiency of this system

- Ignoring the core losses
  - Assumes a large number of customers share these losses
- Including the core losses

Assumes a single customer




```
>> V0 = V(1);
>> V1 = V(2);
>> V2 = V(3);
>> V3 = V(4);
>> P01 = abs(V0 - V1)^2 / R01

P01 =   20.0352

>> P1 = abs(V1)^2 / R1

P1 =  3.8384e+004

>> P12 = abs(V1 - V2)^2 / R12

P12 =    9.5679

>> P2 = abs(V2)^2 / R2

P2 =  8.7063e+003

>> P23 = abs(V2 - V3)^2 / R23

P23 =  144.1967

>> P3 = abs(V3)^2 / R3

P3 =  9.7030e+003
```

If you include everything, the efficiency is 17%

```
>> eff = P3 / (P01 + P1 + P12 + P2 + P23 + P3)

eff =    0.1703
```

If you ignore the core losses (spread these out of thousands of customers), the efficiency is 98%

```
>> eff = P3 / (P01 + P12 + P23 + P3)

eff =    0.9824
```

Meaning:

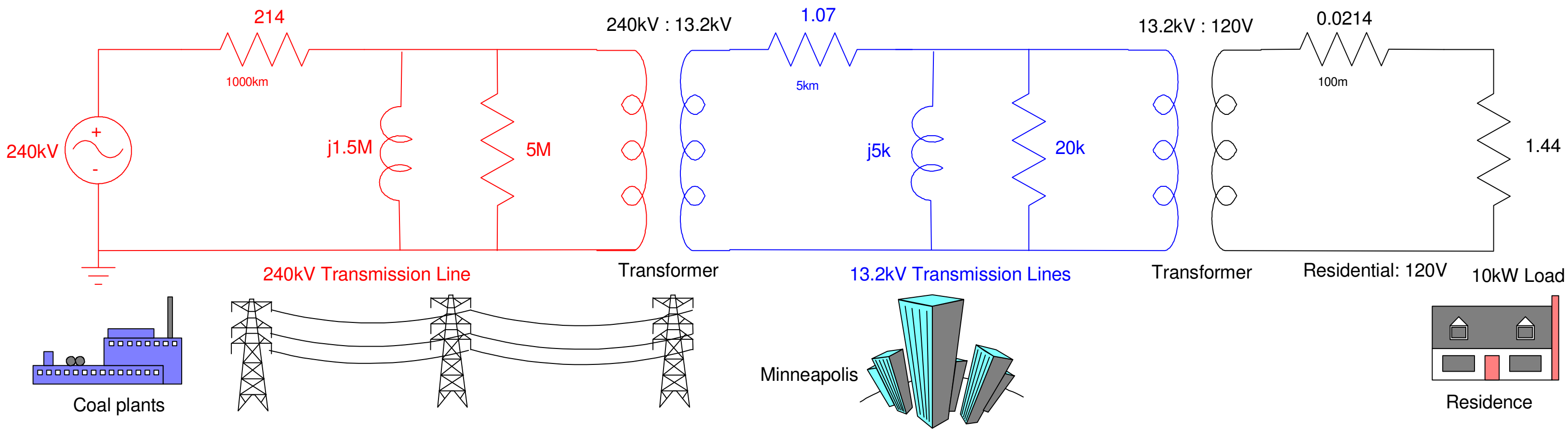
- If you only have one customer, you can't afford to transmit power 1000km (the efficiency is too low). If that's the case, tell the customer to buy a generator.
- If you have a large number of customers (1000+), using transformers and Tesla's solution allows you to transmit power at 98% efficiency.

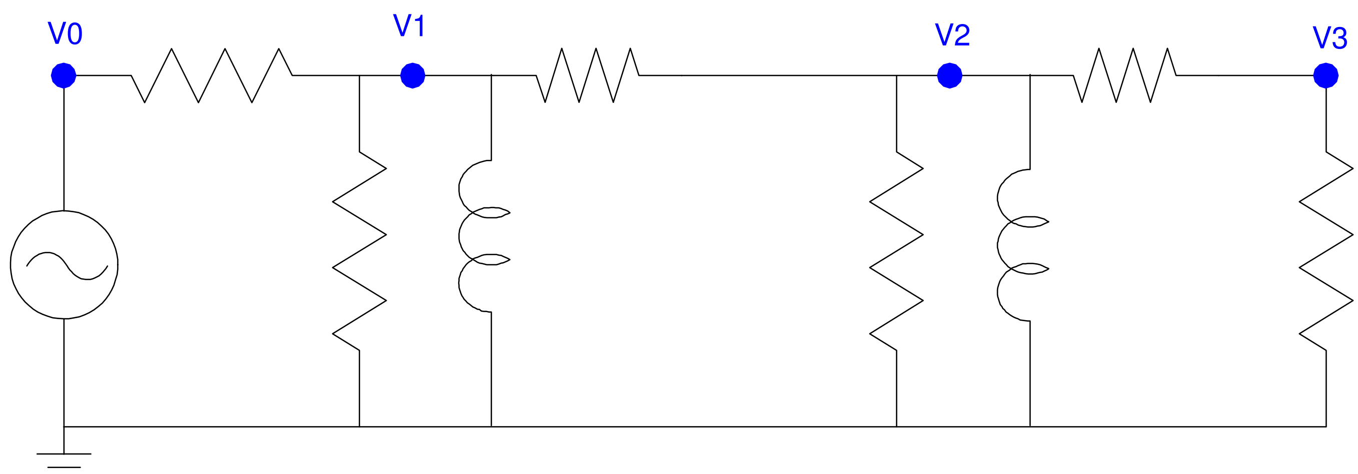
This works due to the transmission line losses being

$$P = I^2 R$$

When you increase the voltage 1000x, the current drops 1000x (power stays constant: P = VI).

By reducing the current 1000x, the power losses drop by one million times.


214
1000km
240kV
j1.5M
5M
240kV : 13.2kV
1.07
5km
j5k
20k
13.2kV : 120V
0.0214
100m
1.44
Transformer
240kV Transmission Line
13.2kV Transmission Lines
Transformer
Residential: 120V
10kW Load
Coal plants
Minneapolis
Residence


V0
V1
V2
V3