Tutorial on Distance and Over Current Protection

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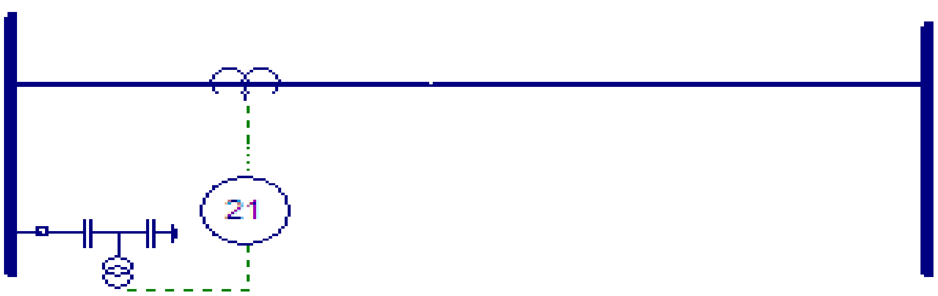
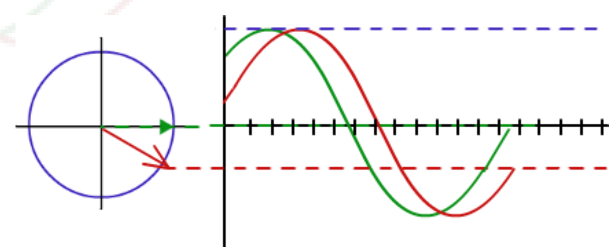




Contents

Protection Philosophy of ERPC

Introduction

- Based on the CEA Report of “The task Force on Power System Analysis Under Contingency”
- Discusses the Coordination practice to be followed for
  - Coordination of Distance protection
  - Coordination of Backup DOC and DEF

Philosophy

Zone	Direction	Protected Reach	Time Setting (s)
Zone 1	Forward	80 % of the PL	Instantaneous
Zone 2 (for 400kV and above)	Forward	For Single Circuit – 120 % of the PL	0.35
		For Double Circuit – 150 % of PL	0.5 to 0.6 – If Z2 reach overreaches 50% of the shortest line; 0.35 – otherwise
Zone 2 (for 220kV and below	Forward	120% of PL or 100% of PL + 50% of ASL	0.35

PL: Protected Line, ASL: Adjacent Shortest Line, ALL: Adjacent Longest Line

Philosophy

Zone	Direction	Protected Reach	Time Setting (s)
Zone 3	Forward	120% of (PL + ALL)	0.8 to 1.0
Zone 4	Reverse	10% for the Long line (>100 km) 20% for short line (<100 km)	0.5 if Z4 overreaches 50% of reverse shortest line 0.35: otherwise

Note : Z2 reach should not encroach the next lower voltage level

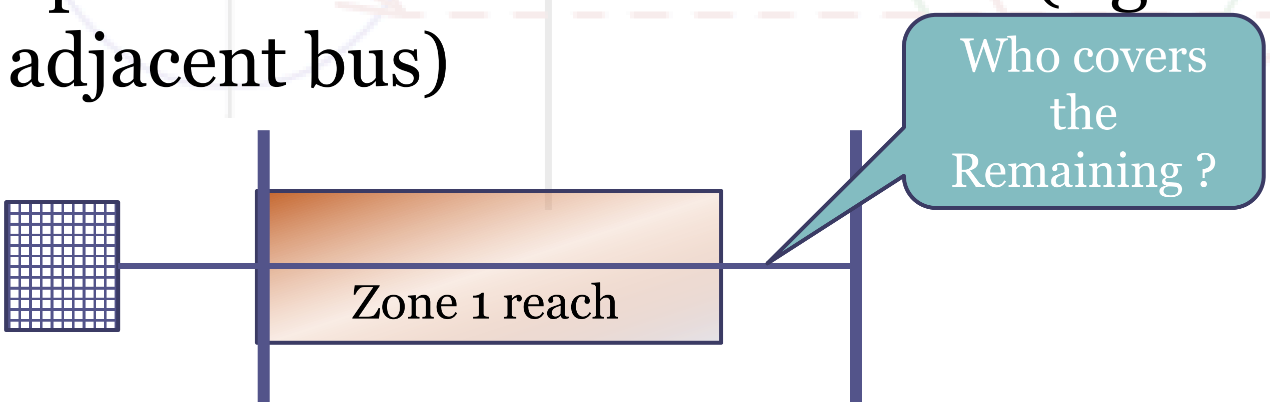
: If Z3 reach encroaches next voltage level (after considering in feed), Z3 time must be coordinated

: If utility uses carrier blocking scheme, then the Z4 reach may be increased as the requirement. It should cover the LBB of local bus bar and should be coordinated with Z2 time of the all other lines.

PL: Protected Line, ASL: Adjacent Shortest Line, ALL: Adjacent Longest Line

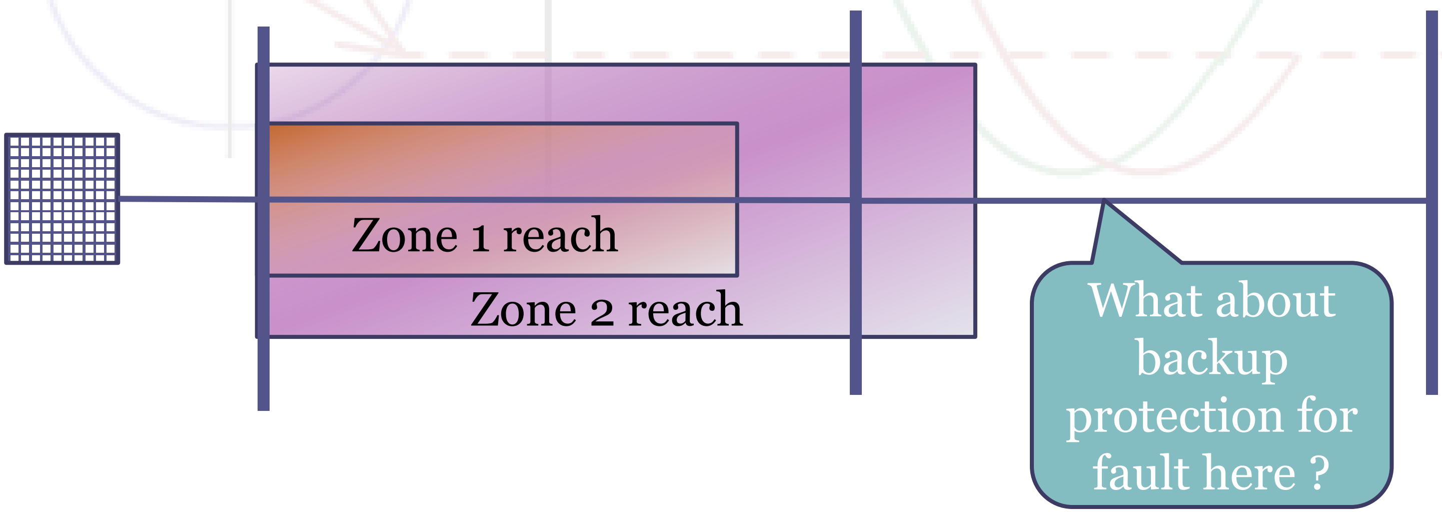
Zone 1

- Instrument Transformer errors
- Transmission line is not completely balanced
- Hence apparent impedance is susceptible to an error of 20%.
- Zone 1 is under reached to prevent incorrect operation for fault on next line (Eg. Close to adjacent bus)



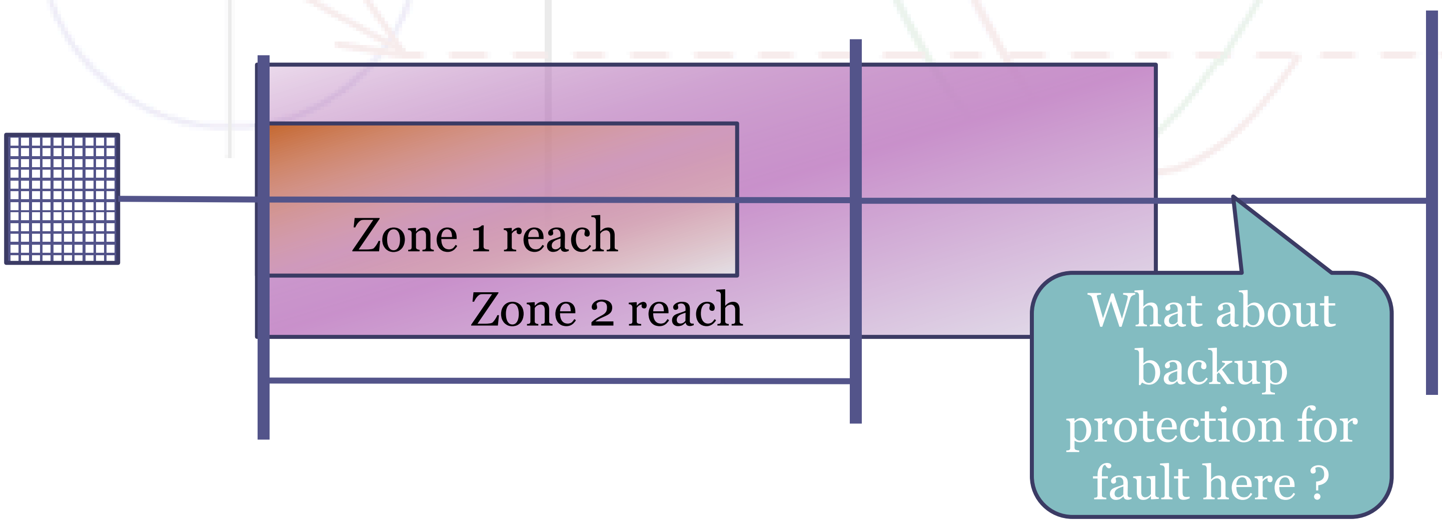
Zone 2 for single circuit line

- To provide coverage to remaining portion of protected line
- Over reach margin should be min 20% (for reason discussed in Zone1)



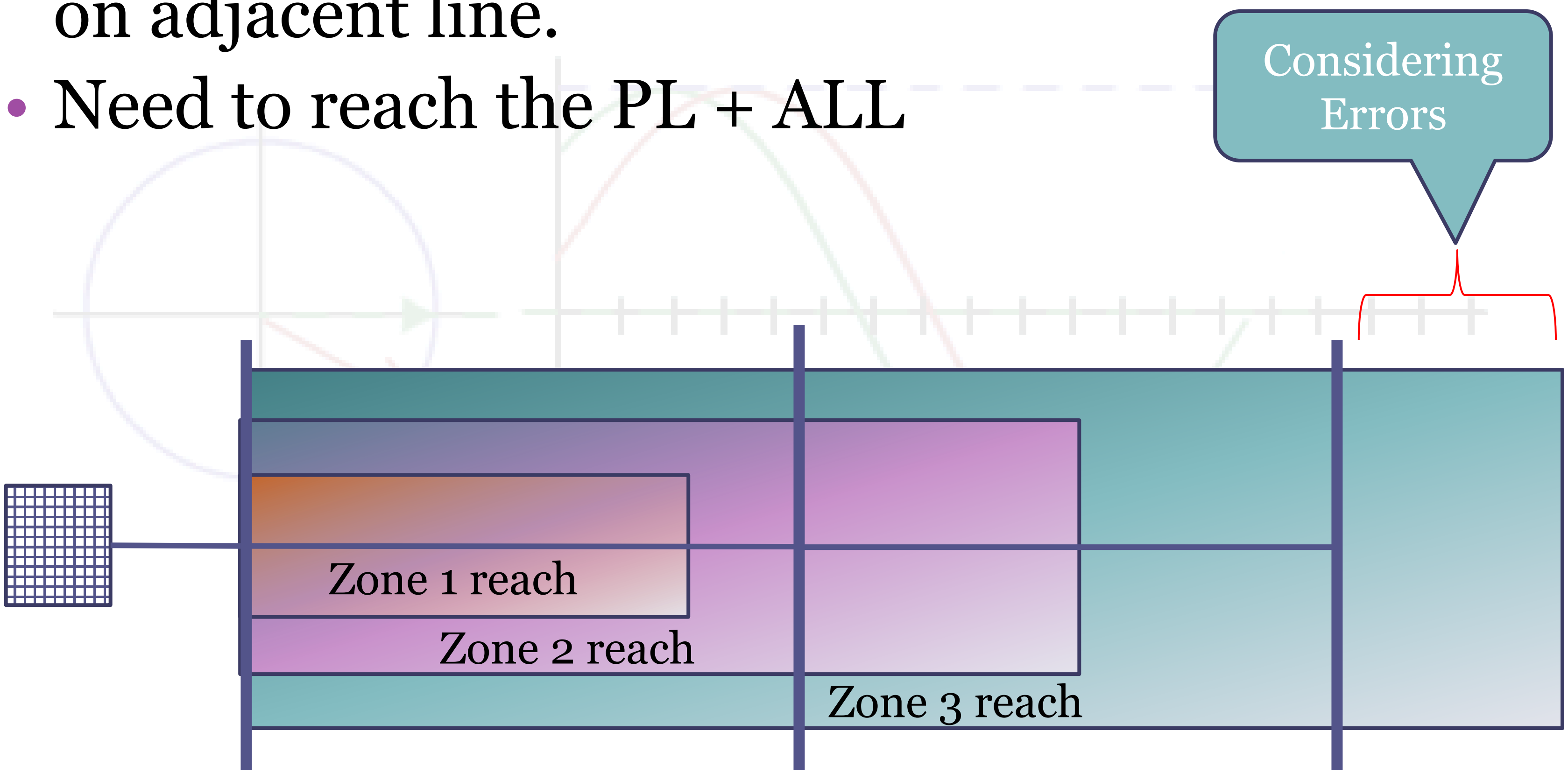
Zone 2 for double circuit line

- Under reach due to mutual coupling between parallel line
- $\Delta Z = \frac{k_{0m}}{1+k_0}, k_{0m} = \frac{Z_{0m}}{3Z_1}, k_0 = \frac{Z_0 - Z_1}{3Z_1}$
- For twin moose, ΔZ = 27% considering additional 20% margin, total 150% of PL



Zone 3

- Zone 3 protection is backup protection for fault on adjacent line.
- Need to reach the PL + ALL



Resistive Reach (Zone 1)

- Earth
  - Should provide maximum coverage considering fault resistance, arc resistance and tower footing resistance.
  - Should be <4.5 * X1 (X1=Zone 1 reach)
- Phase
  - Reach should be set to provide coverage against all types of anticipated phase to phase faults subject to check of possibility against load point encroachment
  - Should be <3*X1

Resistive Reach (Zone 2 and Zone 3)

- The philosophy used for Zone 1 is applicable here also.
- Additionally
  - Due to in-feeds, the apparent fault resistance seen by relay is several times the actual value, this should be considered before arriving at the setting.

Load Encroachment Consideration

- Reach setting is given considering the various "under reach" effect that can occur. This makes the resistive setting "high"
- Phase loop measures the phase impedance and hence has to be set such that it does not trip for abnormal or emergency system loading condition
- Emergency loading condition is to be used to decide the load encroachment point.

Load Encroachment Consideration

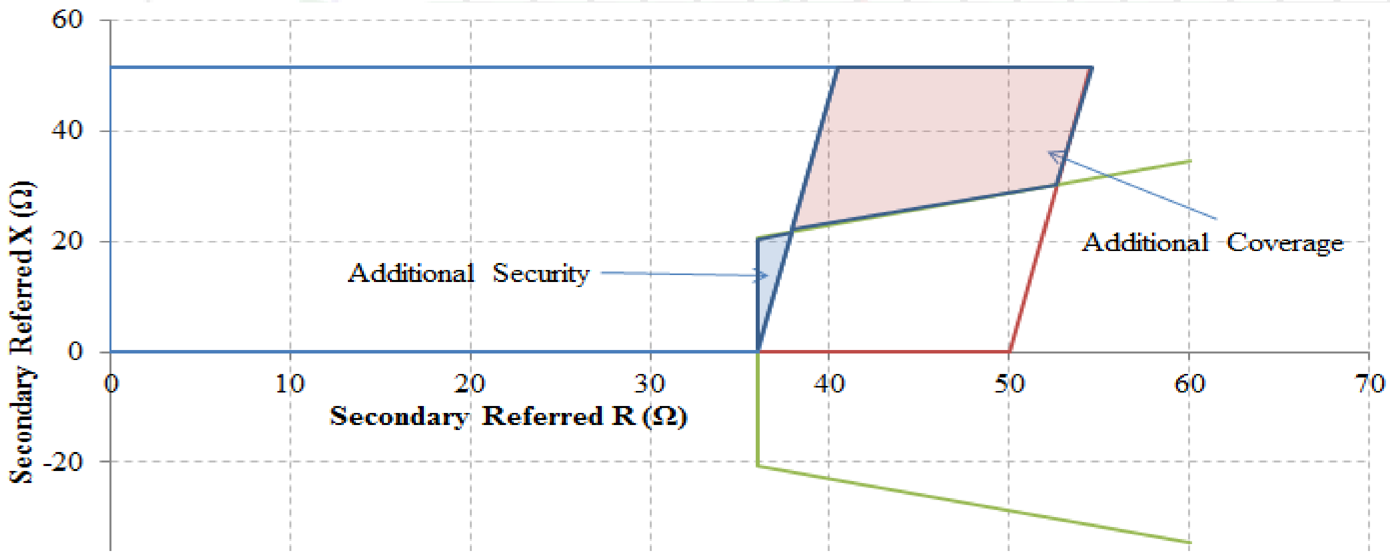
- Following criteria may be considered
  - 1.5 times the thermal rating of line

    OR

  - 1.5 times associated bay equipment rating (minimum of all equipment)
  - Minimum voltage of 0.85 pu to be considered
  - Load encroachment angle can be considered as 30° (approx. 0.85 pf)

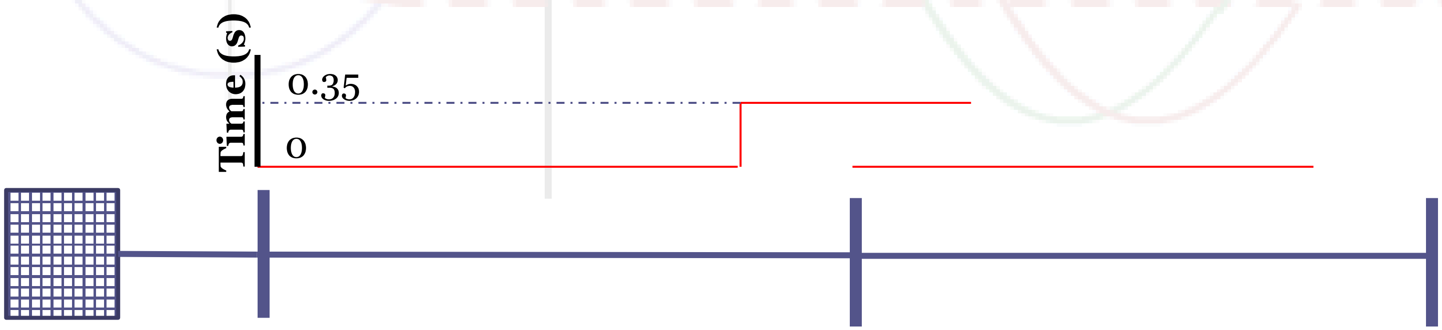
Load Encroachment Consideration

- Basic Check
  - Rated V = 63.5 V and Rated I = 1 A. (Secondary Referred)
  - R reach should always be less than 63.5 Ω
  - Phase Impedance = (0.85*V)/(1.5*I) = 36 Ω



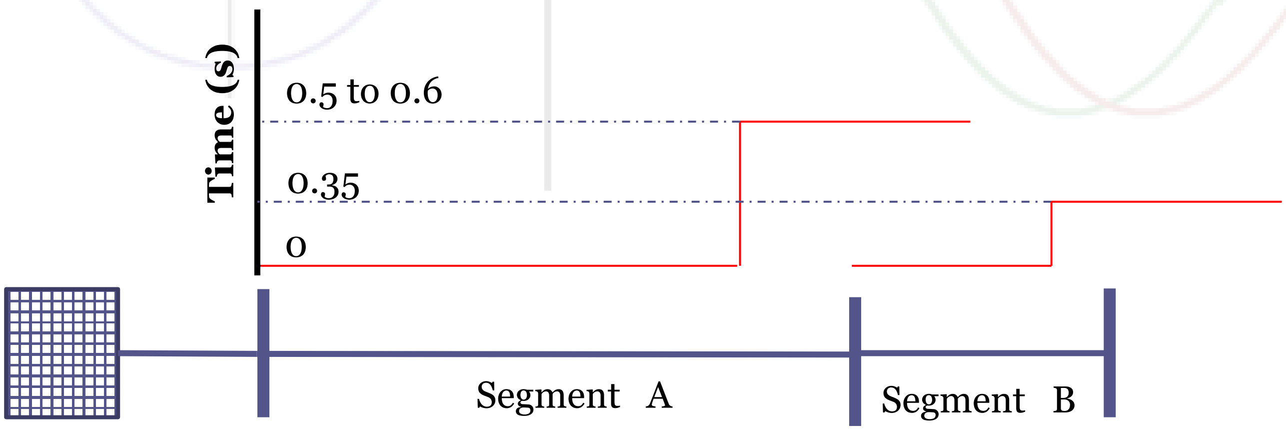
Operating Time coordination

- Zone 1 is primary protection, hence instantaneous operation
- Zone 2 is a overreach zone and hence needs to be delayed.
    - If errors involved is less, then Zone 2 can trigger for Zone 1 fault of adjacent line. Hence Zone 2 is to be coordinated with Zone 1.



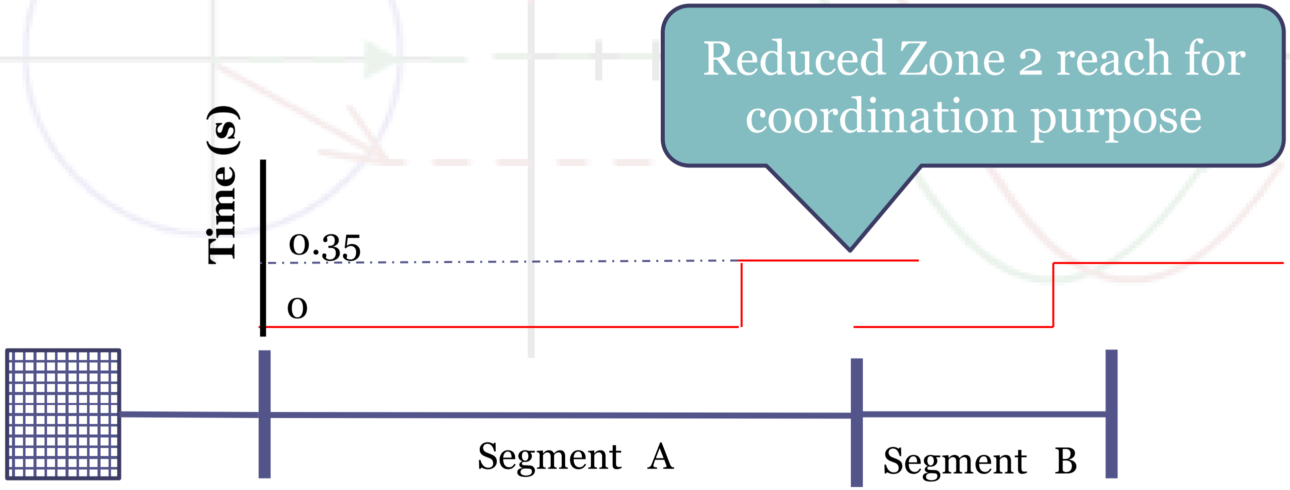
Operating Time Coordination

- For fault at 80% of segment B, Segment B zone 1 can also under reach by 20%
- Hence only Zone 2 of Segment B pick up
- Segment A Zone 2 can also pickup.
- Hence segment A Z2 to be coordinated with segment B Z2



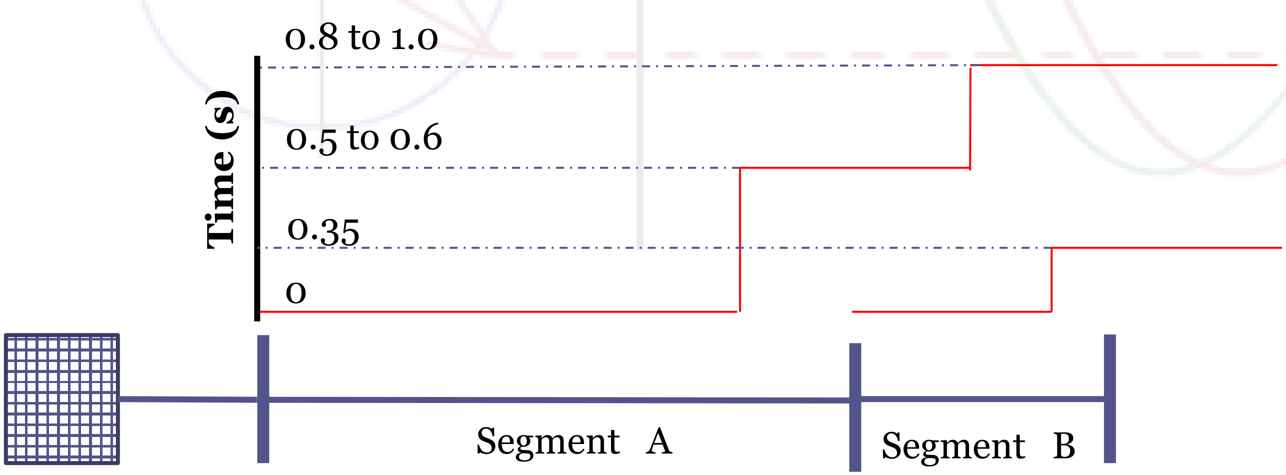
Operating Time coordination

- For 220 kV and below, if Zone 2 of PL can encroach the Zone 2 of ASL, then coordination is achieved by reducing the Zone 2 reach of PL to coordinate with Zone 2 reach of ASL.



Operating Time coordination

- Zone 3 is the backup protection and hence needs to be operate after Zone 1 or Zone 2 has failed to clear the fault.
- Zone 3 is coordinated with Zone 2 time of adjacent line relay.



Computation of Distance Relay Settings

Points to be Considered

- Obtain the actual line parameters from line impedance test results. If not available, consider the standard values.
- Check Relay Setting type
  - Primary or secondary referred values
  - RX or Zθ
  - Computation of Zero sequence compensation factor. (Ko, Kn or Kr-Kx)

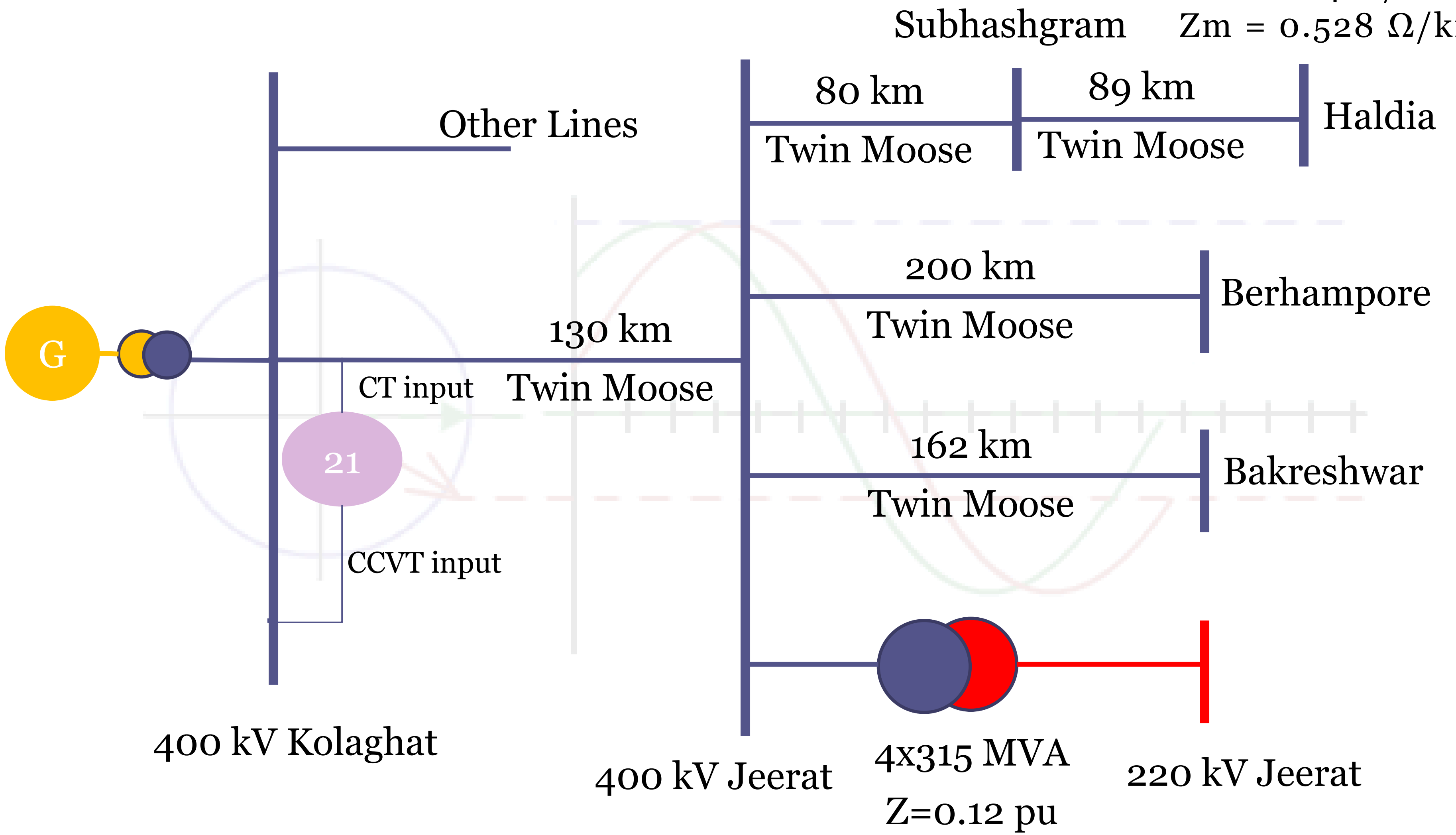
$$k_0 = \frac{Z_0 - Z_1}{3Z_1} \qquad k_n = \frac{Z_0 - Z_1}{Z_1} \qquad k_r = \frac{R_0 - R_1}{3R_1} \quad k_x = \frac{X_0 - X_1}{3X_1}$$

Points to be Considered

- Note the shortest and longest line emanating from the adjacent substation, along with impedance values
- For double circuit lines, check if it is two single circuit tower or one double circuit tower
- If necessary, carry out system study to study the effect of in feed, mutual coupling, power swing to achieve coordinated setting.

Sample System

R1 = 0.0297 Ω/km
X1 = 0.332 Ω/km
R0 = 0.161 Ω/km
X0 = 1.24 Ω/km
Zm = 0.528 Ω/km



Zone 1

- Primary referred
  - $X1\_prim = 0.332 * 130 * 0.8 = 34.5\ \Omega$
- Secondary referred
  - $X1\_sec = 34.5 * CTR/PTR$, CTR:CT Ratio, PTR: PT Ratio
- Operating Time: Instantaneous

Zone 2

- Protected line is single circuit
- ASL: 80 km to subhashgram
- X2_Prim = 0.332*130*1.2 = 51.79 Ω (130+26 km)
- X2 covers only 32% of ASL.
- Operating Time : 0.35s

Zone 3

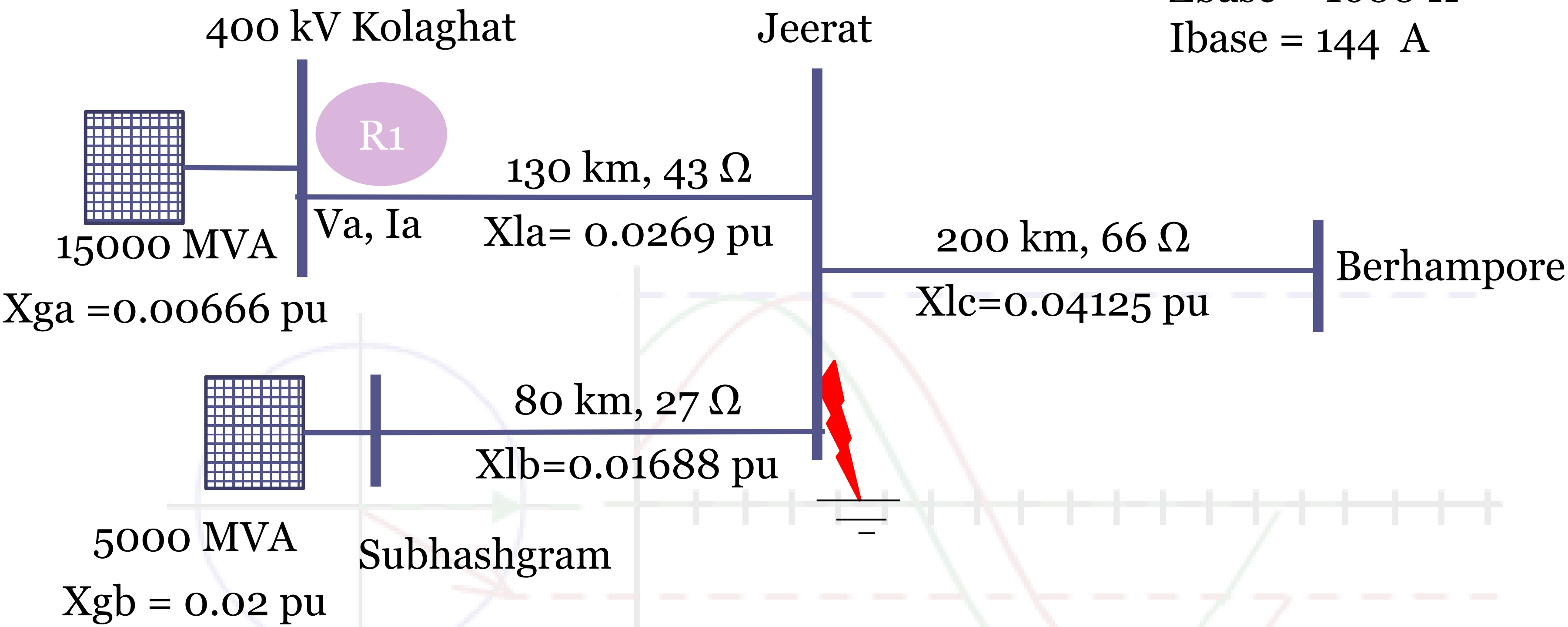
- ALL is 200 km to Berhampore
- X3_Prim = 0.332*(130+200)*1.2 = 131.47 Ω
  - That is 130 km PL + additional 266 km
- Time Setting
  - Check if Zone 3 of PL encroach Zone 3 of adjacent line protection
  - Zone 3 of Jeerat - Subhashgram line is 202.8 km.
  - The Two Zone 3 are overlapping and hence must be time coordinated.
  - Time = 0.8+ 0.06 (t_{cb})+0.03 (t_{reset})+0.06 (t_{sf})= 0.95 (set 1s)

* t_{cb}, t_{reset} and t_{sf} values are as per CEA report

System Study to Understand Distance Relay Behavior

Case 1 (general concept)

Assuming 100 MVA base
Zbase = 1600 Ω
Ibase = 144 A



- Neglecting Resistance of the line
- Considering 3φ fault
- Compute impedance seen by relay R1

- Xa (section a) = Xga+ Xla = 0.03346 pu
- Xb (section b) = Xgb+Xlb = 0.03687 pu

- Xeq = Xa || Xb = 0.01754 pu
- If = 1/Xeq = 57 pu = 57*144 = 8209 A

- Ia = If*Xb/(Xa+Xb) = 4303.5 A
- Ib = If*Xa/(Xa+Xb) = 3905.5 A

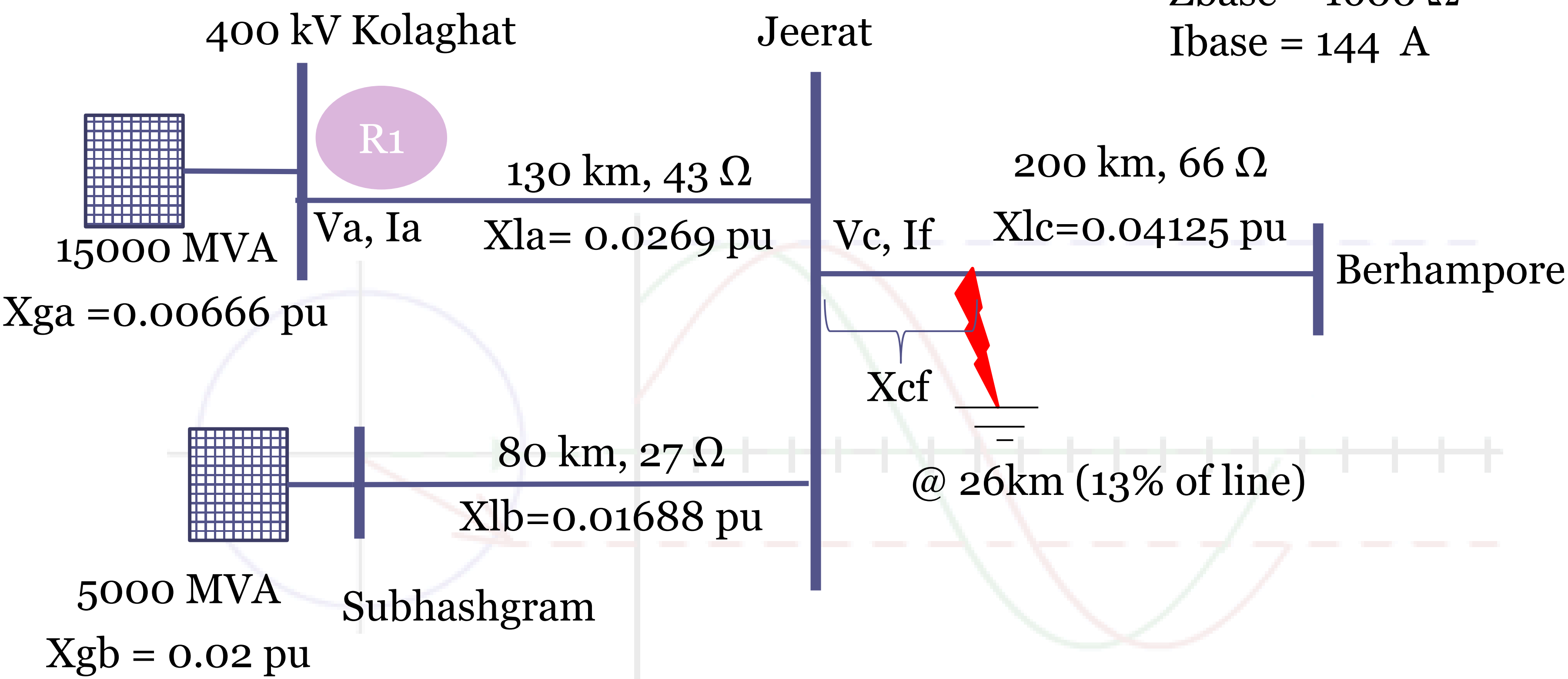
- Va = (Ia*Xla) = 4303.5*43 = 185.05 kV
- Z1 = Va/Ia = 43 Ω

Note: Za=Va/Ia is valid because we are only considering three phase fault.

- The distance relay measures an apparent impedance of 43 which is the actual line impedance. As per setting pick up in Zone 2.
- Consider 5P20 CT class and 1.2R class CVT. For worst case considering -5%CT error and +3% CVT error
- With this the theoretical impedance will change by factor of 1.03/0.95 = 1.085
- Measured impedance with error = 46.655 Ω.
- With Zone2 setting of 51.79 Ω, R1 will pick up in Zone 2.

Case 2 (in feed effect)

Assuming 100 MVA base
Zbase = 1600 Ω
Ibase = 144 A



- Xeq = (Xa || Xb) + Xcf = 0.01754 + 0.00536

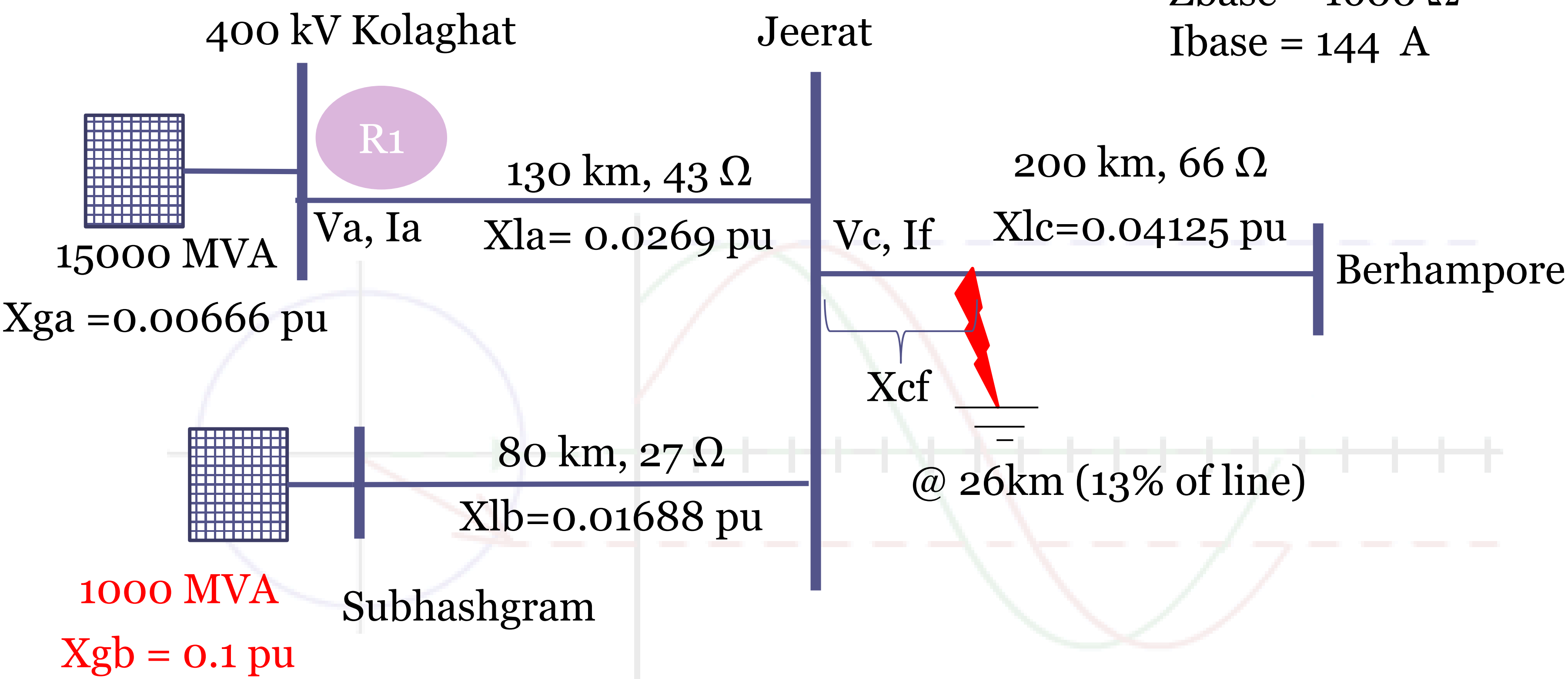
- If = 1/Xeq = 1/0.022935 = 43.601 pu = 6278 A
- Ia = 3286 A

- Vc = If*Xcf = 6278* 8.58 = 53.87 kV
- Va = (Ia*Xla) + Vc = 195.3394 kV

- Z1 = Va/Ia = 59.42 Ω.
- Actual Fault location Xla+(0.13*Xlc) = 51.62
- It can be inferred that Relay R1 will under reach for the fault by 15 %, due to in-feed from section B

Case 3 (Weak in feed effect)

Assuming 100 MVA base
Zbase = 1600 Ω
Ibase = 144 A



Xa (section a) = Xga+ Xla = 0.03346 pu

Xb (section b) = Xgb+Xlb = 0.11687 pu

- Xeq = (Xa || Xb) + Xcf = 0.026017 + 0.00536

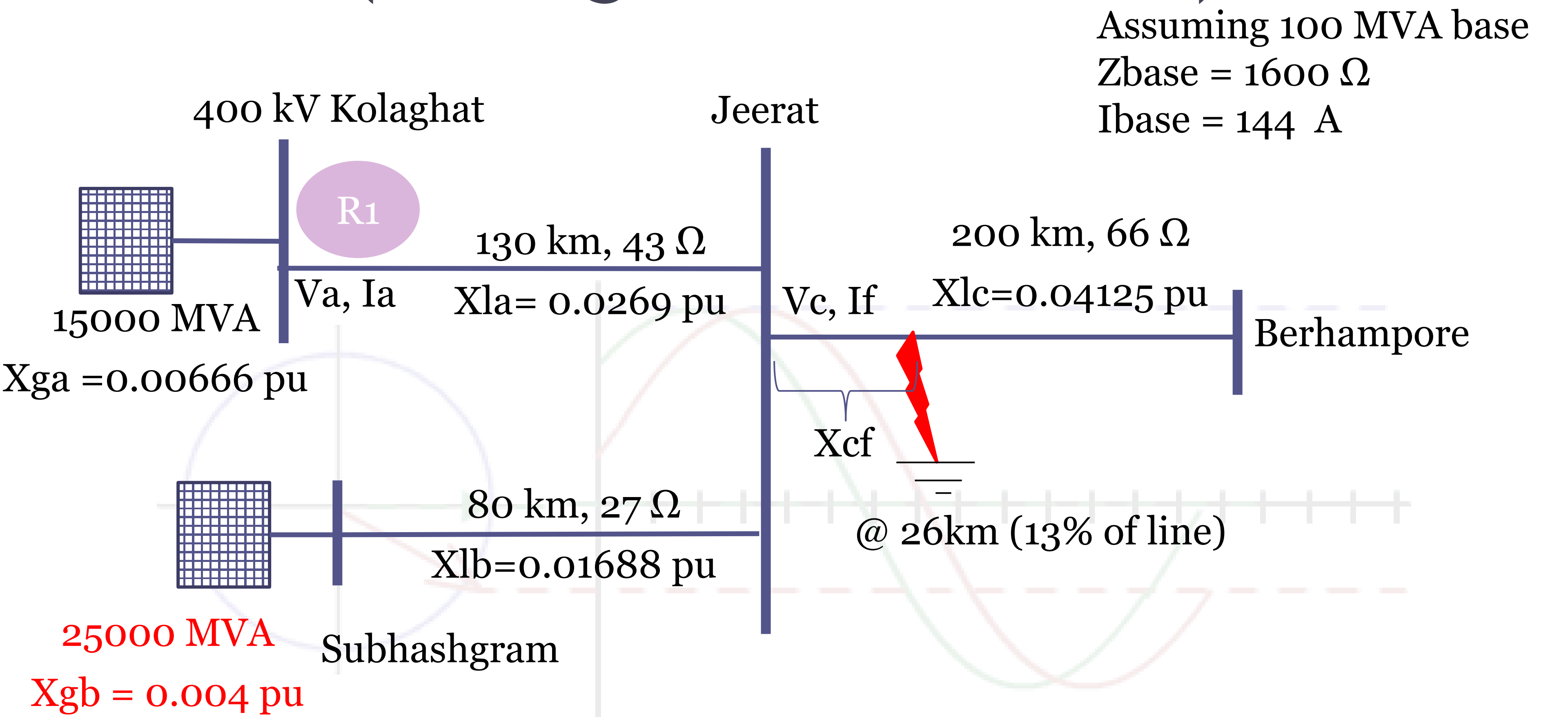
- If = 1/Xeq = 1/0.03144 = 31.806 pu = 4580 A
- Ia = 3558 A

- Vc = If*Xcf = 4580* 8.58 = 39.297 kV
- Va = (Ia*Xla) + Vc = 192.445 kV

Here Xcf and Xla are in ohm

- Z1 = Va/Ia = 54.08 Ω.
- Actual Fault location Xla+(0.13*Xlc) = 51.62
- It can be inferred that Relay R1 will under reach for the fault by 4.7 %, due to in-feed from section B

Case 4 (Strong in feed effect)



Xa (section a) = Xga+ Xla = 0.03346 pu

Xb (section b) = Xgb+Xlb = 0.02087 pu

- $Xeq = (Xa || Xb) + Xcf = 0.01285 + 0.00536$

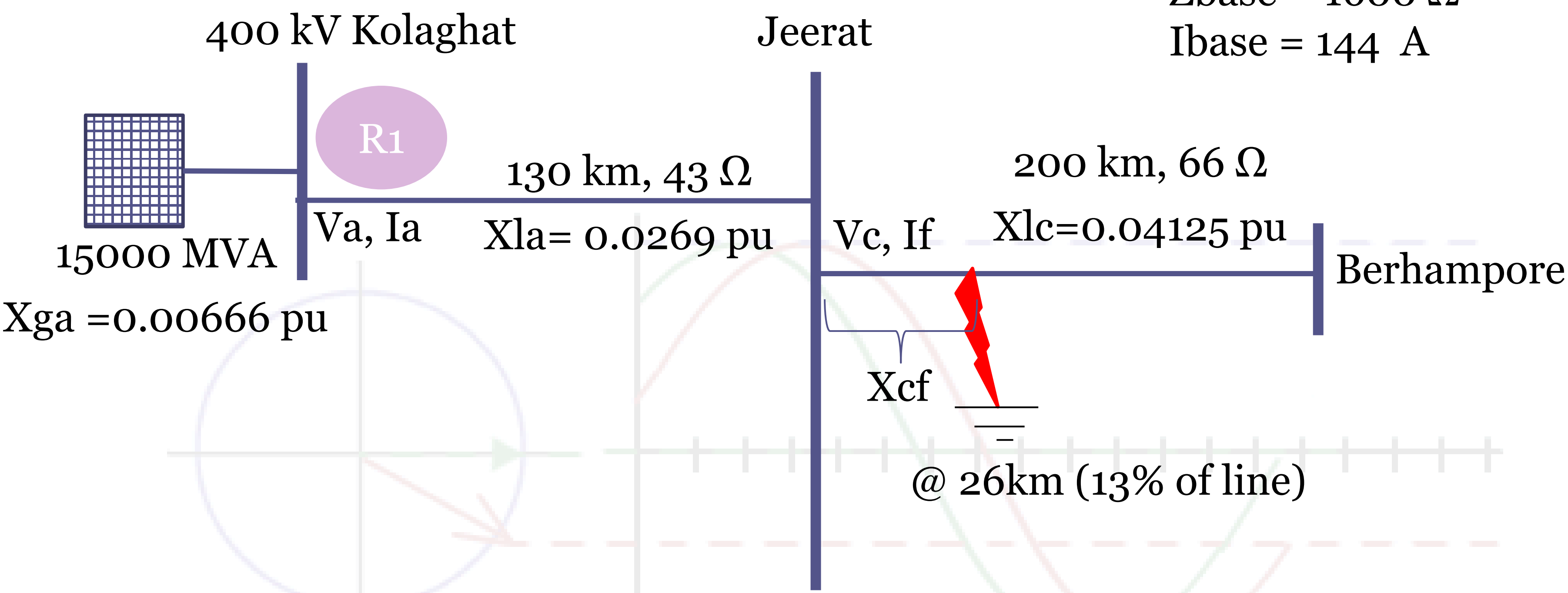
- $If = 1/Xeq = 1/0.018235 = 54.839$ pu = 7896 A
- $Ia = 3028$ A

- $Vc = If*Xcf = 7896*\ 8.58 = 67.75$ kV
- $Va = (Ia*Xla) + Vc = 198.0971$ kV

- $Z1 = Va/Ia = 65.41\ \Omega$.
- Actual Fault location $Xla+(0.13*Xlc) = 51.62$
- It can be inferred that Relay R1 will under reach for the fault by 26.7 %, due to in-feed from section B

Case 5 (without in feed effect)

Assuming 100 MVA base
Zbase = 1600 Ω
Ibase = 144 A



Xa (section a) = Xga+ Xla = 0.03346 pu

- Xeq = Xa + Xcf = 0.03346 + 0.005363

- If = 1/Xeq = 1/0.038929 = 25.6877 pu = 3699 A
- Ia = 3699 A

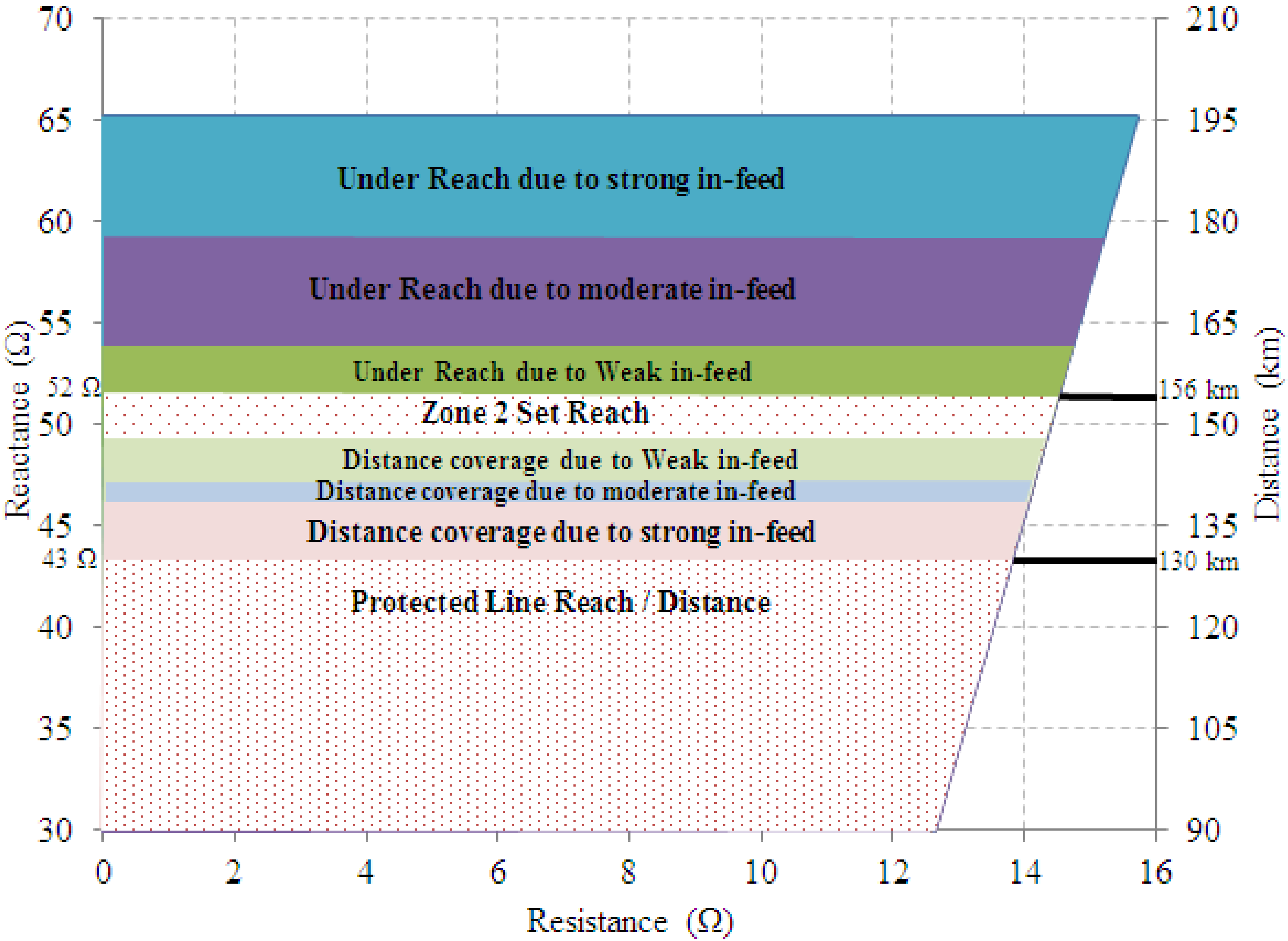
- Vc = Ia*Xcf = 3699* 8.58 = 31.738 kV
- Va = (Ia*Xla) + Vc = 190.943 kV

- Z1 = Va/Ia = 51.62 Ω.
- Actual Fault location Xla+(0.13*Xlc) = 51.62
- It can be inferred that the Relay R1 measures the exact impedance to fault point.

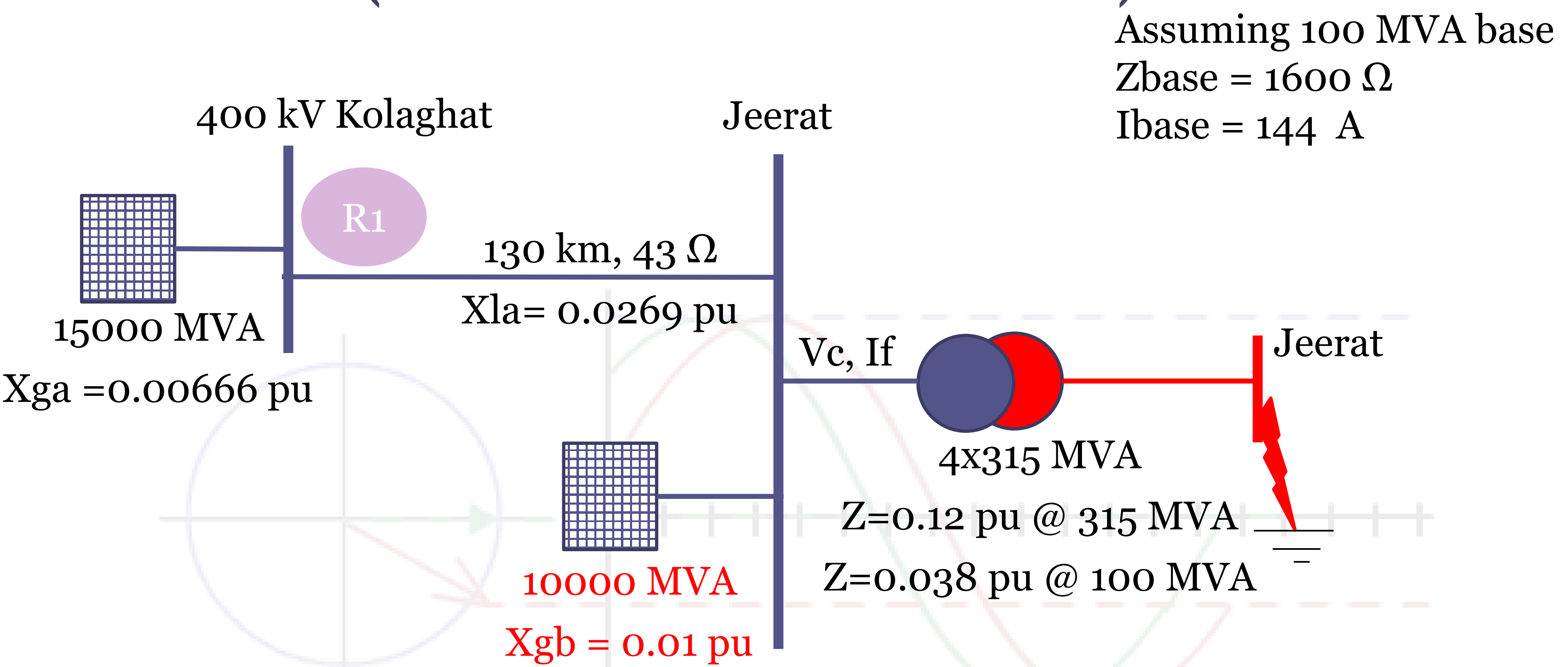
Comparison of in-feed effect

In-feed type	Measured Impedance (Ω)	Voltage Vc (kV)	Voltage Va (kV)	Under Reach margin (%)	Effective Z2 Coverage (%)
No-infeed	51.62	31.738	190.95	0	20
Weak (Xgb/Xga = 0.066)	54.08	39.29	192.44	4.77	16
Moderate (Xgb/Xga = 0.33)	59.429	53.87	195.33	15.13	10
Strong (Xgb/Xga = 1.66)	65.41	67.75	198.09	26.72	7.7

- With increase in in-feed, increases the voltage at the relay location, which is the primary reason for the relay to under reach the fault.
- Therefore, Zone 2 is primarily used to provide complete line coverage only.

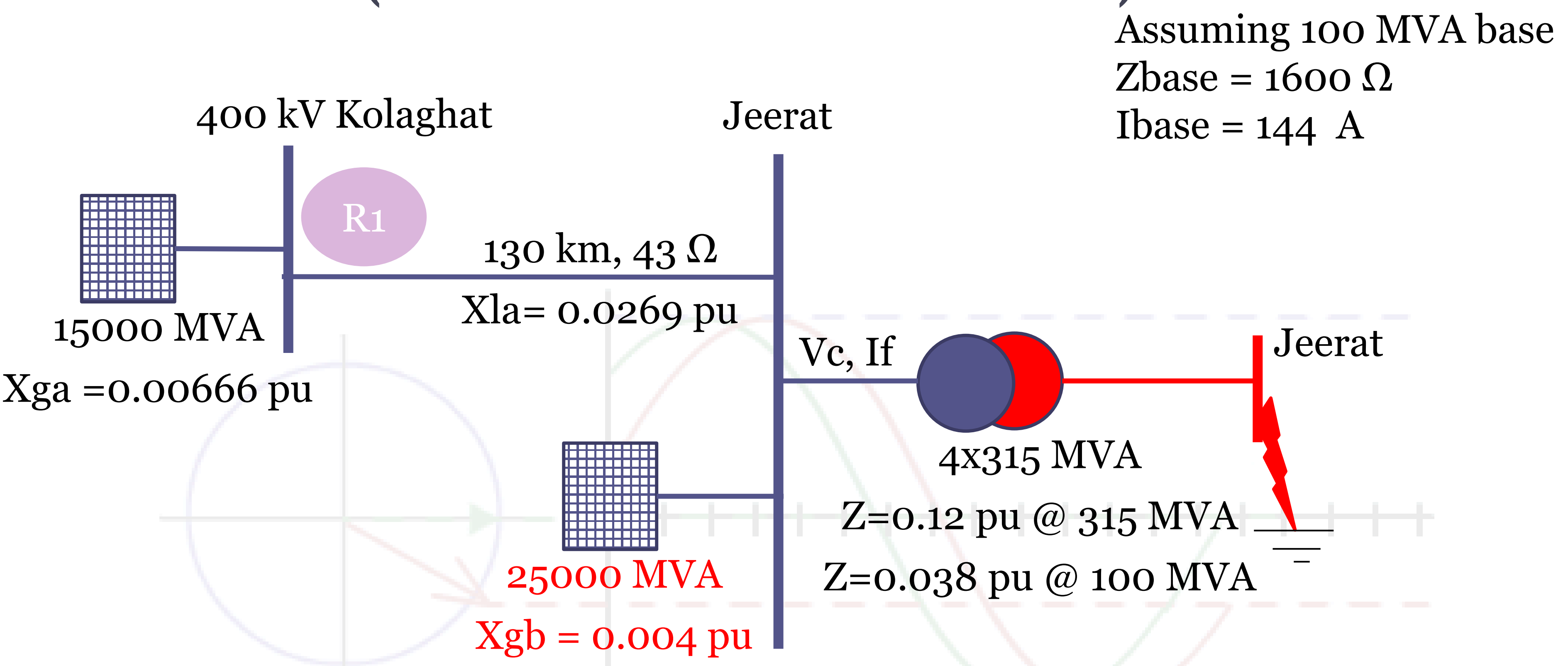

Under Reach due to strong in-feed
Under Reach due to moderate in-feed
Under Reach due to Weak in-feed
Zone 2 Set Reach
Distance coverage due to Weak in-feed
Distance coverage due to moderate in-feed
Distance coverage due to strong in-feed
Protected Line Reach / Distance
52 Ω
43 Ω
156 km
130 km
Reactance (Ω)
Distance (km)
Resistance (Ω)
70
65
60
55
50
45
40
35
30
210
195
180
165
150
135
120
105
90
0
2
4
6
8
10
12
14
16

Case 6 (Zone 3 Over reach)



- Z1 = Va/Ia = 109 Ω (Zone 3 setting is 130 Ω)
- Relay R1 is encroaching the next voltage level.
- Hence Zone 3 time to be coordinated with transformer DOC operating time.

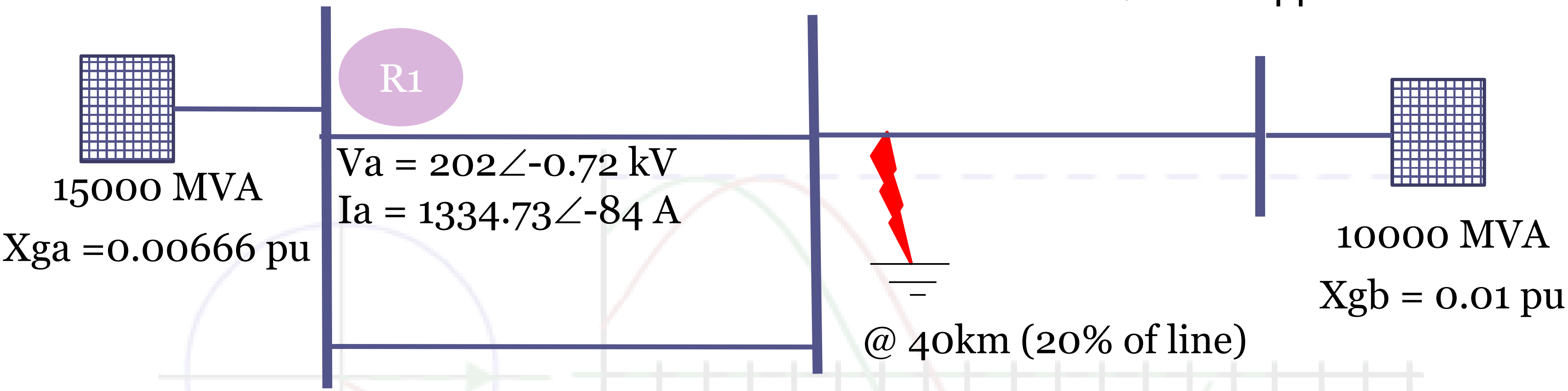
Case 7 (Zone 3 Over reach)



- Z1 = Va/Ia = 186 Ω (Zone 3 setting is 130 Ω)
- Relay R1 is not encroaching the next voltage level.

Case 8 (Mutually coupled lines)

Assuming 100 MVA base
Zbase = 1600 Ω
Ibase = 144 A



- Use Earth loop for computation of apparent impedance

$$Z_1 = \frac{V_a}{I_a * (1 + k_0)} \qquad k_0 = \frac{Z_0 - Z_1}{3Z_1}$$

- Z1 = 32.4 +j 87.84 Ω
- Theoretical X is 56.2 Ω

- It can be observed that with mutually coupled parallel line, the apparent impedance measured in 57% more than the theoretical value

DOC and DEF for EHV System

Introduction

- DOC and DEF are used in majority of the utility as Main 2 protection for 220 kV line.
- DOC and DEF are used at both HV and LV side of ICT as backup protection (87 being the main protection)
- DEF is used in 400 kV line as protection for high impedance earth faults.
- Non directional OC is also used in 400kV line under fuse fail condition

DOC Setting Philosophy

- For 220 kV and 132 kV line with only one main distance protection, DOC must be set in such a way that for fault at remote bus the DOC (IDMT) is coordinated with Zone 2 time (not finalized in ERPC philosophy), typically 1.1 s.
- For DOC at 400 kV side of ICT, it is to be set such that for fault at remote end bus (longest line), DOC (IDMT) is coordinated with Zone 3 time (as per ERPC finalized philosophy).

DOC Setting Philosophy

- Instantaneous DOC can be used at 400 kV side of ICT, set such that
  - It does not pickup for fault on 220 kV bus
  - It does not pickup for transformer charging current
  - Time setting of **0.05 s** to 0.1 s can be considered.

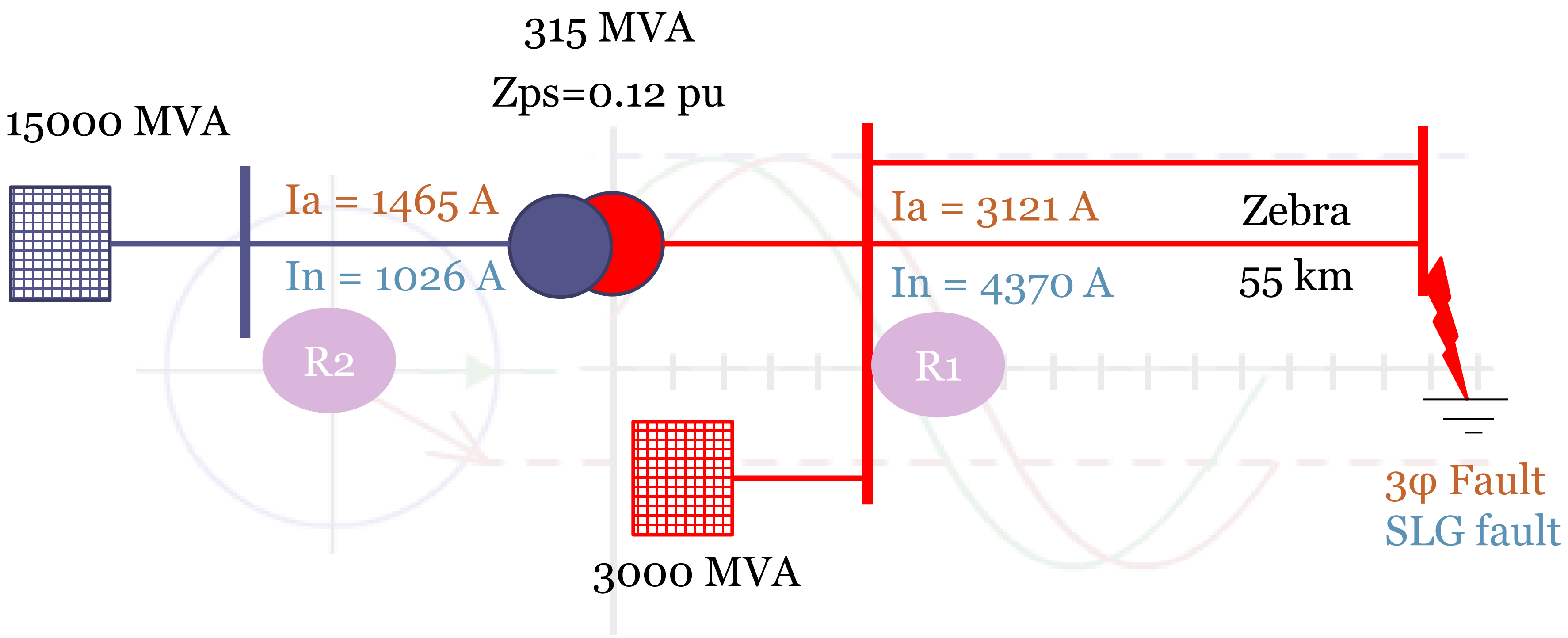
DEF Setting Philosophy

- For 220 kV and 132 kV line with only one main distance protection, DEF (IDMT) must be set in such a way that it is coordinated with Zone 2 time.
- For 400 kV line or where two main distance protection is used, DEF is used only for protection against high impedance faults and is coordinated with Zone 3 time.
- For DEF at 400 kV side of ICT, it is to be set such that for fault at remote end bus (longest line), DEF (IDMT) is coordinated with Zone 3 time (as per ERPC finalized philosophy).

DEF Setting Philosophy

- Instantaneous DEF can be used at 400 kV side of ICT, set such that
  - It does not pickup for fault on 220 kV bus
  - It does not pickup for transformer charging current
  - Time setting of **0.05 s** to 0.1 s can be considered.

Sample Setting Calculation



DOC Setting

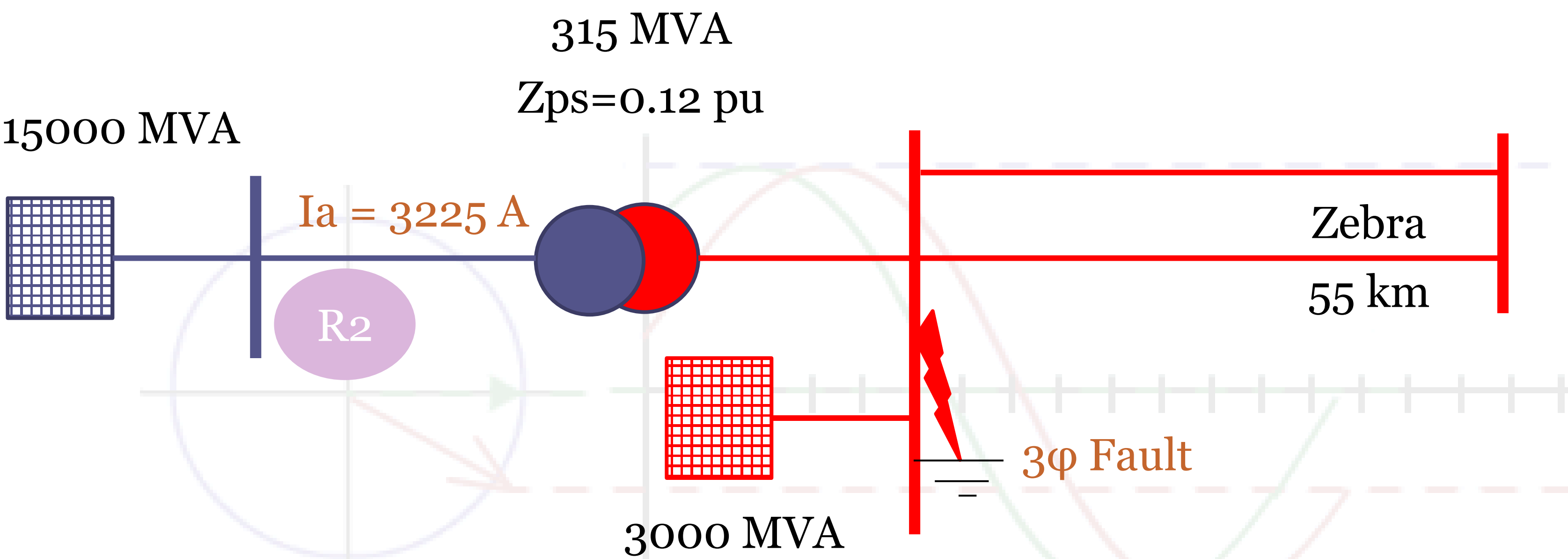
- Line
  - Ip = 1.5*Irated = 1.5*580 =870 A.
  - Irelay = 3121 A
  - Top = Zone 2 + Δt = 0.6s. (Δt = 0.2s)
  - TMS = 0.11 s (Considering NI curve)
- Transformer
  - Ip = 1.5*450 = 675 A
  - Irelay = 1465 A
  - Top = $t_{zone3} + \Delta t$ = 1.0 s
  - TMS = 0.12 s (Considering NI curve)

DEF Setting

- Line
  - Ie = 0.2*Irated = 0.2*580 =116 A.
  - Irelay = 4370 A
  - Top = Zone 2 + Δt = 0.6s.
  - TMS = 0.26 s (Considering NI curve)
- Transformer
  - Ip = 0.2*450 = 90A
  - Irelay = 1026 A
  - Top = $t_{zone3} + \Delta t$ =1.0 s
  - TMS = 0.35 s (Considering NI curve)

Consideration of relay saturation is crucial Here 20 time is assumed

Instantaneous Setting calculation



- Reflected Current = 1.3 * 3225 = 4195 A
- Inrush Current = 8*450 = 3600 A
- Ip>> = Highest of the above two = 4200 A (Set value).

Concluding Remarks

- Recommended philosophy for setting distance relay are well established and can provide fairly effective setting
- Based on the network condition, protection engineer should be able to decide if system study is required for obtaining effective setting.

Thank You

Duration spectra of Main effects

Electrical Switching Transients **Over Voltages** **Fault Transients**	**Electrical machine & System Dynamics**	**System Governin g & load Controls**	**Prime mover energy supply system dynamics**	**Energy resource dynamics**
μs/ms	Few seconds	Seconds to minutes	Several minutes	Days to weeks

Transient Phenomena

❖ **Scale** ⇨

- **μs** ⟶ **Initial transient, Recovery Voltage**
- **ms** ⟶ **Switching surges, Fault transients**
- **Several cycles** ⟶ **Ferro - resonance**

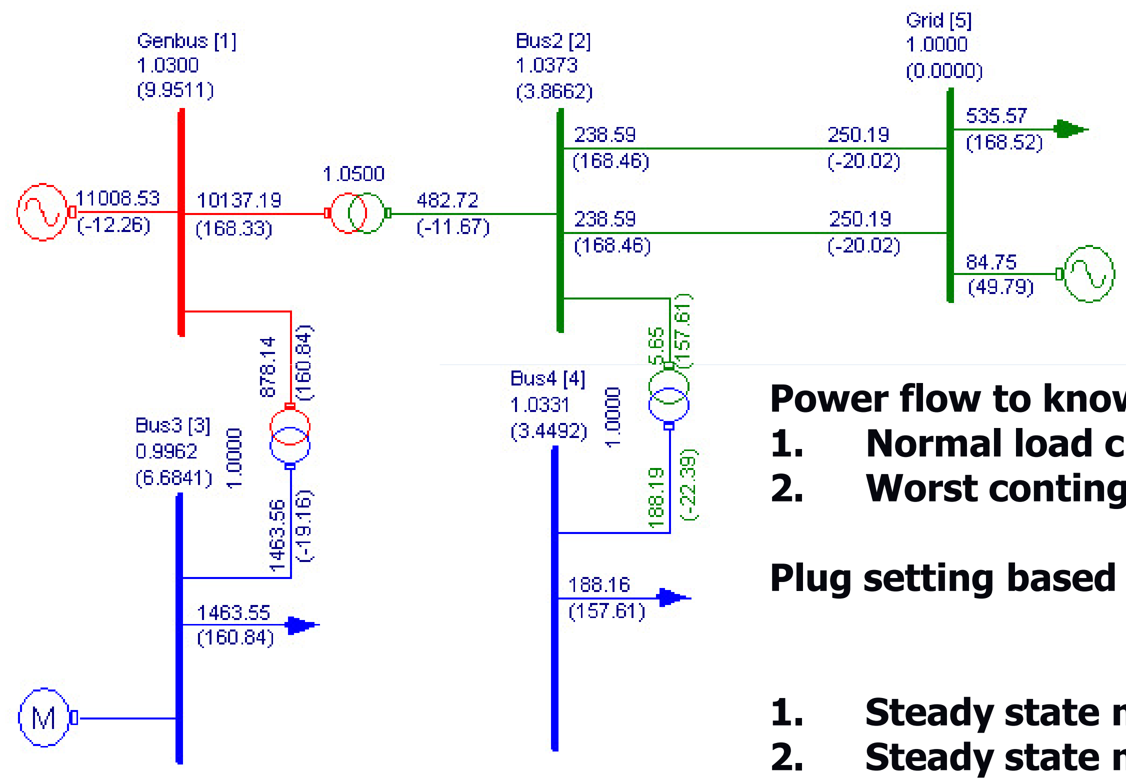
❑ **Surge period**

❑ **Dynamic period**

❑ **Steady State period**

Simulation Cases

Why Load flow study for protection engineer?



Power flow to know

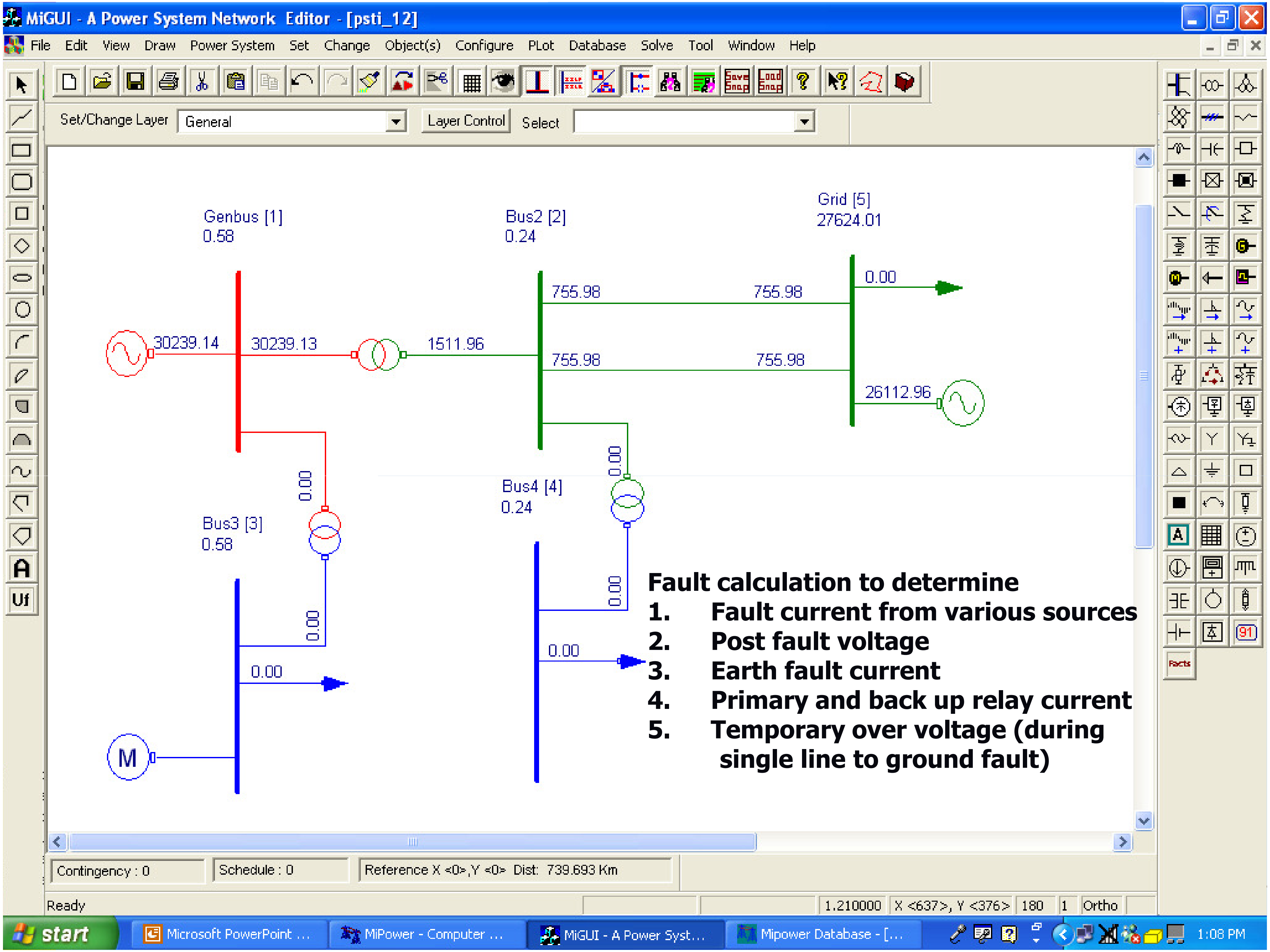
1. **Normal load current**
2. **Worst contingency load current**

Plug setting based on this information

1. **Steady state maximum voltage**
2. **Steady state minimum voltage**

Voltage relay setting based on this info.

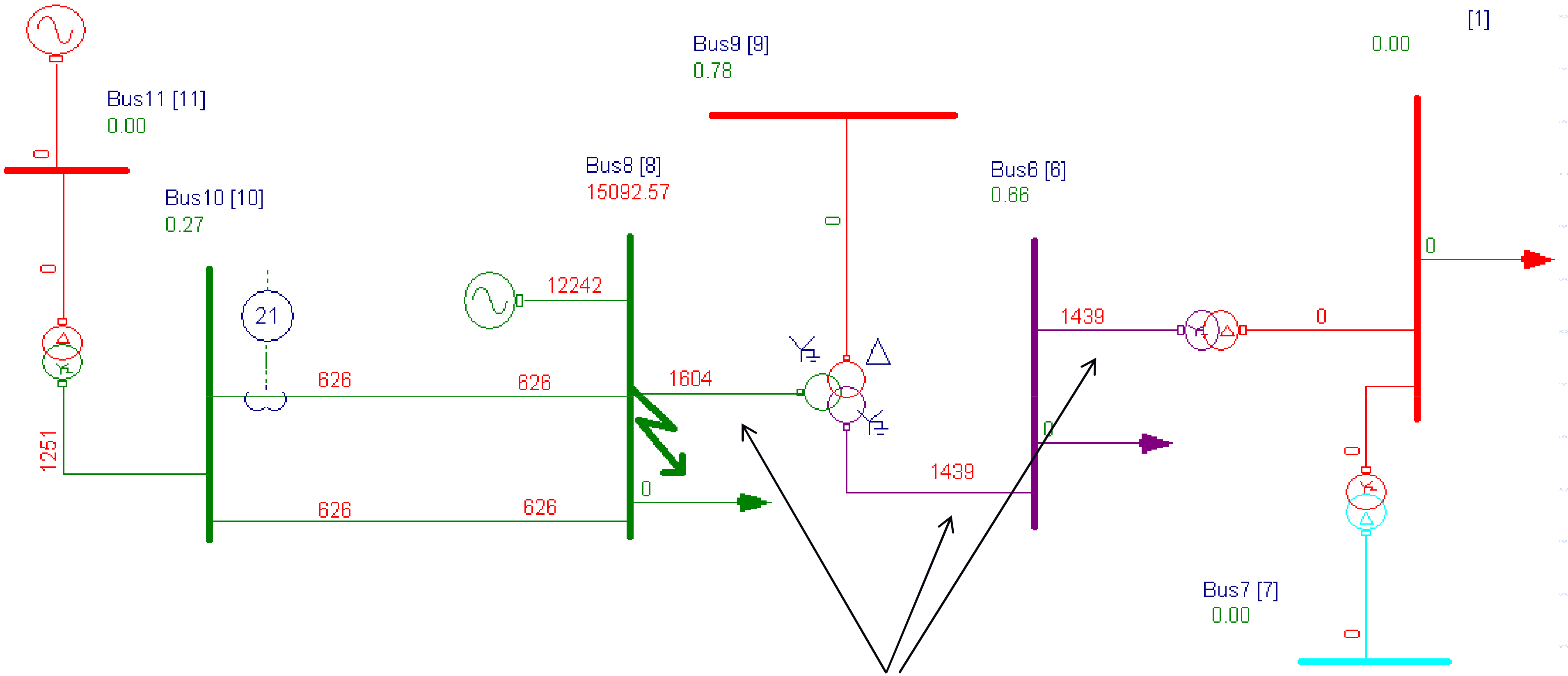
Fault simulation to aid protection engineer



Fault calculation to determine

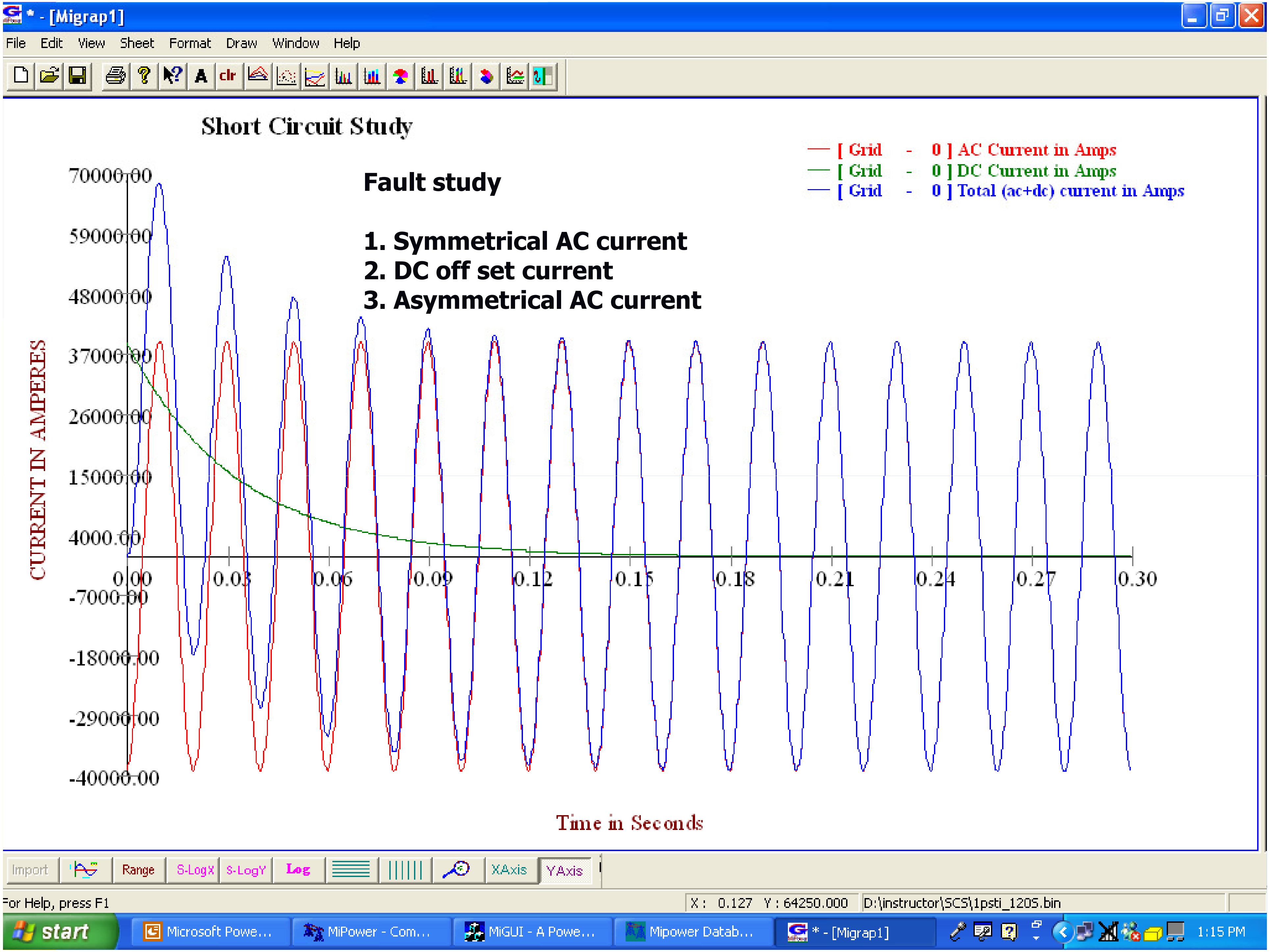
1. **Fault current from various sources**
2. **Post fault voltage**
3. **Earth fault current**
4. **Primary and back up relay current**
5. **Temporary over voltage (during single line to ground fault)**

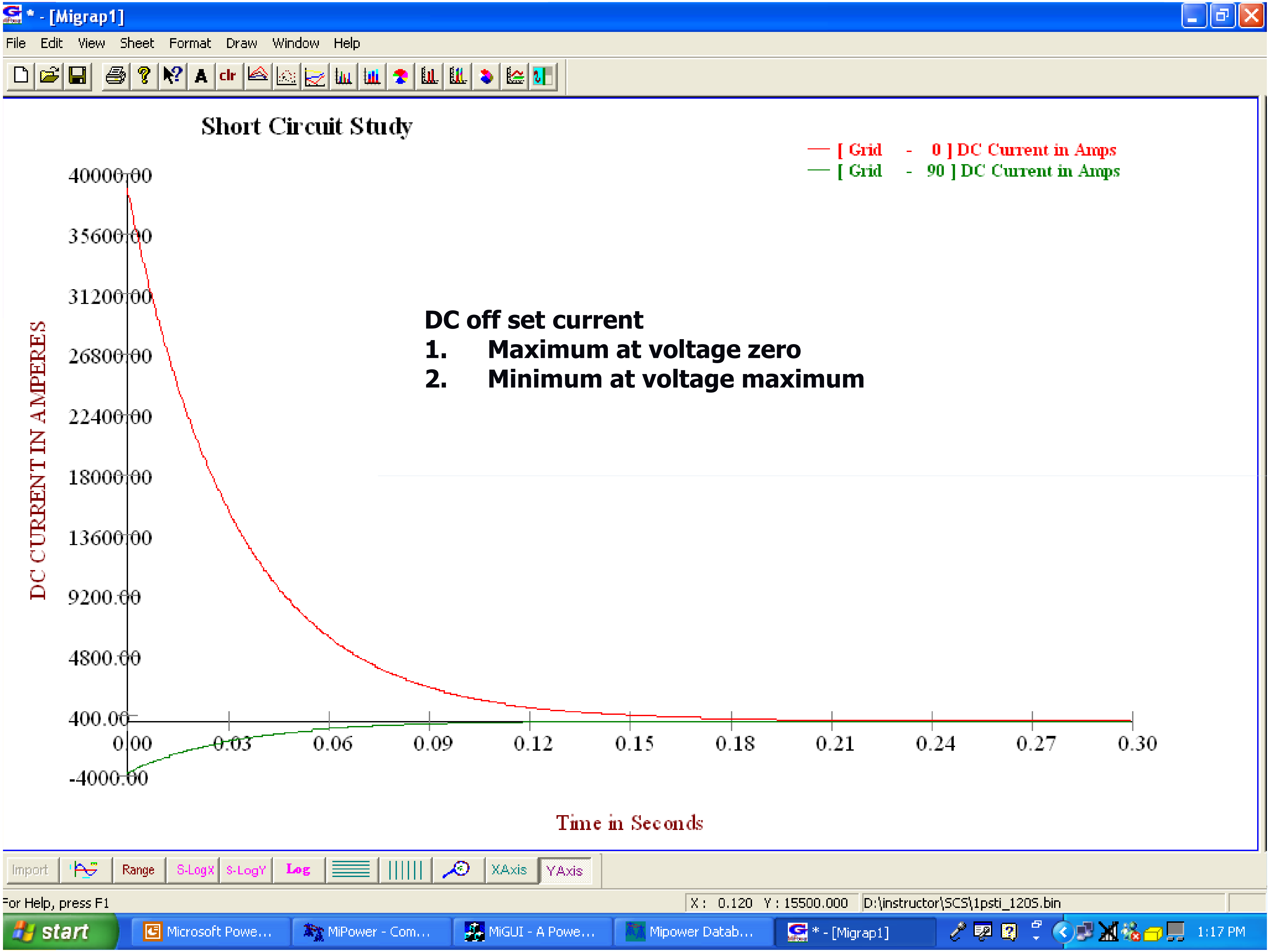
Earth fault relay operation - Explained



No source in this part of the network

Earth fault relay picks up, because of transformer Vector group

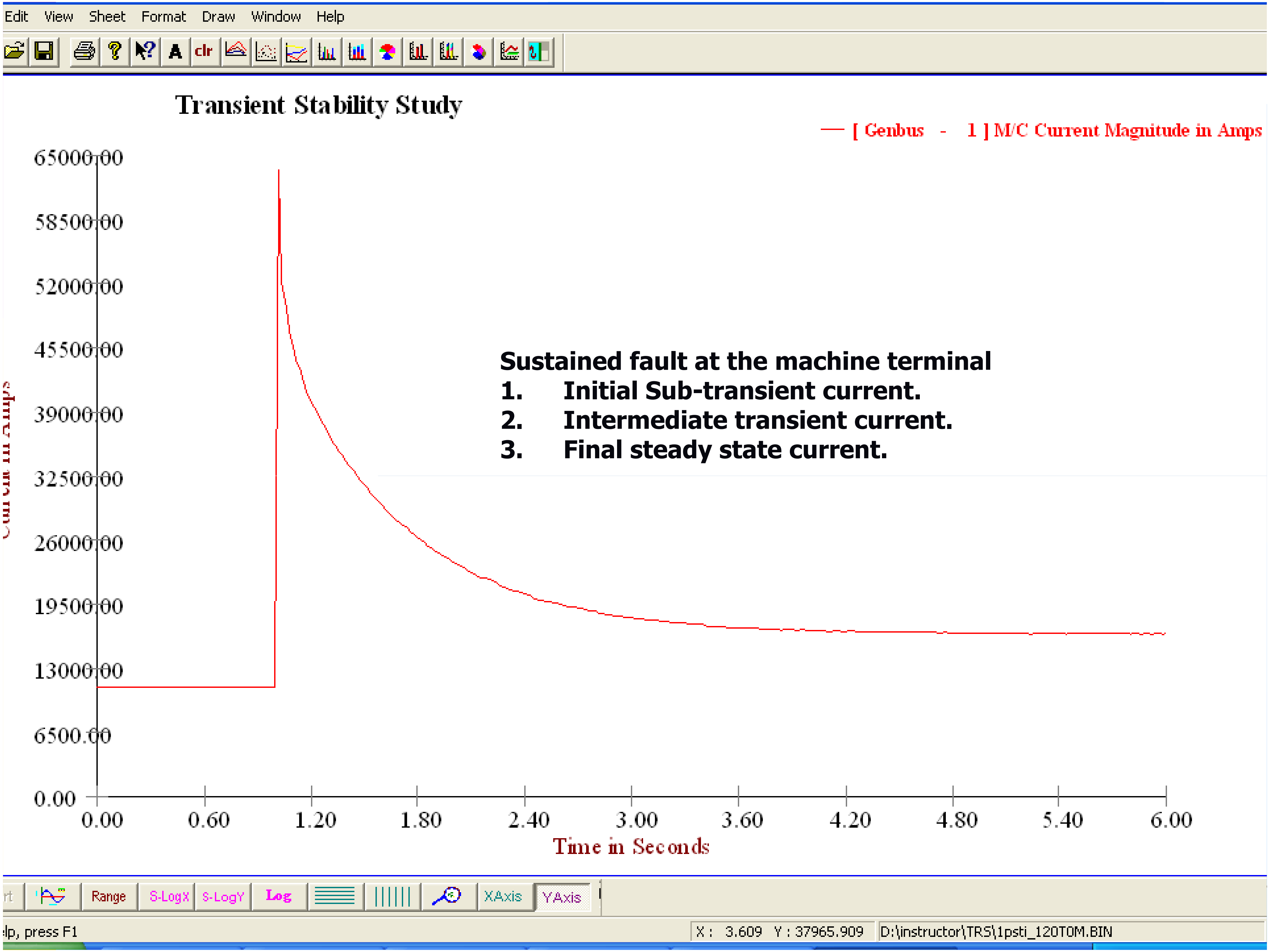

* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Short Circuit Study
Fault study
1. Symmetrical AC current
2. DC off set current
3. Asymmetrical AC current
[Grid - 0] AC Current in Amps
[Grid - 0] DC Current in Amps
[Grid - 0] Total (ac+dc) current in Amps
CURRENT IN AMPERES
70000.00
59000.00
48000.00
37000.00
26000.00
15000.00
4000.00
-7000.00
-18000.00
-29000.00
-40000.00
0.00
0.03
0.06
0.09
0.12
0.15
0.18
0.21
0.24
0.27
0.30
Time in Seconds
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X : 0.127 Y : 64250.000
D:\instructor\SCS\1psti_120S.bin
start
Microsoft Powe...
MiPower - Com...
MiGUI - A Powe...
Mipower Datab...
* - [Migrap1]
1:15 PM



DC off set current

1. **Maximum at voltage zero**
2. **Minimum at voltage maximum**

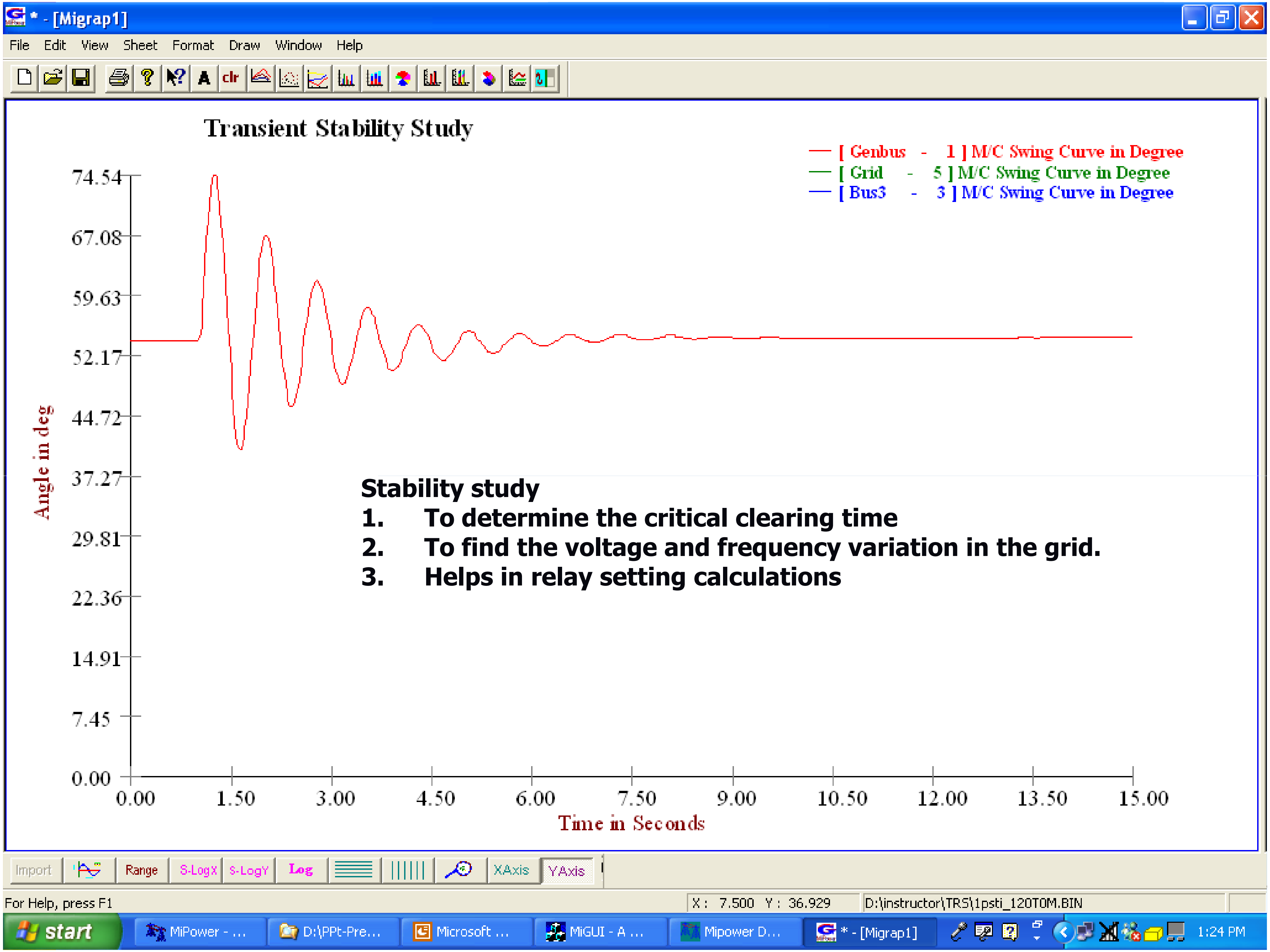
What machine impedance to consider for fault study and relay-coordination?



Sustained fault at the machine terminal

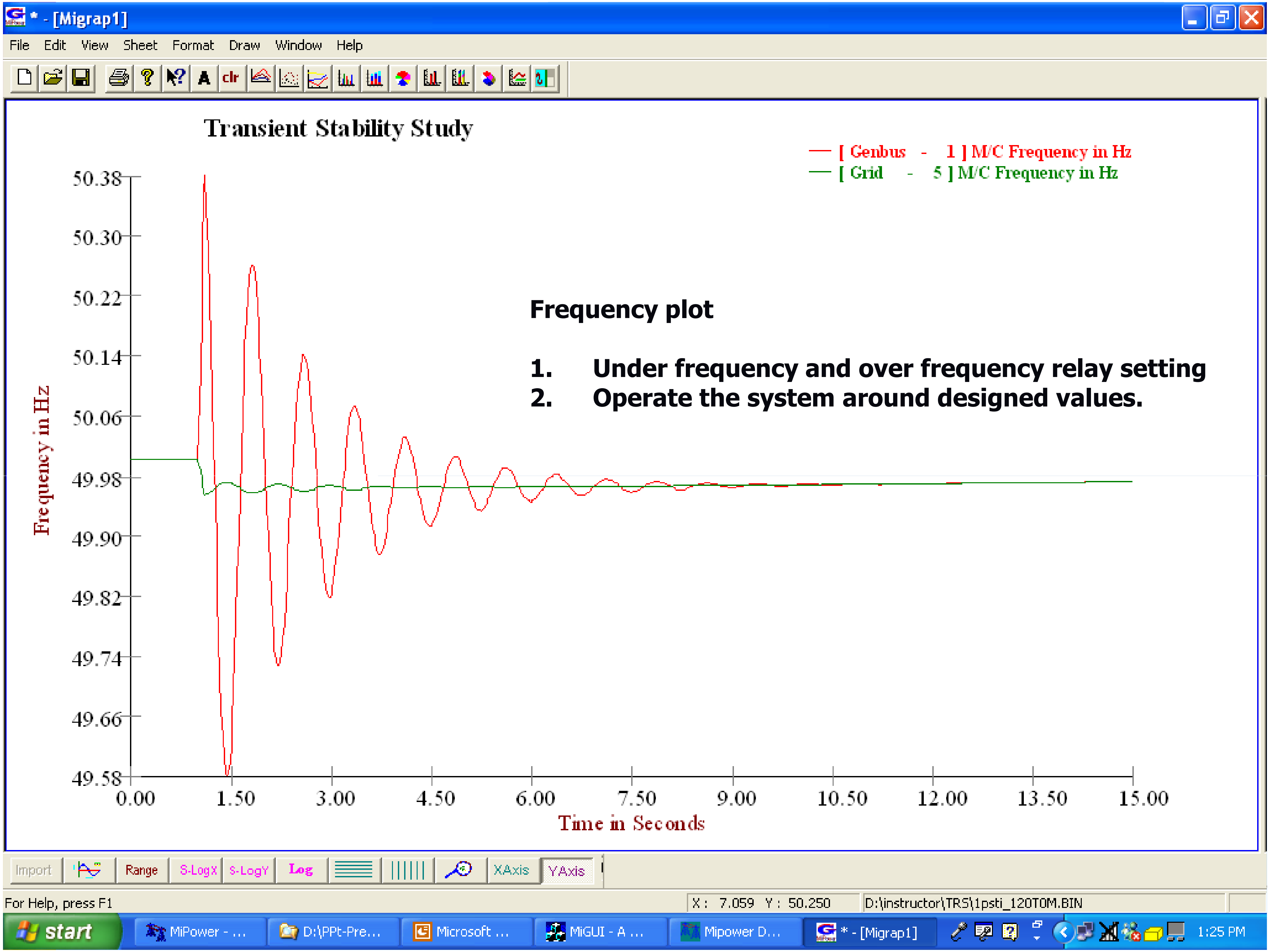
1. **Initial Sub-transient current.**
2. **Intermediate transient current.**
3. **Final steady state current.**

Stability study simulation and its importance



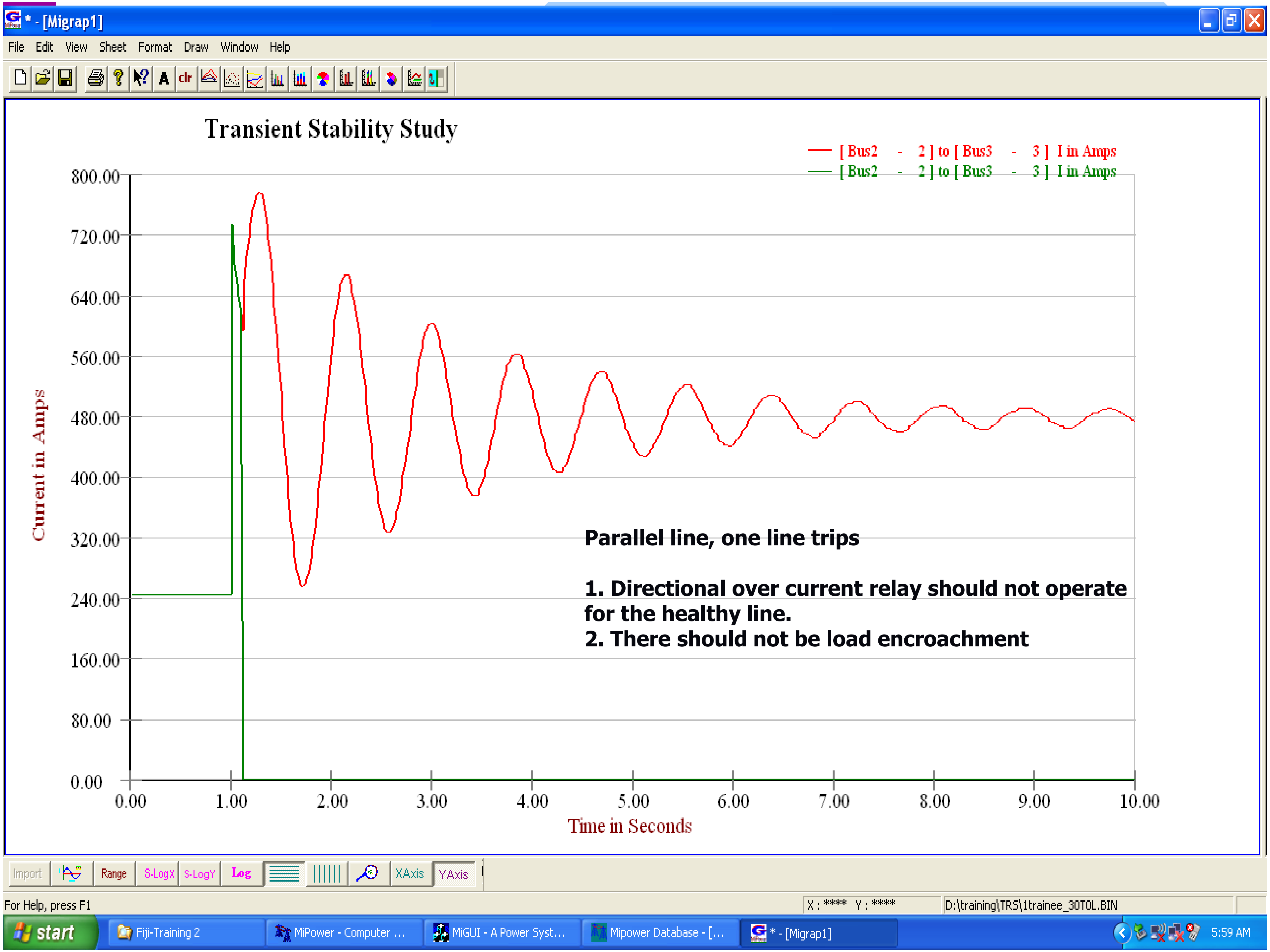
Stability study

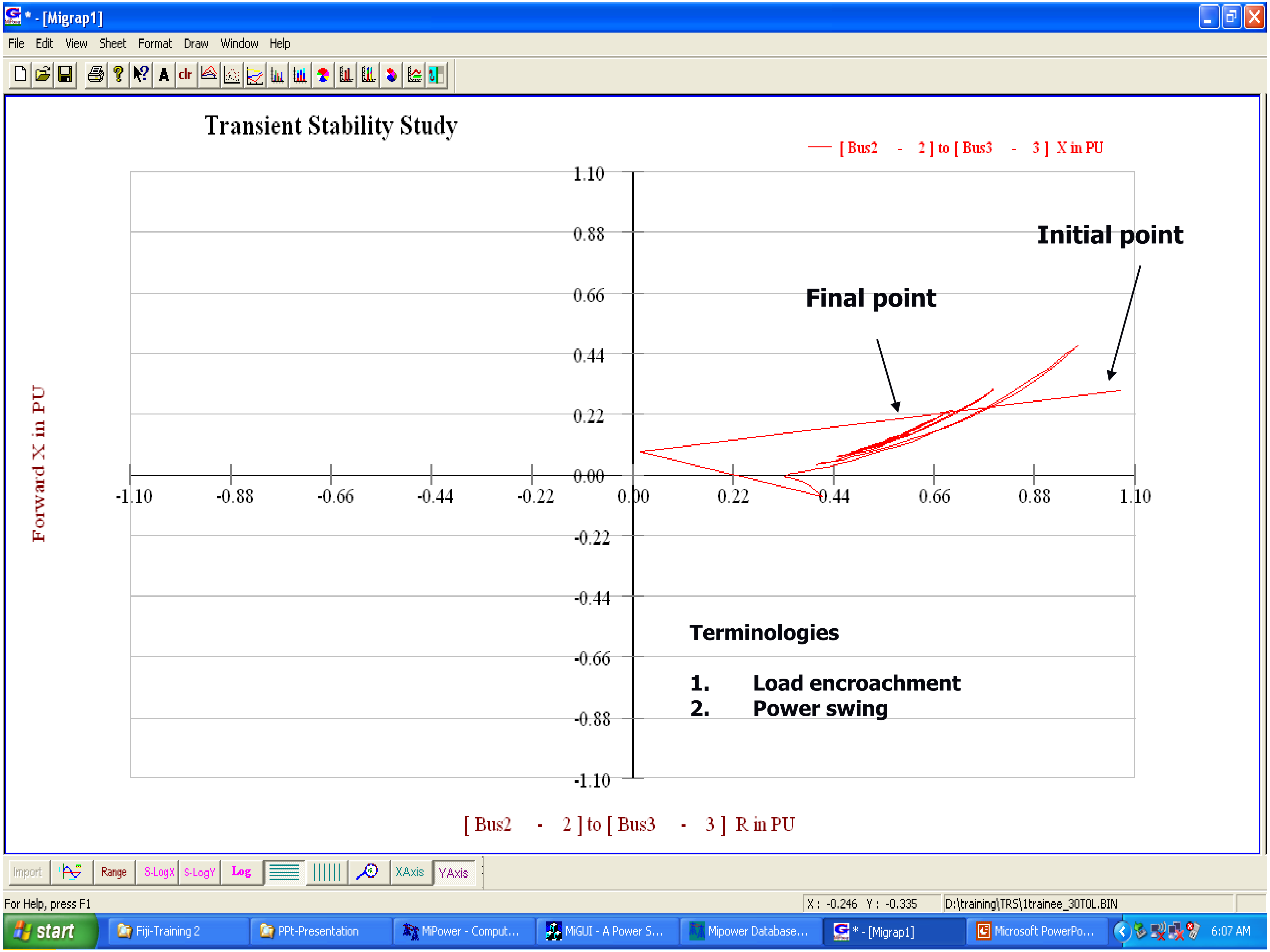
1. **To determine the critical clearing time**
2. **To find the voltage and frequency variation in the grid.**
3. **Helps in relay setting calculations**

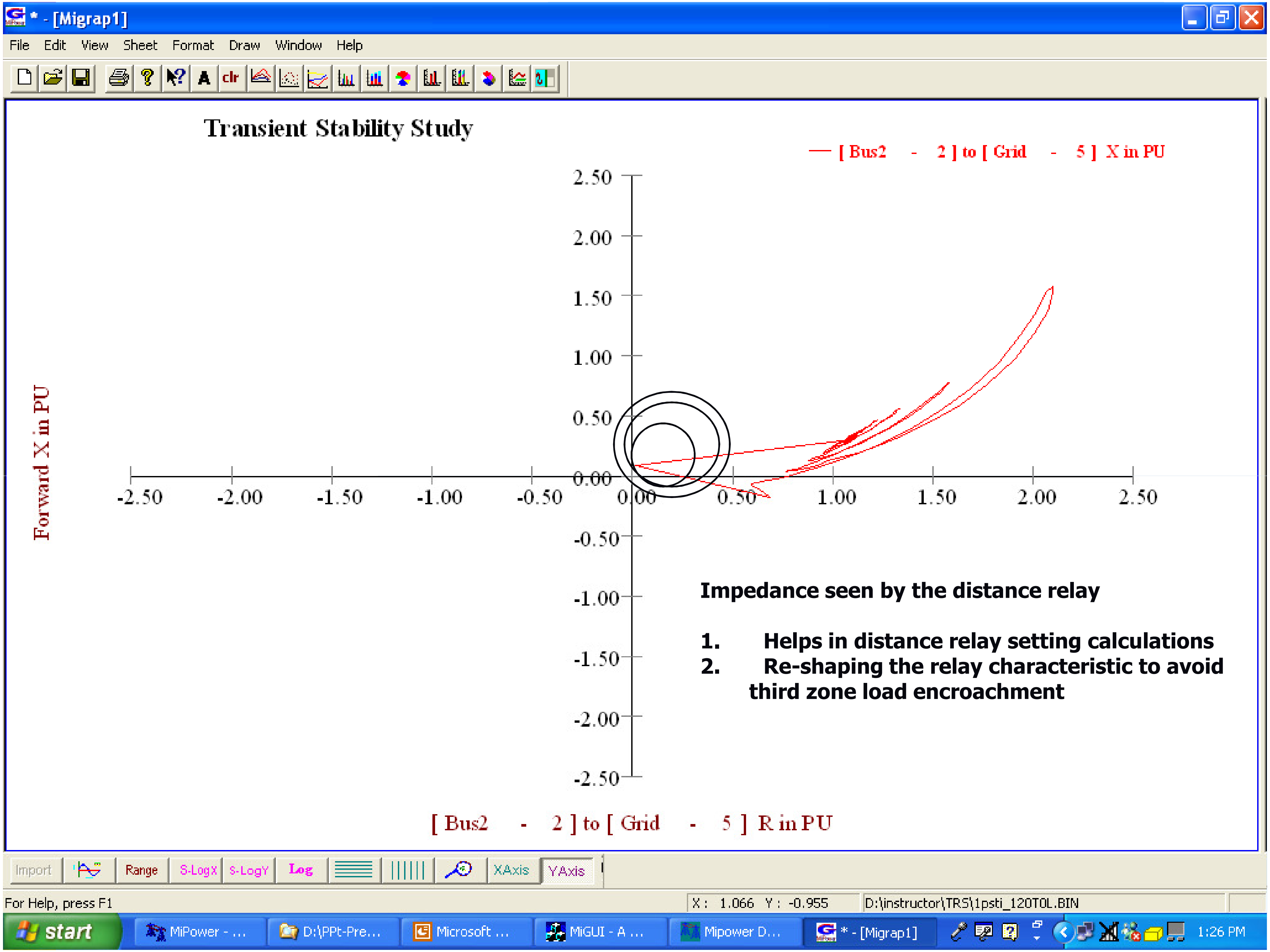


Frequency plot

1. Under frequency and over frequency relay setting
2. Operate the system around designed values.

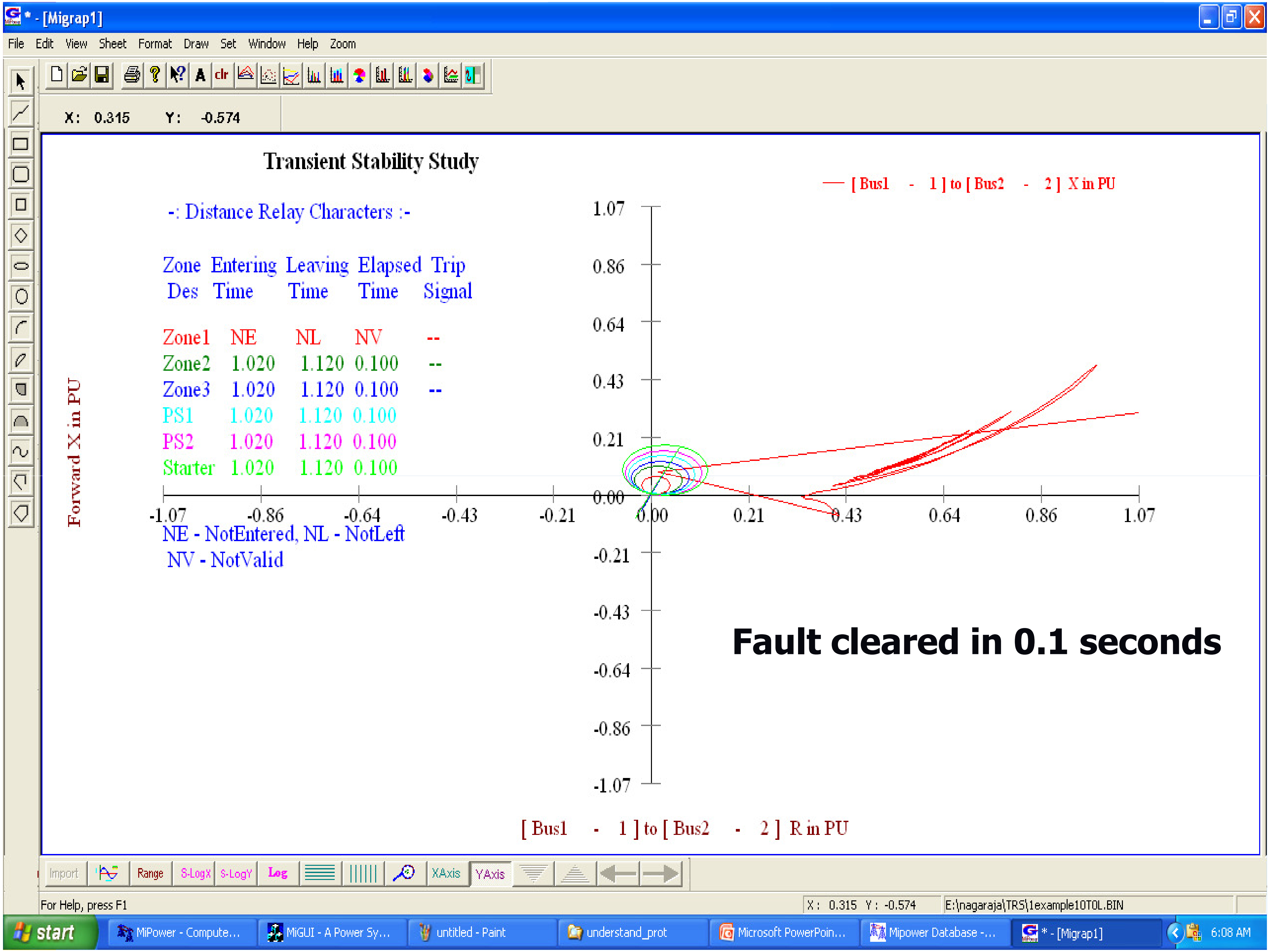

* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Transient Stability Study
[Bus2 - 2] to [Bus3 - 3] I in Amps
[Bus2 - 2] to [Bus3 - 3] I in Amps
Curent in Amps
Time in Seconds
Parallel line, one line trips
1. Directional over current relay should not operate for the healthy line.
2. There should not be load encroachment
For Help, press F1
D:\training\TRS\1trainee_30TOL.BIN

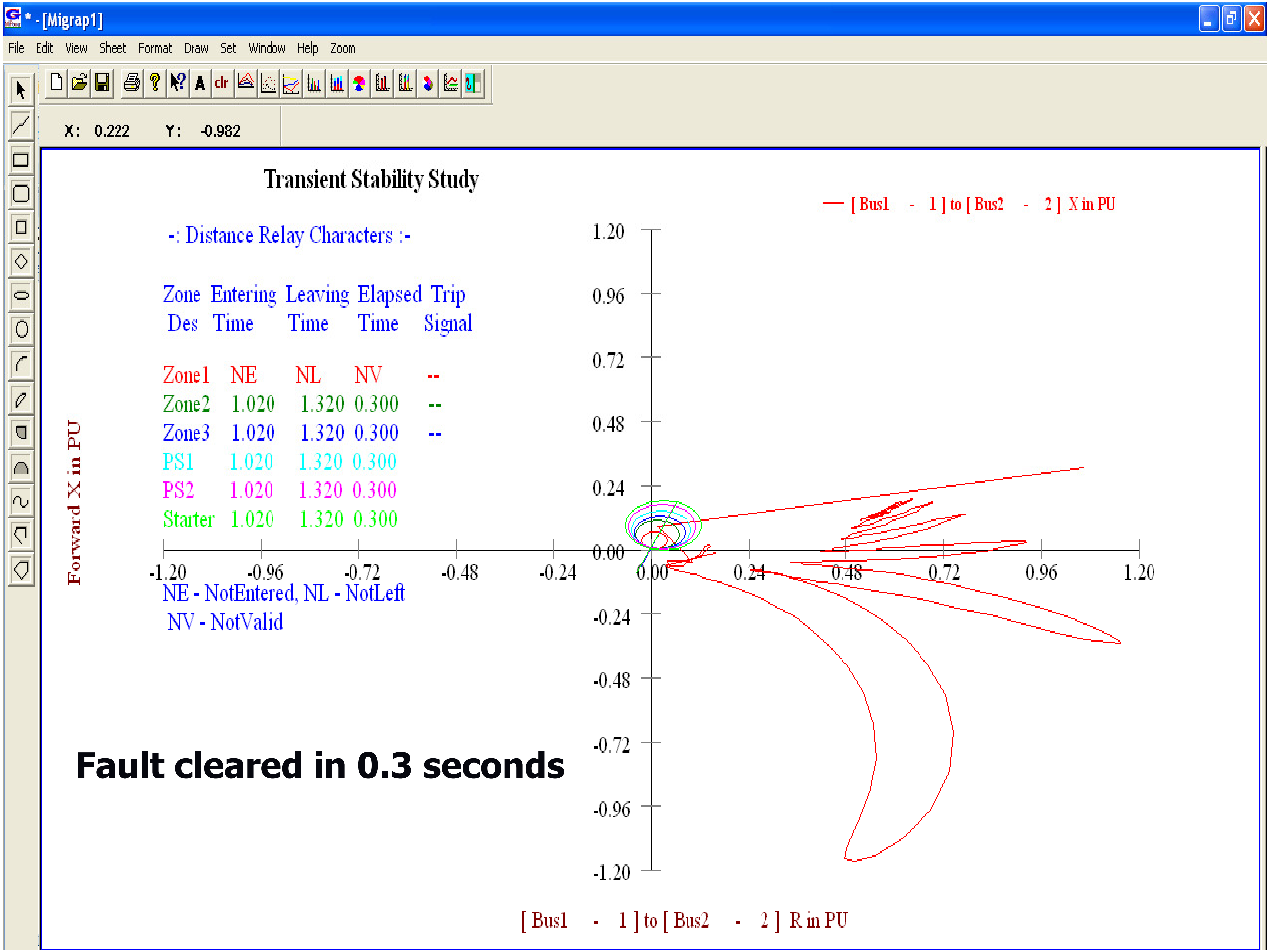

* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Transient Stability Study
[Bus2 - 2] to [Bus3 - 3] X in PU
Initial point
Final point
Forward X in PU
1.10
0.88
0.66
0.44
0.22
0.00
-0.22
-0.44
-0.66
-0.88
-1.10
-1.10 -0.88 -0.66 -0.44 -0.22 0.00 0.22 0.44 0.66 0.88 1.10
Terminologies
1. Load encroachment
2. Power swing
[Bus2 - 2] to [Bus3 - 3] R in PU
Import Range S-LogX S-LogY Log XAxis YAxis
For Help, press F1
X : -0.246 Y : -0.335
D:\training\TRS\1trainee_30TOL.BIN
start
Fiji-Training 2
PPt-Presentation
MiPower - Comput...
MiGUI - A Power S...
Mipower Database...
* - [Migrap1]
Microsoft PowerPo...
6:07 AM



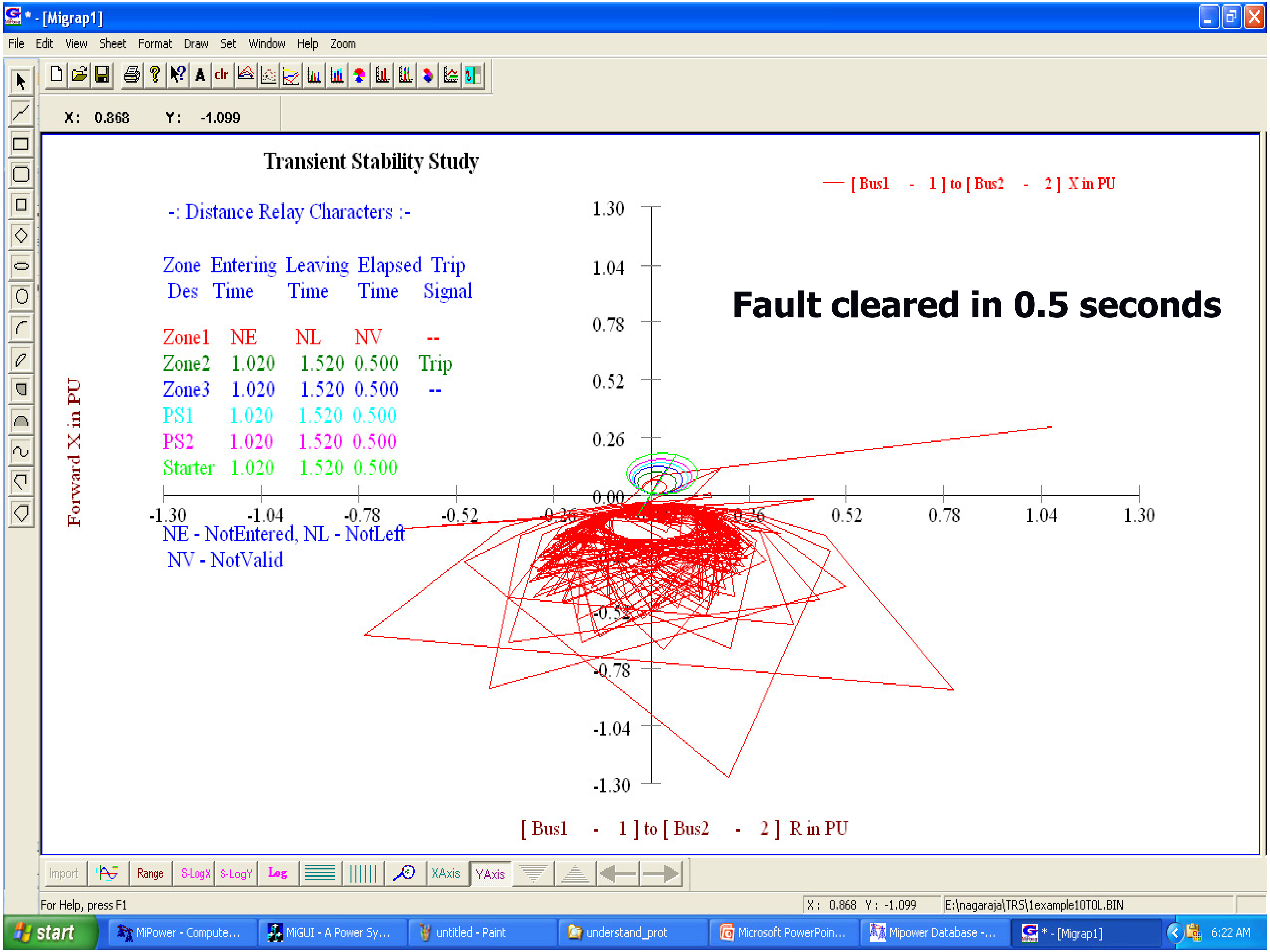
Impedance seen by the distance relay

1. **Helps in distance relay setting calculations**
2. **Re-shaping the relay characteristic to avoid third zone load encroachment**

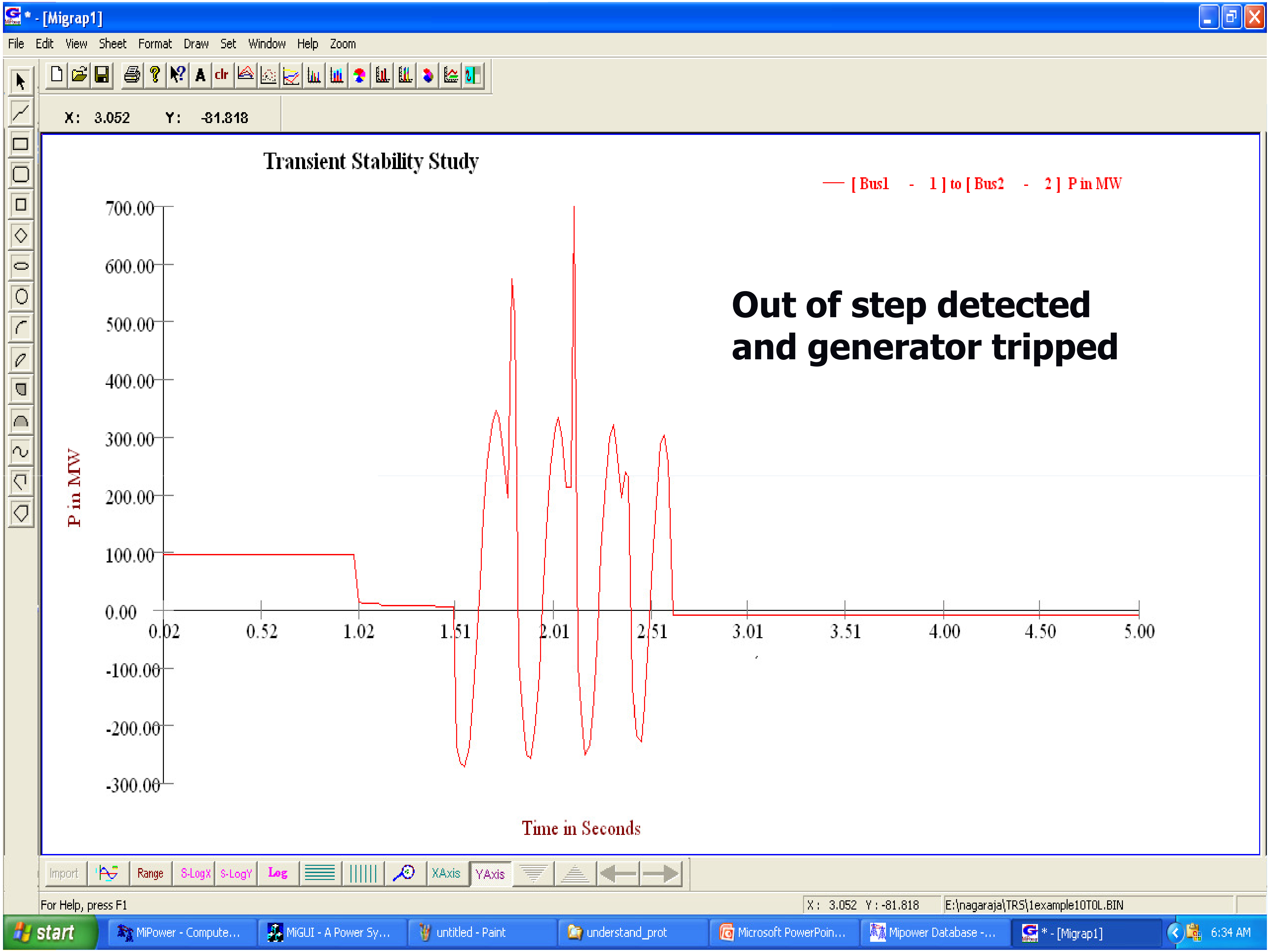

* - [Migrap1]
File Edit View Sheet Format Draw Set Window Help Zoom
X: 0.315 Y: -0.574
Transient Stability Study
-: Distance Relay Characters :-
Zone Des | Entering Time | Leaving Time | Elapsed Time | Trip Signal
Zone1 NE NL NV --
Zone2 1.020 1.120 0.100 --
Zone3 1.020 1.120 0.100 --
PS1 1.020 1.120 0.100
PS2 1.020 1.120 0.100
Starter 1.020 1.120 0.100
NE - NotEntered, NL - NotLeft
NV - NotValid
[Bus1 - 1] to [Bus2 - 2] X in PU
Forward X in PU
[Bus1 - 1] to [Bus2 - 2] R in PU
1.07
0.86
0.64
0.43
0.21
0.00
-0.21
-0.43
-0.64
-0.86
-1.07
Fault cleared in 0.1 seconds
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X: 0.315 Y: -0.574
E:\nagaraja\TRS\1example10TOL.BIN
start
MiPower - Compute...
MiGUI - A Power Sy...
untitled - Paint
understand_prot
Microsoft PowerPoin...
Mipower Database -...
* - [Migrap1]
6:08 AM

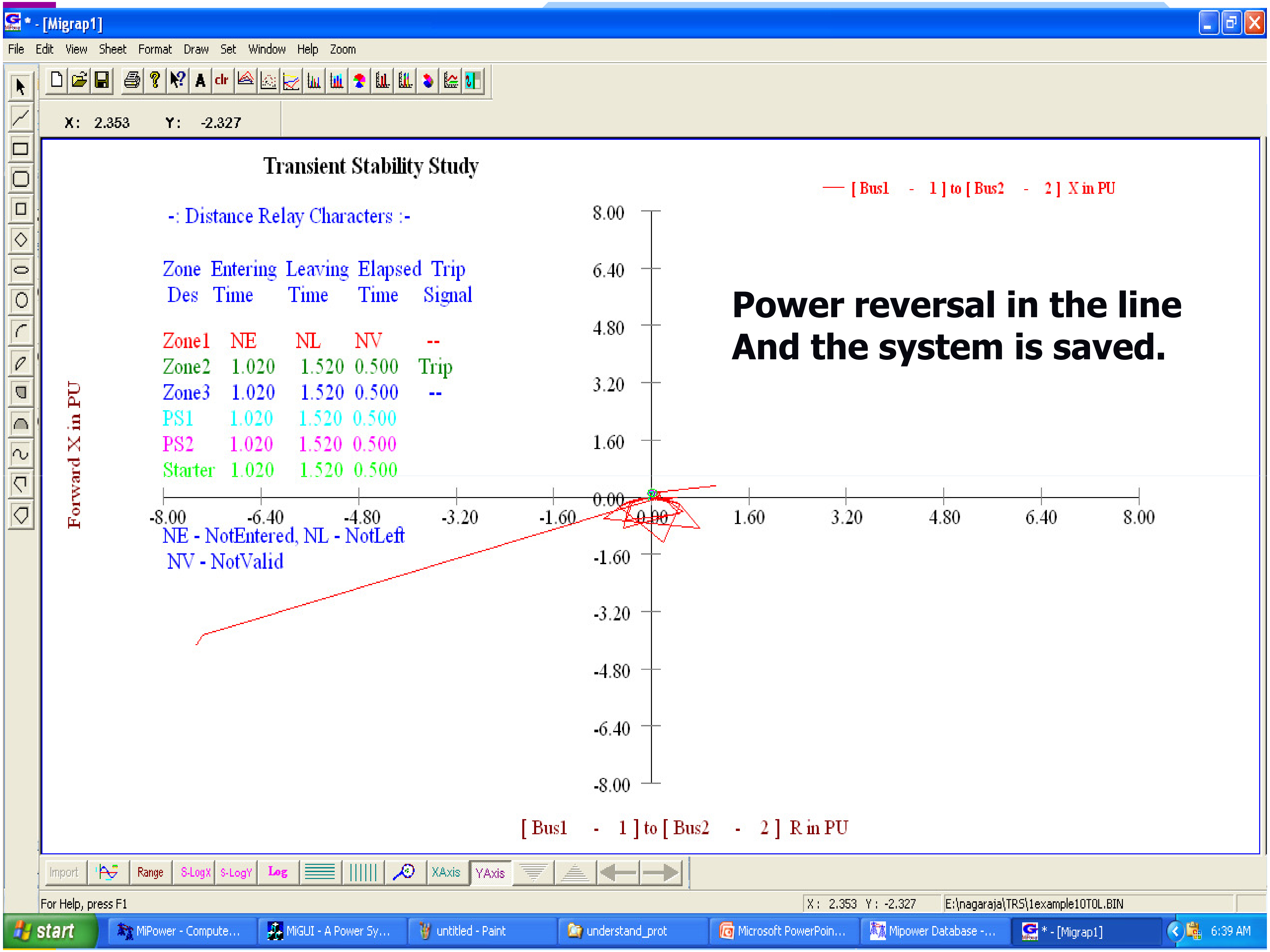


Fault cleared in 0.3 seconds



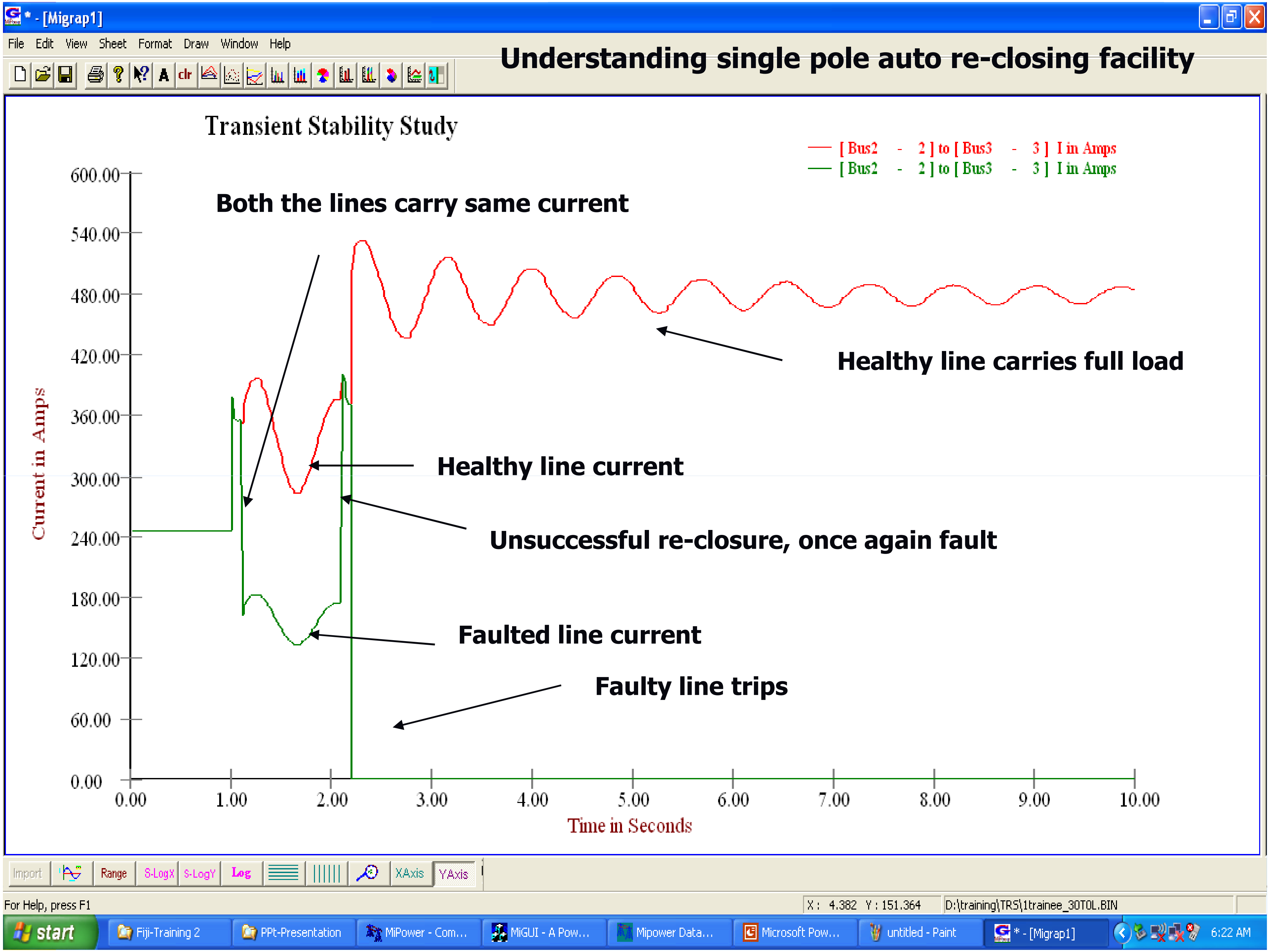
* - [Migrap1]
File Edit View Sheet Format Draw Set Window Help Zoom
X: 0.868 Y: -1.099
Transient Stability Study
-: Distance Relay Characters :-
Zone Des
Entering Time
Leaving Time
Elapsed Time
Trip Signal
Zone1 NE NL NV --
Zone2 1.020 1.520 0.500 Trip
Zone3 1.020 1.520 0.500 --
PS1 1.020 1.520 0.500
PS2 1.020 1.520 0.500
Starter 1.020 1.520 0.500
NE - NotEntered, NL - NotLeft
NV - NotValid
[Bus1 - 1] to [Bus2 - 2] X in PU
Fault cleared in 0.5 seconds
Forward X in PU
[Bus1 - 1] to [Bus2 - 2] R in PU
1.30
1.04
0.78
0.52
0.26
0.00
-0.52
-0.78
-1.04
-1.30
0.52
0.78
1.04
1.30
Import Range S-LogX S-LogY Log XAxis YAxis
For Help, press F1
X: 0.868 Y: -1.099
E:\nagaraja\TRS\1example10TOL.BIN
start
MiPower - Compute...
MiGUI - A Power Sy...
untitled - Paint
understand_prot
Microsoft PowerPoin...
Mipower Database -...
* - [Migrap1]
6:22 AM

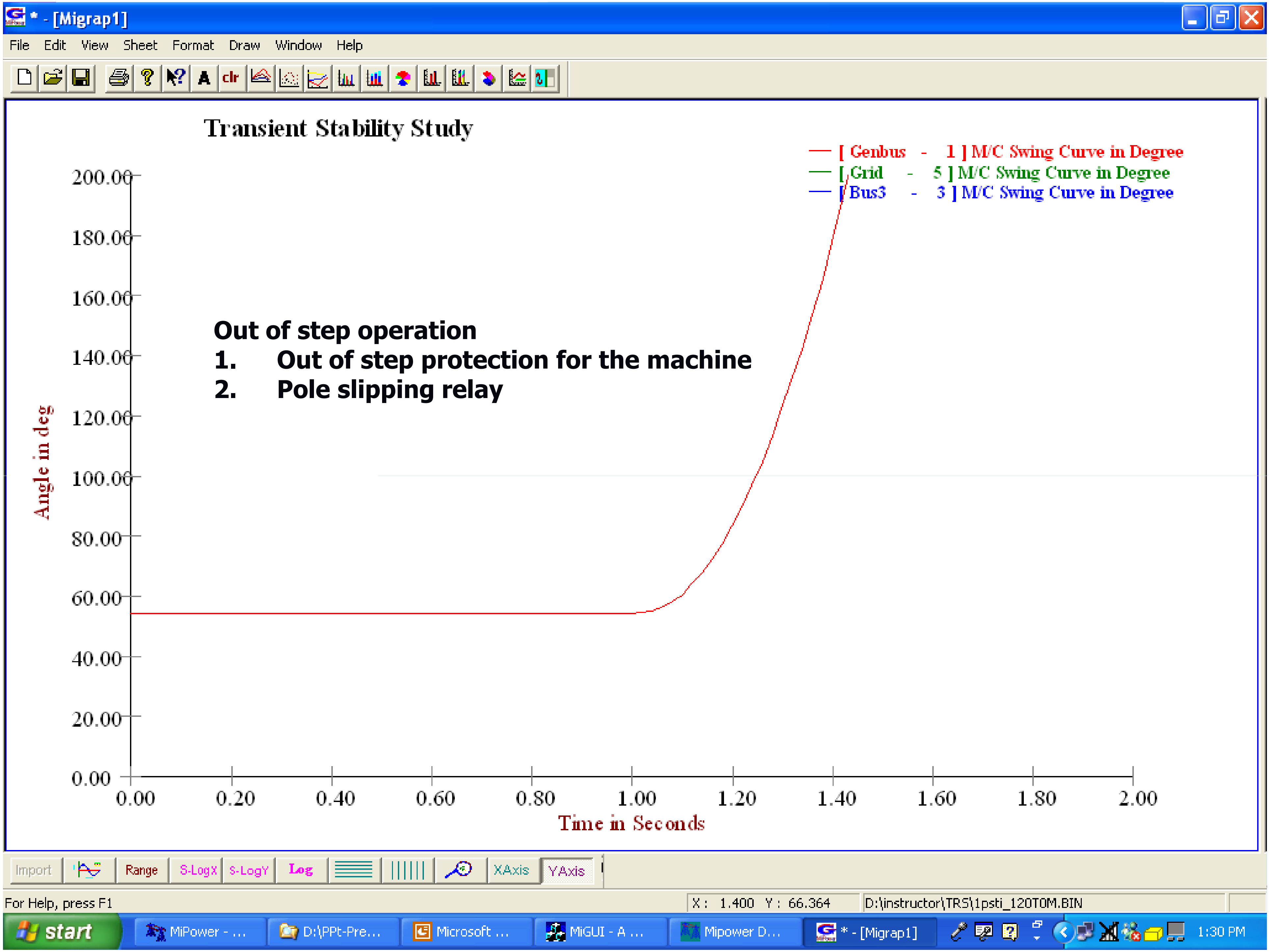

* - [Migrap1]
File Edit View Sheet Format Draw Set Window Help Zoom
X: 3.052 Y: -81.818
Transient Stability Study
— [Bus1 - 1] to [Bus2 - 2] P in MW
Out of step detected and generator tripped
P in MW
Time in Seconds
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
-100.00
-200.00
-300.00
0.02
0.52
1.02
1.51
2.01
2.51
3.01
3.51
4.00
4.50
5.00
Import Range S-LogX S-LogY Log XAxis YAxis
For Help, press F1
X: 3.052 Y: -81.818
E:\nagaraja\TRS\1example10TOL.BIN
start
MiPower - Compute...
MiGUI - A Power Sy...
untitled - Paint
understand_prot
Microsoft PowerPoin...
Mipower Database -...
* - [Migrap1]
6:34 AM



Power reversal in the line
And the system is saved.

Understanding single pole auto re-closing facility

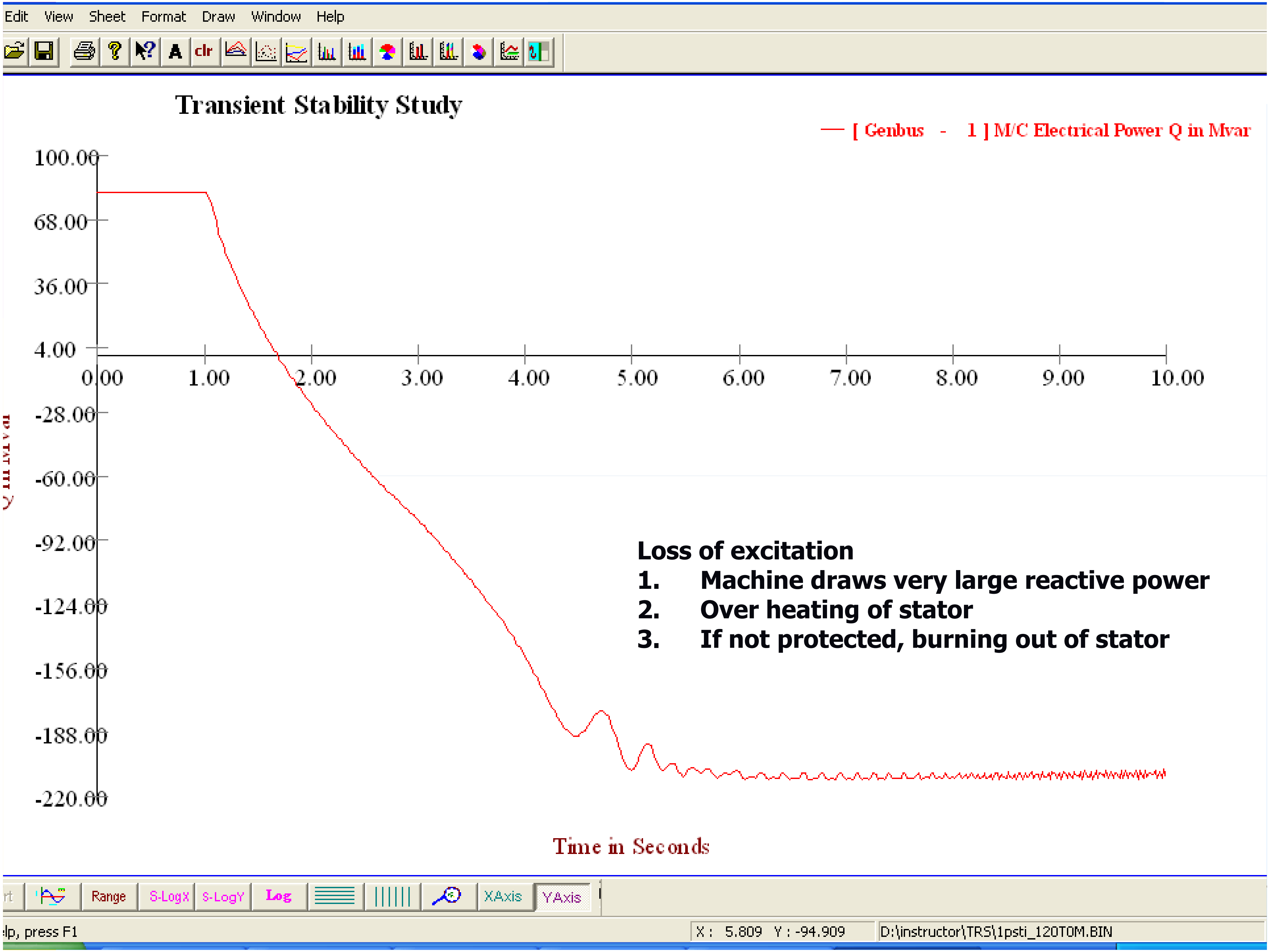




Out of step operation

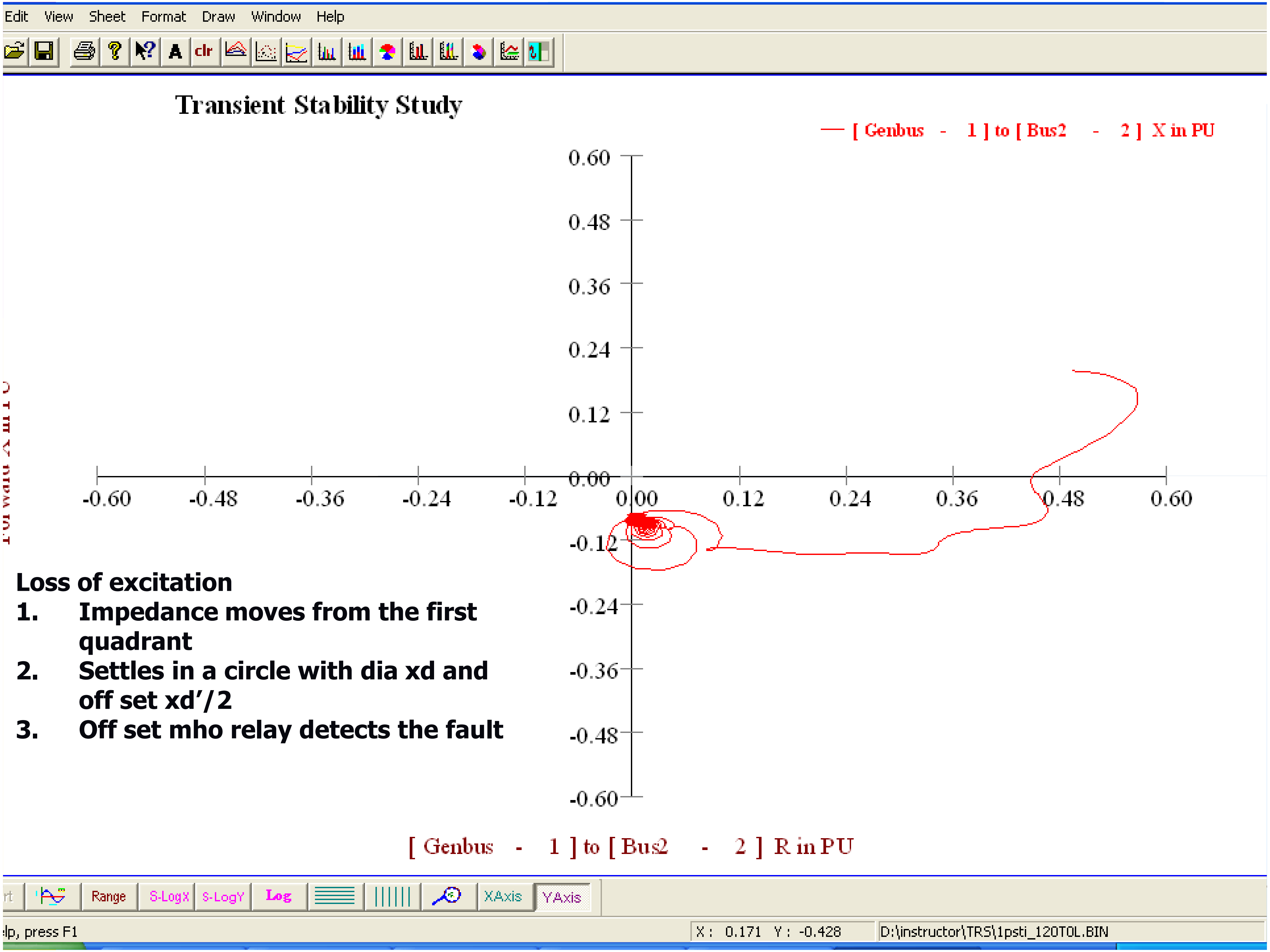
1. **Out of step protection for the machine**
2. **Pole slipping relay**

Protection Engineer designs the relay, based on system behaviour



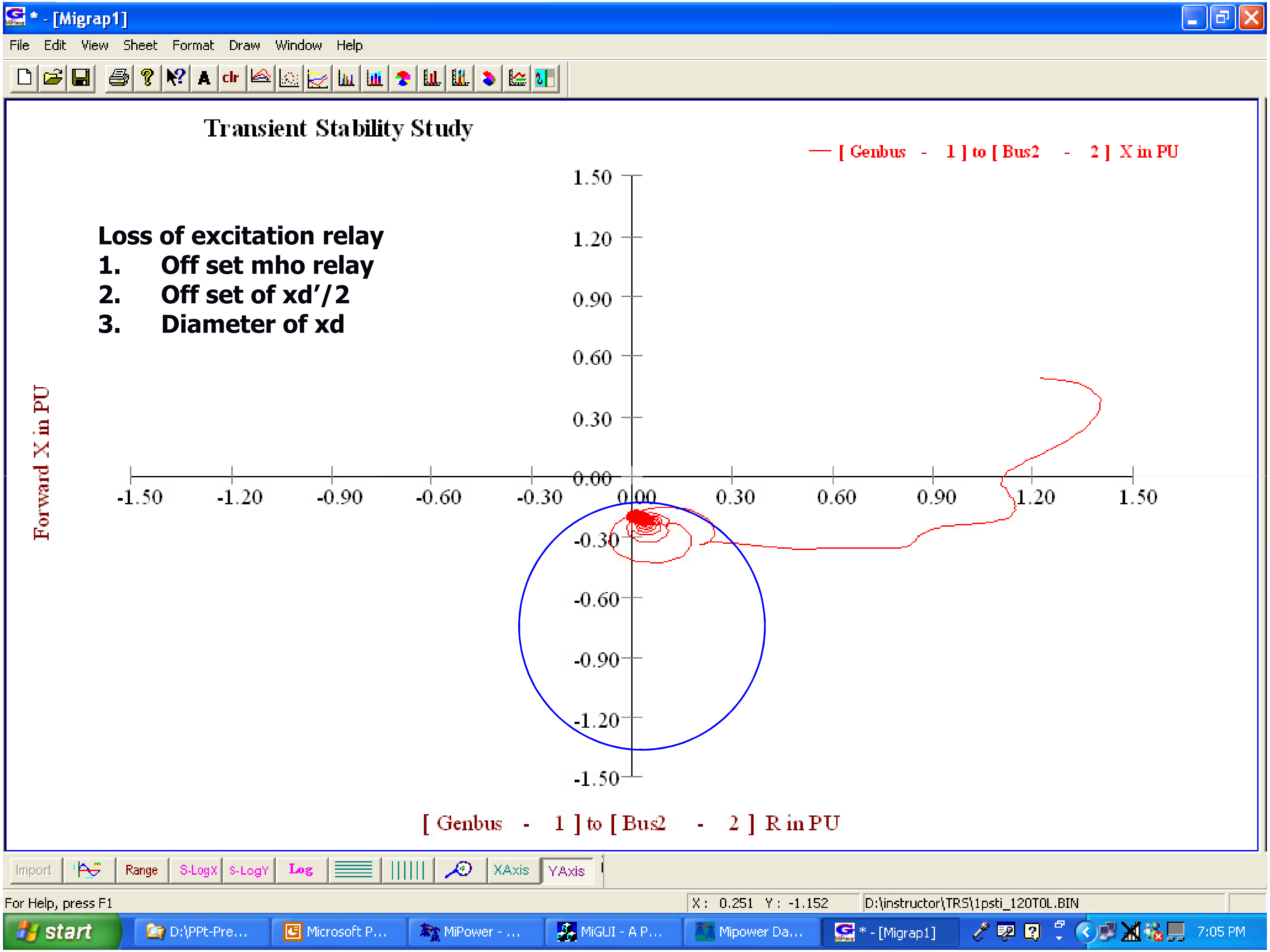
Loss of excitation

1. **Machine draws very large reactive power**
2. **Over heating of stator**
3. **If not protected, burning out of stator**

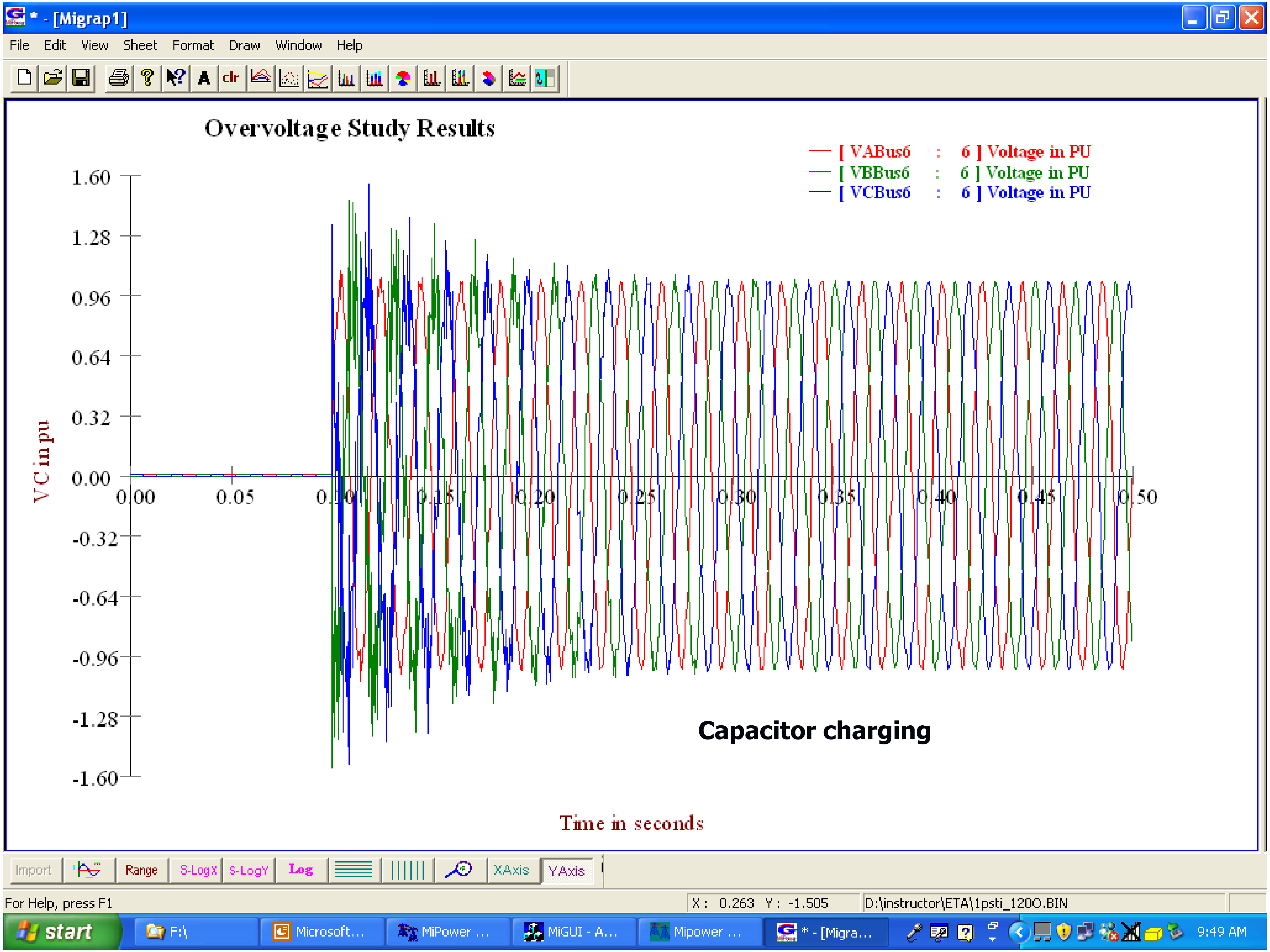


Loss of excitation

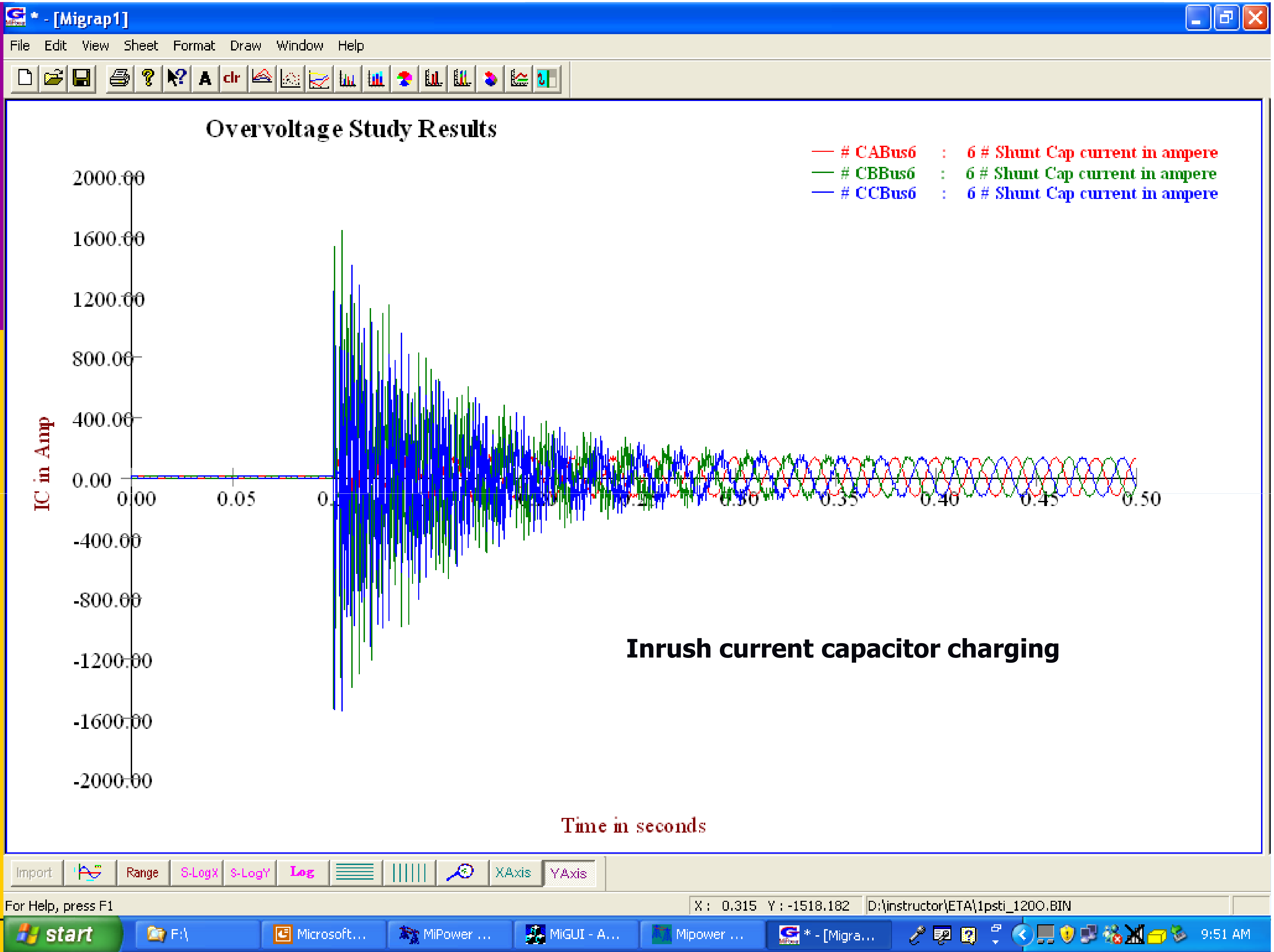
1. **Impedance moves from the first quadrant**
2. **Settles in a circle with dia xd and off set xd'/2**
3. **Off set mho relay detects the fault**


* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Transient Stability Study
[Genbus - 1] to [Bus2 - 2] X in PU
Loss of excitation relay
1. Off set mho relay
2. Off set of xd'/2
3. Diameter of xd
Forward X in PU
[Genbus - 1] to [Bus2 - 2] R in PU
1.50
1.20
0.90
0.60
0.30
0.00
-0.30
-0.60
-0.90
-1.20
-1.50
-1.50
-1.20
-0.90
-0.60
-0.30
0.00
0.30
0.60
0.90
1.20
1.50
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X : 0.251 Y : -1.152
D:\instructor\TRS\1psti_120T0L.BIN
start
D:\PPt-Pre...
Microsoft P...
MiPower - ...
MiGUI - A P...
Mipower Da...
* - [Migrap1]
7:05 PM

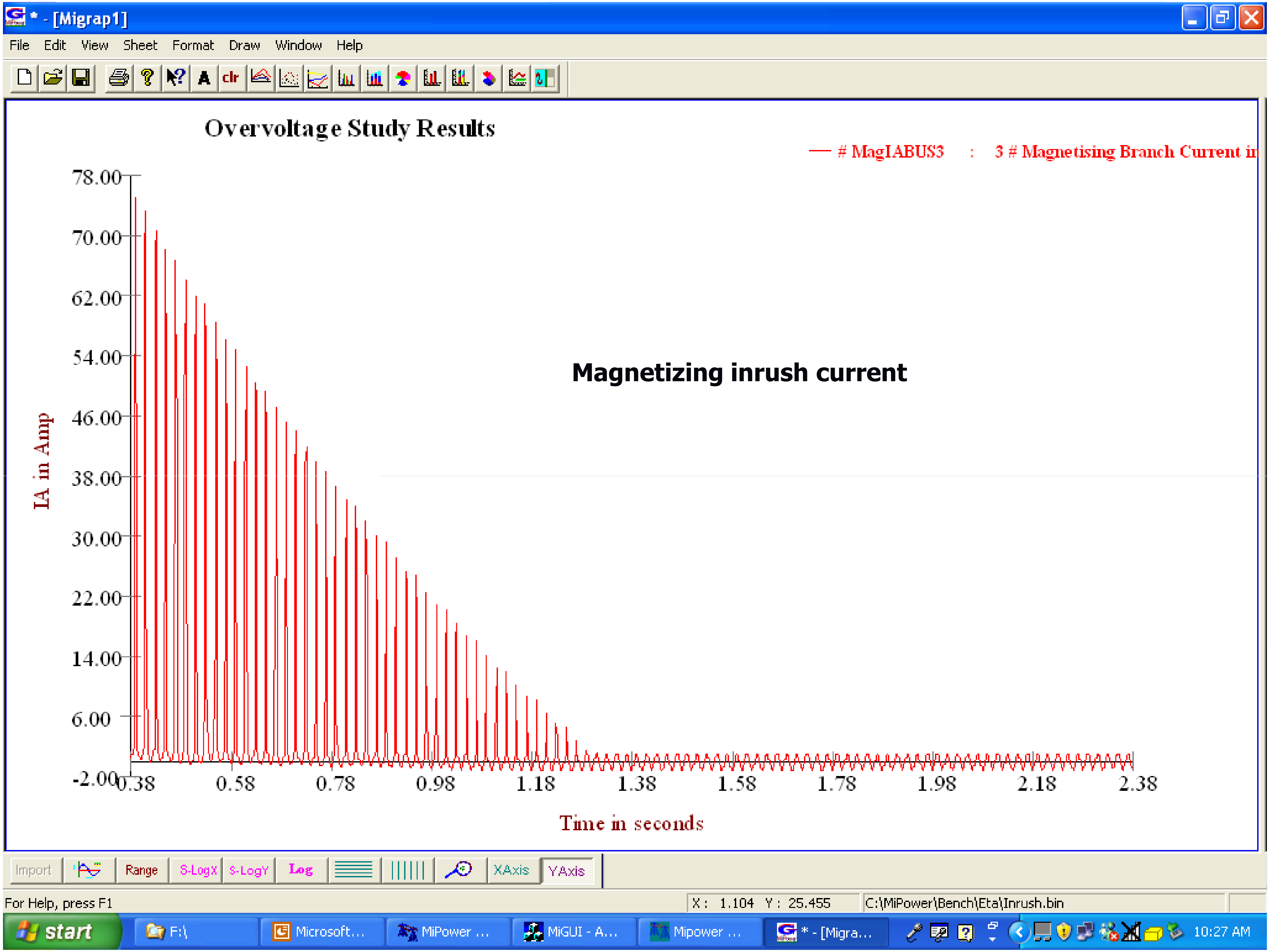
Why current limiting reactor for capacitor banks?



* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Overvoltage Study Results
[VABus6 : 6] Voltage in PU
[VBBus6 : 6] Voltage in PU
[VCBus6 : 6] Voltage in PU
1.60
1.28
0.96
0.64
0.32
0.00
-0.32
-0.64
-0.96
-1.28
-1.60
VC in pu
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
Capacitor charging
Time in seconds
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X : 0.263 Y : -1.505
D:\instructor\ETA\1psti_120O.BIN
start
F:\
Microsoft...
MiPower ...
MiGUI - A...
Mipower ...
* - [Migra...
9:49 AM

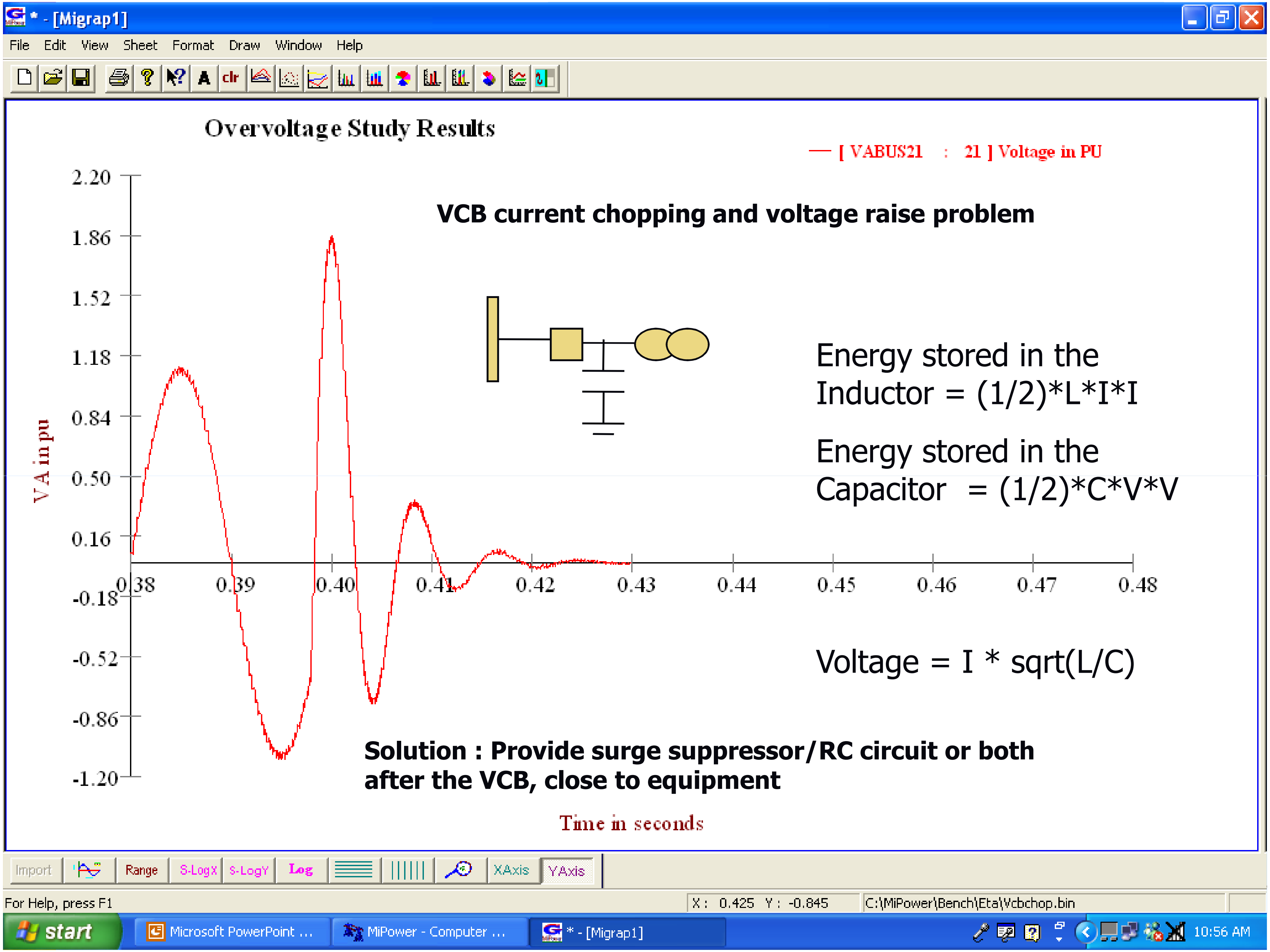

* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Overvoltage Study Results
CABus6 : 6 # Shunt Cap current in ampere
CBBus6 : 6 # Shunt Cap current in ampere
CCBus6 : 6 # Shunt Cap current in ampere
IC in Amp
Time in seconds
Inrush current capacitor charging
For Help, press F1
X : 0.315 Y : -1518.182
D:\instructor\ETA\1psti_1200.BIN

2^{nd} Harmonic and 5^{th} Harmonic restraint for transformer differential protection

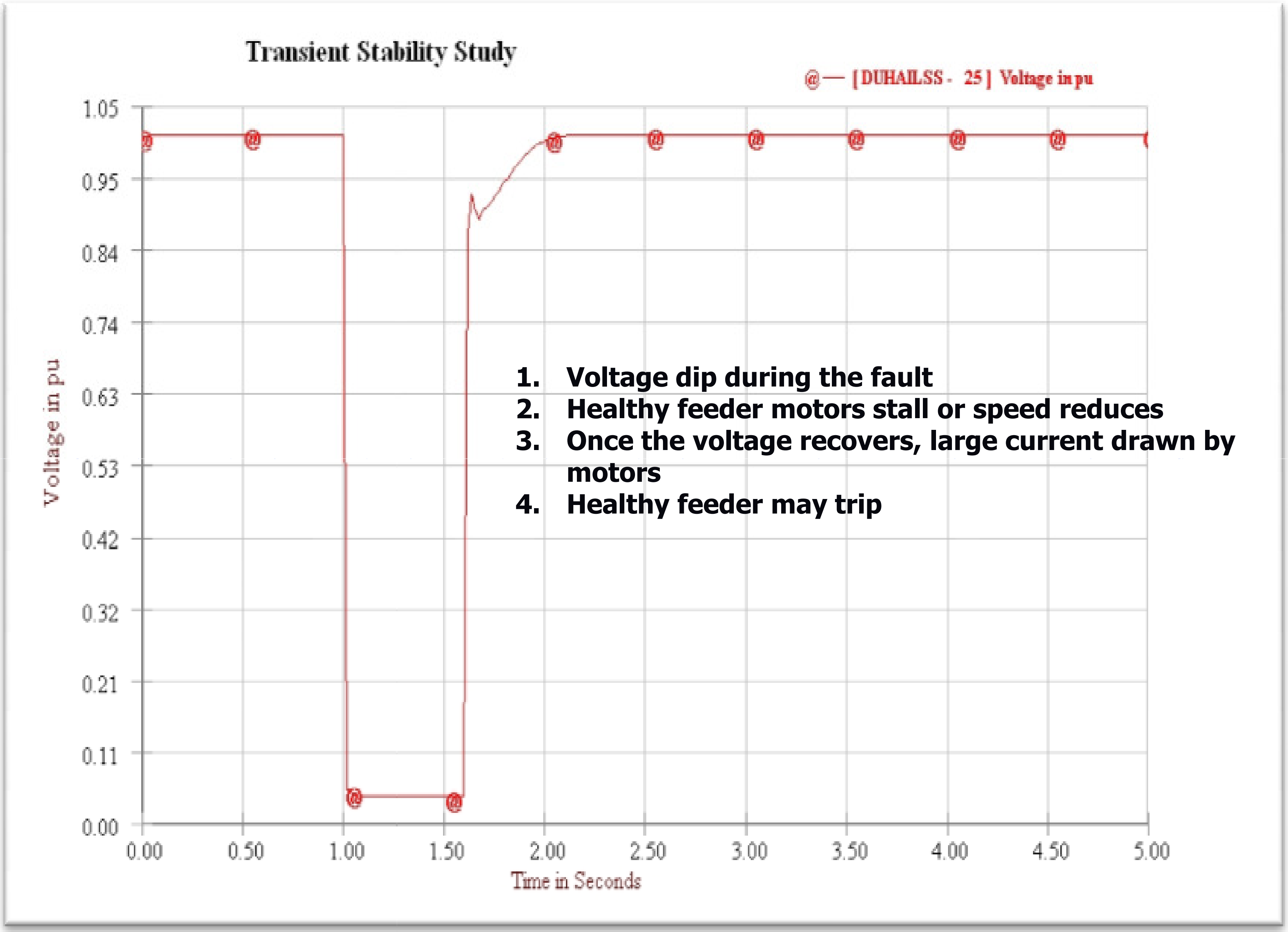


* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Overvoltage Study Results
MagIABUS3 : 3 # Magnetising Branch Current in
78.00
70.00
62.00
54.00
46.00
38.00
30.00
22.00
14.00
6.00
-2.00
IA in Amp
0.38 0.58 0.78 0.98 1.18 1.38 1.58 1.78 1.98 2.18 2.38
Time in seconds
Magnetizing inrush current
Import Range S-LogX S-LogY Log XAxis YAxis
For Help, press F1
X : 1.104 Y : 25.455
C:\MiPower\Bench\Eta\Inrush.bin
start
F:\
Microsoft...
MiPower ...
MiGUI - A...
Mipower ...
* - [Migra...
10:27 AM

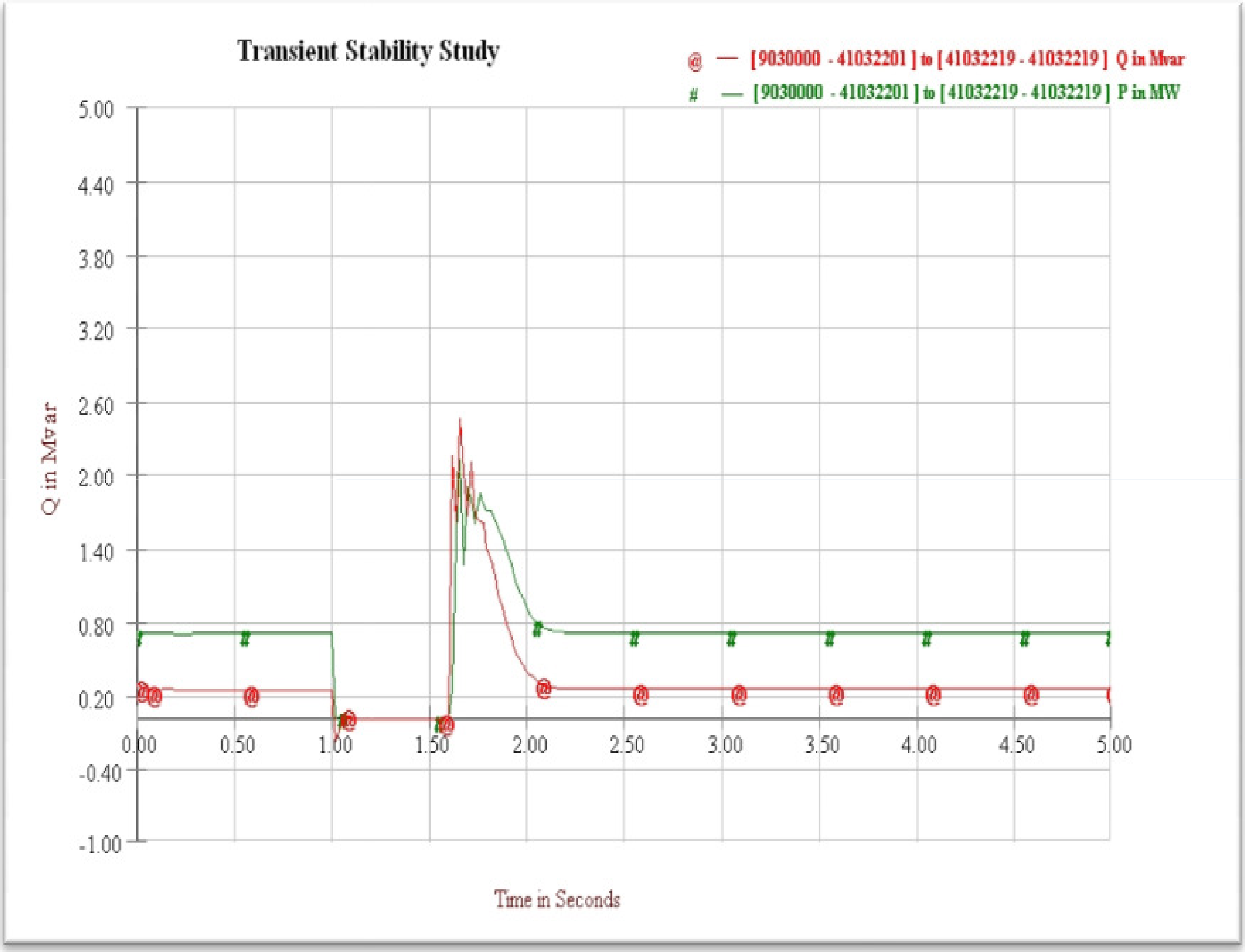
Why to provide surge arrestor and RC circuit for VCB switching


* - [Migrap1]
File Edit View Sheet Format Draw Window Help
Overvoltage Study Results
— [VABUS21 : 21] Voltage in PU
VCB current chopping and voltage raise problem
Energy stored in the Inductor = (1/2)*L*I*I
Energy stored in the Capacitor = (1/2)*C*V*V
Voltage = I * sqrt(L/C)
Solution : Provide surge suppressor/RC circuit or both after the VCB, close to equipment
2.20
1.86
1.52
1.18
0.84
0.50
0.16
-0.18
-0.52
-0.86
-1.20
V A in pu
0.38
0.39
0.40
0.41
0.42
0.43
0.44
0.45
0.46
0.47
0.48
Time in seconds
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X : 0.425 Y : -0.845
C:\MiPower\Bench\Eta\Vcbchop.bin
start
Microsoft PowerPoint ...
MiPower - Computer ...
* - [Migrap1]
10:56 AM

Simphatic Tipping, what it means?



1. **Voltage dip during the fault**
2. **Healthy feeder motors stall or speed reduces**
3. **Once the voltage recovers, large current drawn by motors**
4. **Healthy feeder may trip**

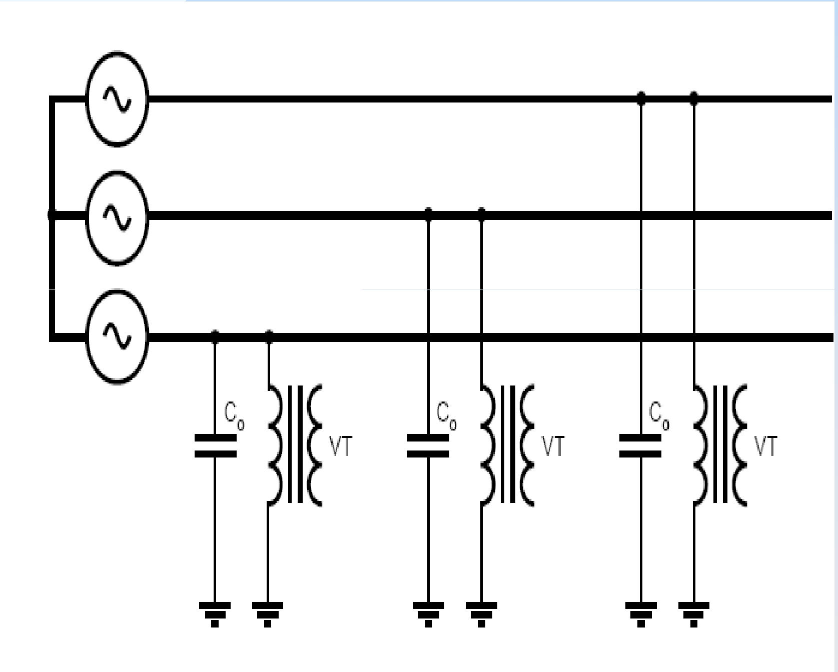

Transient Stability Study
@ — [9030000 - 41032201] to [41032219 - 41032219] Q in Mvar
# — [9030000 - 41032201] to [41032219 - 41032219] P in MW
5.00
4.40
3.80
3.20
2.60
2.00
1.40
0.80
0.20
-0.40
-1.00
Q in Mvar
0.00
0.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
Time in Seconds

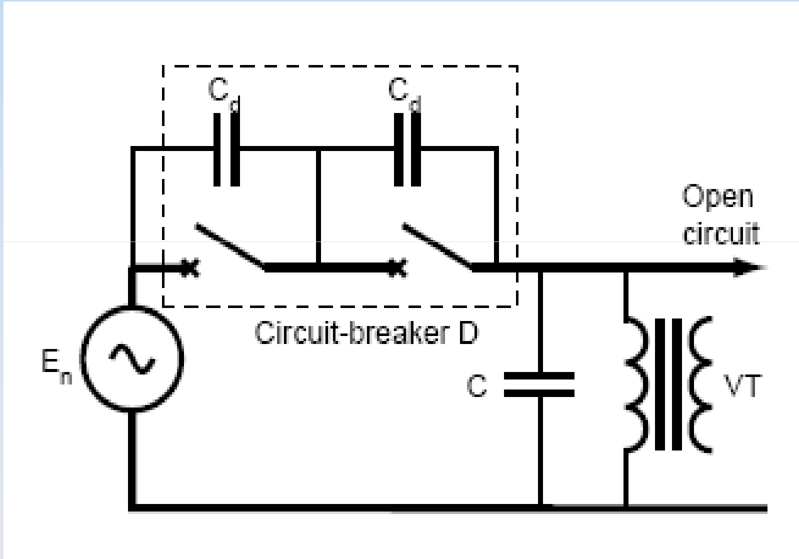
Ferroresonance when and how?

Ferroresonance (FR) TOV

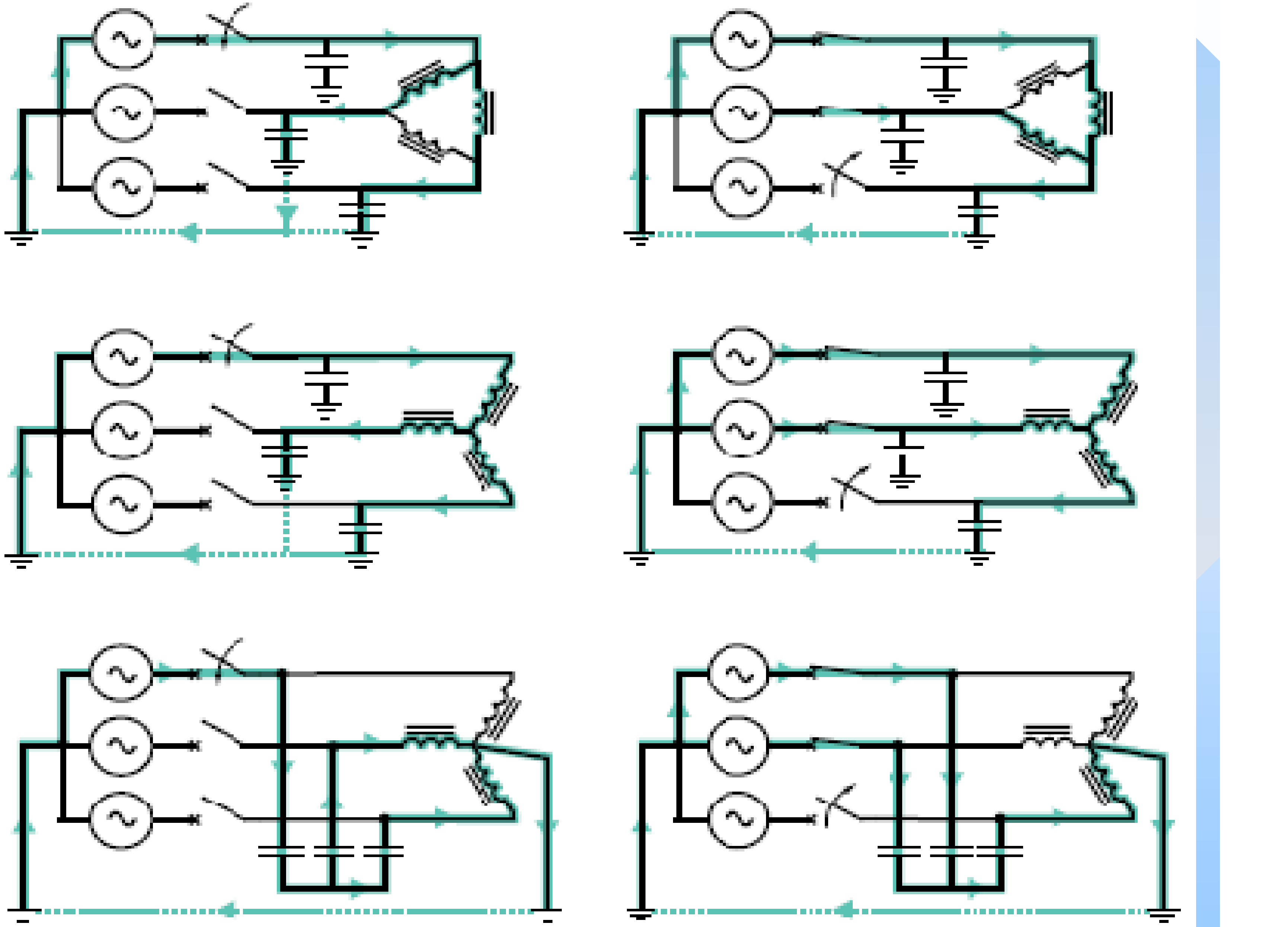
- An oscillating phenomena occurring in an electric circuit which must contain at least:
  1. a non-linear inductance
  2. a capacitor,
  3. a voltage source (generally sinusoidal),
  4. low losses.
- Transients, lightning over voltages, energizing or de-energizing transformers or loads, occurrence or removal of faults, etc…may initiate ferroresonance.
- The main feature of this phenomenon is that more than one stable steady state response is possible for the same set of the network parameters.

Examples of systems at risk from ferroresonance.

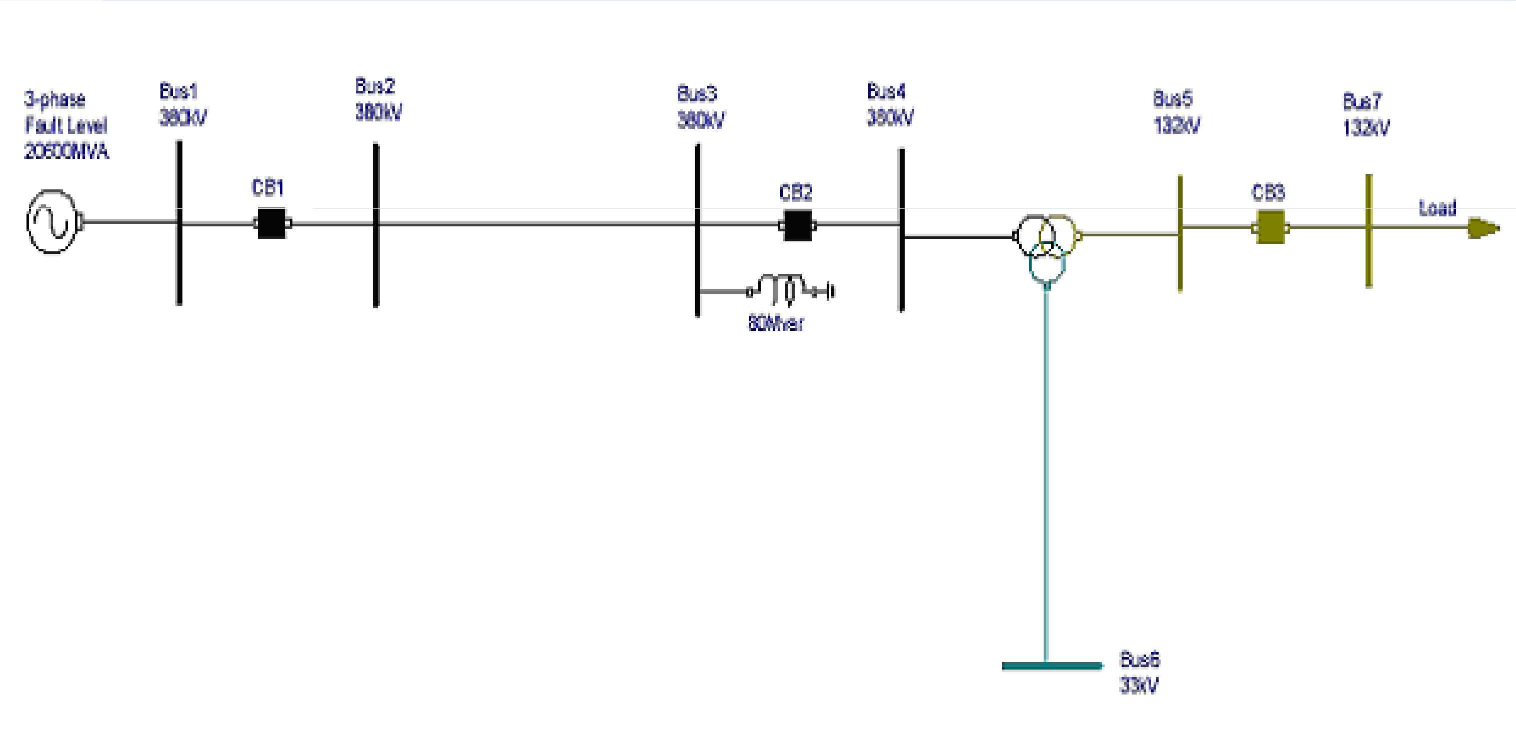


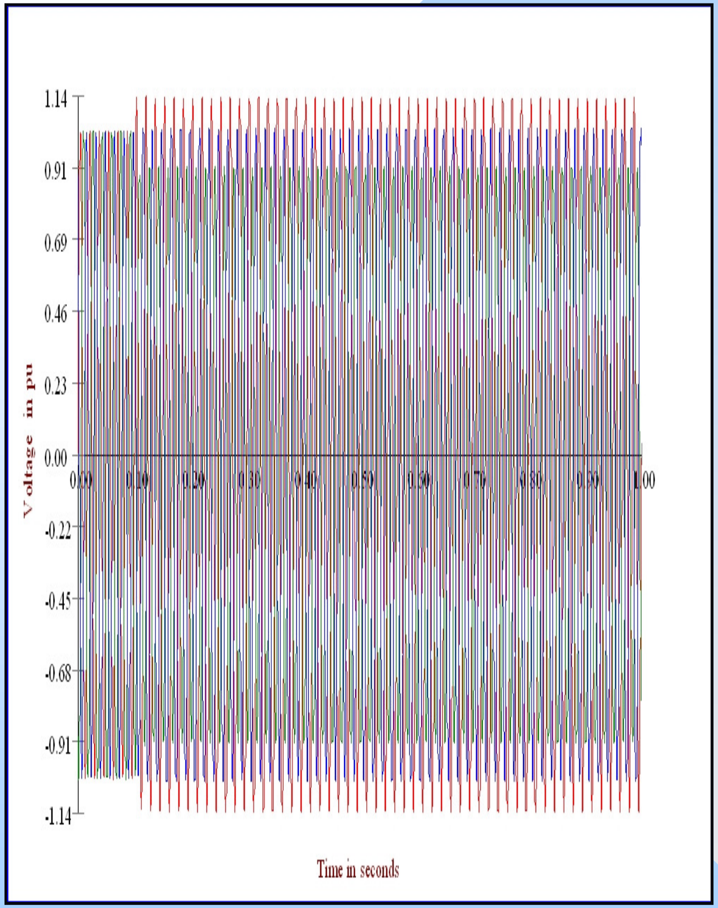


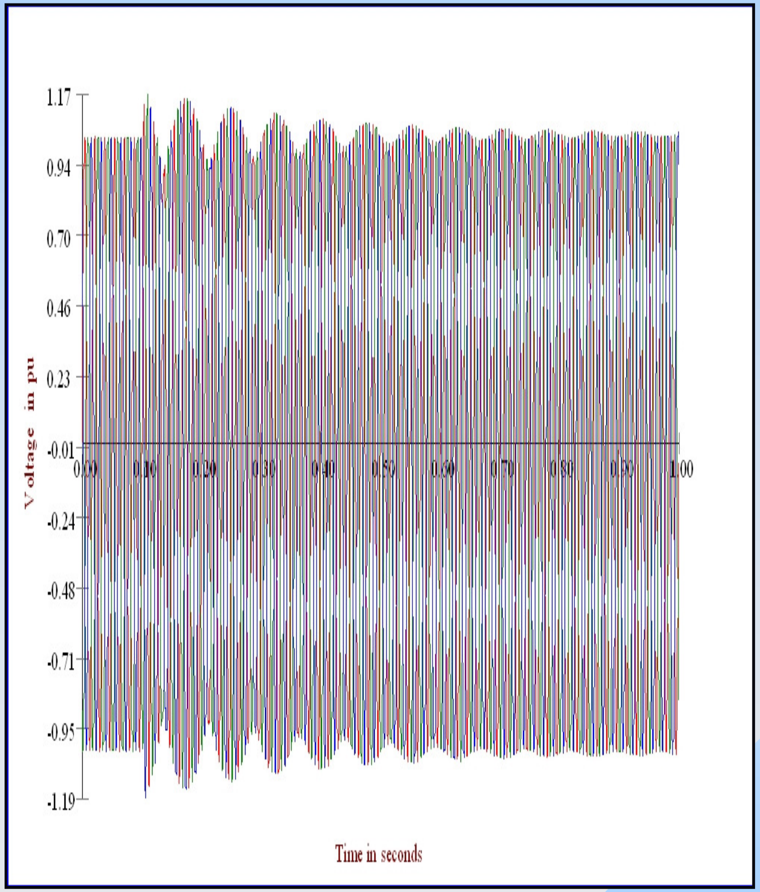
Contd.



Case study for predicting and understanding of TOV and FR



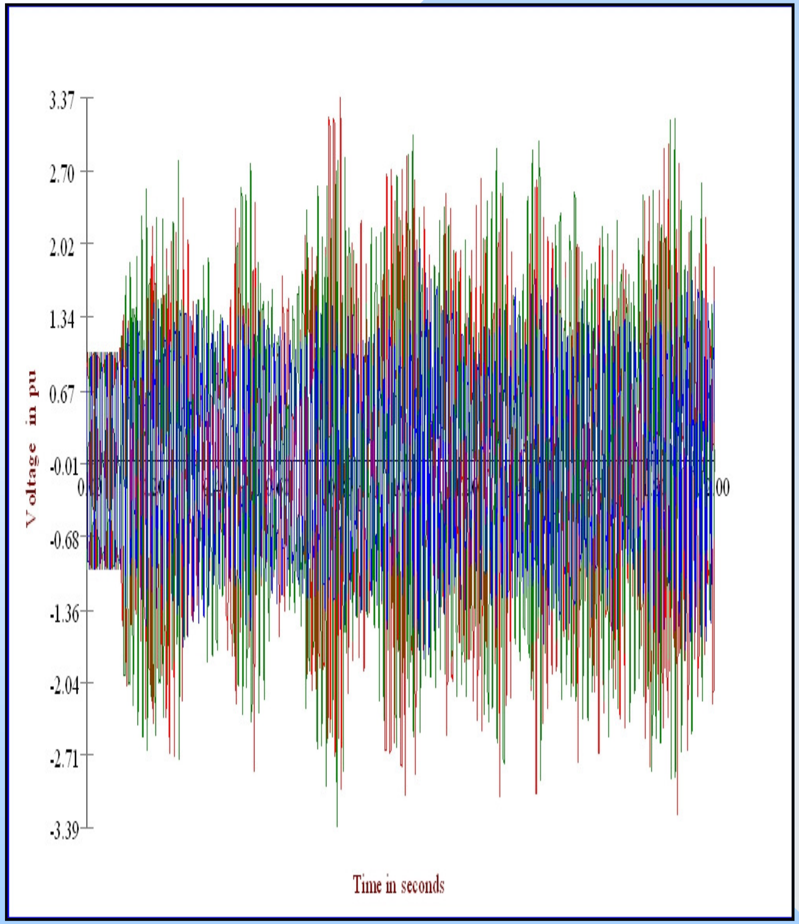




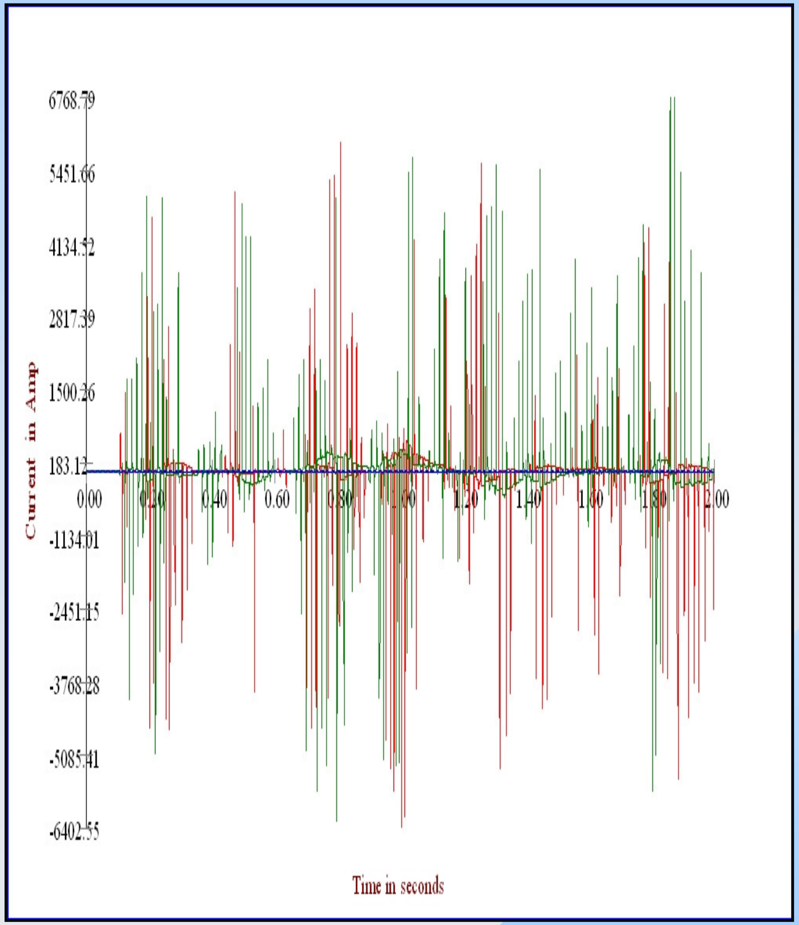
1-pole

3-pole

HT side LR by opening CB2



Voltage



Current

FR existence when 2-poles opening of CB1

Conclusions

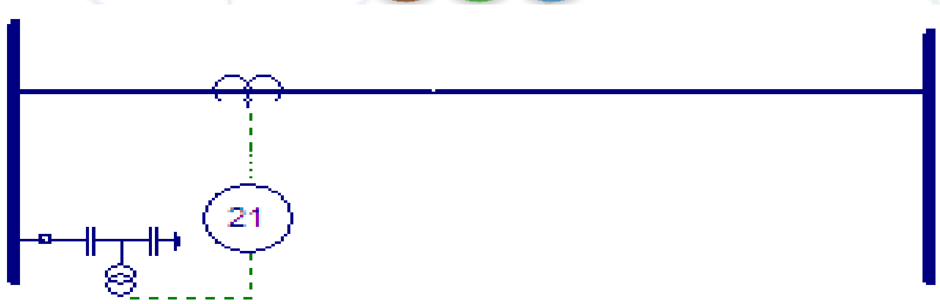
1. The various issues in the protection are discussed
2. It is concluded that close co-ordination for protection department with other departments are required.
3. The simulation tools help in learning the protection aspects
4. Automated fault analysis system will help in understanding the relay tripping incidences better.

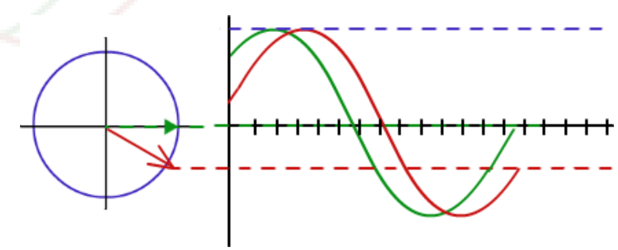
Discussions

Thank You

Tripping Analysis - Methodology

Dr. Nagaraja R,
Managing Director,
Power Research and Development Consultant Pvt. Ltd





Contents

- Importance
- Source of Data for Analysis
- Analysis Approach
- Simulation Model
- Conclusion and Recommendations

Importance

- Helps in identifying issues related to
  - Commissioning errors (Eg. CT polarity reversal)
  - Setting errors
  - Adequacy of present relaying philosophy
- Helps in preventing incorrect operations in future
- Improves effectiveness of the protection system

Sources of Data for Analysis

- COMTRADE files from
  - Relay
  - DR
- SCADA Data (understanding the operating scenario)
- PMU
  - Time Synchronized data for sequence of operation
- Observation

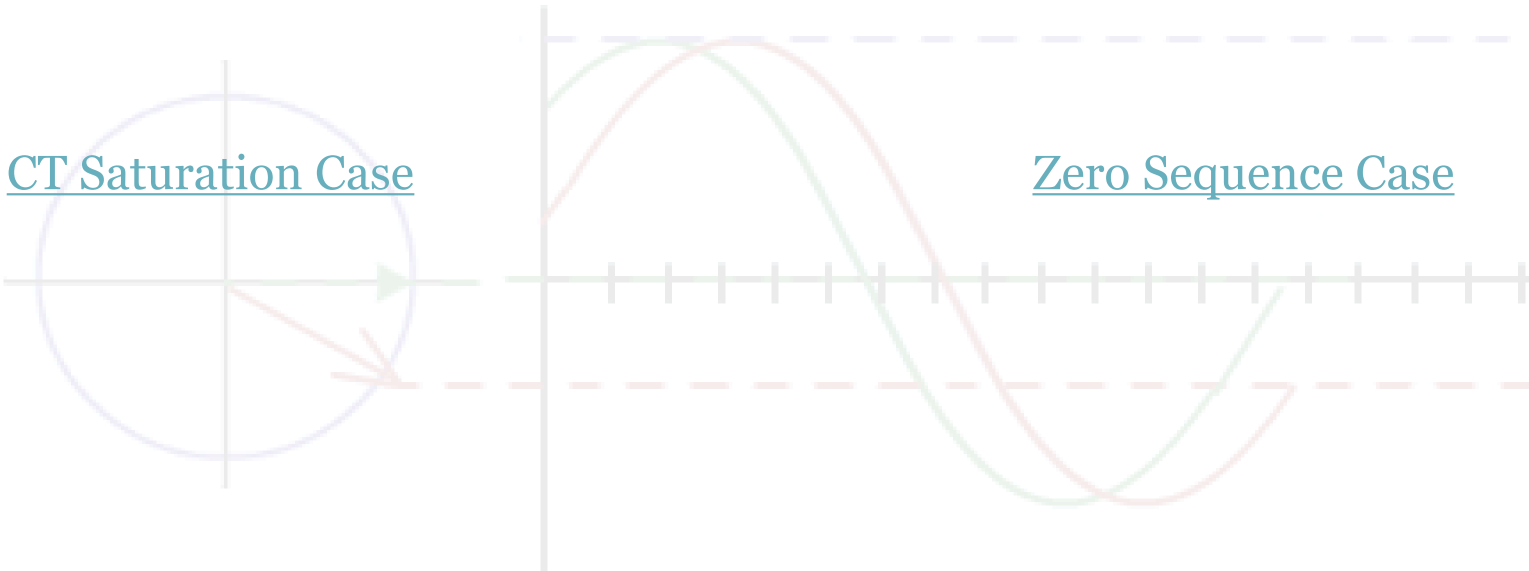
Analysis Approach

- Analyze every data to classify it as use full "information" for fault analysis
- The use full information is studied in greater detail to derive meaning full results
- Aid for analysis
  - Instantaneous / RMS plots
  - Phasor Angle Comparison
  - Harmonic Plot
  - Relay trajectories (Eg. Impedance and differential)
  - Reasoning of obtained Waveforms and observations

Simulation Model

- The scenario can be reconstructed in simulation platform
  - Electro-Magnetic Transient Study
  - Transient Stability Study
- Validate the analysis results derived using disturbance data
- Can also help to find solution for identified issues.

Case Study



CT Saturation Case

Zero Sequence Case

Conclusion and Recommendations

- Modification in relay settings
- Correction of any commissioning related issues
- Enhancement in operating philosophy that can prevent future occurrence
- Recommendations that can help reduce occurrence of disturbance
- If no incorrect operation – protection scheme healthiness can be studied.

Thank You

POWER SWING AND OUT-OF-STEP CONSIDERATIONS ON TRANSMISSION LINES

Tutorial on Protection

Contents

- Introduction
- Definitions
- Power-swing phenomena and their effect on transmission line relaying
- Power-swing detection methods
- PSB and OST protection philosophy
- Summary and conclusions

Acknowledgements: All contents are based on references [1] and [2]

INTRODUCTION

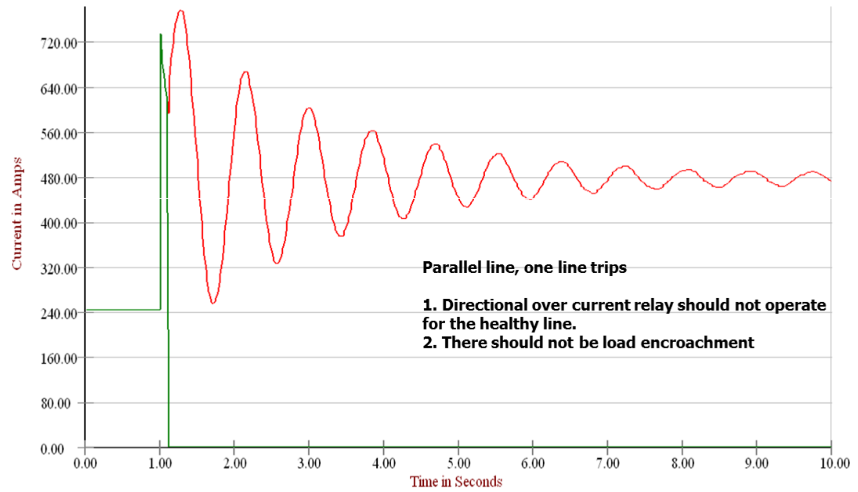
- Changes in regulations and the opening of the power markets are causing rapid changes in the way the power grid is operated.
- Large amounts of power are commonly shipped across a transmission system that was not designed for such transactions.
- Independently owned and operated generating units are being built in locations that may not be optimum for system stability and system needs.
- Power plant systems are being upgraded to get every possible megawatt out.
- The results of these upgrades often make the generating units more susceptible to instability.

Impact

The August 14, 2003 blackout in the Northeastern United States and Southeastern Canada has led to substantial scrutiny of many aspects of transmission line protection. One of the more difficult and commonly misunderstood issues being addressed is that of power swing and out-of-step protection applied to transmission lines.

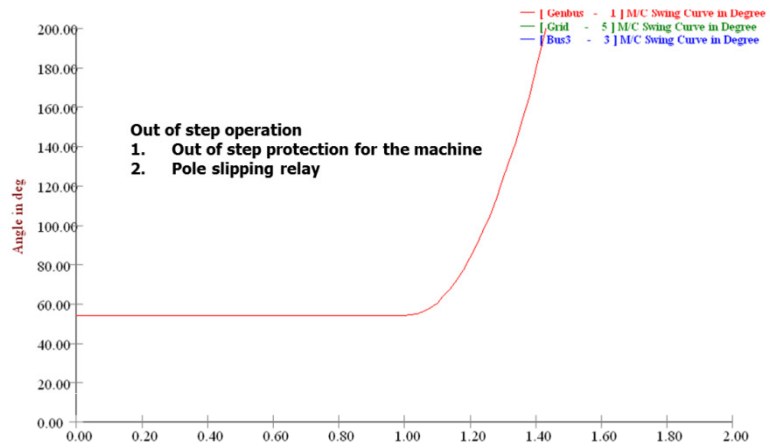
DEFINITIONS

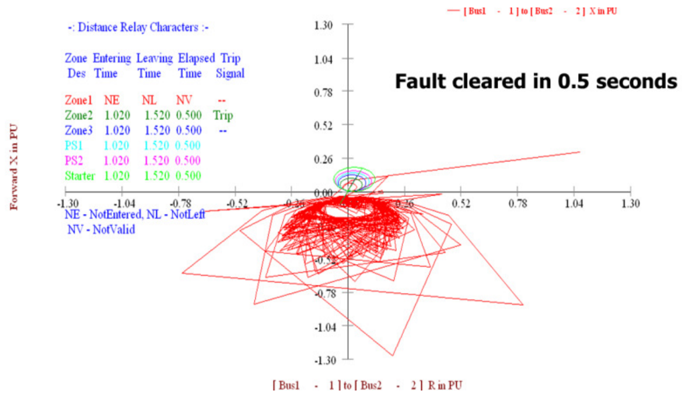
Power Swing: a variation in three phase power flow which occurs when the generator rotor angles are advancing or retarding relative to each other in response to changes in load magnitude and direction, line switching, loss of generation, faults, and other system disturbances.



DEFINITIONS

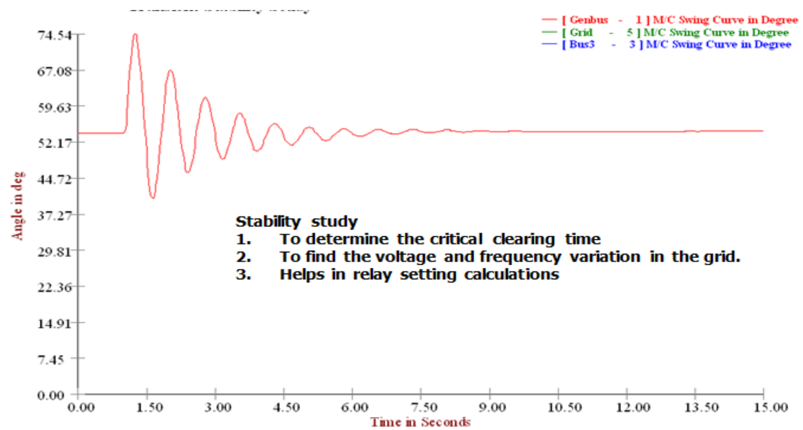
Pole Slip: a condition whereby a generator, or group of generators, terminal voltage angles (or phases) go past 180 degrees with respect to the rest of the connected power system.





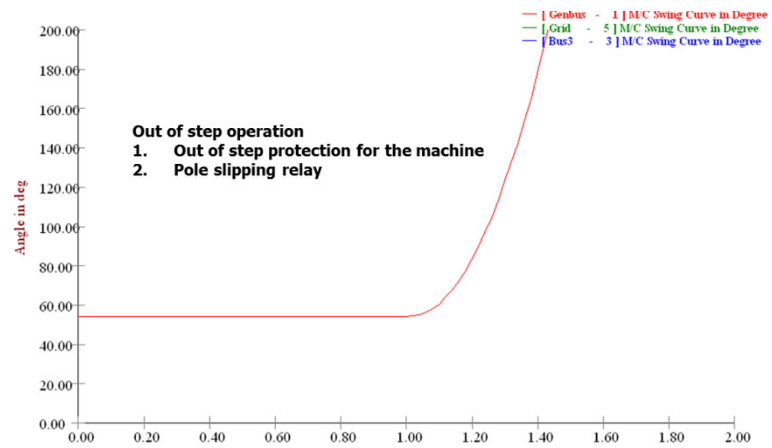
DEFINITIONS

Stable Power Swing: a power swing is considered stable if the generators do not slip poles and the system reaches a new state of equilibrium, i.e. an acceptable operating condition.



Unstable Power Swing: a power swing that will result in a generator or group of generators experiencing pole slipping for which some corrective action must be taken.

Out-of-Step Condition: Same as an unstable power swing.

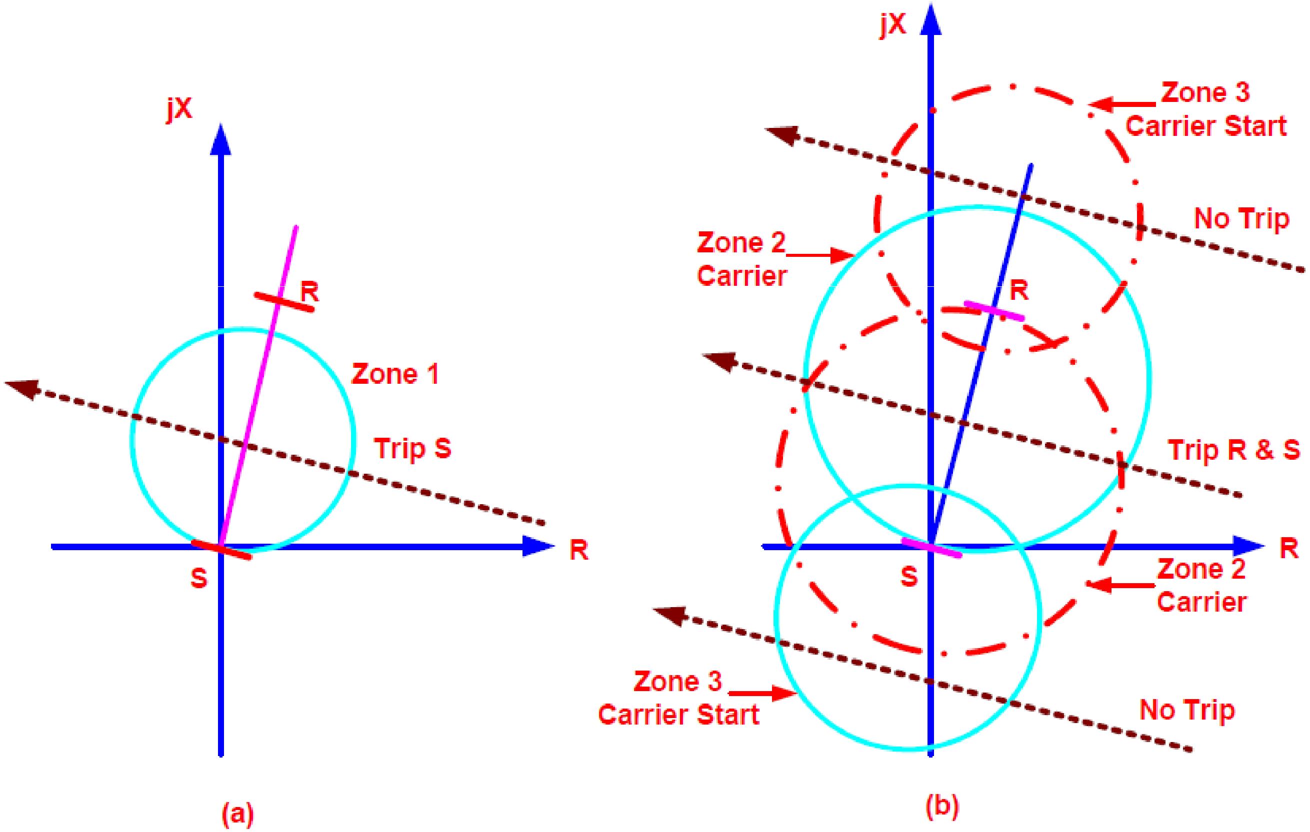


Electrical System Center or Voltage Zero: it is the point or points in the system where the voltage becomes zero during an unstable power swing.

POWER-SWING PHENOMENA AND THEIR EFFECT ON TRANSMISSION LINE RELAYING

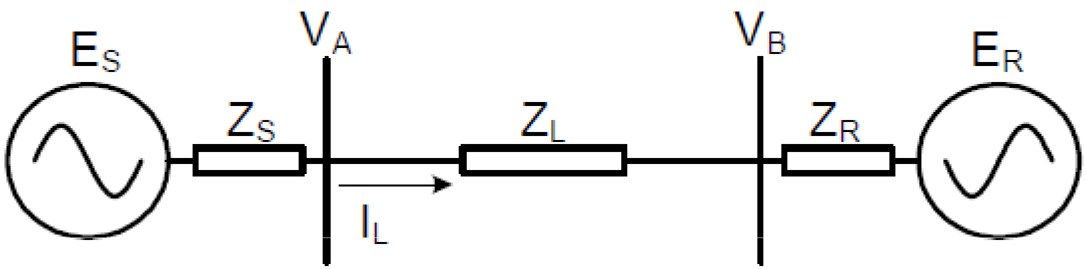
1. Fundamental power-swing detection problem: The power grid is a very dynamic network connecting generation to load via transmission lines. Power systems under steady-state conditions operate very close to their nominal frequency and typically maintain absolute voltage differences between busses of 5%. The system frequency on a 60 Hz system normally varies by less than +/- 0.02 Hz.

2. Effect of power swings on transmission line relays and relay Systems



Zone 1 and Directional Comparison Blocking Scheme Characteristics

3. Impedance measured by distance relays during power swings



Two Machine System

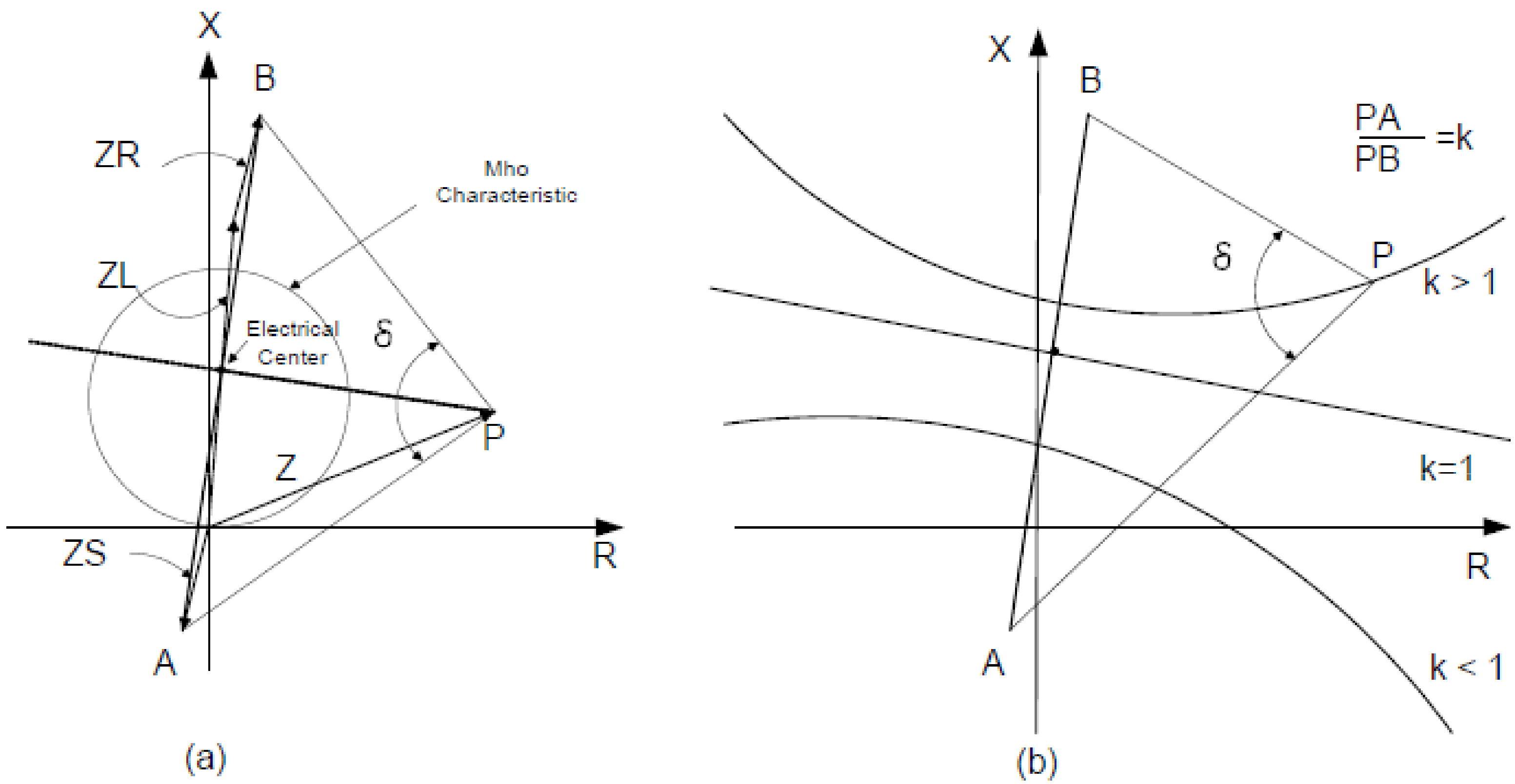
$$IL = \frac{ES - ER}{ZS + ZL + ZR}$$

$$Z = \frac{VA}{IL} = \frac{ES - IL \cdot ZS}{IL} = \frac{ES}{IL} - ZS = \frac{ES \cdot (ZS + ZL + ZR)}{ES - ER} - ZS$$

$$\frac{ES}{ES - ER} = \frac{k(\cos\delta + j\sin\delta)}{k(\cos\delta + j\sin\delta) - 1} = \frac{k[(k - \cos\delta) - j\sin\delta]}{(k - \cos\delta)^2 + \sin^2\delta}$$

$$\frac{ES}{ES - ER} = \frac{1}{2}(1 - j\cot\frac{\delta}{2})$$

$$Z = \frac{VA}{IL} = \frac{(ZS + ZL + ZR)}{2}(1 - j\cot\frac{\delta}{2}) - ZS$$

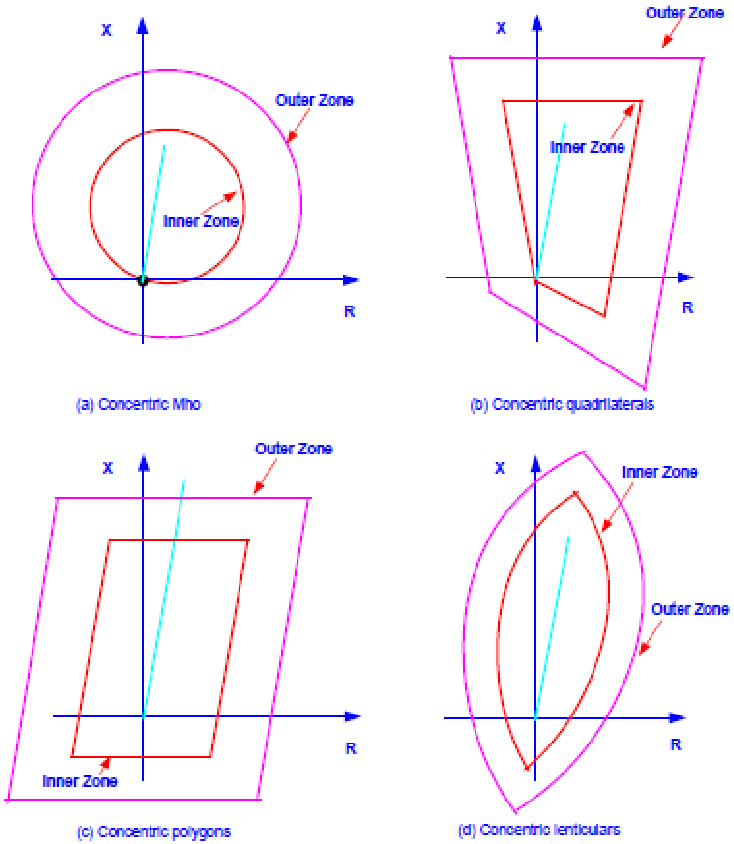


Impedance trajectories at the Relay During a Power Swing for Different k values

POWER-SWING DETECTION METHODS

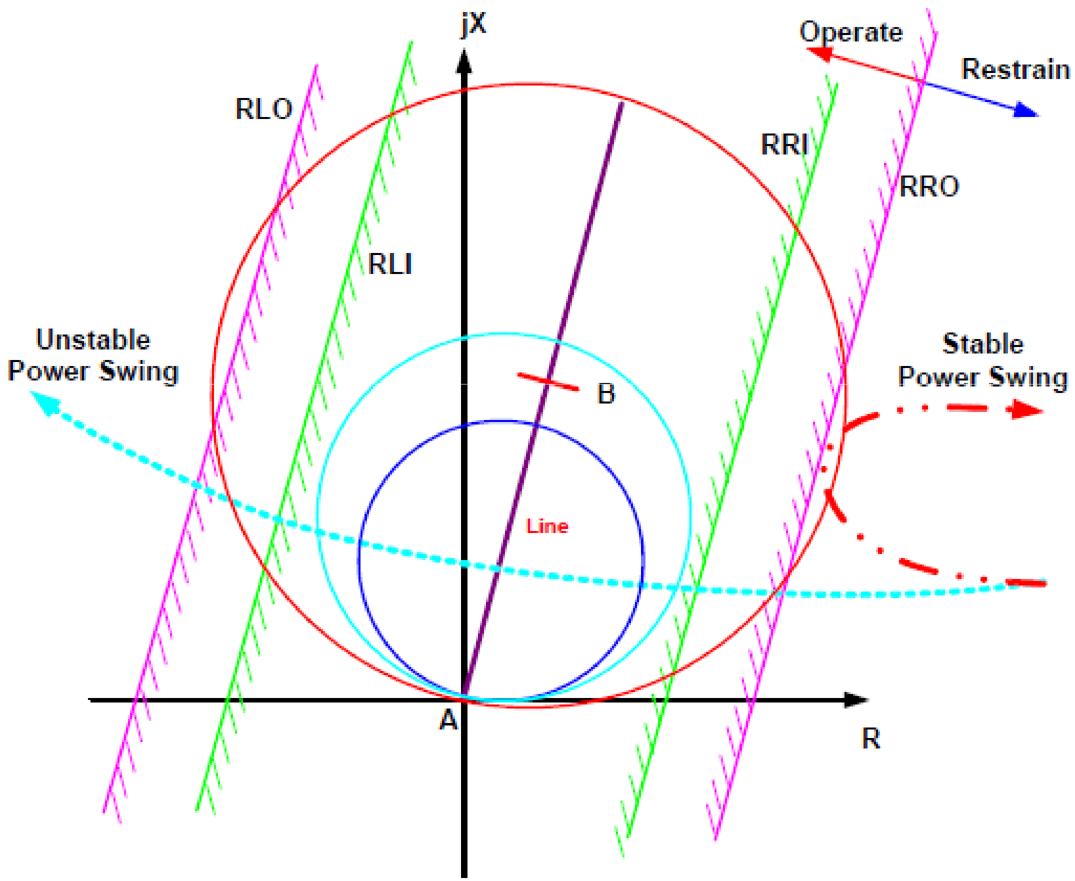
1.Conventional rate of change of impedance PSB and OST methods

a. Concentric Characteristic Schemes



PSB and OST
Concentric Distance
Relay Characteristics

b. Blinder Schemes.



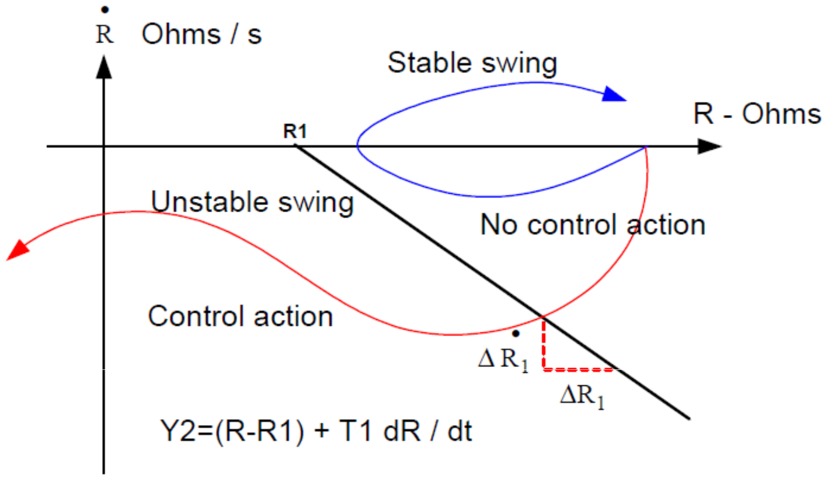
Two-Blinder Scheme

C. Rdot Scheme

Conventional OST Relay
$Y1 = (R-R1) <= 0$

R-dot relay:
$Y2 = (R-R1)+T1*dR/dt <= 0$

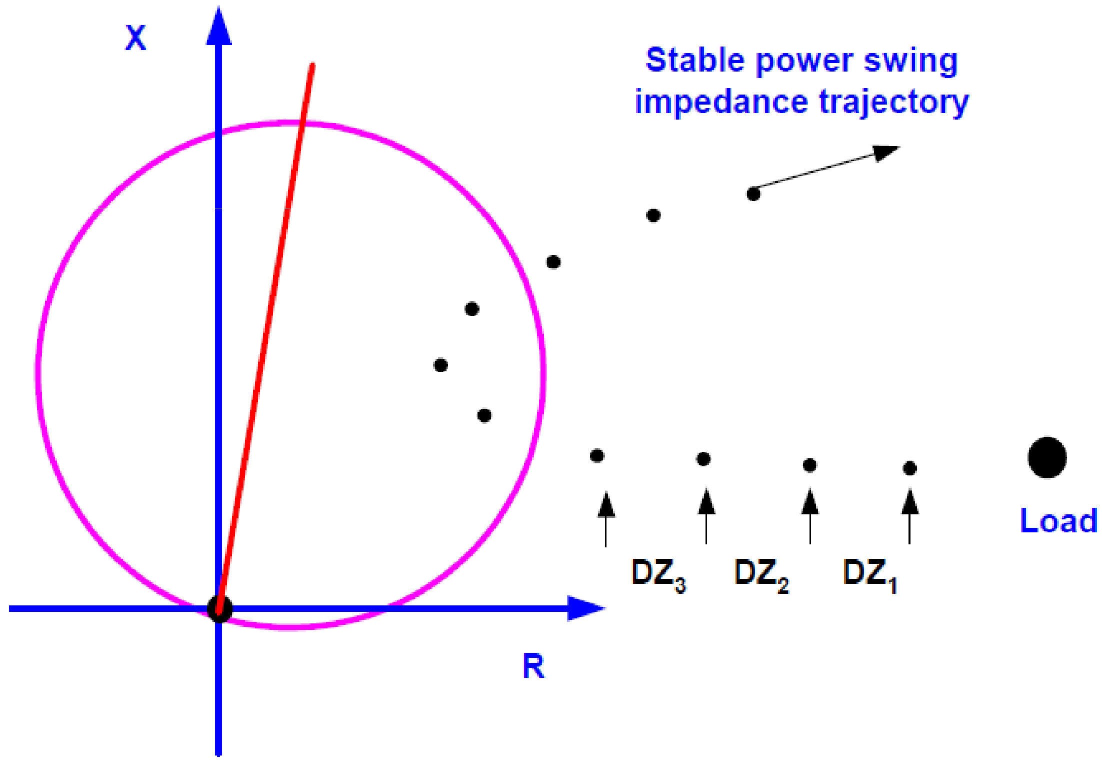
Wherein
Y1 and Y2 are control outputs
R: Apparent resistance
R1 and T1: Relay settings



Phase-plane Diagram Illustrating the Concept of R-dot Principle

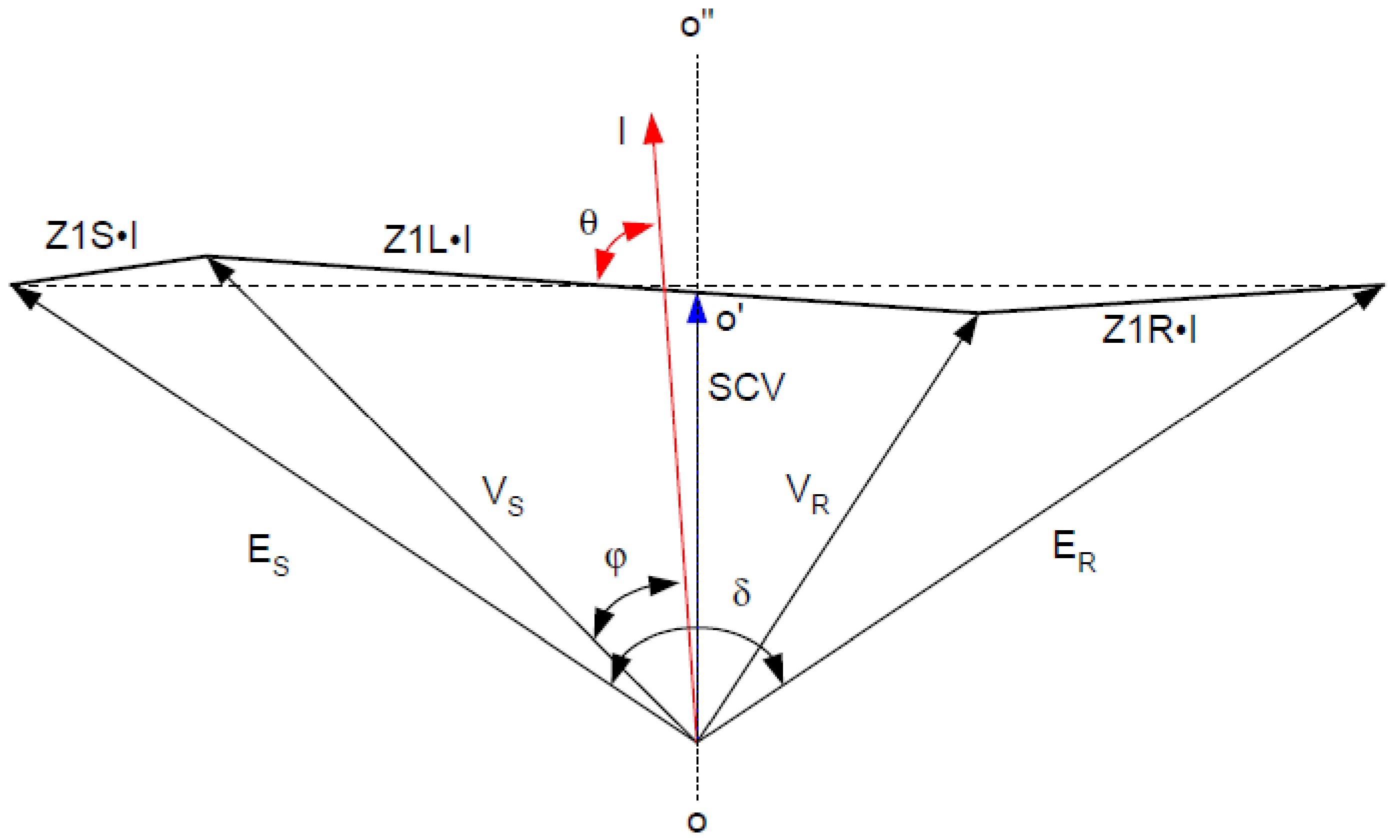
2. Additional power swing detection methods

a. Continuous Impedance Calculation



Power swing detection with continuous impedance calculation

b. Swing-Center Voltage and its Rate of Change



VScosØ is a Projection of Local Voltage, VS, Onto Local Current, I
Measure of Swing Center Voltage is going to detect the out of step

C. Synchrophasor-Based Out-Of-Step Relaying

1. To the extent that a two-machine system equivalent can represent a network, one approach consists of synchronous measurement of the phase angle between the voltages behind the transient reactances of the two machines. When a disturbance occurs, the new phase angle between the two machines is computed and the equal area algorithm is implemented in real time to determine whether the new point of operation is stable

2. second approach consists of measuring the positive sequence phasors at two or more strategically located buses. During a disturbance, the phase angle between the signal pairs is computed in real time, and a predictive algorithm is used to establish whether the disturbance will be stable. One application uses a model of the phase angle time waveform in the form of an exponentially damped sine wave.

   $\delta 0$: *Initial phase angle*; α: *damping constant*; A: *Oscillation amplitude*;

β is the phase displacement.

$$\delta(t) = \delta_0 + A\, e^{\alpha t} \sin(\omega t + \beta)$$

3. Remarks on power-swing detection methods

Quantities Used for Power-Swing Detection
Wherein XT: Total system impedance
ES=ER=E1

Power: $$P = E1 \cdot I \cdot \cos\varphi = \frac{E1^2}{XT} \cdot \sin\delta$$

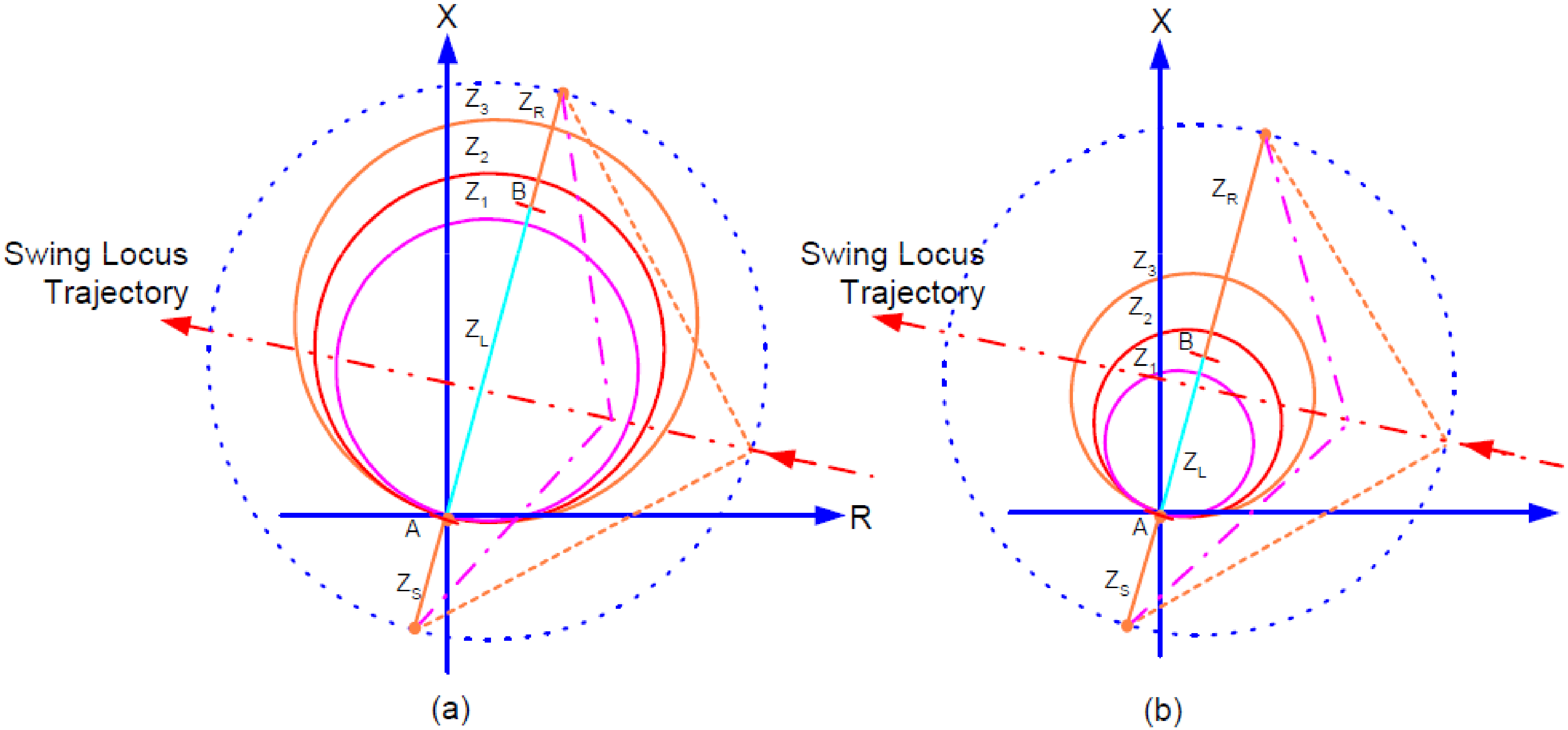
Current: $$I = 2 \cdot \frac{E1}{XT} \cdot \sin(\frac{\delta}{2})$$

Impedance: $$Z = \frac{V}{I} = \frac{XT}{2} \cdot \cot(\frac{\delta}{2})$$

Rate of change of Z: $$\frac{dZ}{dt} = -\frac{XT}{2}\left(\frac{1}{1-\cos\delta}\right)\frac{d\delta}{dt}$$

SCV: $$V\cos\varphi = \frac{P}{I} = E1 \cdot \cos(\frac{\delta}{2})$$

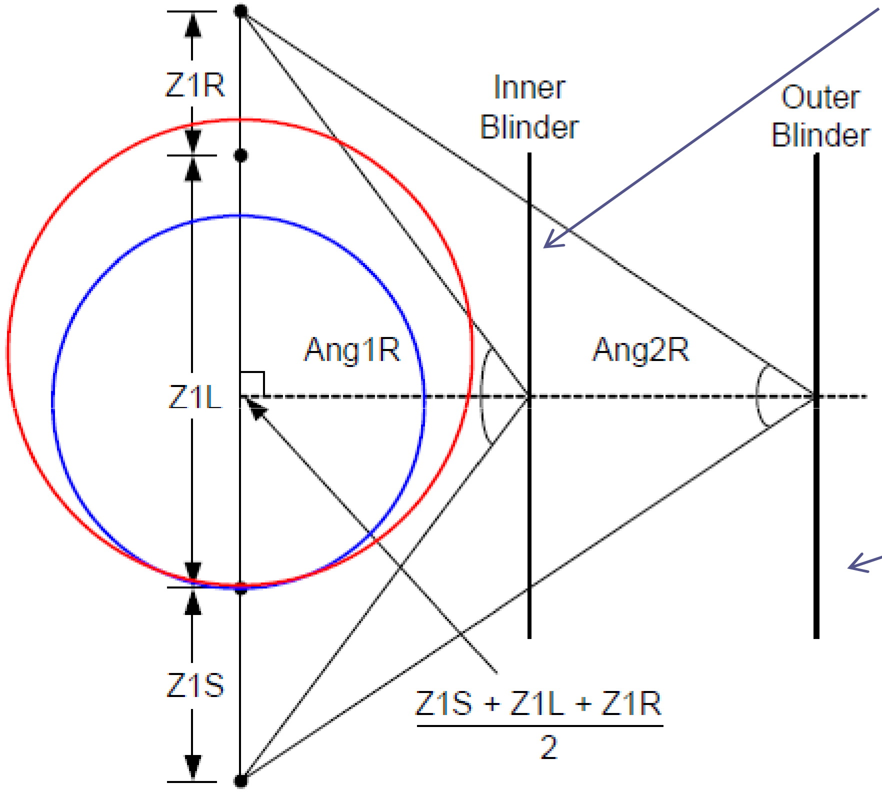
b. Setting Issues for Concentric Impedance Elements and Blinder-Based schemes



Effects of Source and Line Impedance on the PSB Function

$$T1 = \frac{(Ang1R - Ang2R) \cdot Fnom(Hz)}{360 \cdot Fslip(Hz)}(cycle)$$

Set outside most overreaching protective zone



Set inside Maximum Possible load

Equivalent Two-Source Machine Angles During OOS
T1: Power swing blocking timer value
Fslip: 4 to 7 Hz;

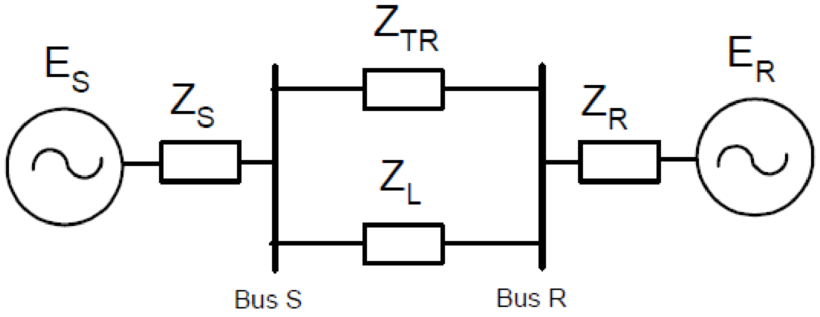
PSB And OST Protection Philosophy

1. Power-swing protection functions

One of the traditional methods of minimizing the spread of a cascading outage caused by loss of synchronism is the application of power swing protection elements that detect OOS conditions and take appropriate actions to block relay elements that are prone to mis-operate during power swings and to separate affected system areas, minimize the loss of load, and maintain maximum service continuity.

2. Method for determining need for power swing and oos protection

1. Determine Zoos = ZS+ZR+(ZTR||ZL)
2. Determine (Zoos/2) > ZS or ZR, then electrical center falls within the line under consideration.



Two-Source System Equivalent

Where,
Es = Equivalent sending end voltage
Zs = Equivalent sending end source impedance
ZL = Line impedance
ER = Equivalent receiving end voltage
ZR = Equivalent receiving end source impedance
ZTR = Equivalent impedance of the system interconnecting sending and receiving busses

3. Application of PSB and OST protection functions

1. PSB and OST Options
   a. No Power Swing Detection
   b. Block All Elements Prone to Operate During Power Swings
   c. Block Zone 2 and Higher / Trip with Zone 1
   d. Block All Zones / Trip with OST Function

2. Placement of OST System

3. Additional Considerations
   a. Distance Protection Requirements During OOS Conditions
   b. Power Swing Protection During Single Pole Open Conditions
   c. Three-Phase Faults Following Power Swings

4. Effects of Small Generators

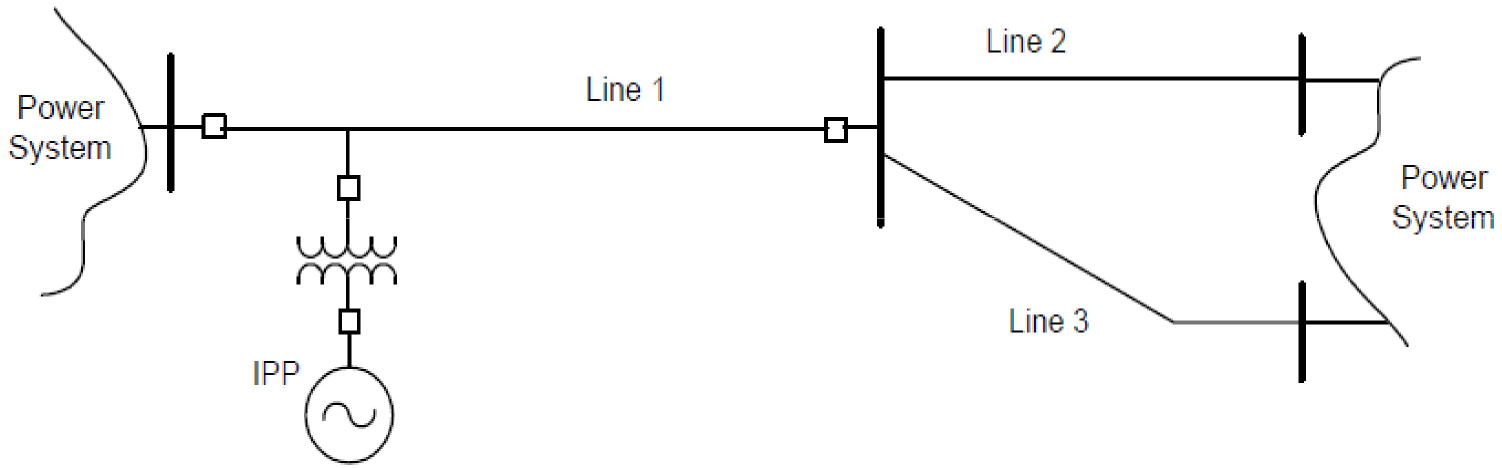


Figure : Transmission Line Connected IPP

5. System risks due to power swings and oos conditions

1. Transient Recovery Voltage (TRV) causing Breaker Failure
2. Isolating Load and Generation
3. Equipment Damage
4. Cascading Tripping of Lines
5. Unwanted Cascading Tripping of Generating Units

6. Methods to improve transient stability

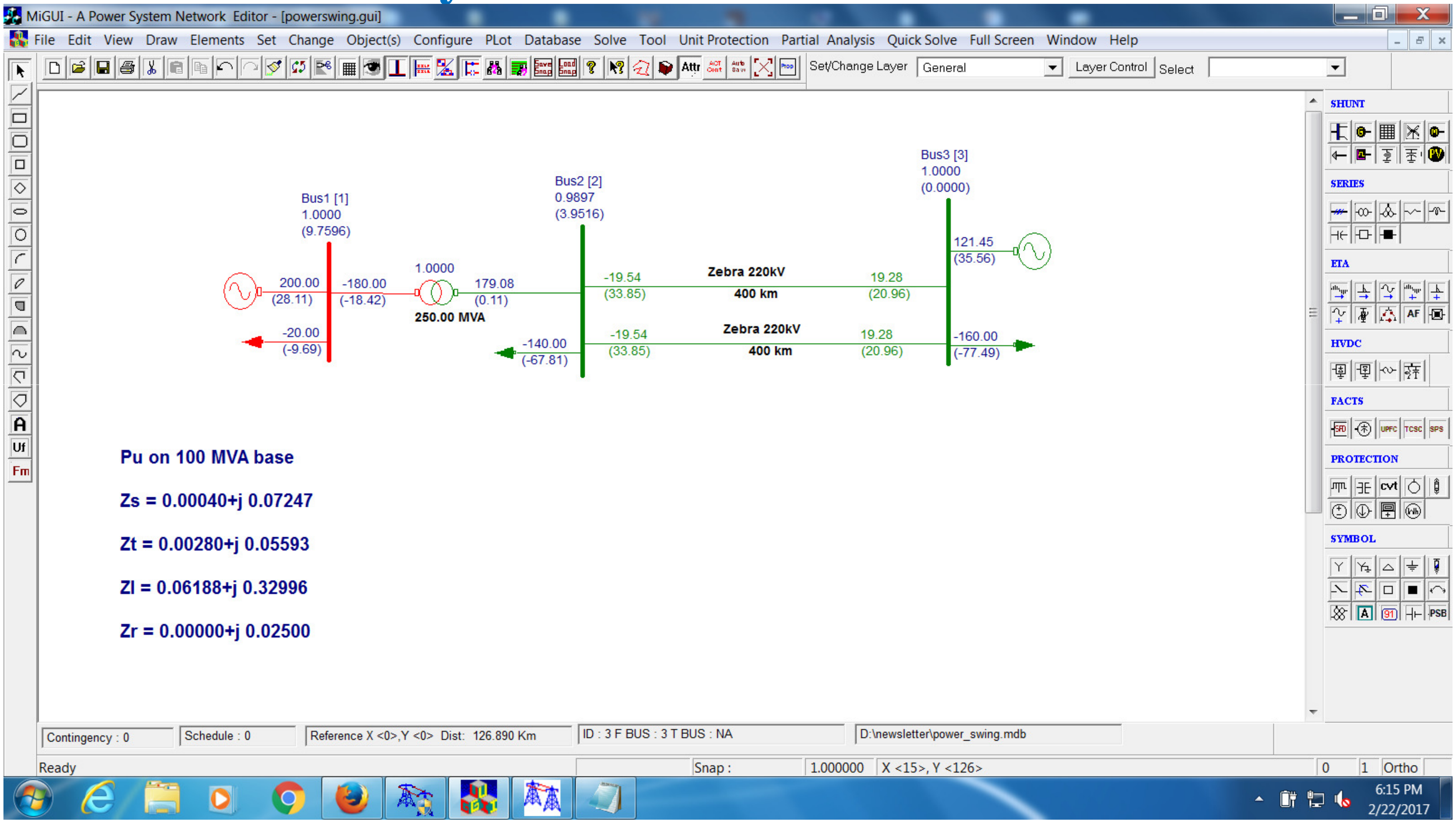
Methods that can improve the transient stability are briefly discussed in this section and they try to achieve one or more of the following effects:

1. Minimize fault severity and duration.
2. Increase of the restoring synchronizing forces.
3. Reduction of the accelerating torque by:
    a. Control of prime-mover mechanical power.
    b. Application of artificial loads.

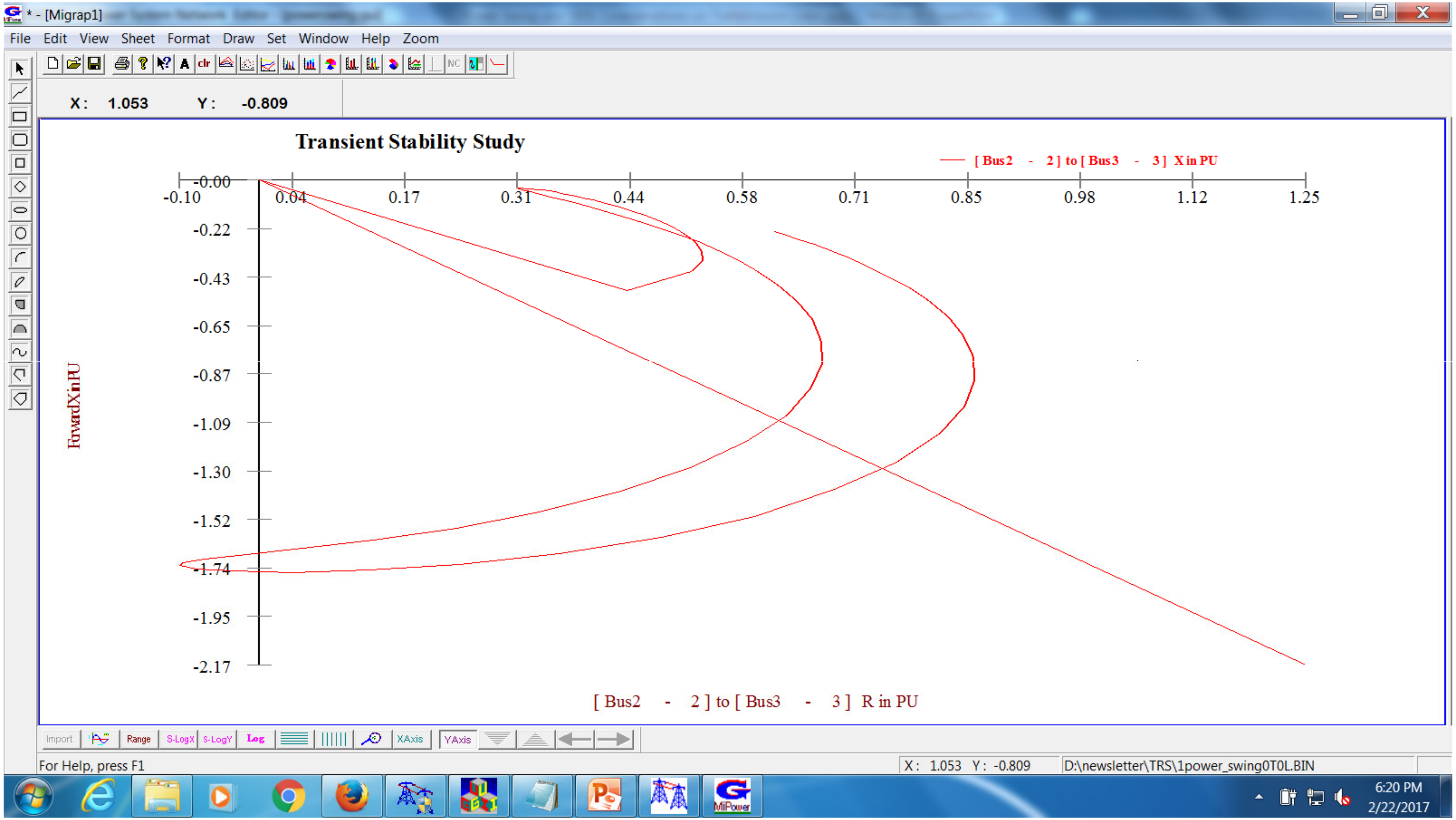
Methods to improve transient stability

1. High-Speed Fault Clearing
2. Local Breaker Failure Protection
3. Independent-Pole Operation of Circuit Breakers
4. Single-Pole Tripping
5. Dynamic Braking
6. Shunt Compensation
7. Steam Turbine Fast Valving
8. Generator Tripping
9. High-Speed Excitation Systems
10. Controlled Separation and Load shedding Using Special Protection Systems+
    a. Generator dropping.
    b. Turbine fast valving.
    c. Direct load shedding.
    d. Insertion of breaking resistors.
    e. Series capacitor insertion.
    f. Shunt capacitor insertion.
    g. Controlled islanding.
11. Reduction of Transmission System Reactance
12. Power System Stabilizers
13. High-Speed Reclosing

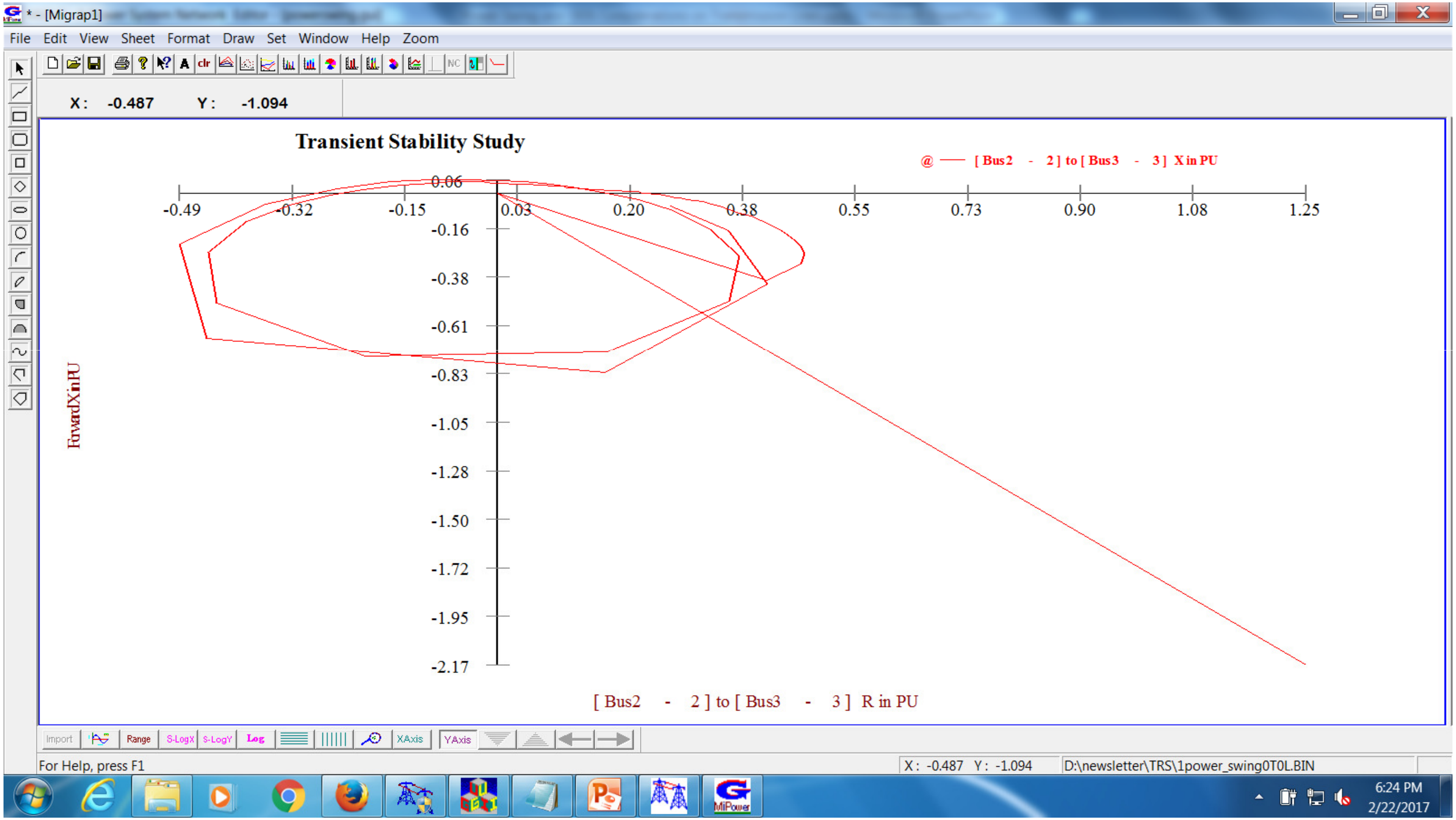
Case study


MiGUI - A Power System Network Editor - [powerswing.gui]
File Edit View Draw Elements Set Change Object(s) Configure PLot Database Solve Tool Unit Protection Partial Analysis Quick Solve Full Screen Window Help
Set/Change Layer
General
Layer Control
Select
SHUNT
SERIES
ETA
HVDC
FACTS
PROTECTION
SYMBOL
Bus1 [1]
1.0000
(9.7596)
Bus2 [2]
0.9897
(3.9516)
Bus3 [3]
1.0000
(0.0000)
200.00
(28.11)
-180.00
(-18.42)
1.0000
179.08
(0.11)
250.00 MVA
-20.00
(-9.69)
-140.00
(-67.81)
-19.54
(33.85)
Zebra 220kV
400 km
19.28
(20.96)
-19.54
(33.85)
Zebra 220kV
400 km
19.28
(20.96)
121.45
(35.56)
-160.00
(-77.49)
Pu on 100 MVA base
Zs = 0.00040+j 0.07247
Zt = 0.00280+j 0.05593
Zl = 0.06188+j 0.32996
Zr = 0.00000+j 0.02500
Contingency : 0
Schedule : 0
Reference X <0>,Y <0> Dist: 126.890 Km
ID : 3 F BUS : 3 T BUS : NA
D:\newsletter\power_swing.mdb
Ready
Snap :
1.000000
X <15>, Y <126>
Ortho
6:15 PM
2/22/2017

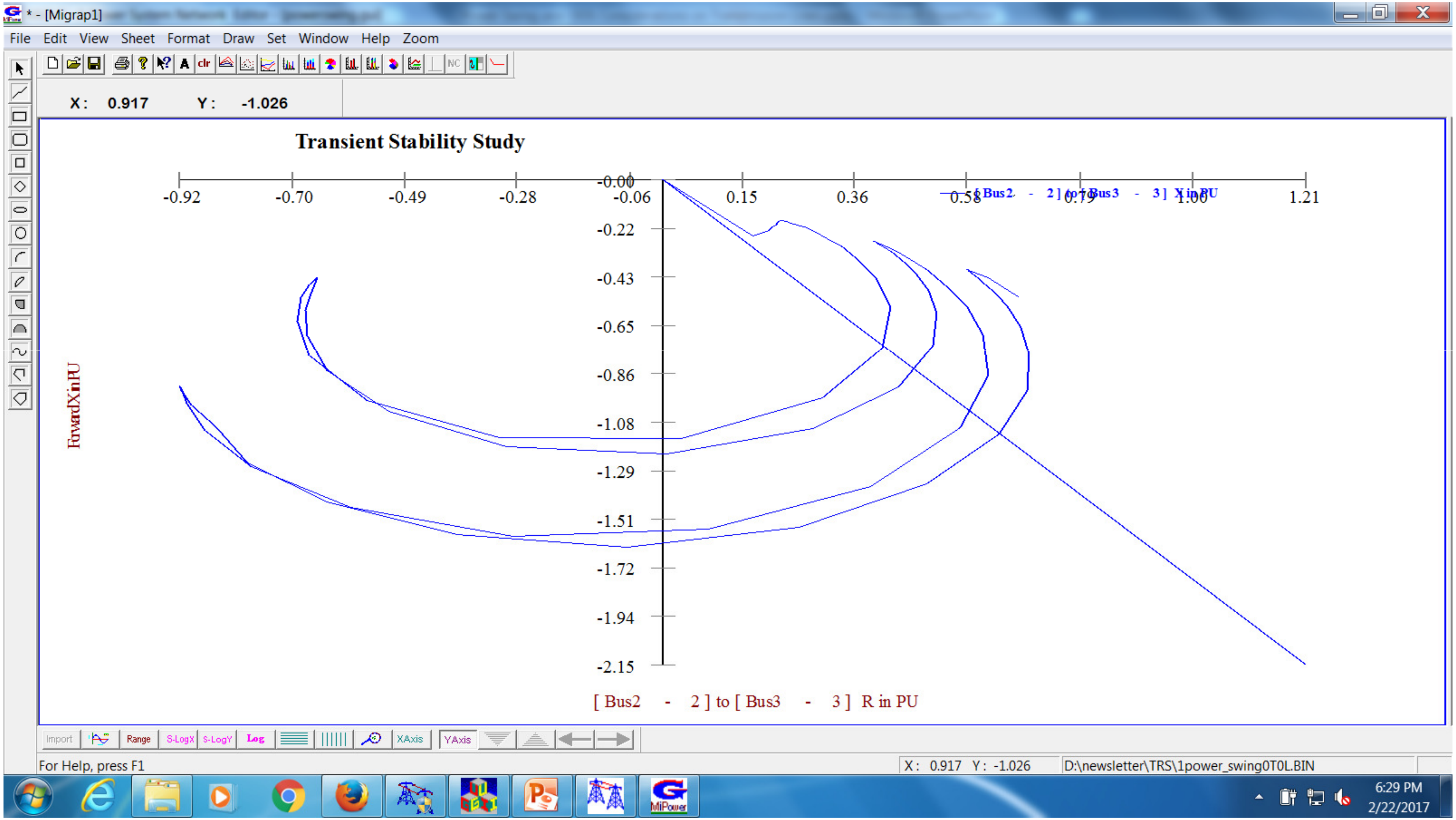
Fault Cleared in 0.1 s; Impedance seen by healthy line



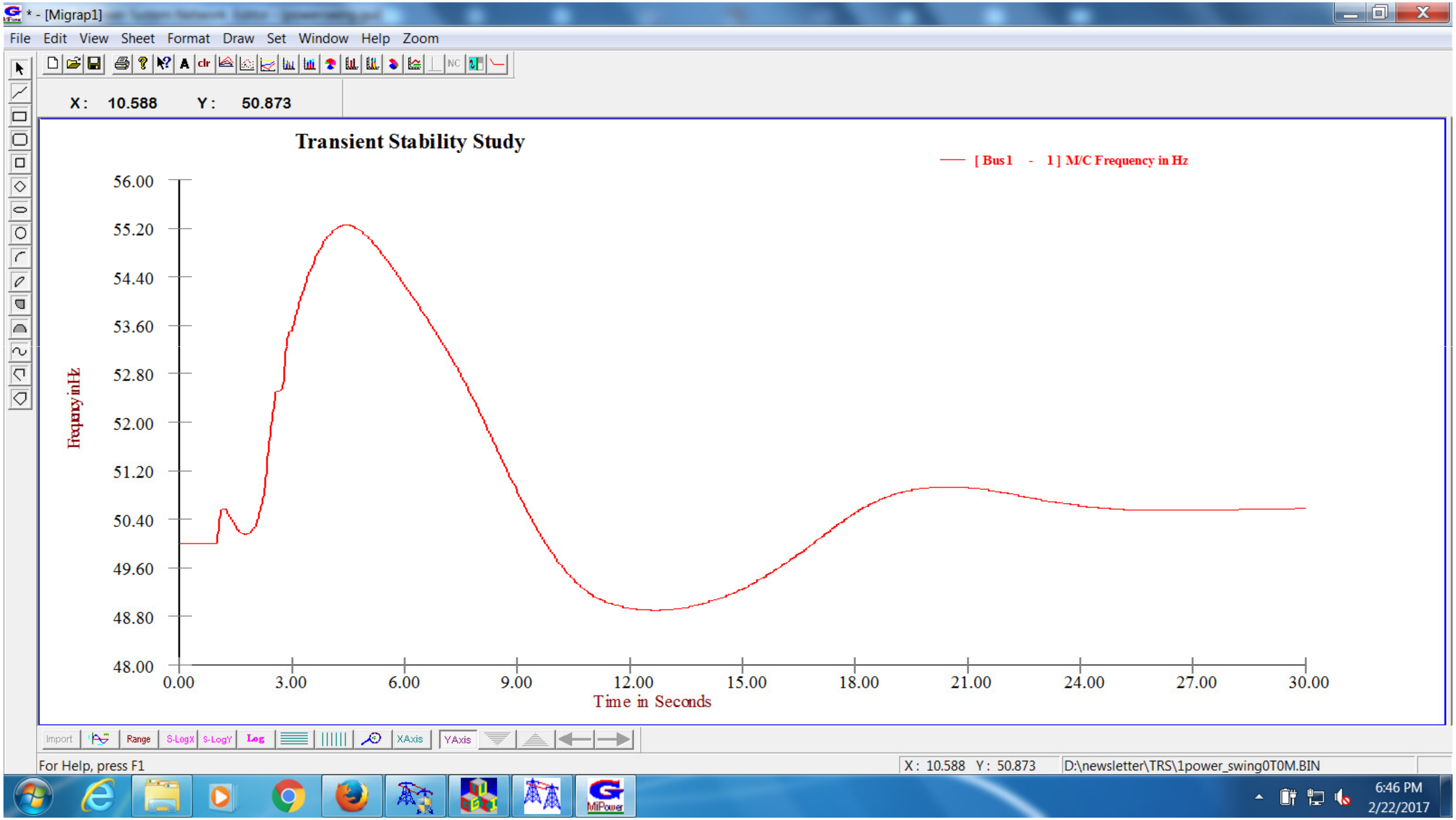
Fault Cleared in 0.12 s; Impedance seen by healthy line



Line length 40 km; Fault Cleared in 0.12 s; Impedance seen by healthy line



Line length 400 km; Fault Cleared in 0.12 s; Out of step cleared the healthy line in 2 s;



SUMMARY AND CONCLUSIONS

Power swings both stable and unstable can precipitate wide spread outages to power systems with the result that cascade tripping of the power system elements occur. Protection of power systems against the effects of power swings both stable and unstable has been described in this paper. The paper has given an overview of power swings, their causes and detection. Methods of detecting and protecting the power system against power swings have been developed and elaborated.

References

[1] POWER SWING AND OUT-OF-STEP CONSIDERATIONS ON TRANSMISSION LINES, IEEE PSRC D6

[2] POWER SYSTEM STABILITY & CONTROL, PRABHA KUNDUR, TATA McGraw HILL PUBLICATIONS