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ECE 525 - HWK 4

In [1]:

```python
# Import Libraries
import numpy as np
import matplotlib.pyplot as plt
import eepower as eep
from eepower import p,n,u,m,k,M
```

In [40]:

```
# Define Time-Overcurrent Trip Time Function
def toctriptime(I,Ipickup,TD,curve="U1"):
    """
    toctriptime Function

    Time-OverCurrent Trip Time Calculator, evaluates the time
    to trip for a specific TOC (51) element given the curve
    type, current characteristics and time-dial setting.

    Parameters
    ----------
    I:          float
                Measured Current in Amps
    Ipickup:    float
                Fault Current Pickup Setting (in Amps)
    TD:         float
                Time Dial Setting
    curve:      string, optional
                Name of specified TOC curve, may be entry from set:
                {U1,U2,U3,U4,U5,C1,C2,C3,C4,C5}, default=U1

    Returns
    -------
    tt:         float
                Time-to-Trip for characterized element.
    """
    # Condition Inputs
    curve = curve.upper()
    # Define Dictionary of Constants
    const = {   "U1" : {"A": 0.0104, "B": 0.2256, "P": 0.02},
                "U2" : {"A": 5.95, "B": 0.180, "P": 2.00},
                "U3" : {"A": 3.88, "B": 0.0963, "P": 2.00},
                "U4" : {"A": 5.67, "B": 0.352, "P": 2.00},
                "U5" : {"A": 0.00342, "B": 0.00262, "P": 0.02},
                "C1" : {"A": 0.14, "B":0, "P": 0.02},
                "C2" : {"A": 13.5, "B":0, "P": 2.00},
                "C3" : {"A": 80.0, "B":0, "P": 2.00},
                "C4" : {"A": 120.0, "B":0, "P": 2.00},
                "C5" : {"A": 0.05, "B":0, "P": 0.04}}
    # Load Constants
    A = const[curve]["A"]
    B = const[curve]["B"]
    P = const[curve]["P"]
    # Evaluate M
    M = I / Ipickup
    # Evaluate Trip Time
    tt = TD * (A/(M**P-1)+B)
    return(tt)

# Define Time Overcurrent Reset Time Function
def tocreset(I,Ipickup,TD,curve="U1"):
    """
    tocreset Function

    Function to calculate the time to reset for a TOC
    (Time-OverCurrent, 51) element.
```

```

    Parameters
    ----------
    I:          float
                Measured Current in Amps
    Ipickup:    float
                Fault Current Pickup Setting (in Amps)
    TD:         float
                Time Dial Setting
    curve:      string, optional
                Name of specified TOC curve, may be entry from set:
                {U1,U2,U3,U4,U5,C1,C2,C3,C4,C5}, default=U1

    Returns
    -------
    tr:         float
                Time-to-Reset for characterized element.
    """
    # Condition Inputs
    curve = curve.upper()
    # Define Dictionary of Constants
    C = {   "U1" : 1.08,"U2" : 5.95,"U3" : 3.88,
            "U4" : 5.67,"U5" : 0.323,"C1" : 13.5,
            "C2" : 47.3,"C3" : 80.0,"C4" : 120.0,
            "C5" : 4.85}
    # Evaluate M
    M = I / Ipickup
    # Evaluate Reset Time
    tr = TD * (C[curve]/(1-M**2))
    return(tr)

# Define Pickup Current Calculation
def pickup(Iloadmax,Ifaultmin,scale=0,printout=False,units="A"):
    """
    pickup Function

    Used to assist in evaluating an optimal phase-over-current pickup
    setting. Uses maximum load and minimum fault current to provide
    user assistance.

    Parameters
    ----------
    Iloadmax:   float
                The maximum load current in amps.
    Ifaultmin:  float
                The minimum fault current in amps.
    scale:      int, optional
                Control scaling to set number of significant figures.
                default=0
    printout:   boolean, optional
                Control argument to enable printing of intermediate
                stages, default=False.
    units:      string, optional
                String to be appended to any printed output denoting
                the units of which are being printed, default="A"

    Returns
```

```
    -------
    setpoint:   float
                The evaluated setpoint at which the function suggests
                the phase-over-current pickup setting be placed.
    """
    IL2 = 2*Iloadmax
    IF2 = Ifaultmin/2
    exponent = len(str(IL2).split('.')[0])
    setpoint = np.ceil(IL2*10**(-exponent+1+scale))*10**(exponent-1-scale)
    if printout:
        print("Range Min:",IL2,units,"\t\tRange Max:",IF2,units)
    if IF2 < setpoint:
        setpoint = IL2
        if IL2 > IF2:
            raise ValueError("Invalid Parameters.")
    if printout:
        print("Current Pickup:",setpoint,units)
    return(setpoint)

# Define Time-Dial Coordination Function
def tdcoordradial(I,CTI,Ipu_up,Ipu_dn,TDdn,curve="U1",scale=1,freq=60):
    """
    tdcoordradial Function

    Function to evaluate the Time-Dial (TD) setting in radial schemes
    where the Coordinating Time Interval (CTI) and the up/downstream
    pickup settings are known along with the TD setting for the
    downstream protection.

    Parameters
    ----------
    I:          float
                Measured fault current in Amps, typically set using the
                maximum fault current available.
    CTI:        float
                Coordinating Time Interval in cycles.
    Ipu_up:     float
                Pickup setting for upstream protection,
                specified in amps
    Ipu_dn:     float
                Pickup setting for downstream protection,
                specified in amps
    TDdn:       float
                Time-Dial setting for downstream protection,
                specified in seconds
    curve:      string, optional
                Name of specified TOC curve, may be entry from set:
                {U1,U2,U3,U4,U5,C1,C2,C3,C4,C5}, default=U1
    scale:      int, optional
                Scaling value used to evaluate a practical TD
                setting, default=1
    freq:       float, optional
                System operating frequency, default=60

    Returns
    -------
    TD:         float
```

```
                        Calculated Time-Dial setting according to radial
                        scheme logical analysis.
    """
    # Condition Inputs
    curve = curve.upper()
    CTI = CTI/freq # Evaluate in seconds from cycles
    # Define Dictionary of Constants
    const = {   "U1" : {"A": 0.0104, "B": 0.2256, "P": 0.02},
                "U2" : {"A": 5.95, "B": 0.180, "P": 2.00},
                "U3" : {"A": 3.88, "B": 0.0963, "P": 2.00},
                "U4" : {"A": 5.67, "B": 0.352, "P": 2.00},
                "U5" : {"A": 0.00342, "B": 0.00262, "P": 0.02},
                "C1" : {"A": 0.14, "B":0, "P": 0.02},
                "C2" : {"A": 13.5, "B":0, "P": 2.00},
                "C3" : {"A": 80.0, "B":0, "P": 2.00},
                "C4" : {"A": 120.0, "B":0, "P": 2.00},
                "C5" : {"A": 0.05, "B":0, "P": 0.04}}
    # Load Constants
    A = const[curve]["A"]
    B = const[curve]["B"]
    P = const[curve]["P"]
    # Evaluate M
    M = I / Ipu_dn
    # Evaluate Trip Time
    tpu_desired = TDdn * (A/(M**P-1)+B) + CTI
    # Re-Evaluate M
    M = I / Ipu_up
    # Calculate TD setting
    TD = tpu_desired / (A/(M**2-1)+B)
    # Scale and Round
    TD = np.ceil(TD*10**scale)/10**scale
    return(TD)
```

Problem 1

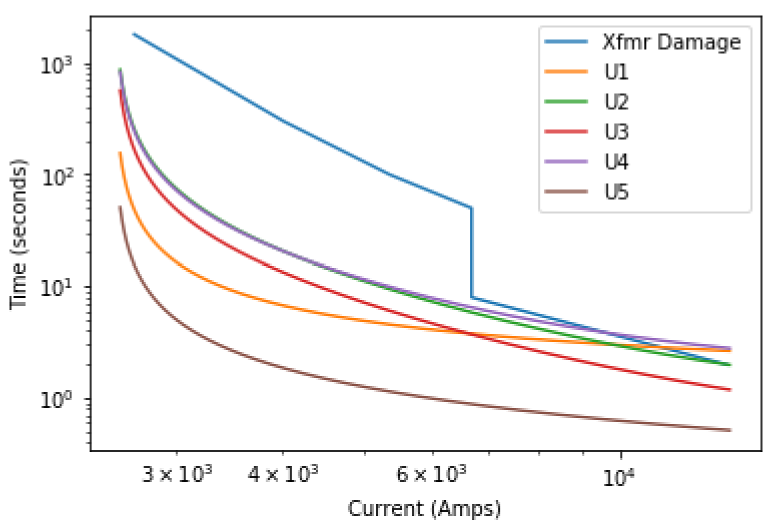
Start by determining the best fit curve associated with breaker B2. We will work from the recloser back, but let us first determine the best curve to use.

A few simplifying assumptions have been made here. It has been assumed that the current drop (due to a fault) down the line increments linearly. Thus the fault current at 60% between two busses will be 40% of the difference in fault currents between those two busses.

In [16]:

```python
# Plot Transformer Damage Curve and US-TOC Curves

# Load Transformer Data
xfm_mult = np.array([2,3,4,5,5,10])
xfm_Tlim = np.array([1800,300,100,50,8,2])
# Calculate Rated Transformer Current
Irated = 50*M/(12.47*k*3)
print("Rated Current:",Irated,"A-primary")
xfm_crnt = xfm_mult*Irated

# Plot Transformer Data
plt.plot(xfm_crnt,xfm_Tlim,label="Xfmr Damage")
plt.xscale("log")
plt.yscale("log")

Iload = (3.3*3*M)/(12.47*k*np.sqrt(3)) + 2*3/10*Irated
print("Max Load Current:",Iload,"A-primary")

# Plot TOC Curves
curves = ["U1","U2","U3","U4","U5"]
I = np.arange(min(xfm_crnt)-100,max(xfm_crnt)+100)
Ipickup = pickup(Iload,5728,2,printout=True,units="A-primary")
TD = 5
for curve in curves:
    t = toctriptime(I,Ipickup,TD,curve)
    plt.plot(I,t,label=curve)
plt.legend()
plt.ylabel("Time (seconds)")
plt.xlabel("Current (Amps)")
plt.show()
print("Choose U3 - Very Inverse Curve")
```

```
Rated Current: 1336.5410318096765 A-primary
Max Load Current: 1260.28609984 A-primary
Range Min: 2520.57219968 A-primary          Range Max: 2864.0 A-primary
Current Pickup: 2530.0 A-primary
```




```
Choose U3 - Very Inverse Curve
```

In [17]:

```
# Evaluate CTR For B3 and R1/2

# First determine load
il_b3 = (3.3*3*M)/(12.47*k*np.sqrt(3))
il_r1 = (3.3*2*M)/(12.47*k*np.sqrt(3))
il_r2 = (3.3*M)/(12.47*k*np.sqrt(3))

CTR_b3 = int(np.ceil(il_b3))/5
CTR_r1 = int(np.ceil(il_r1))/5
CTR_r2 = int(np.ceil(il_r2))/5
print("B3 CTR:",CTR_b3)
print("R1 CTR:",CTR_r1)
print("R2 CTR:",CTR_r2)
```

```
B3 CTR: 91.8
R1 CTR: 61.2
R2 CTR: 30.6
```

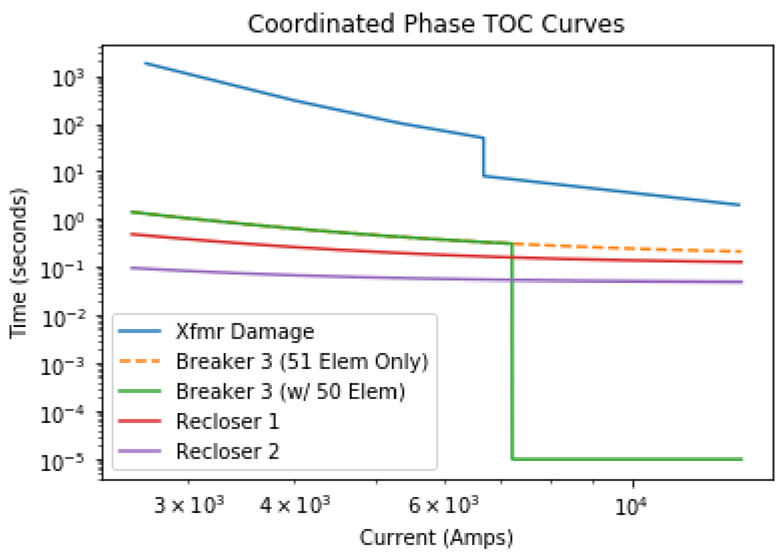
In [18]:

```
# Evaluate the Trip Parameters for Reclosers and Breaker 3

# Current Pickup
R2_pu = pickup(il_r2,5728)
print("R2 Pickup:",R2_pu,"A-primary")
R1_pu = pickup(il_r1,5728)
print("R1 Pickup:",R1_pu,"A-primary")
B3_pu = pickup(il_b3,5728)
print("B3 Pickup:",B3_pu,"A-primary")

# Time Dial Settings
TD_r2 = 0.5
print("R2 Time-Dial:",TD_r2,"sec")
TD_r1 = tdcoordradial(7761.5,6,R1_pu,R2_pu,TD_r2,curve="U3")
print("R1 Time-Dial:",TD_r1,"sec")
TD_b3 = tdcoordradial(9259.8,6,B3_pu,R1_pu,TD_r1,curve="U3")
print("B3 Time-Dial:",TD_b3,"sec")

# Formulate the Instantaneous Element Pickup
# Assume Linear Current Drop Across Line
If_bus3 = 8019.3
If_bus4 = 6682.7
B3_50_pu = np.ceil((If_bus3 - (If_bus3-If_bus4)*0.6)/10)*10
print("B3 50-element Pickup:",B3_50_pu,"A-primary")
```

```
R2 Pickup: 400.0 A-primary
R1 Pickup: 700.0 A-primary
B3 Pickup: 1000.0 A-primary
R2 Time-Dial: 0.5 sec
R1 Time-Dial: 1.2 sec
B3 Time-Dial: 1.8 sec
B3 50-element Pickup: 7220.0 A-primary
```

In [19]:

```
# Plot Trip Curves

# Plot Transformer Data
plt.plot(xfm_crnt,xfm_Tlim,label="Xfmr Damage")
plt.xscale("log")
plt.yscale("log")
# Plot Curves
R2_crv = toctriptime(I,R2_pu,TD_r2,curve="U3")
R1_crv = toctriptime(I,R1_pu,TD_r1,curve="U3")
B3_crv = toctriptime(I,B3_pu,TD_b3,curve="U3")
B3_wo50 = np.copy(B3_crv)
for i, mag in enumerate(I):
    if mag > B3_50_pu:
        B3_crv[i] = 10*u
plt.plot(I,B3_wo50,label="Breaker 3 (51 Elem Only)",linestyle="--")
plt.plot(I,B3_crv,label="Breaker 3 (w/ 50 Elem)")
plt.plot(I,R1_crv,label="Recloser 1")
plt.plot(I,R2_crv,label="Recloser 2")
plt.legend()
plt.ylabel("Time (seconds)")
plt.xlabel("Current (Amps)")
plt.title("Coordinated Phase TOC Curves")
plt.show()
```



Problem 2

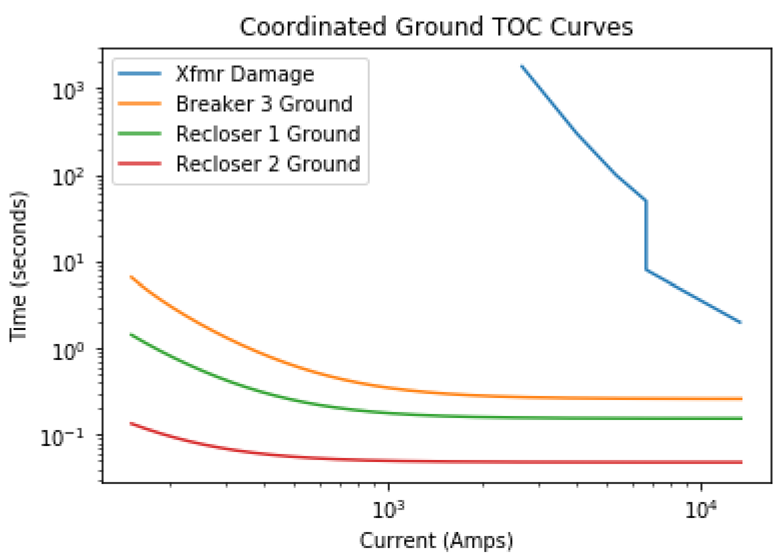
In [20]:

```
# Evaluate Ground Element Settings

# Evaluate Zero-Sequence Current Pickups
I0_bus5 = np.ceil( il_r2 * 0.2 )
I0_bus4 = np.ceil( il_r1 * 0.2 )
I0_bus3 = np.ceil( il_b3 * 0.2 )
print("Recloser 2 Ground Pickup:",I0_bus5,"A-primary")
print("Recloser 1 Ground Pickup:",I0_bus4,"A-primary")
print("Breaker 3 Ground Pickup:",I0_bus3,"A-primary")

# Evaluate Time-Dial Settings
R2_gtd = 0.5
R1_gtd = tdcoordradial(6944.9,6,I0_bus4,I0_bus5,R2_gtd,curve="U3")
B3_gtd = tdcoordradial(9259.8,6,I0_bus3,I0_bus4,R1_gtd,curve="U3")
print("Recloser 2 Ground TD:",R2_gtd,"sec")
print("Recloser 1 Ground TD:",R1_gtd,"sec")
print("Breaker 3 Ground TD:",B3_gtd,"sec")
```

```
Recloser 2 Ground Pickup: 31.0 A-primary
Recloser 1 Ground Pickup: 62.0 A-primary
Breaker 3 Ground Pickup: 92.0 A-primary
Recloser 2 Ground TD: 0.5 sec
Recloser 1 Ground TD: 1.6 sec
Breaker 3 Ground TD: 2.7 sec
```

In [44]:

```
# Plot Trip Curves

# Plot Transformer Data
plt.plot(xfm_crnt,xfm_Tlim,label="Xfmr Damage")
plt.xscale("log")
plt.yscale("log")
# Plot Curves
Ig = np.arange(150,max(I))
R2g_crv = toctriptime(Ig,I0_bus5,R2_gtd,curve="U3")
R1g_crv = toctriptime(Ig,I0_bus4,R1_gtd,curve="U3")
B3g_crv = toctriptime(Ig,I0_bus3,B3_gtd,curve="U3")
plt.plot(Ig,B3g_crv,label="Breaker 3 Ground")
plt.plot(Ig,R1g_crv,label="Recloser 1 Ground")
plt.plot(Ig,R2g_crv,label="Recloser 2 Ground")
plt.legend()
plt.ylabel("Time (seconds)")
plt.xlabel("Current (Amps)")
plt.title("Coordinated Ground TOC Curves")
plt.show()
```



Problem 3

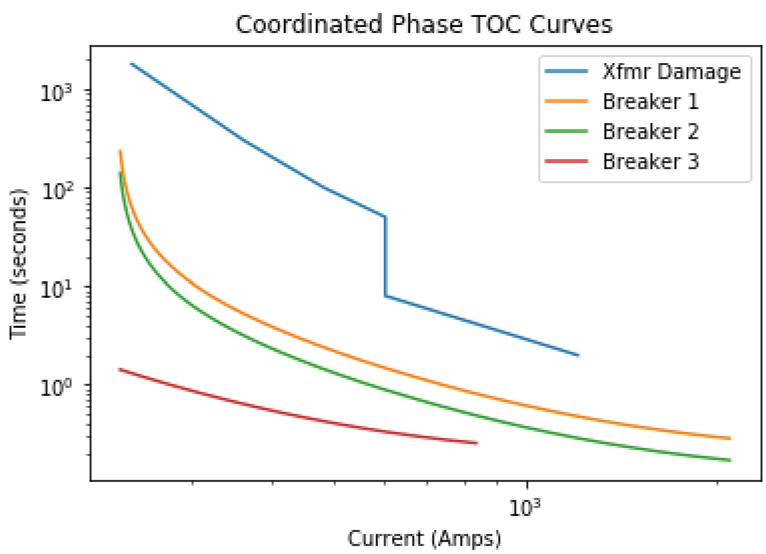
In [41]:

```
# Evaluate the Load Currents

# Begin by evaluating load currents on low-side
Iload = (3.3*3*M)/(12.47*k*np.sqrt(3)) + 2*3/10*Irated
print("Max Load Current:",Iload,"A-primary")
# Convert to High-Side
Iload_prim = 12.47*k/(138*k) * Iload
print("Max Load Current (High-Side):",Iload_prim,"A-prim")

# Evaluate Smallest Phase Fault on High-Side
Ifault_prim = 12.47*k/(138*k) * 5728
print("Smallest Phase Fault (High-Side):",Ifault_prim,"A-prim")

# Evaluate Pickup Setting
B2_pu = pickup(Iload_prim,Ifault_prim,scale=0,printout=False,units="A")
print("Breaker 2 Pickup Setting:",B2_pu,"A-primary")
B1_pu = B2_pu
print("Breaker 1 Pickup Setting:",B1_pu,"A-primary")

# Evaluate Time-Dial Settings
TD_b2 = tdcoordradial(11575*12.47/138,6,B2_pu,B3_pu*12.47/138,TD_b3,curve="U
TD_b1 = tdcoordradial(2091.85,6,B1_pu,B2_pu,TD_b2,curve="U3",scale=1,freq=60
print("Breaker 2 Time-Dial Setting:",TD_b2,"seconds")
print("Breaker 1 Time-Dial Setting:",TD_b1,"seconds")
```

```
Max Load Current: 1260.28609984 A-primary
Max Load Current (High-Side): 113.882374384 A-prim
Smallest Phase Fault (High-Side): 517.5953623188406 A-prim
Breaker 2 Pickup Setting: 227.764748768 A-primary
Breaker 1 Pickup Setting: 227.764748768 A-primary
Breaker 2 Time-Dial Setting: 1.2 seconds
Breaker 1 Time-Dial Setting: 2.0 seconds
```

In [43]:

```
# Plot Trip Curves

# Plot Transformer Data
plt.plot(xfm_crnt*12.47/138,xfm_Tlim,label="Xfmr Damage")
plt.xscale("log")
plt.yscale("log")
# Evaluate Curves
I_prim = np.arange(min(xfm_crnt*12.47/138)-10,2092)
I_sec = np.arange(min(xfm_crnt*12.47/138)-10,9259.8*12.47/138)
B3 = toctriptime(I_sec*138/12.47,B3_pu,TD_b3,curve="U3")
B2 = toctriptime(I_prim,B2_pu,TD_b2,curve="U3")
B1 = toctriptime(I_prim,B1_pu,TD_b1,curve="U3")
plt.plot(I_prim,B1,label="Breaker 1")
plt.plot(I_prim,B2,label="Breaker 2")
plt.plot(I_sec,B3,label="Breaker 3")
plt.legend()
plt.ylabel("Time (seconds)")
plt.xlabel("Current (Amps)")
plt.title("Coordinated Phase TOC Curves")
plt.show()
```



In [ ]:

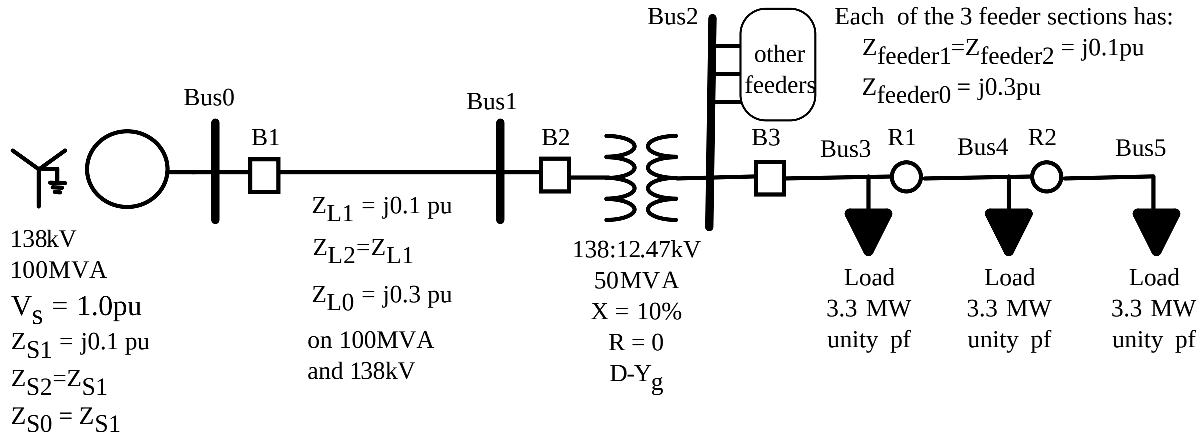
```

```

ECE 525: Homework #4

Due Session 20 (Oct. 25)

For the power system below, do the following, and ***verify proper coordination for each***:

1. Determine phase element relay settings for feeder relay (B3) and reclosers (R1 and R2). Coordinate settings between the protective devices for phase faults (phase to phase and 3 phase) and with the transformer damage curve. Include an instantaneous element for B3 to improve response time. You should determine the CTR and the select the TOC curve type.
2. Determine ground element relay settings for feeder relay (B3) and reclosers (R1 and R2). Coordinate settings between the protective devices for ground faults (SLG) and with the transformer damage curve.
3. Determine phase element relay settings for transformer HV side relay (B2) and line relay (B1). Ensure effective coordination between these protective devices. The transformer protection (B2) needs to coordinate with B3. Assume rated load on transformer is 40MVA at unity power factor (note it supplies multiple feeders)



Assume the following:

1. Set the coordinating time interval at 6 cycles for each device (relay/recloser control)
2. The worst case zero sequence imbalance for each load current on the distribution feeder is 20% (3*I0)
3. The transformer follows the ANSI/IEEE standard phase shift
4. The fault currents by location and fault type are as follows (note that you will need refer currents across the transformer for some coordination cases. The fault currents by fault type and fault location are as follow.

Three Phase Fault	Bus 1		Bus 2		Bus 3		Bus 4		Bus 5	
IA (Mag and angle)	2091.85	-90	11575	-90	9259.8	-90	7761.5	-90	6614.2	-90
IB (Mag and angle)	2091.85	-210	11575	-210	9259.8	-210	7761.5	-210	6614.2	-210
IC (Mag and angle)	2091.85	30	11575	30	9259.8	30	7761.5	30	6614.2	30

SLG Fault	Bus 1		Bus 2		Bus 3		Bus 4		Bus 5	
IA (Mag and angle)	1568.9	-90	13889.7	-90	9259.8	-90	6944.9	-90	5555.9	-90
IB (Mag and angle)	0	0	0	0	0	0	0	0	0	0
IC (Mag and angle)	0	0	0	0	0	0	0	0	0	0

LL Fault	Bus 1		Bus 2		Bus 3		Bus 4		Bus 5	
IA (Mag and angle)	0	0	0	0	0	0	0	0	0	0
IB (Mag and angle)	1811.6	180	10024.1	180	8019.3	180	6682.7	180	5728	180
IC (Mag and angle)	1811.6	0	10024.1	0	8019.3	0	6682.7	0	5728	0

- Possible Relay Inverse Time Overcurrent Curves:

- All are in the format: $t_m = TD\cdot\left(\frac{A}{M^P - 1} + B\right)$ where A, B and P come from US curves U1-U4 (listed in the lecture 14 handout)

- Moderately inverse (U1):

$$t_{MI}(TD, M) := TD\cdot\left(\frac{0.0104}{M^{0.02} - 1} + 0.2256\right)\cdot sec$$

- Inverse (U2):

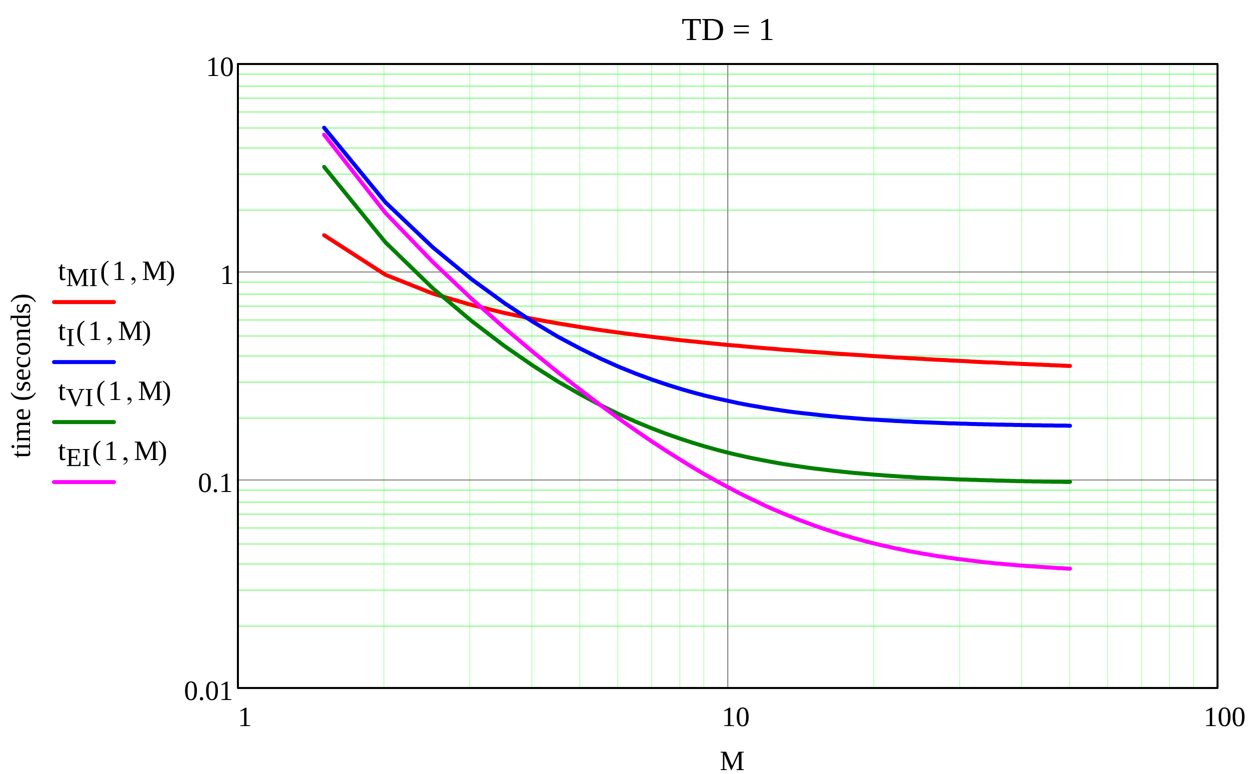
$$t_I(TD, M) := TD\cdot\left(\frac{5.95}{M^2 - 1} + 0.180\right)\cdot sec$$

- Very inverse (U3):

$$t_{VI}(TD, M) := TD\cdot\left(\frac{3.88}{M^2 - 1} + 0.0963\right)\cdot sec$$

- Extermely inverse (U4):

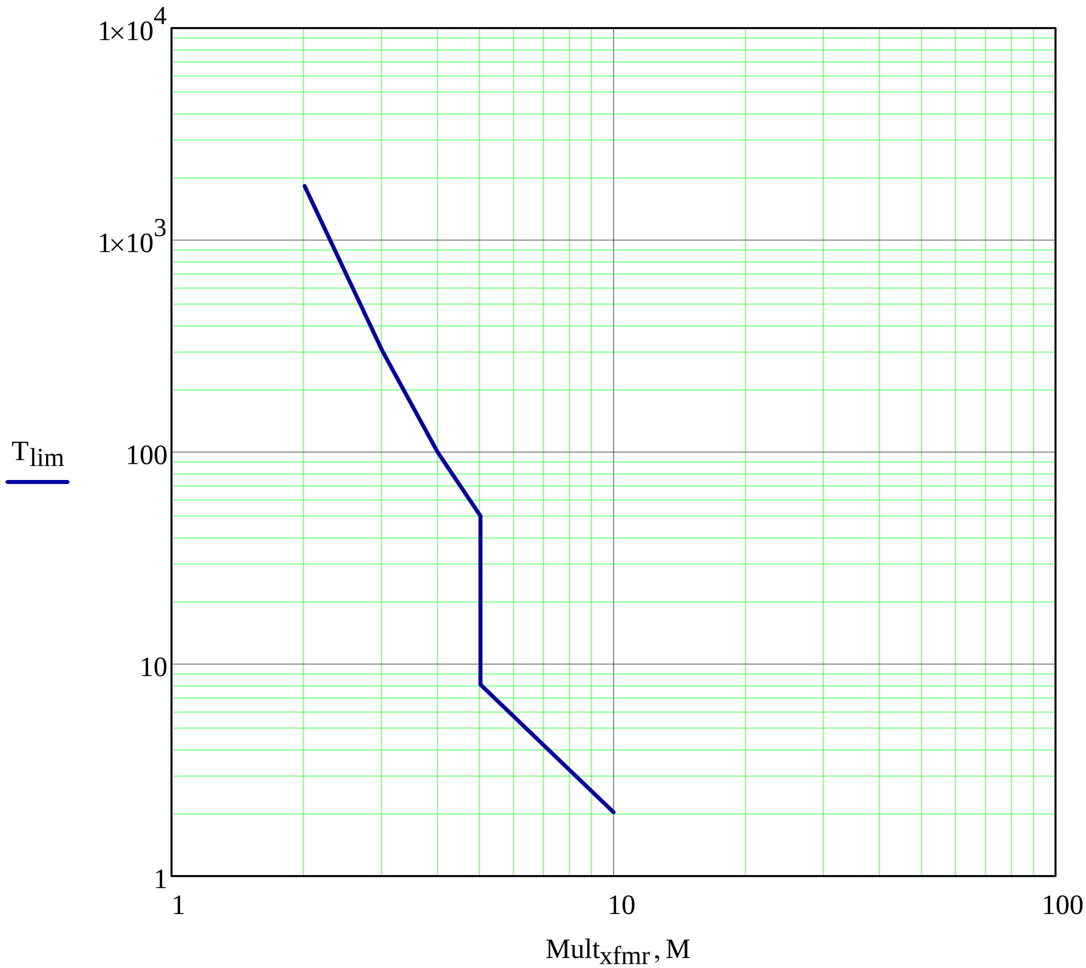
$$t_{EI}(TD, M) := TD\cdot\left(\frac{5.67}{M^2 - 1} + 0.0352\right)\cdot sec \qquad M := 1, 1.5 .. 50$$

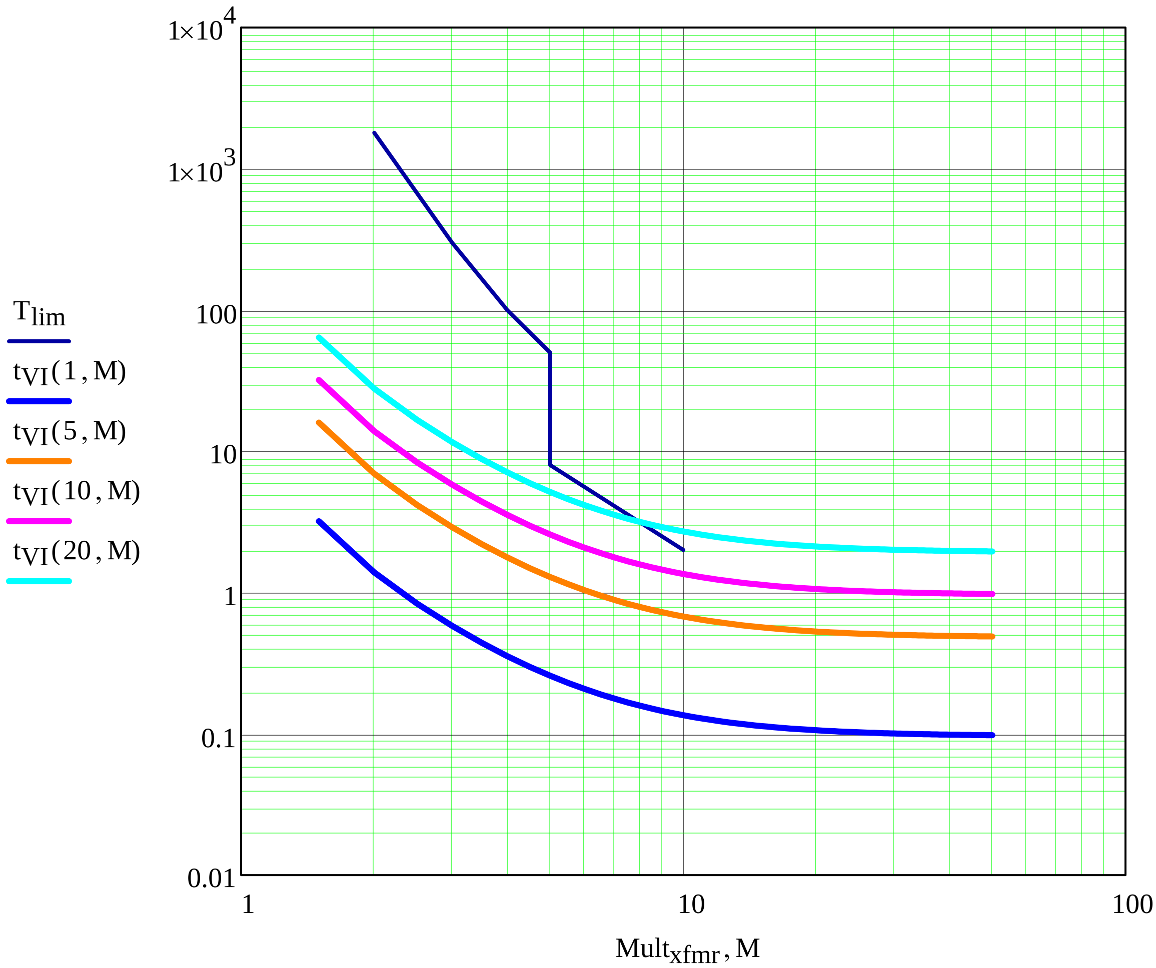


Current (multiples of pick up)

- Transformer Damage Curve (where M is multiples of rated current):

$$Mult_{xfmr} := \begin{pmatrix} 2.00 \\ 3.00 \\ 4.00 \\ 5.00 \\ 5.00 \\ 10.00 \end{pmatrix} \qquad T_{lim} := \begin{pmatrix} 1800.0 \\ 300.0 \\ 100.0 \\ 50.0 \\ 8.0 \\ 2.0 \end{pmatrix} sec$$




1×10^4
1×10^3
100
10
1
0.1
0.01
1
10
100
Mult_xfmr, M
T_lim
t_VI(1, M)
t_VI(5, M)
t_VI(10, M)
t_VI(20, M)