University of Idaho

ECE 525

POWER SYSTEM PROTECTION AND RELAYING

SESSION no. 15

8/17 5/18

- Determine the relay R2 response time

$$M_{R2\_If\_max} := \frac{\left(\frac{I_{3ph\_bus1}}{CTR_{R2}}\right)}{I_{pu\_R2}} \qquad M_{R2\_If\_max} = 10.69$$

$$t_{pu\_R2\_If\_max} := t_{VI}\left(TD_{R2}, M_{R2\_If\_max}\right) \qquad t_{pu\_R2\_If\_max} = 0.065\,s$$

- Desired minimum pick up time relay 1 for a bus 1 fault:

$$t_{pu\_R1\_desired} := t_{pu\_R2\_If\_max} + CTI \qquad t_{pu\_R1\_desired} = 0.365\,s$$

- Now find M for relay 1 for this fault

$$M_{R1\_If\_max} := \frac{\left(\frac{I_{3ph\_bus1}}{CTR_{R1}}\right)}{I_{pu\_R1}} \qquad M_{R1\_If\_max} = 6.84$$

- Now rewrite the response time equation so we can solve for time dial setting
- Note that we could also do this step graphically

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

$$TD_{R1} := TD_{VI}\left(t_{pu\_R1\_desired}, M_{R1\_If\_max}\right)$$

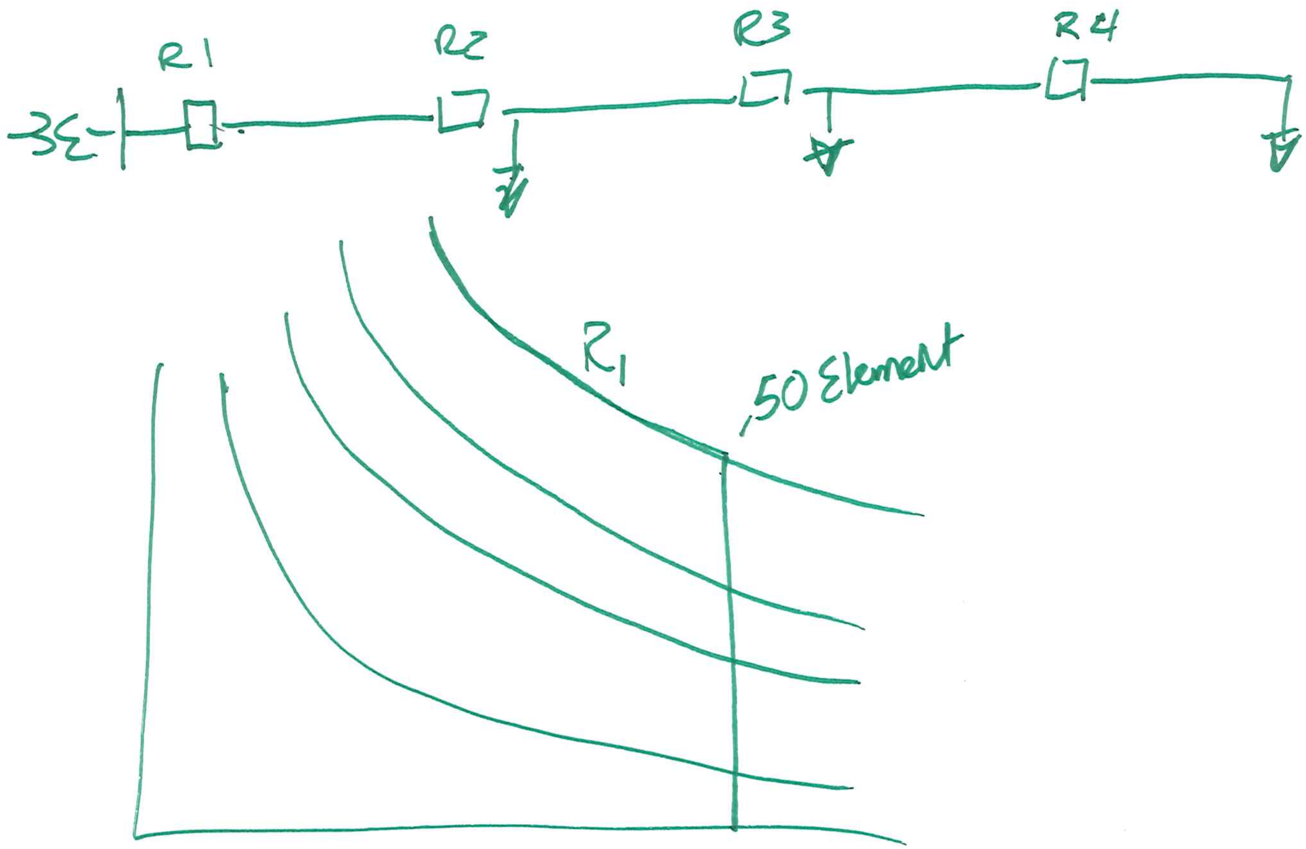
$$TD_{R1} = 2.02$$

Set TD to nearest 0.1:

$$TD_{R1\_set} := 2.1$$

$$t_{VI}\left(TD_{R1\_set}, M_{R1\_If\_max}\right) = 0.38\,s$$

L15 2/18



L13 3/16

So we see a time interval of:

$$t_{VI}(TD_{R1\_set}, M_{R1\_If\_max}) - t_{VI}(TD_{R2}, M_{R2\_If\_max}) = 0.315\,s \quad \text{Meets criteria}$$

- Now check the coordination with the other extreme:

$$M_{R1\_If\_min} := \frac{\left(\frac{I_{LL\_bus2}}{CTR_{R1}}\right)}{I_{pu\_R1}} \qquad M_{R1\_If\_min} = 1.97$$

$$M_{R2\_If\_min} := \frac{\left(\frac{I_{LL\_bus2}}{CTR_{R2}}\right)}{I_{pu\_R2}} \qquad M_{R2\_If\_min} = 3.09$$

$$t_{VI}(TD_{R1\_set}, M_{R1\_If\_min}) - t_{VI}(TD_{R2}, M_{R2\_If\_min}) = 2.74\,s$$

Other types of elements:

- Ground elements: set Ipu based on the worst case zero sequence load current
  - Make sure you are clear on whether you are using I0 or IR = 3I0 (residual current)
- Negative sequence elements use a similar criteria.

$I_A + I_B + I_C$

, 50

Adding an instantaneous element at B1 to increase response time for a close-in, high current faults.

- Calculate 3 phase fault current 60% of the length of the feeder.

$$I_{f3phpu60\%} := \frac{1}{Z_{S1} + 0.6 \cdot Z_{fd11}} \qquad I_{f3phpu60\%} = -0.91i \qquad I_{f3ph60\%} := \left|I_{f3phpu60\%}\right| \cdot I_b$$

$$I_{f3ph60\%} = 2186.93\,A$$

- Convert secondary amps

$$I_{f3ph60\%\_sec} := \frac{I_{f3ph60\%}}{CTR_{R1}} \qquad I_{f3ph60\%\_sec} = 68.34\,A$$

LLS 4/18

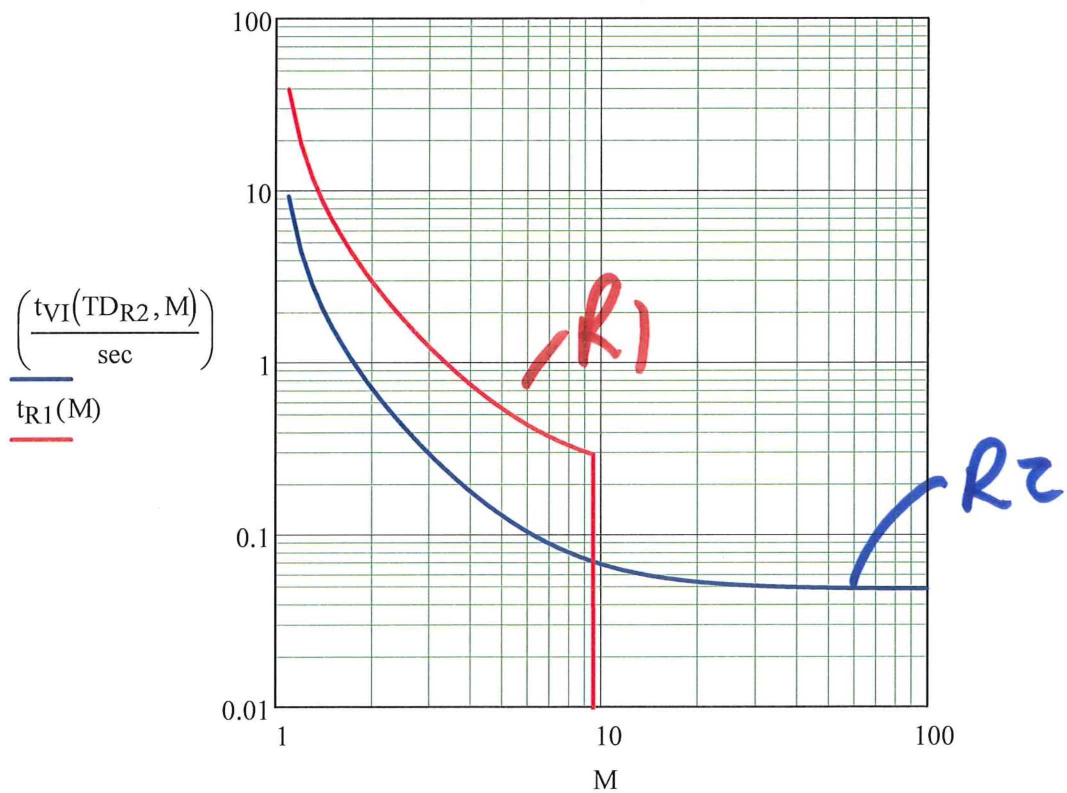
- Round this value up and use this as the pick up setting for the 50P (instantaneous) element

  - $I_{R1\_50\_set} := 70A$

- Combine this with the output for the 51 element for R1 using a Mathcad If-Then-Else element
- Also convert the response of the 50 element to be functions of M (not generally done otherwise)

$$t_{R1}(M) := \begin{cases} \dfrac{t_{VI}(TD_{R1\_set}, M)}{sec} & \text{if } 0 \le M \le \dfrac{I_{R1\_50\_set}}{I_{pu\_R1}} \\ 0.00001 & \text{otherwise} \end{cases}$$

$M := 1, 1.1 .. 100$



→ Inverse time overcurrent elements

- Assumptions
  - Assumed No R_f
    - kind of adapted
  - Fault current varies significantly with location
    - coordination based on current magnitude
    - can also do with 50 elements and time delays for backup zones

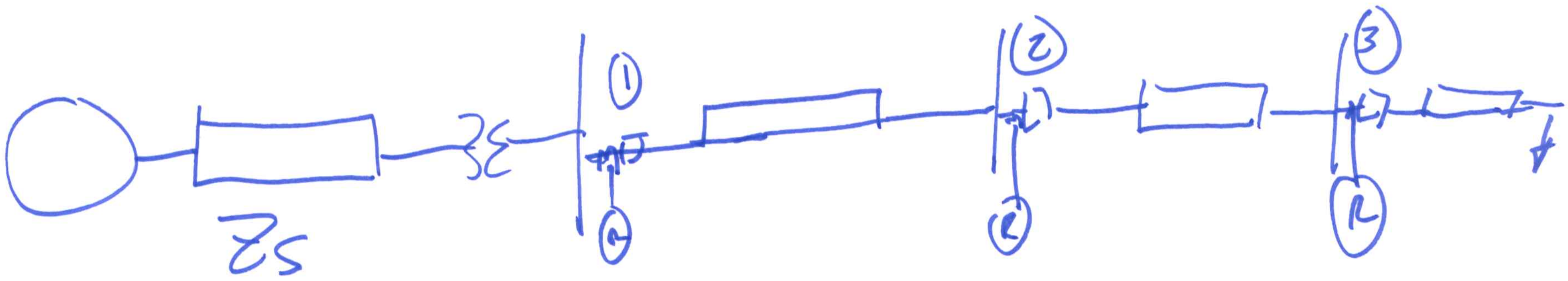
- Also assumed fault current flows 1 direction
  - directional supervision later

What if fault current doesnt vary much with fault location?

- high source impedance compared to line impedance

1. Try use extremely inverse elements
2. Time graded protection
3. Use communication

Time graded protection



If a fault is detected R1, R2 & R3 have set time delays

(R3) - $T_{delay} = 0$

(R2) $T_{delay} = CTI$

(R1) $T_{delay} = 2 \cdot CTI$

50V (51V)

- voltage supervised overcurrent element
- Generator relays acting as backup for line protection
  - If V below threshold the overcurrent element is enabled

generators connected to distribution
- coordinate overcurrent elements

L15 9/14

Symmetrical Components

ECE525

Lecture 15

- Review of basics
- Sequence Equivalents
- Fault Analysis

ECE525

Lecture 15

References

- Your power systems analysis class text book
- NPAG: Chapter 4 (analysis) Chapter 5 (equipment models)
- J.L. Blackburn, *Protective Relaying: Principles and Applications,* Any Edition: Chapter 4
- P.M. Anderson, *Analysis of Faulted Power Systems*, IEEE Press 1995
- J.L. Blackburn, *Symmetrical Components for Power Systems Engineering*, Marcel-Dekker, 1993.
- Nasser Tleis, *Power Systems Modelling and Fault Analysis: Theory and Practice*. Newnes Power Engineering Series. 2008

ECE525

Lecture 15

History

- Fortescue, 1918
  - » Unbalanced n-phase system can be broken down into sets of balanced n-phase systems
  - » Add using superposition

Symmetrical Components Fall 2018

ECE525

Lecture 15

What is it?

- Method for analysis of multiphase systems under unbalanced conditions
  - » Steady-state conditions
  - » Phasor Analysis
  - » Visualization
- Allows a fast, efficient way to analyze unbalanced condition in real time
- Relays set to look at specific components

Symmetrical Components Fall 2018

L15 11/18

Basic Equations

ECE525

Lecture 15

- De-couple voltage or current into 3 balanced 3 phase sets
  - » Positive phase sequence (ABCABC…): V_1
  - » Negative phase sequence (ACBACB…): V_2
  - » Zero phase sequence (A=B=C), V_0
  - » All RMS phasors
  - » Per phase analysis

Symmetrical Components Fall 2018

Per Phase Symmetrical Component Equations

ECE525

Lecture 15

$\mathbf{a} = 1 @ 120^0$

$\mathbf{V}_{AG} = \mathbf{V}_{A0} + \mathbf{V}_{A1} + \mathbf{V}_{A2}$ - phase A ref

$\mathbf{V}_{BG} = \mathbf{V}_{B0} + \mathbf{V}_{B1} + \mathbf{V}_{B2}$ - phase B ref

$= \mathbf{V}_{A0} + \mathbf{a}^2\mathbf{V}_{A1} + \mathbf{a}\mathbf{V}_{A2}$

$\mathbf{V}_{CG} = \mathbf{V}_{C0} + \mathbf{V}_{C1} + \mathbf{V}_{C2}$ ⇐ phase C ref components

$= \mathbf{V}_{A0} + \mathbf{a}\mathbf{V}_{A1} + \mathbf{a}^2\mathbf{V}_{A2}$

Symmetrical Components Fall 2018

L15 S17 12/18

Basic Sequence Networks

ECE525

Lecture 15

- Impedance will differ between sequences
- Zero sequence will also include ground impedance
- Connect them as appropriate for different fault types

Fault Analysis

ECE525

Lecture 15

- Fault Types:
  - » Single line to ground
  - » Line to line
  - » Double line to ground
  - » Three phase (positive sequence unless unbalanced fault impedances)
  - » Phase open — 1 or 2 ɸ series imbalance
  - » Phase open and line to ground
  - » Simultaneous faults

shunt fault

series

L15 12/3/18

Fault Detection For Protection Purposes

ECE525 Lecture 15

setting
- Basic fault analysis techniques calculate currents/voltages at fault location
  - » ABC or symmetrical components
- Need fault signature as seen at the relay location
  - » Rough location of fault for correct response

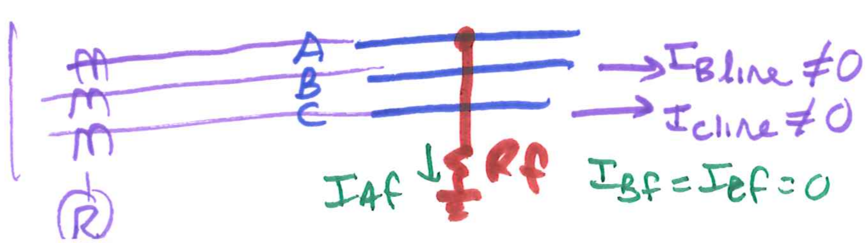
Symmetrical Components Fall 2018

Single Line to Ground Connections

ECE525 Lecture 15

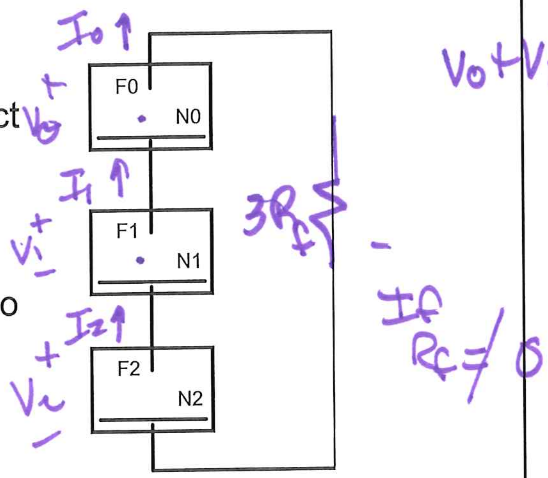
- Constraints at fault location (phase A):
  - » $V_A=0$ (If $R_f=0$, $V_f = I_f \cdot R_f$
  - » $I_B=I_C\cong 0$
- Therefore: - phase A ref
  - ① » $V_A = V_0 + V_1 + V_2 = 0$
  - » $I_0=(I_A + 0 + 0)/3$ and
  - » $I_1= I_2 =(I_A + 0 + 0)/3$ so
  - ② » $I_0 = I_1= I_2 =(I_A)/3$

Symmetrical Components Fall 2018



SLG Connections

- To Satisfy these constraints we connect the three networks in series
- Connect reference point of one network to fault location of next one



SLG Faults

- Solve for $\mathbf{I}_0$, can calculate $\mathbf{I}_A$
- Next solve for $\mathbf{V}_1$, $\mathbf{V}_2$, and $\mathbf{V}_0$ and calculate phase voltage
- Note that in general jX_o will be replaced with $\mathbf{Z}_0 = jX_0 + 3\mathbf{Z}_{gr} + 3Z_f$
  - » The factor of 3 results since 0 sequence is the same to all 3 phases

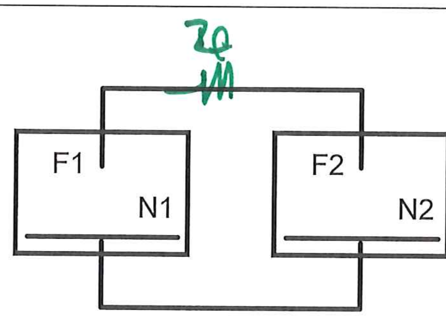
L15 5/15/18

Phase to Phase Faults

- Two phases (often B and C for analysis) shorted together
  - » Not shorted to ground
  - » $V_B=V_C$
  - » $I_B= -I_C$
- From symmetrical component equations:
  - » $I_0=0$
  - » $I_1= -I_2$ and $V_1=V_2$

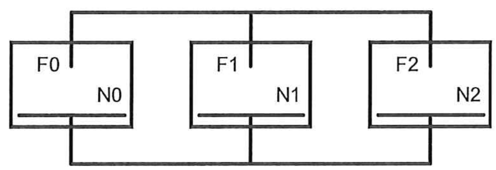
Phase to Phase Faults

- Fault impedance (if any) appears between the networks
- No Zero Sequence Network
- $V_B=I_B*Z_f + V_C$



Double Line to Ground

- Two phases shorted together and to ground
- Could have several impedances
  - » $I_A \cong 0$
  - » $V_B = (Z_f + Z_{gr})^*I_B + Z_f^*I_f$
  - » $V_c = (Z_f + Z_{gr})^*I_C + Z_f^*I_f$



Fault Detection For Protection Purposes

- Basic fault analysis techniques calculate currents/voltages at fault location
  - » ABC or symmetrical components
- Need fault signature as seen at the relay location
  - » Rough location of fault for correct response

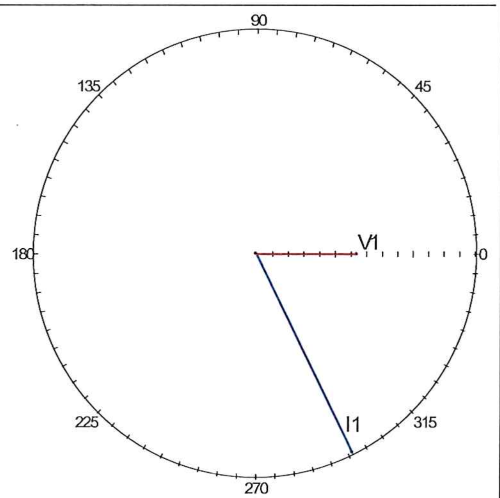
measurements
IA
IB
IC
VAG
VBG
VCG

L15 5/17/18

A Symmetrical Component View of an Three-Phase Fault

ECE525
Lecture 15

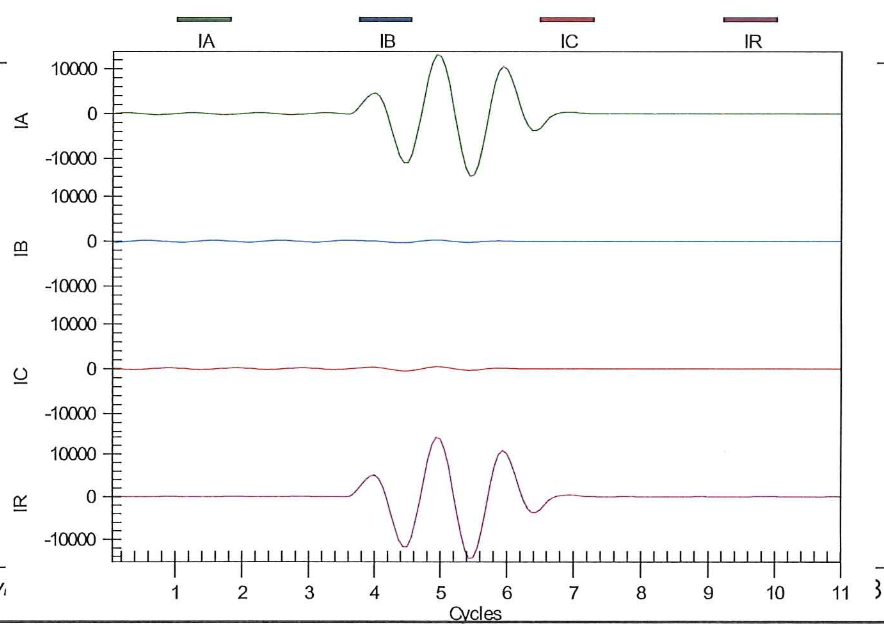
A-Ground Fault		
Component	Magnitude	Angle
Ia0	7.6	175
Ia1	2790	→ -64
Ia2	110	75.8
Va0	0	0
Va1	18.8	0



Symmetrical Components
Fall 2018

A to Ground Fault, Okay?

ECE525
Lecture 15



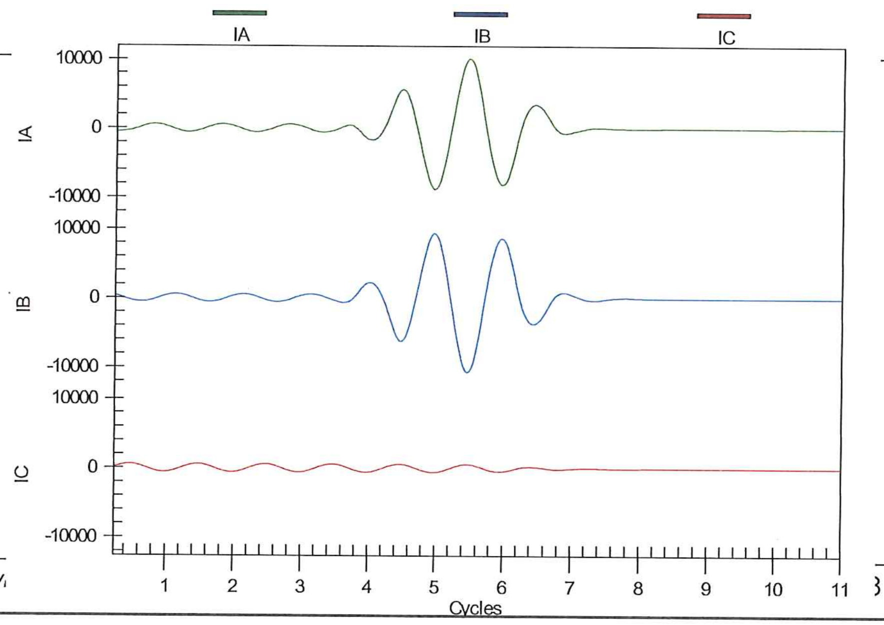
Sy...

L15 10/18

A to B Fault, Easy?

ECE525

Lecture 15



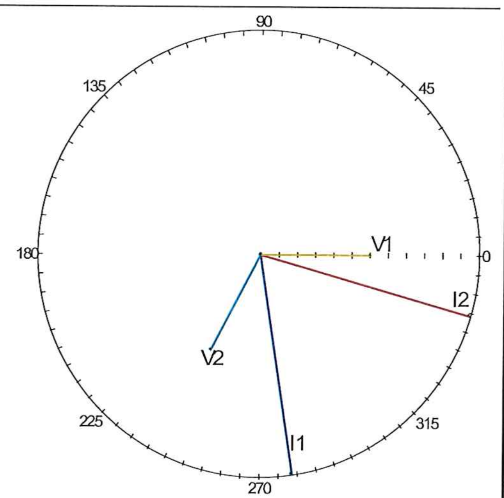
Sy

A Phase Symmetrical Component View of an A to B Phase Fault

ECE525

Lecture 15

	A-B Fault	
Component	Magnitude	Angle
Ia0	3	-102
Ia1	5993	-81
Ia2	5961	-16
Va0	1	45
Va1	99	0
V_{12}	99	-120°



not B-C

we cant use phase A ref