ECE 111: Homework 15

Week #15 - ECE 331 Energy Conversion. Due Deember 14th

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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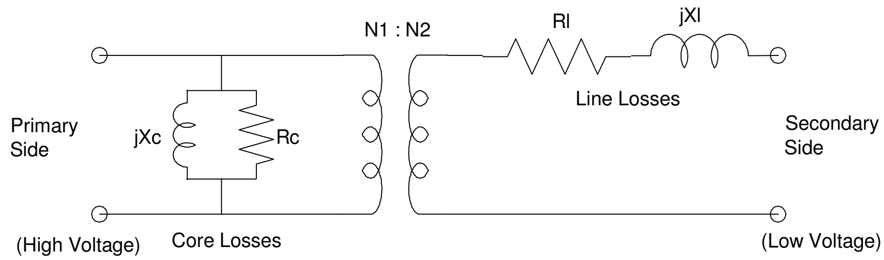
1) Determine the circuit model for a 13.2V : 240V transformer is tested with the following test results:



Transformer Model

	V	Power	pf
Open-Circuit Test	V1 = 9.6kV	85 W	0.06
Short-Circuit Test	V2 = 24V	15 W	0.97

Open Circut Test:

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

$$I = \left(\frac{P}{V \cdot pf}\right) = \left(\frac{85W}{9600V \cdot 0.06}\right) = 0.1476A$$

$$Z = \left(\frac{V}{A}\right) \angle \arccos(pf) = \left(\frac{9600V}{0.1476A}\right) \angle 86.56^0$$

$$Z = 65054 \angle 85.56^0 = 3903.2 + j64,937$$

This is the series model (resistors in series add). The parallel model uses the inverse

$$\frac{1}{Z} = 9.2231 \cdot 10^{-7} - j1.5344 \cdot 10^{-5}$$

$$R_c = \left(\frac{1}{9.2231 \cdot 10^{-7}}\right) = 1.0842M\Omega$$

$$X_c = \left(\frac{1}{1.5344 \cdot 10^{-5}}\right) = 65.172k\Omega$$

In Matlab

```
>> V = 9600;
>> P = 85;
>> pf = 0.06;
>> I = P / (V*pf)

I =    0.1476

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

```
Z =  3.9032e+003 +6.4937e+004i

>> 1/Z

ans =  9.2231e-007 -1.5344e-005i

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

Rc =  1.0842e+006

>> Xc = 1 / abs(imag(1/Z))

Xc =

  6.5172e+004
```

Line Model:

$$I = \left(\frac{P}{V \cdot pf}\right) = \left(\frac{15W}{24V \cdot 0.97}\right) = 0.6443A$$

$$Z = \left(\frac{V}{A}\right) \angle \arccos(pf) = \left(\frac{24V}{0.6443A}\right) \angle 14.07^0$$

$$Z = 36.1306 + j9.0552$$

This is the series model ($R_L + jX_L$

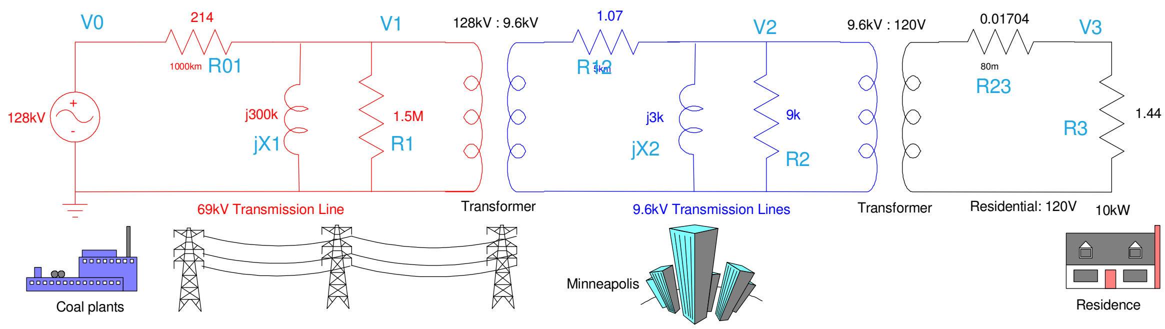
$$R_L = 36.1306\Omega$$

$$jX_L = j9.0552\Omega$$

In Matlab

```
>> P = 15;
>> V = 24;
>> pf = 0.97;
>> I = P / (V*pf)

I =    0.6443

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

Z =  36.1306 + 9.0552i

>>
```

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



Voltages convert as the turn ratio:

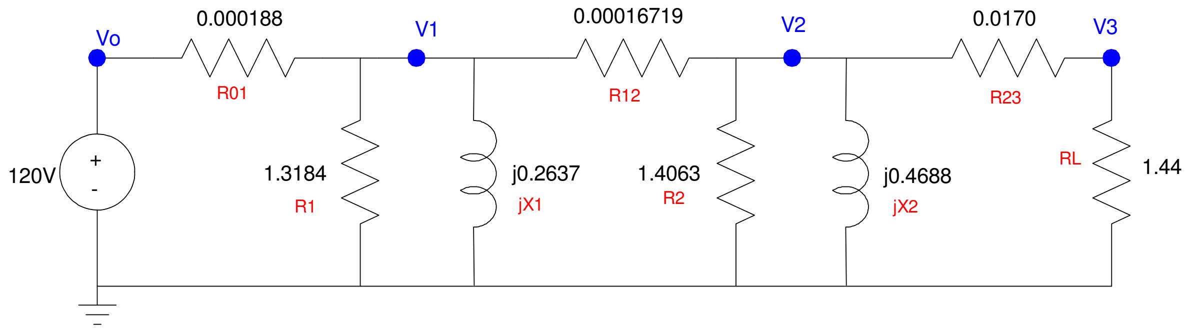
$$128kV \Rightarrow (128kV)\left(\frac{9.6kV}{128kV}\right)\left(\frac{120V}{9.6kV}\right) = 120V$$

Impedances convert as the turn ratio squared

$$R_{01} \Rightarrow 214\left(\frac{120V}{128kV}\right)^2 = 0.000188\Omega$$

In matlab

```
>> R01 = 214 * (120/128000)^2

R01 =  1.8809e-004

>> X1 = 300000 * (120/128000)^2

X1 =    0.2637

>> R1 = 1.5e6 * (120/128000)^2

R1 =    1.3184

>> R12 = 1.07 * (120/9600)^2

R12 =  1.6719e-004

>> X2 = 3e3 * (120/9600)^2

X2 =    0.4688

>> R2 = 9e3 * (120/9600)^2

R2 =    1.4063

>> R23 = 0.01704

R23 =    0.0170

>> R3 = 1.44

R3 =    1.4400
```



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]

>> A = [a1;a2;a3;a4]

A =

  1.0e+004 *

   0.0001                  0                   0                   0
  -0.5317             1.1299 - 0.0004i  -0.5981                   0
        0            -0.5981              0.6041 - 0.0002i  -0.0059
        0                  0            -0.0059              0.0059


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

   120
     0
     0
     0

>> V = inv(A)*B

  1.0e+002 *

   1.2000 + 0.0000i
   1.1995 + 0.0013i
   1.1992 + 0.0018i
   1.1852 + 0.0017i

>> abs(V)

V0  120.0000
V1  119.9513
V2  119.9232
V3  118.5208
```

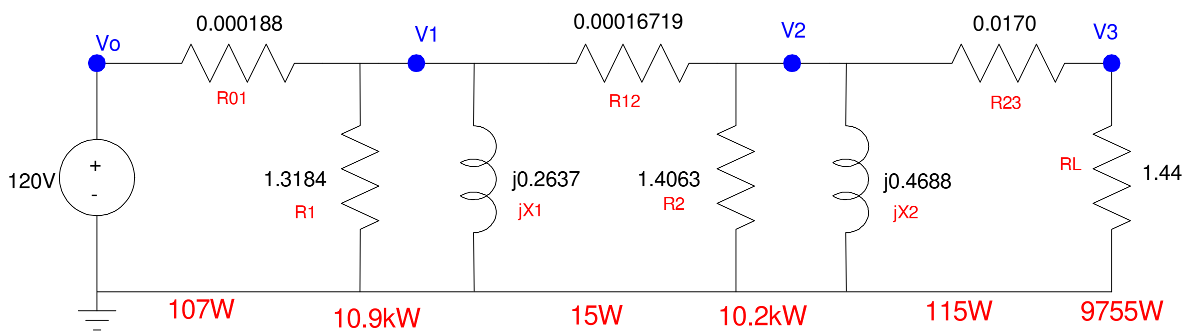
The customer's voltage drops to 118.52V

4) Determine the efficiency of this system a) Ignoring the core losses, and b) Including the core losses

```
V0 = V(1);
V1 = V(2);
V2 = V(3);
V3 = V(4);

P01 = (abs(V1-V0))^2 / R01
P12 = (abs(V1-V2))^2 / R12
P23 = (abs(V2-V3))^2 / R23

P1 = (abs(V1))^2 / R1
P2 = (abs(V2))^2 / R2
P3 = (abs(V3))^2 / R3

eff1 = P3 / (P3 + P01 + P12 + P23)
eff2 = P3 / (P3 + P01 + P12 + P23 + P1 + P2)
```

results in

```
P01 =  107.5859
P12 =   15.6382
P23 =  115.4339
P1 =  1.0914e+004
P2 =  1.0227e+004
P3 =  9.7550e+003
```



The efficiency when ignoring the core losses is 97.6%

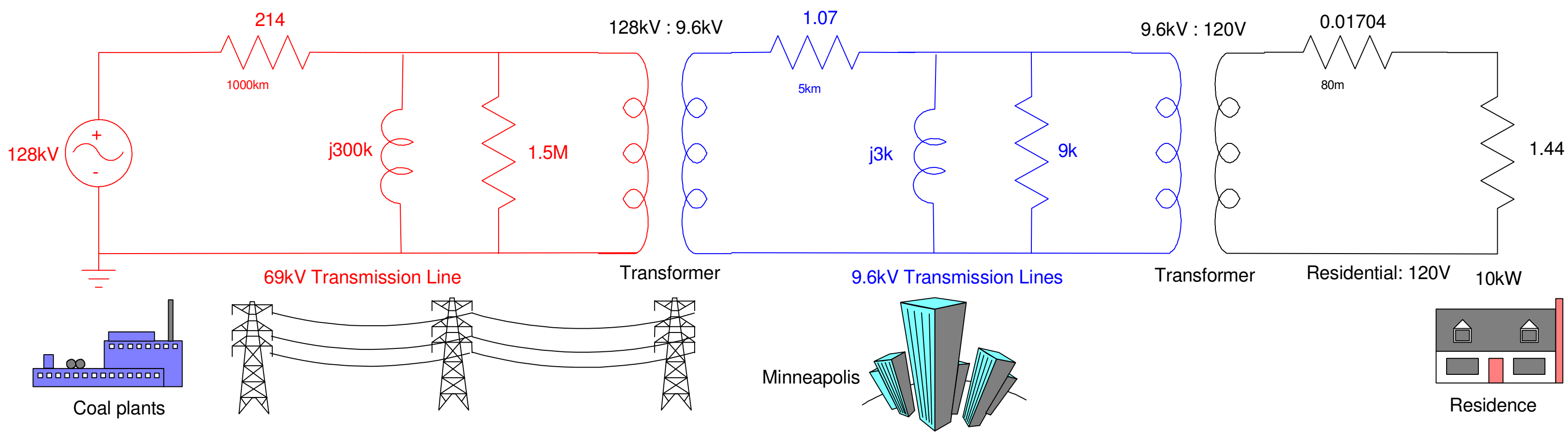
- 98.8% of the power transmitted gets to the customer as long as you're serving a city (so the core losses are spread out over a large number of customers)

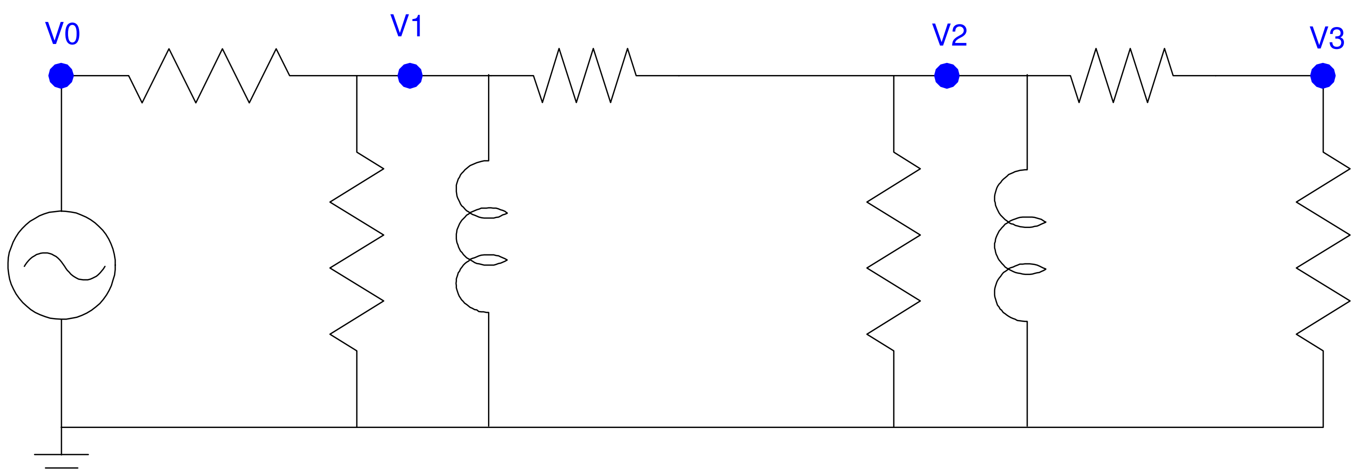
```
eff1 =    0.9761
```

The efficiency when including the core losses is only 31.3%

- If there is only one customer, only 31% of the energy transmitted gets to the customer
- It's not efficient or economic to build a power grid to serve a single customer

```
eff2 =    0.3133
```


214
1000km
128kV : 9.6kV
1.07
5km
9.6kV : 120V
0.01704
80m
128kV
j300k
1.5M
j3k
9k
1.44
69kV Transmission Line
Transformer
9.6kV Transmission Lines
Transformer
Residential: 120V
10kW
Coal plants
Minneapolis
Residence


V0
V1
V2
V3