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Generator Protection

Generator Protection - Introduction

- Size of individual generating unit 30 MW to 500/1000 MW
- Loss of even a single unit is a serious problem
- Consequence : Protection systems of such generators have also become more stringent
- Required to reduce the outage period to a minimum
- Achieved by rapid discriminative clearance of all fault conditions associated with the units
- Damage due to faults is none or to the minimum

Aspects of Generator Protection

Fault Classification

- Internal faults
- Abnormal Service conditions
- External Faults (as back up protection)
- The hazards and problems considered
- Phase to phase faults in winding
- Phase-ground faults in winding
- Ground faults in the rotor

Abnormal Conditions

- Loss or insufficient excitation
- Overload
- Overvoltage
- Under and Over frequency
- Unbalance current
- Inadvertent energization
- Out of step (loss of synchronism)
- Loss of prime mover (motoring)

Protective Relays

- Over voltage protection
- Over fluxing protection
- Low forward power and reverse power protection
- Dead machine protection
- Stator over current protection
- Rotor Over current protection
- Generator Loss of excitation protection
- Generator negative phase sequence protection
- Back up distance protection
- Shaft damage protection
- Under frequency protection
- Generator pole slipping protection
- UAT breaker failure protection

Protection Schemes

- Generator differential
- Generator and generator transformer overall differential
- Transformer (GT-UAT) differential
- Inter turn fault
- Generator rotor earth fault
- Generator stator earth fault
- UAT differential
- Generator transformer restricted earth fault
- Fire protection for GT and UAT

Protection Schemes (contd..)

Backup protection

- GT backup over current protection
- GT neutral over current protection
- UAT backup over current protection
- Distance protection of generator
- UAT (LV side) earth fault protection

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Function number for generator protection

- Ground Fault (50/51-G/N, 27/59, 59N, 27-3N, 87N)
- Phase Fault (51, 51V, 87G)
- Backup Remote Fault Detection (51V, 21)
- Reverse Power (32)
- Loss of Field (40)
- Thermal (49)
- Fuse Loss (60)
- Over excitation and Over/Under voltage (24, 27/59)
- Inadvertent Energization (50IE, 67)
- Negative Sequence (46, 47)
- Off-Frequency Operation (81O/U)
- Sync Check (25) and Auto Synchronizing (25A)
- Out of Step (78)

IEEE Function number for generator protection

IEEE No	Function	IEEE No	Function
24	Over excitation	50/51N	Stator ground over current (Low, Med Z Gnd, Neutral CT of flux summatin CT)
25	Synchronism check	51GN, 51N	Stator ground over current (High Z gnd)
32	Reverse power (one stage)	51VC	Voltage controlled overcurrent
32-1	Reverse power, Non electrical trip supervision	51VR	Voltage restrained overcurrent
40	Loss of field (Var flow approach)	59N, 27-3N, 59P	Ground overvotlage
46	Negative sequence overcurrent	67IE	Directional O/C for inadvertent energization
49	Stator temperature (RTD)	81	Over/Under frequency
50/87	Differential via flux summation CTs	87G	Generator phase differential
50/27IE	Inverdent energization overcurrent with 27, 81 supervision	87N	Generator ground differential
51N	Stator ground over current (Low, Med Z ground, Phase CT residual	87UD	Unit differential

Stator Earth Fault Protection

95% Stator Protection

- Neutral Overvoltage Scheme
- Overcurrent Scheme

100% Stator Protection

- 3rd Harmonic Under-voltage Scheme
- Neutral Injection Scheme

95% Stator – Ground fault protection

- Provided by a neutral voltage relay with harmonic restraint and adjustable time delay

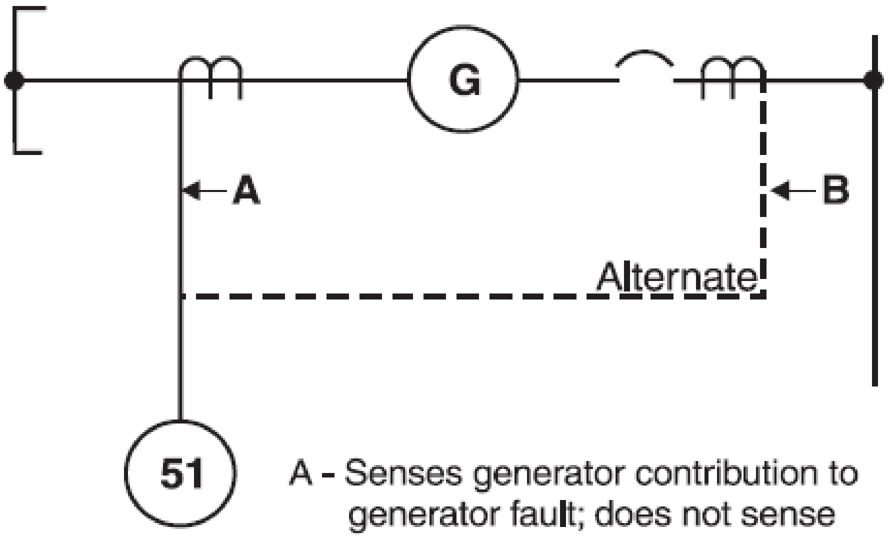
- The relay is fed either from a neutral voltage transformer or from the broken delta winding of 3-phase voltage transformers on the generator line side

- Normally set to operate at 5% of the maximum neutral voltage with a delay of 0.3 to 0.5 seconds

Generator phase fault protection

Generator over current protection should be delayed and co-ordinated with downstream faults.

Manufacturers of generator generally set the typical or minimum value. Lack of proper co-ordination results in generator tripping to downstream faults.



A - Senses generator contribution to generator fault; does not sense utility contribution to generator fault.
B - Senses utility contribution to generator fault; blind to generator fault when breaker open and when running isolated from utility.

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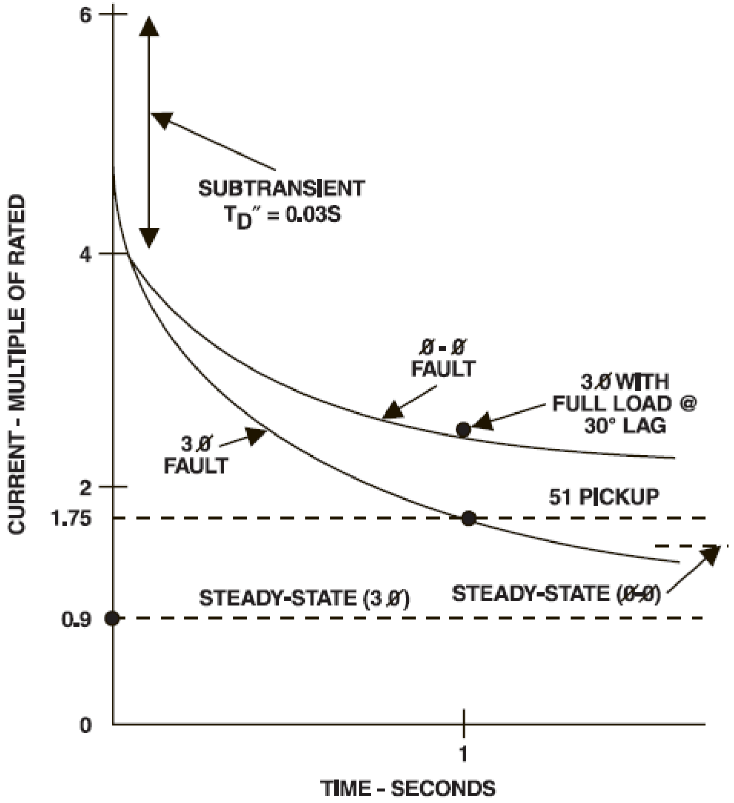
Generator fault current

- Sub transient current
- Transient current
- Steady state current

- Xd” : 0.15pu to 0.25pu
- Xd’ : 0.25pu to 0.3pu
- Xd : 1pu for Hydro
  2pu for Thermal.



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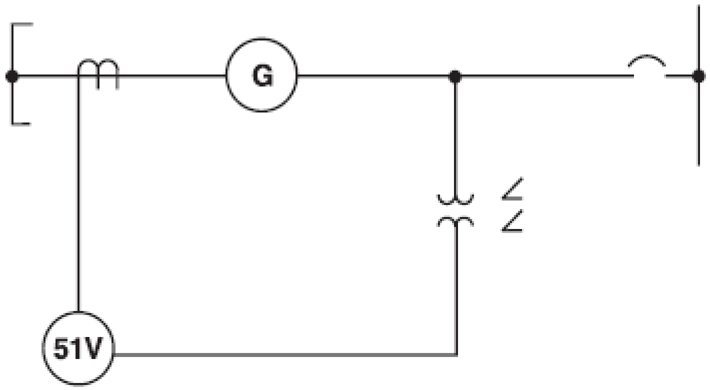
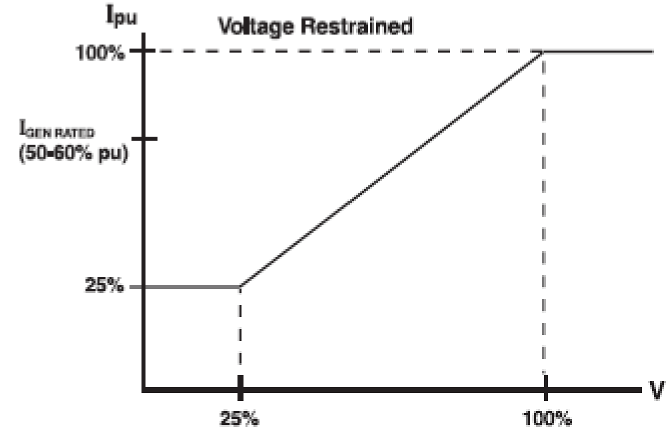
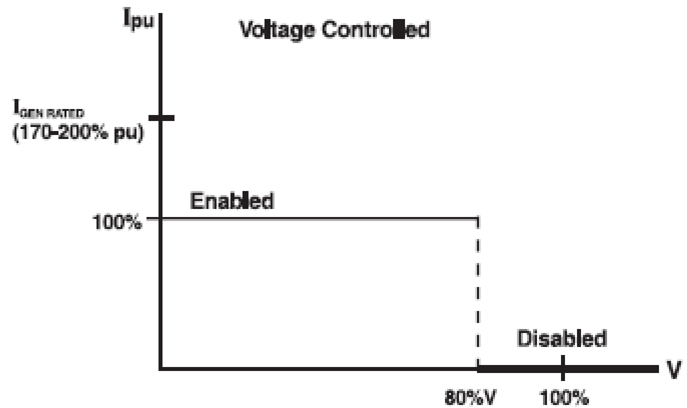
Voltage restrained or voltage controlled over current relay





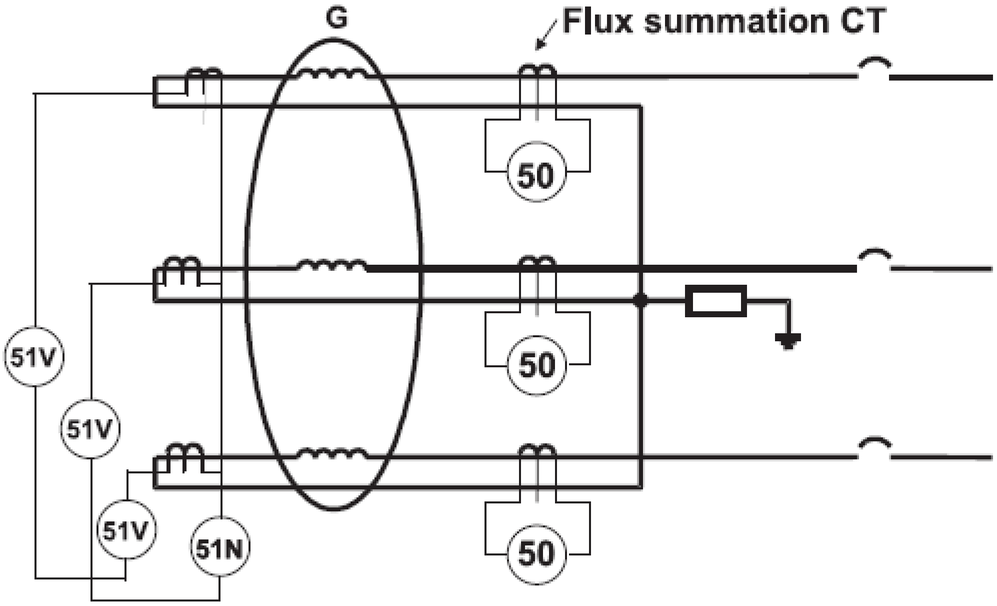
Voltage restrained –
If the voltage falls, the pickup will be at the reduced current.



Voltage controlled –
Enabled if the voltage falls below the pre-set value.

Differential protection

- Flux summation CT acts as sensitive differential protection.



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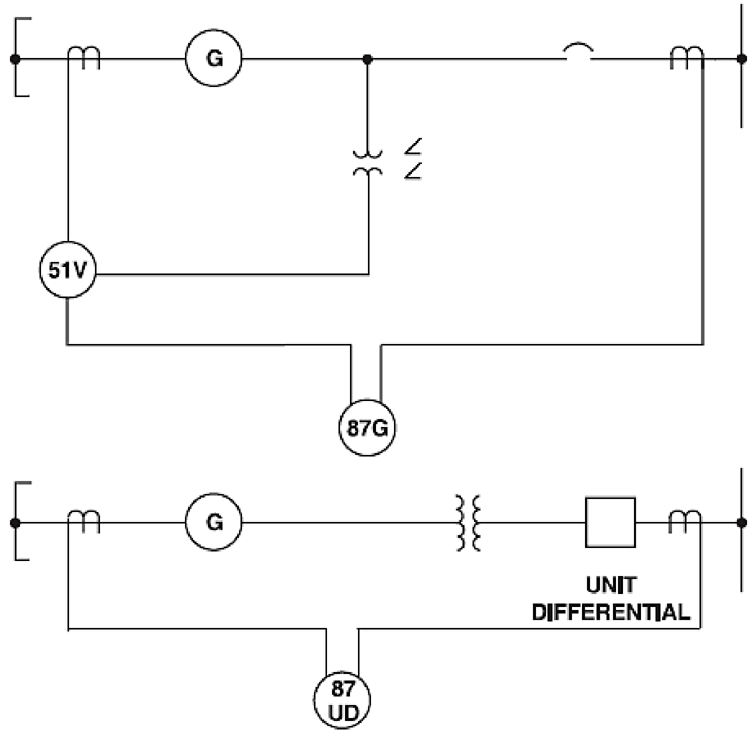
Generator differential and unit differential scheme.

Only generator is covered
in case of generator breaker

Generator and generator transformer are covered in case of breaker only at HT side.

Overall differential protection Covers generator, generator transformer and UAT.

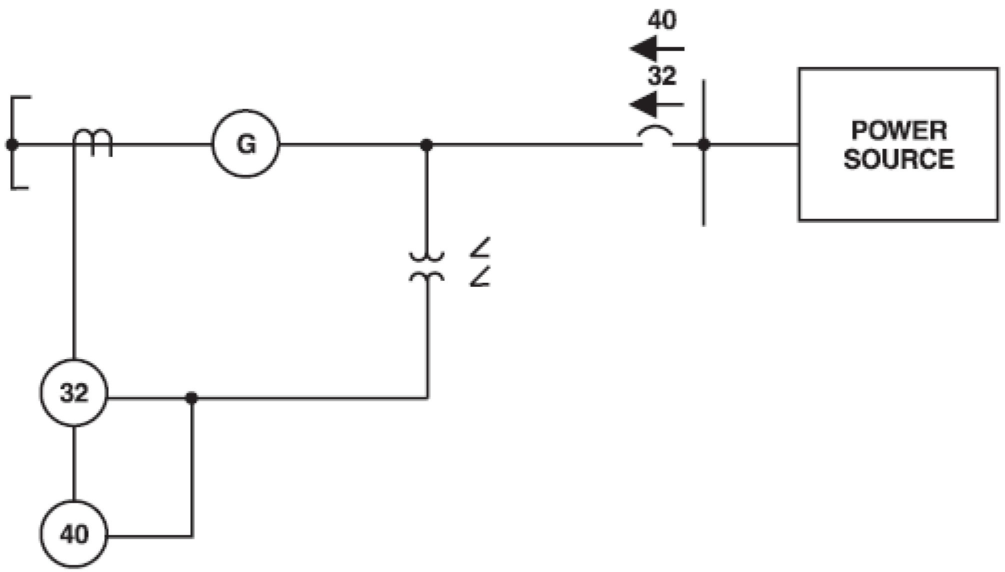


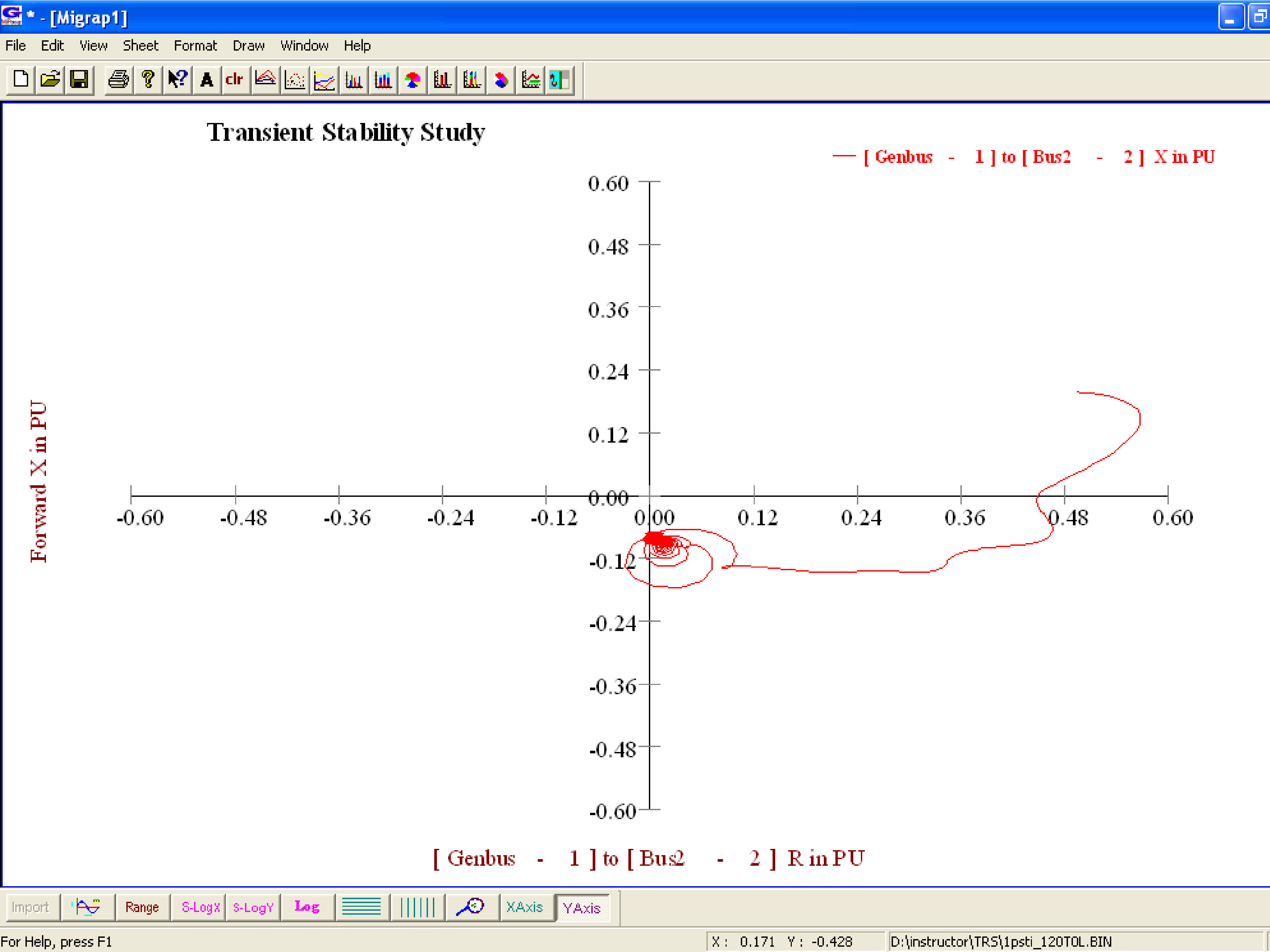
Reverse Power Relay

- This relay is for the protection of Prime Mover (Turbine or motor)
- If the driving torque becomes less than the total losses in the generator and the prime mover, the generator starts to work as a synchronous compensator, taking the necessary active power from the network
- In case of steam turbines, a reduction of the steam flow reduces the cooling effect on the turbine blades and overheating may occur
- For thermal units, this setting is normally 1%

Anti-motoring (32) and loss of field (40) protection

- Senses the voltage and current.
- Can be used as reverse power or low forward power relay.
- Generally set at 0.5% with 3-5 sec. time delay.
- Should never be instantaneous to avoid tripping during synchronization.




* - [Migrap1]
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clr
Transient Stability Study
[Genbus - 1] to [Bus2 - 2] X in PU
Forward X in PU
0.60
0.48
0.36
0.24
0.12
0.00
-0.12
-0.24
-0.36
-0.48
-0.60
-0.60
-0.48
-0.36
-0.24
-0.12
0.00
0.12
0.24
0.36
0.48
0.60
[Genbus - 1] to [Bus2 - 2] R in PU
Import
Range
S-LogX
S-LogY
Log
XAxis
YAxis
For Help, press F1
X : 0.171 Y : -0.428
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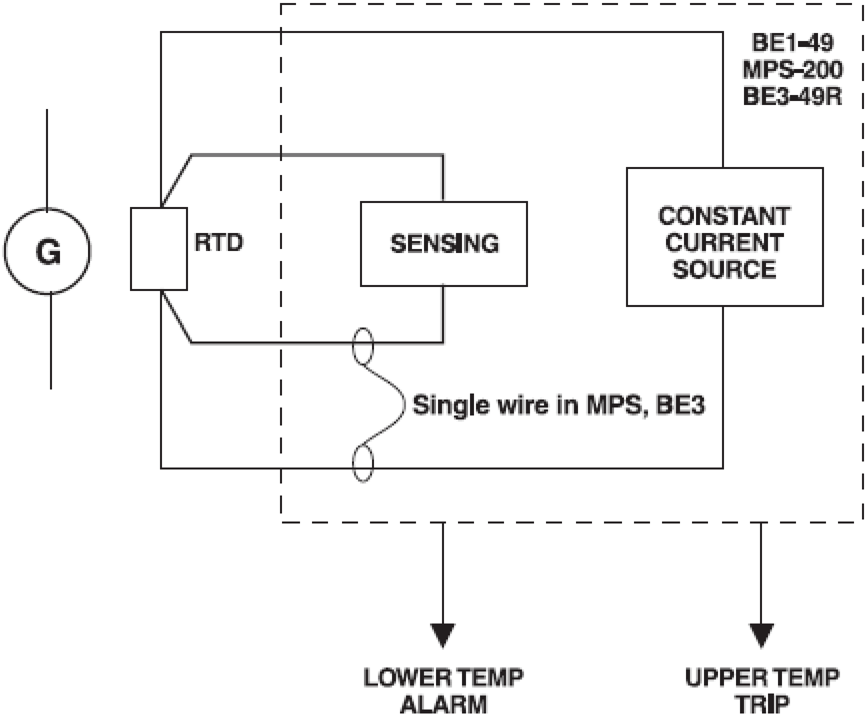
Stator temperature (thermal) protection

- Resistance temperature detector (RTD) embedded in the stator slot is used for temperature measurement.
- Relay provides a constant current source to measure the voltage across the RTD.
- It is possible to have two settings, one for alarm and the other for tripping.



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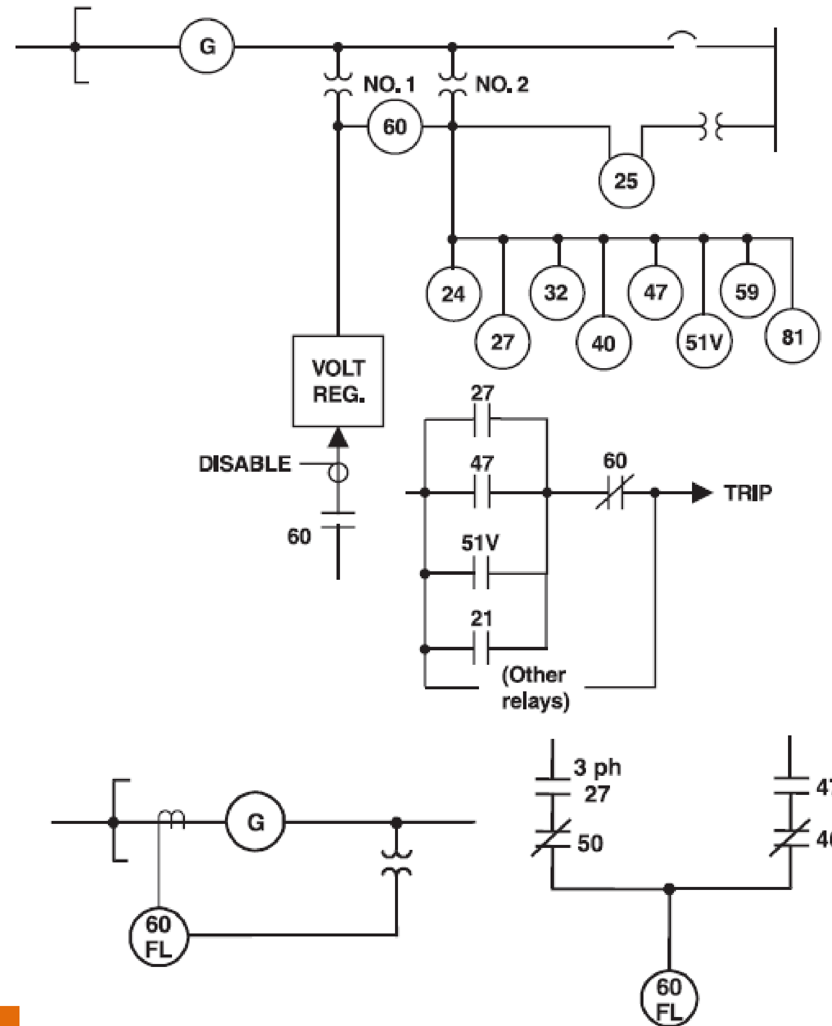
Loss of VT detection

- The operation of voltage based relays should be blocked during loss of VT.
- Achieved by comparing the voltage of two VTs.
- Can also be achieved by voltage and current comparison



60 Logic

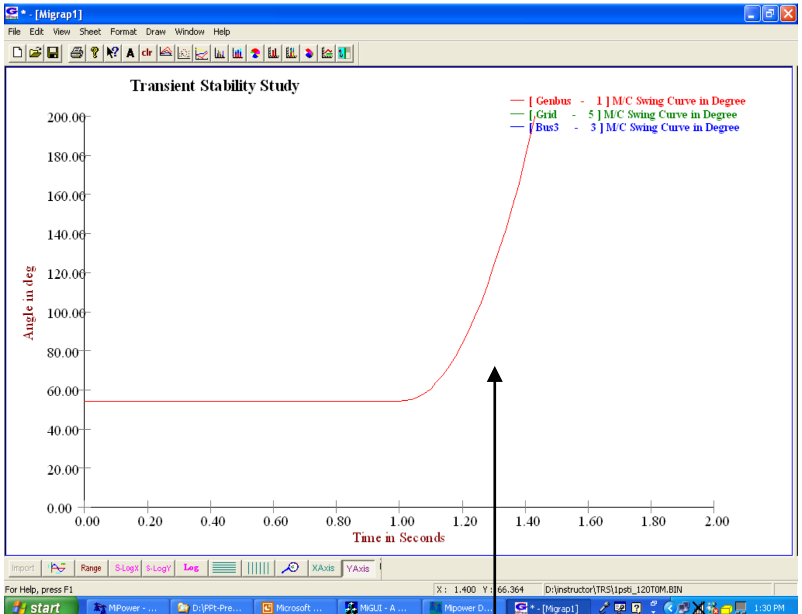
Out of Step Operation

- Causes
  - Loss of excitation with resulting asynchronous running
  - Falling out of step with existing excitation intact, as a result of faults in the system
- Due to Generator out of step operation, alternating mechanical stresses are impressed on generator stators, rotors, shafts and coupling
- Cyclic depression of the rms voltage supplied to loads may severely disturb operation of consumer drivers through synchronous motors falling out of step and induction motors stalling

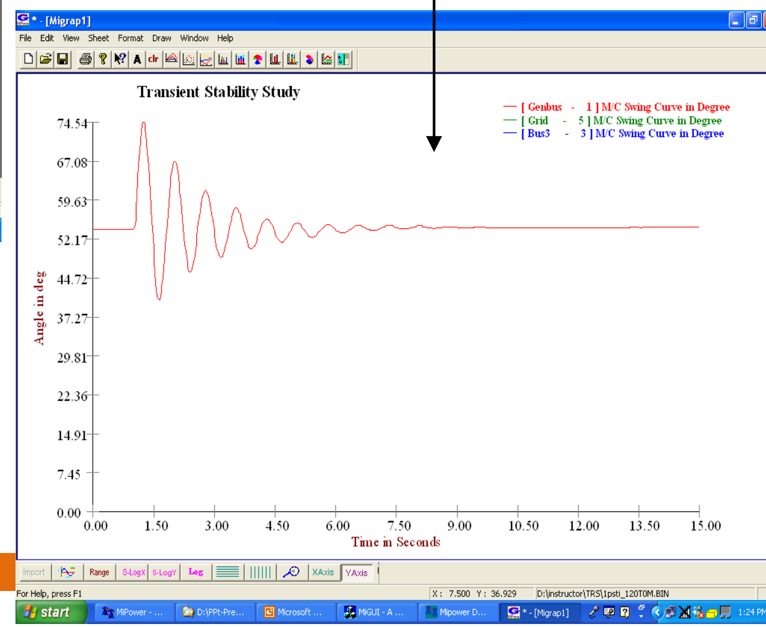
Out of Step Operation

- Out of step operation starting with generator or part of the system may spread to the other parts of the system and system may collapse
- Out of step conditions which result from short circuits in the system persist for some time and are characterized by strong oscillation of the reactive and active power
- Presently offset mho relays are being employed for the detection of loss of excitation and loss of synchronism condition

Out of step protection



Rotor angle for fault cleared within the critical clearing time



Rotor angle for fault cleared beyond the critical clearing time.

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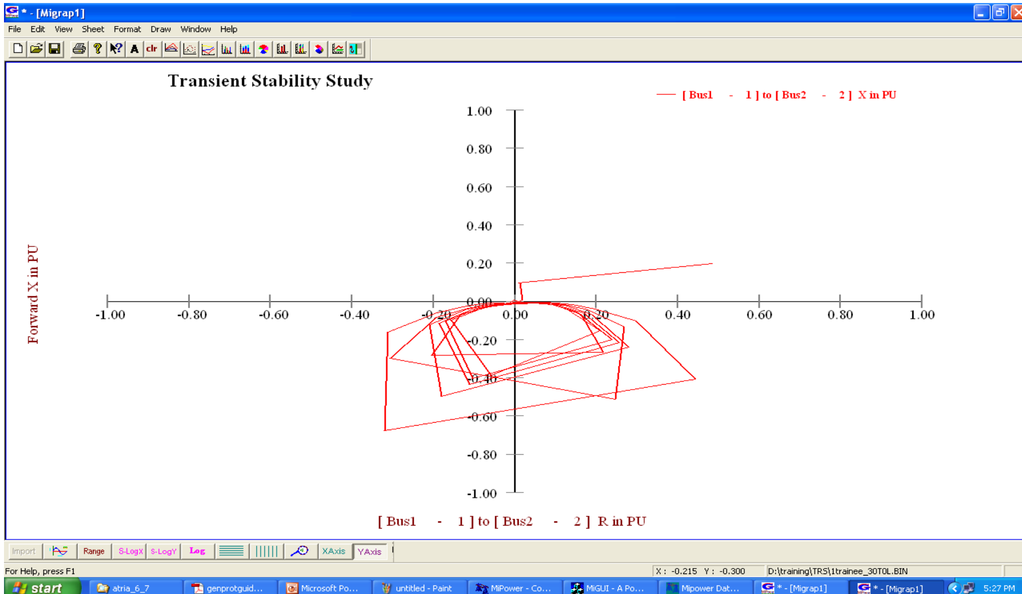
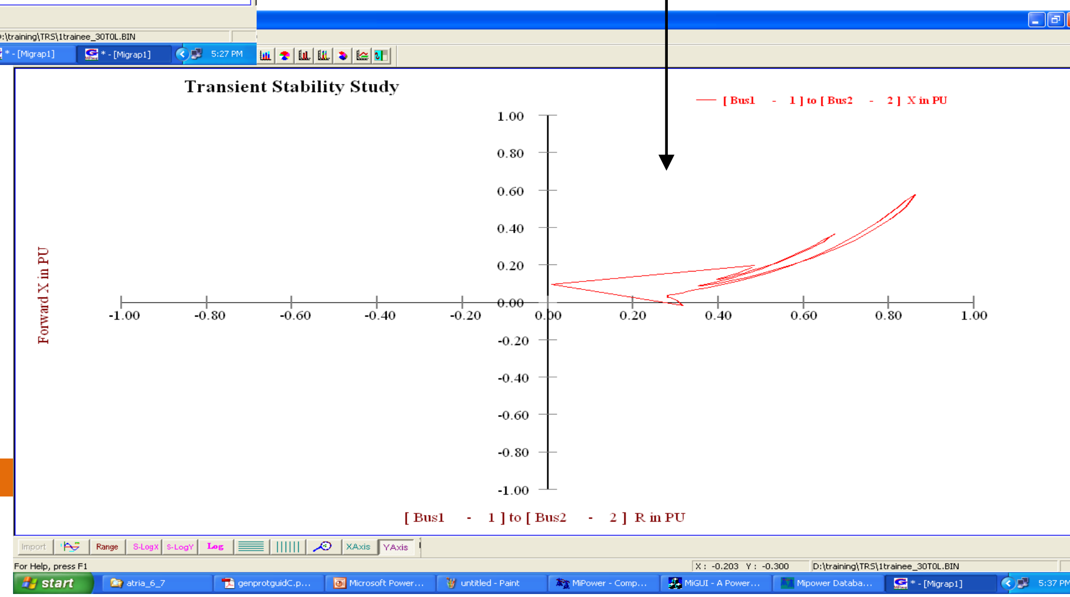
Out of step operation



Fault cleared within the critical clearing time



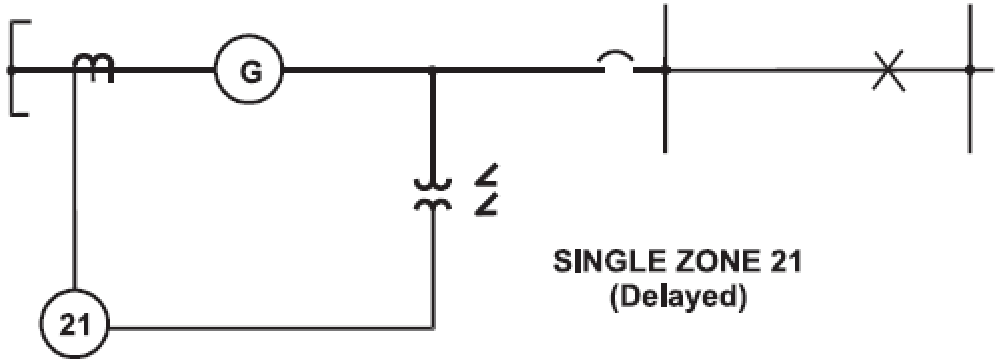
Fault cleared beyond the critical clearing time.

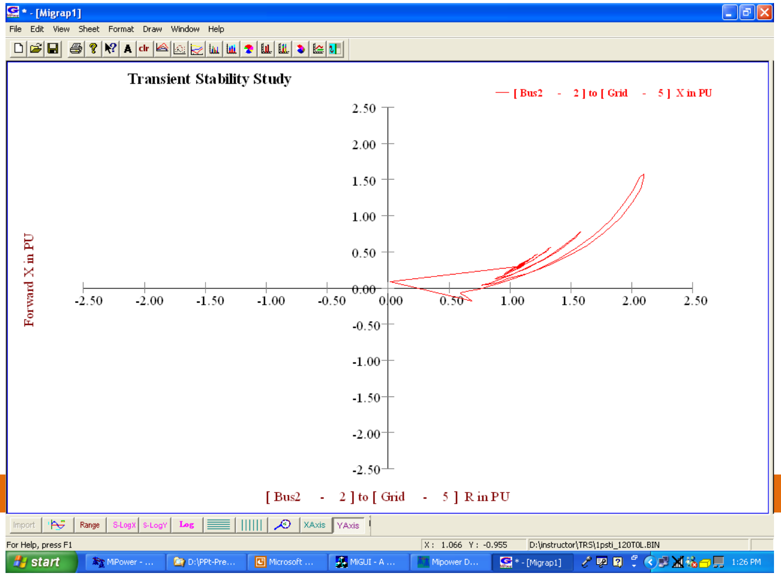
Generator Backup Impedance Relay

- A three phase impedance relay with a circular operating characteristics
- This is mainly intended as back up short circuit protection to the differential relays of generators and to the line relays of network
- Relay must be able to operate even when the fault current is lower than the rated current and likewise in the even of close up faults when the output voltage from the generator disappears
- If the voltage drops to zero volts the relay operates for a current as low as 20% of the rated current
- The relay is normally set to operate at 70% of the generator load impedance

Generator impedance relay

- An impedance relay can also be used to detect the external fault.
- CT position is generally after the generator unit.
- Operation is always time-delayed.





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Generator Impedance Relay

Example

Consider a generator of

141.5 MVA 10.5 kV 50 Hz 0.85 pf

Assuming generator is operating at 95 % of the rated terminal voltage, the load impedance is given by

$Z_{load} = (10.5 \times 0.95)^2/141.5 = 0.70318\ \Omega$/phase

Assuming 1.4 times the rated current, the primary side impedance is approximately equal to 0.4922 Ω

Generator Impedance Relay

Secondary side impedance is given by

[CT ratio : 9000/5 PT ratio : 10.5 kV/110 V]

$Z_{LOAD\text{-}Secondary} = (110/10.5 \times 10^3) \times 9000/5 \times 0.4922$

$= 9.282\ \Omega$

The impedance relay is set around 9 Ω with a time delay of 0.5 to 1 second

Interlock Over Current Relay

This is a breaker failure relay

- Introduced due to shorter and shorter fault clearing times
- Each circuit breaker is provided with a local backup protection scheme
- If a power circuit breaker is unsuccessful to clear a fault say due to a struck breaker pole adjacent circuit breaker is tripped by the breaker failure relay after pre-set time
- This relay provides local back up protection when a primary circuit breaker has failed to operate
- It also initiates tripping of adjacent back up breakers for disconnection of the fault, thus preventing system instability

Generator Over Voltage Relay

- Automatic Voltage regulator : controls the terminal voltage, during the starting up of a generator prior to synchronization
- After synchronization, the terminal voltage of the machine is dictated by its own AVR and the AVR's of the nearby machines
- If the generator CB is tripped while the machine is running at full load and rated pf, the subsequent rise in terminal voltage will normally be limited by a quick acting AVR

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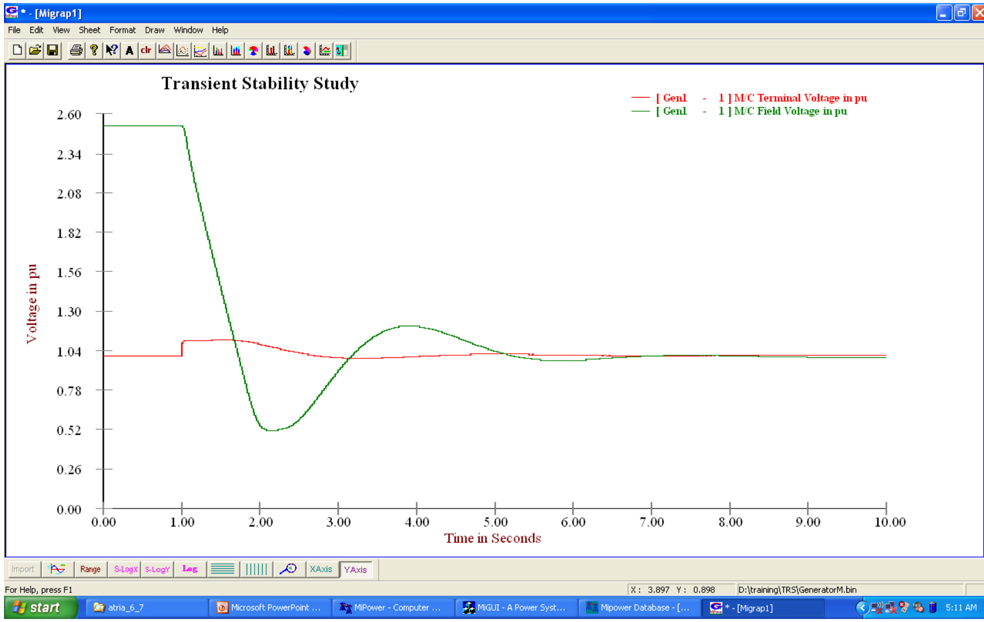
Over Voltage Relay

- However, if the AVR is faulty, or at this particular time, switched for manual control, severe over voltages will occur
- This voltage rise will be further increase if simultaneous over speeding occurs, owing to a slow acting Turbine-Governor System



Overall Differential Protection Relay

- Relay with three fold restraint namely
  - ✓ Through fault restraint for external faults
  - ✓ Magnetising inrush restraint
  - ✓ Over excitation restraint to counteract operation at abnormal magnetizing currents caused by high voltage

Overall Differential Protection Relay

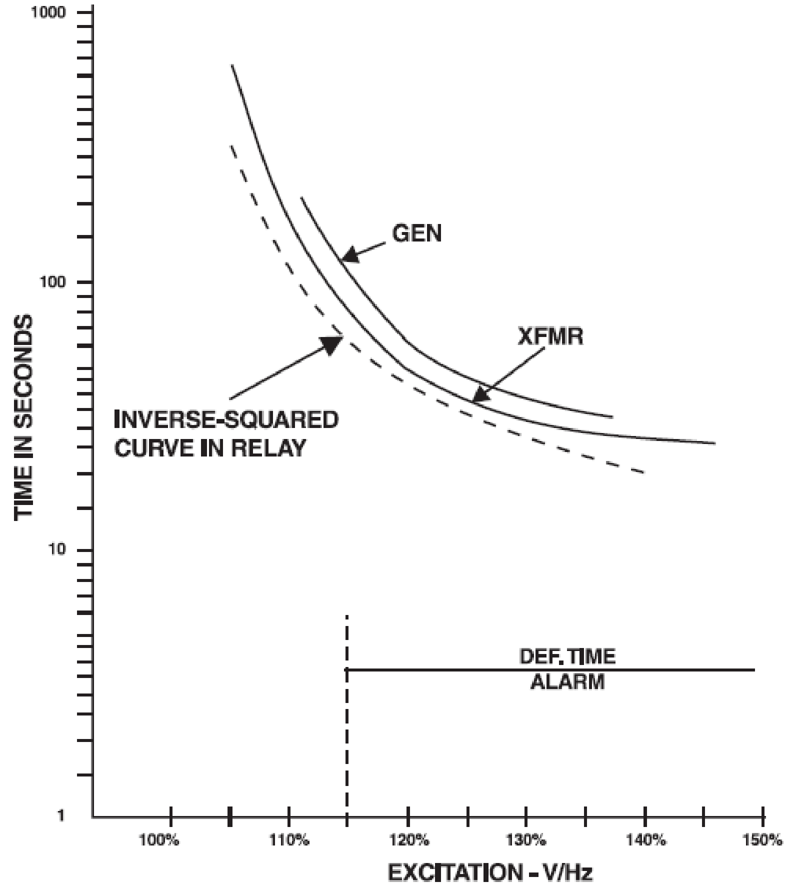
- During normal conditions, a small current flows through the differential circuit of the relay. This current corresponds to the excitation current of the power transformer and to a current depending on the ratio error of the CT's
- With power transformer with tap change, at rated load and with the tap changer in extreme end position, differential current may be 20-30%

GT Over-fluxing Relay Detection

- The excitation flux in the core of a power transformer is
  - ✓ Directly proportional to the excitation voltage
  - ✓ Inversely proportional to the frequency
- The losses due to eddy currents and hysteresis and hence the temperature rise, increase in proportion to the level of excitation
- As long as the GT is connected to the network, the risk of over excitation is relatively small
- However when the GT is disconnected from the network, there is an obvious risk of over excitation, mainly during generator start up and shut down

Over excitation relay

- Over excitation occurs with higher voltage or at rated voltage and lower frequency.
- Inverse squared curve can be used for tripping and definite time for alarm.
- Over voltage and under frequency relays can also be used as back up to over excitation relay.



Over Excitation Relay

- The risk of over-excitation is largest during periods when the frequency is below rated value. Hence, over voltage relays alone cannot be used to protect the GT unit against over fluxing
- The proper way of doing this is to use a relay which measures the ratio between voltage and frequency (V/Hz relay)
- Modern power transformers are designed to operate at very high flux levels, very close to the ultimate simulation level
- Therefore, even a slight increase in the flux above the designed value saturates the core and forces the flux into areas which normally carry very little or no flux at all

Over Excitation

Causes

- Running or shutting down an alternator with the AVR in service. The regulator will attempt to maintain normal voltage regardless of frequency, and hence at sub normal frequency, the connected generator transformer will be over excited
- Similar effect to above can occur if the alternator is started up with the manual control set inadvertently to a very high level of excitation, the AVR being out of service as per normal practice. The resultant voltage to frequency ratio will be excess of normal value

Over Excitation

Causes (contd..)

- A deliberate attempt to export a large VAR component as an aid to system control results in a over fluxing condition in a transformer, the control operation usually consists of leaving the AVR control normal but operating the tap changer to reduce primary turns which results in a higher voltage per turn and hence, an increase in flux

- With the transformer connected to the bus, the bus voltage being greater than the rated value, operation of the tap changer over its full range as a maintenance operation can also produce over fluxing conditions

Line Backup Impedance Relay

- For large generators, an extra impedance relay with short time delay of 15-200 ms is sometimes included to obtain a fast backup protection for phase short circuit on the generator terminals, the generator bus and the low voltage winding of the unit transformer
- A circular impedance characteristic is used for this application and the relay is set to operate at 50-60% of the unit transformer short circuit impedance. Assuming relay is located at the generator terminal

Line backup relay

Example

CT ratio is 9000/5 and PT ratio 10.5 kV/110kV

Generator transformer impedance (primary side)

$Z_{GTprimary} = 0.13 \times 10.5^2/140 = 0.1023\ \Omega$

$Z_{GTSecondary} = 0.1023 \times 9000/5 \times 110/10.5 \times 10^3$

$= 1.93\ \Omega$

Assuming that the maximum loading of the GT is 150 MVA (worst condition loading)

$Z_{load\ min}$ on the primary side $= (10.5)^2/150 = 0.735\ \Omega$

Line backup relay

$Z_{load\ min}$ on the secondary side

$= 0.725 \times 9000/5 \times 110/(10.5 \times 10^3)$

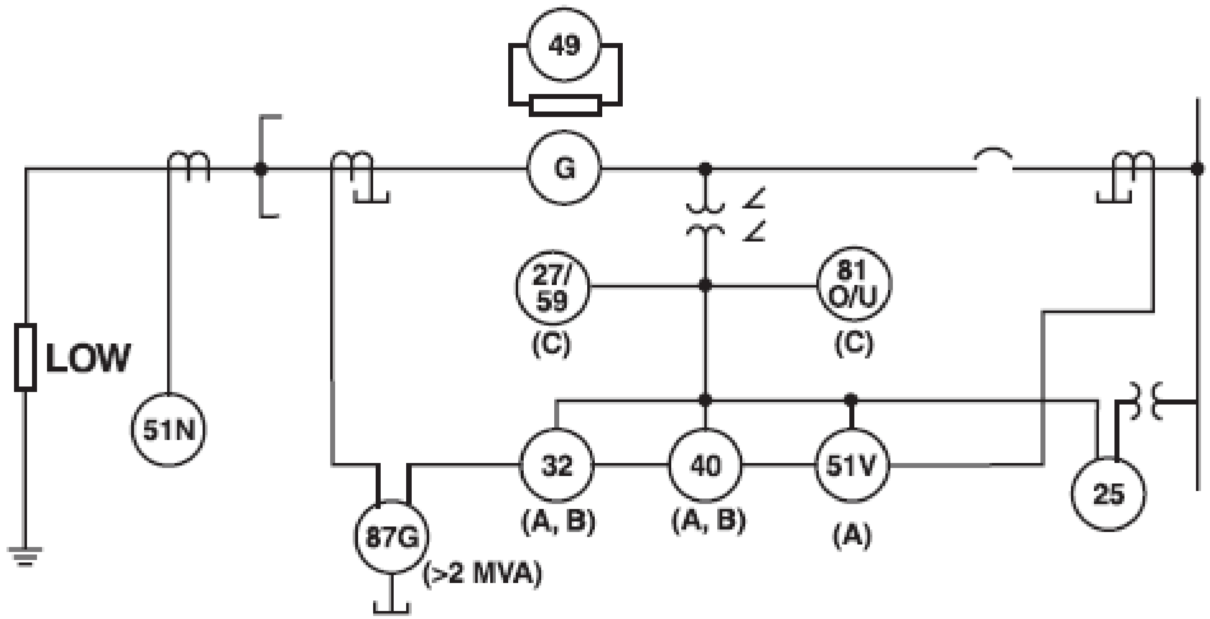
$= 13.84\ \Omega$

This implies that the relay setting should be less than this value $Z_{(load)min}$ to avoid load encroachment problem.

Also, 50% of $Z_{load\ min} = 6.92\ \Omega$

Thus $Z_{load\ min} = 6.92 – 1.93 = 4.99\ \Omega$

Suggested bare minimum protection for low impedance grounded generators

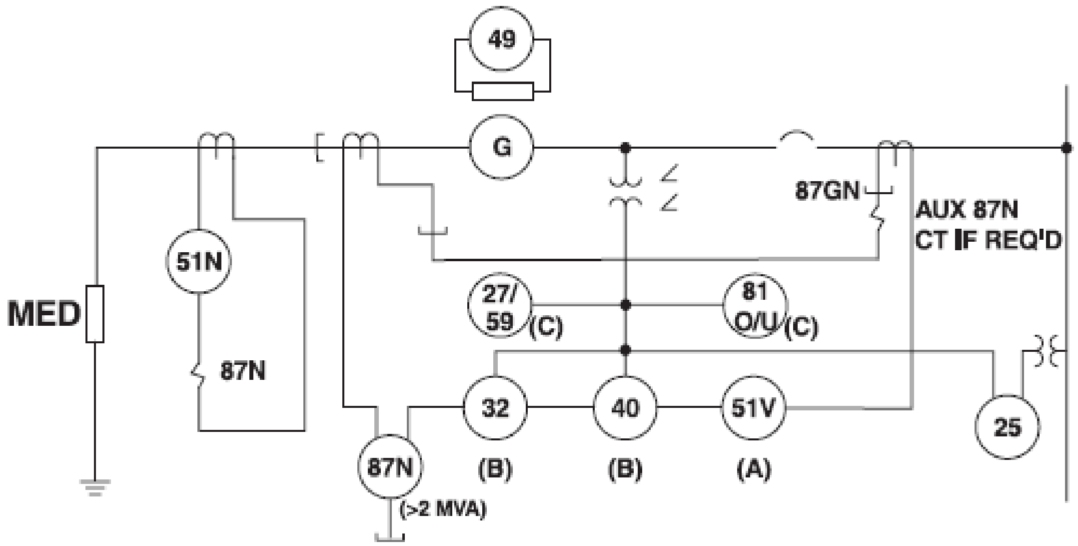


(A) CONNECT TO NEUTRAL-SIDE CTS IF NO EXTERNAL POWER SOURCE OR NO 87B.

(B) OMIT IF NO EXTERNAL POWER SOURCE.

(C) LESS CRITICAL.

Suggested bare minimum protection for medium impedance grounded generators

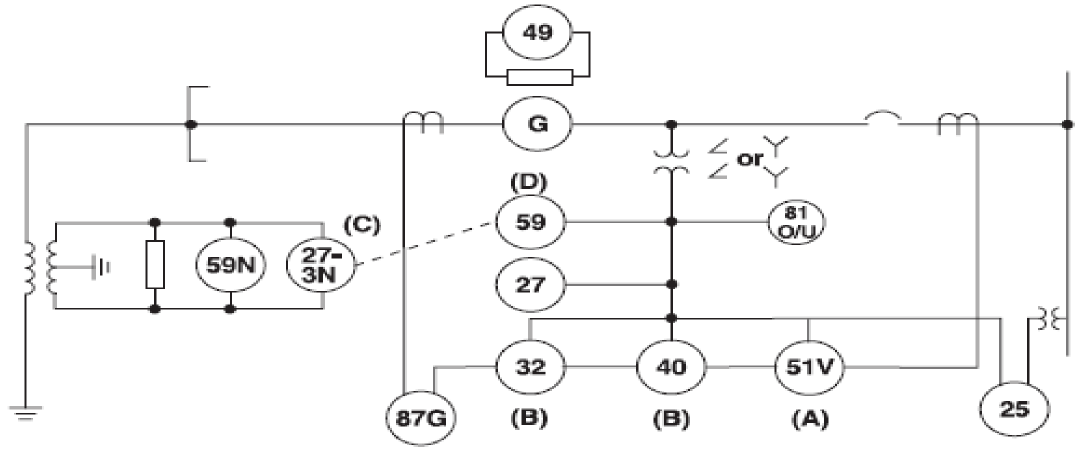


(A) CONNECT TO NEUTRAL-SIDE CTS IF NO EXTERNAL POWER SOURCE.

(B) OMIT IF NO EXTERNAL POWER SOURCE.

(C) LESS CRITICAL.

Suggested bare minimum protection for high impedance grounded generators



(A) CONNECT TO NEUTRAL-SIDE CTS IF NO EXTERNAL POWER SOURCE.

(B) OMIT IF EXTERNAL POWER SOURCE.

(C) INCLUDED IN 59N RELAY.

(D) SUPERVISES 27-3N TRIP.

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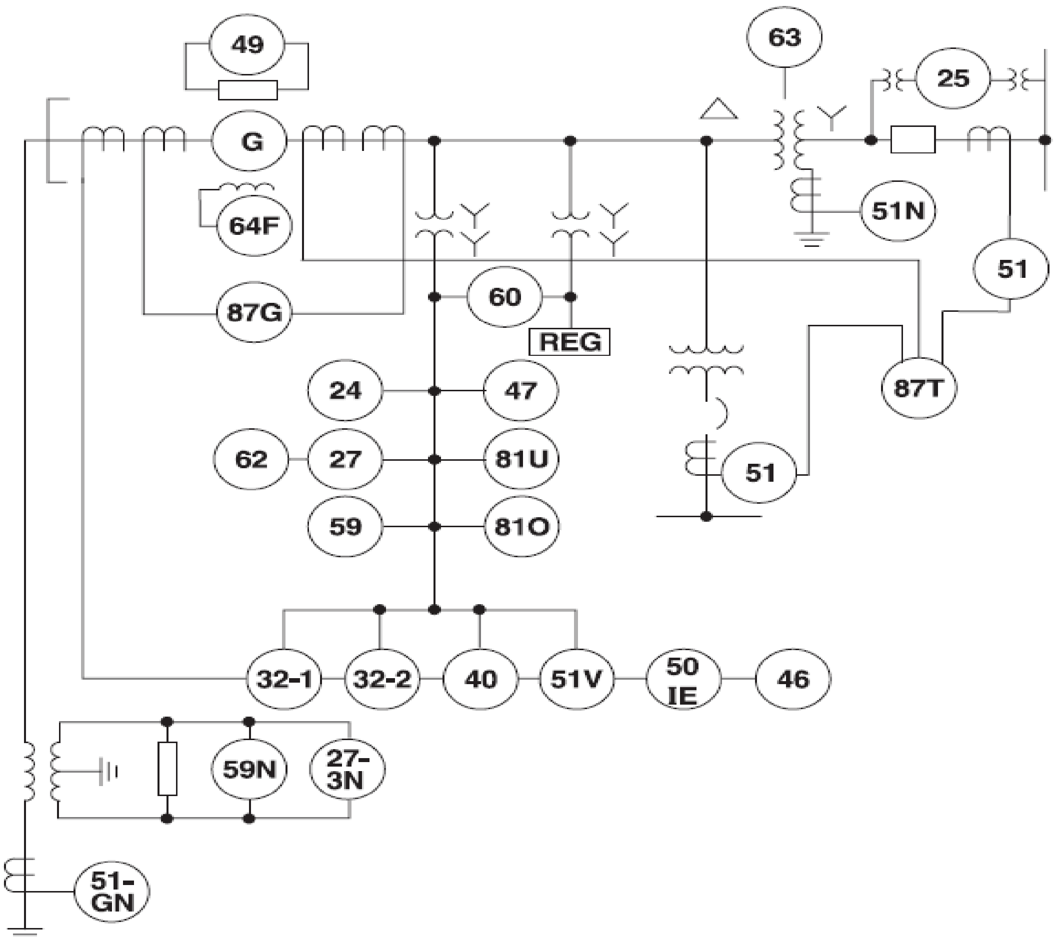
Extended protection for high impedance grounded generators



Reference

- **Generator Protection Application Guide by Basler Electric / other relay manufacturers.**

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Queries & Discussion

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Thank You

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Frequency Relays

Contents

- Introduction
- Under Frequency Relay
- dF/dT Relay
- Design of Load Shedding Scheme
- Example Problem
- Simulation of Frequency Relay Using MiPower

Introduction

- Load Generation balance
- Mismatch in load and generation results in frequency change
- Machine frequency limits
- Tripping of machine to prevent damage, resulting in black out condition
- Use of frequency relay to maintain L-G balance
- Types of frequency relay
  - Over frequency relay
  - Under frequency relay
  - dF/dT relay

Under Frequency Relay

- When Pm < Pe, results in deceleration of machine and frequency decreases below nominal
  - ✓ P_m = Mechanical Power input to Generator
  - ✓ P_e = Electrical Power output of generator
- Generally used to throw off load in order to obtain equilibrium between Pm and Pe
- Operates when the system frequency falls below the set point
- In industrial systems can also be used for islanding

... Continued

- Relationship between variation in frequency and Load generation mismatch can be given by
- $dF/dT = P_A \; f_0 / 2 \; G \; H$ -------(1), where
  - ✓ G= Nominal MVA of machine under consideration
  - ✓ H= MWs/MVA or MJ/MVA
  - ✓ f_0= Nominal frequency
  - ✓ P_A = Net accelerating or decelerating Power
- Operates when the rate of frequency change in above the set point.

dF/dT relay

- In case of group of generators the inertia constant H is calculated from
  - $H = (H_1 * MVA_1 + H_2 * MVA_2 + \ldots\ldots\ldots) / (MVA_1 + MVA_2 + \ldots.)$
  - Where 1,2 etc. refer to individual generators in the group
  - and H is expressed to a MVA base equal to the total MVA capacity of the group

Design of Load Shedding scheme

- Following need to be defined for design of Automatic Load shedding System
  - A model that defines different Generating Machines
  - Load Parameters
  - Criteria for setting Frequency Relays

...Continued

- Model :
  - A single machine is considered to illustrate Load Shedding Scheme
  - It can also be considered as an equivalent to a number of machines electrically connected with negligible oscillations among themselves
  - Loads are represented as constant Power, neglecting the change in load due to variation in Voltage and frequency.

...Continued

The rate of change of frequency is calculated using eqn. (1) with the assumptions:

- Mechanical Power entering the Machine remains at the initial value (for purpose of hand calculation)
- Load does not change wrt time, voltage or frequency, it only gets reduced due to load shedding

...Continued

Following parameters need to be defined to implement a Load shedding Scheme

Maximum Load that can be disconnected and identify the loads to be disconnected in a sequence

- Quantum of load to be disconnected depends on loss of generation or import from the utility

Starting frequency of Load shedding scheme

- It should be below the system normal working frequency range
- Should be coordinated with islanding relay setting

Minimum permissible frequency

- Running below nominal speed at reduced system frequency can cause cumulative damage by excessive vibration. Table shows typical allowable operation durations at reduced frequencies

... Continued

% of rated frequency at full load	Max. permissible Time (Min.)
99.0	Continuously
97.3	90
97.0	10
96.0	1

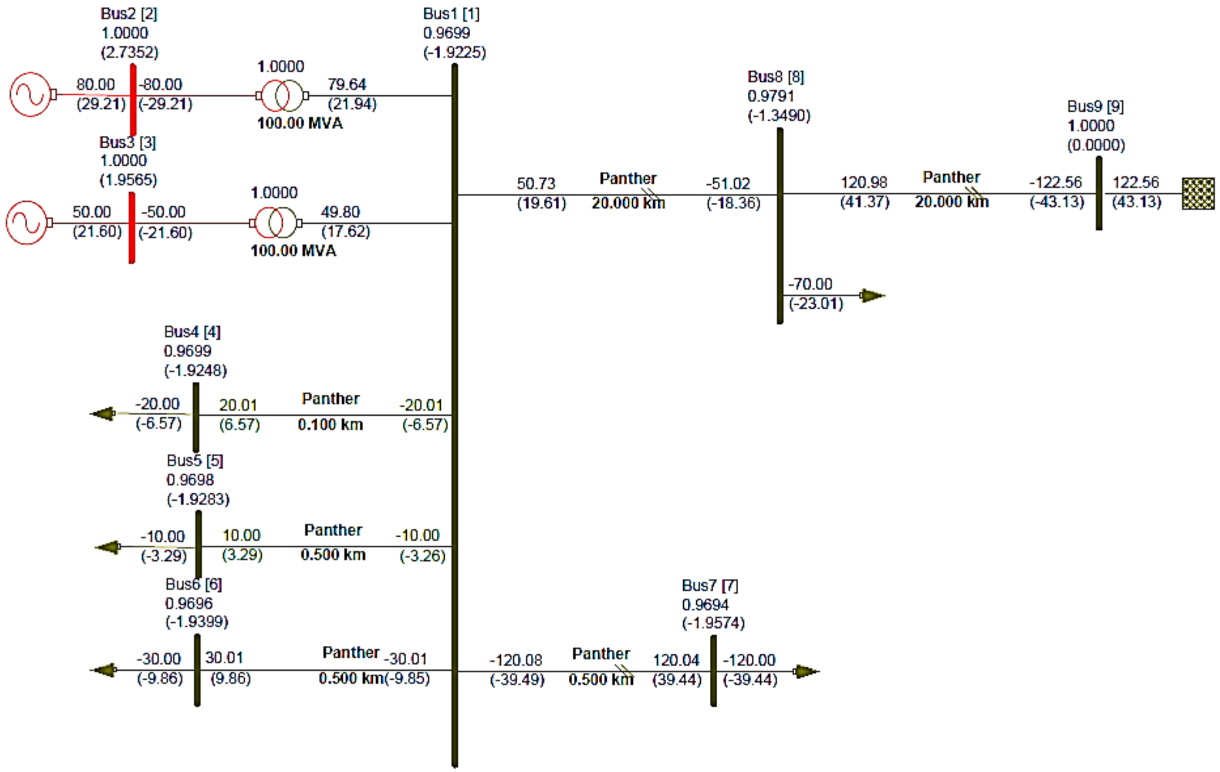
- Operating times at low frequency and full load are cumulative
- However, in majority of cases, during transient conditions with load below nominal, reduction of frequency to 93% is permitted without causing damage to turbine or TG auxiliary lubrication and cooling systems.

… Continued

- Setting of Frequency Relays
  - Settings should be such that final settings satisfy both speed and coordination
  - It is to be ensured that least amount of load is shed depending on initial over load condition
- Determination of operating times:
  - Operating times which indicate final effective load disconnection for successive stages of load shedding should be worked out considering the relay pickup time, intentional delay introduced and the breaker operating time
  - For industrial systems relay pickup time of 50ms and breaker operating time of 100ms are usually considered

Example

- SLD of the system under consideration



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System Data

- Gen 1 – 100 MVA, Inertia constant = 3 MJ/MVA
- Gen 2 – 62.5 MVA, Inertia constant = 2.5 MJ/MVA
  - H_{eff} = (100*3)+(62.5*2.5) / 162.5 = 2.8
  - GH constant = 162.5*2.8 = 455
- Total Generation = 130 MW
- Total Load = 180 MW
  - Critical = 120 MW
  - Non Critical = 60 MW
- Import = 50 MW
- System frequency = 50 Hz

... Continued

- Over load considering total loss of grid :

  % Over load = (180-130)/130 * 100 = 27.8 %
- Total Load to be shed = 50 MW (120 MW of critical load)
- Frequency at which load shedding will start = 48.2 Hz
  - Such that it is coordinated with grid islanding relay setting
- Minimum acceptable frequency = 47.5 Hz
  - Such that it is coordinated with the machine under frequency setting
- The entire load shedding is divided into three stages based on priority of load
  - Stage 1 – 20 MW
  - Stage 2 – 10 MW
  - Stage 3 – 30 MW

... Continued

- Determination of Frequency Relay settings:
  - The settings are decided such that each stage is disconnected when the frequency reaches a predetermined value as shown below

First stage setting:

- First stage is disconnected when the frequency reaches 48.2 Hz

Second Stage setting:

- Second stage is to be set such that it does not operate for over loads of first stage
- An over load equal to 1st stage load is considered and rate of frequency drop is worked out as

  df/dt = (-20/2 G H)*50 = -1.09 Hz/s

  - Frequency as a function of time : $f_1 = f_0 - (df/dt)*t$

... Continued

- Trip time of first stage $t_{trip} = t_{pick\ up} + t_{breaker} + t_{relay}$
  - $t_{pick\ up} = (50-48.2) / 1.09 = 1.65$ s
- $t_{trip} = 1.65 + 0.1 + 0.1 = 1.85$ s
- Frequency drop up to operation of 1st stage is
  $= 50 – (1.09*1.85) = 48$ Hz
- Therefore second stage is set to operate below this frequency value @ 47.9 Hz and delay of 0.1 s.

Third Stage setting:

- Third stage is set such that it will not operate for over loads corresponding to stages 1 & 2 i.e. for an over load of 30 MW
  - df/dt corresponding to this = (-30/2 G H)*50 = -1.65 Hz/s
  - Pick up time for first stage relay at this rate = (50-48.2) / 1.65 = 1.09 s
  - Trip time of first stage t_{trip1}= 1.09+0.1+0.1 = 1.29 s
  - Frequency at this time = 50-(1.65*1.29) = 47.87 Hz

... Continued

- As second stage pick up is set at 47.9 Hz, 2nd stage pickup time is

  $t_{pickup2}$ = (50 - 47.9)/ 1.65 = 1.27 s
- t_{trip2} = 1.27+0.1+0.1 = 1.47 s
- After tripping of 1st stage load, there will be a change in rate of fall of frequency as after tripping of 1st stage , the deceleration power is only 10 MW
- The rate of fall is given by df/dt = (-10 /2 G H) *47.87 = -0.52 Hz/s
- After tripping of first stage f_0 = 47.87 Hz, therefore now we have (f-47.87) = -0.52*(t-1.27)

  i.e. f = 48-0.52*t
- Therefore frequency drop after 2nd stage tripping

  f = 48.53 - 0.52*1.47 = 47.75 Hz

– Therefore third stage pick up is set below this @47.65 Hz

Protection Analytic tool

Queries & Discussions

PSCT | Protection Analytic tool

Thank You

Electromagnetic Transient Analysis (ETA) & Overvoltage Studies

Contents

- Introduction
- System studies
- Electromagnetic Transient Analysis
- Need of Overvoltage studies
- Different types of Overvoltage studies
- Overvoltage protection

Introduction

Considerations for PSOC and design

1.Power quality: Maintain continuity of power supply at desired voltage and frequency levels

2. Reliability: Minimize loss of load probability or failure rate of components and systems.

3. Security: Robustness of system to remain in normal state, even if some contingency takes place.

4. Stability: Ability of system to maintain the synchronism under disturbances or to ensure steady state post disturbance operation.

5. Economy: Minimize capital cost, operating (running) cost and maintenance cost.

System studies

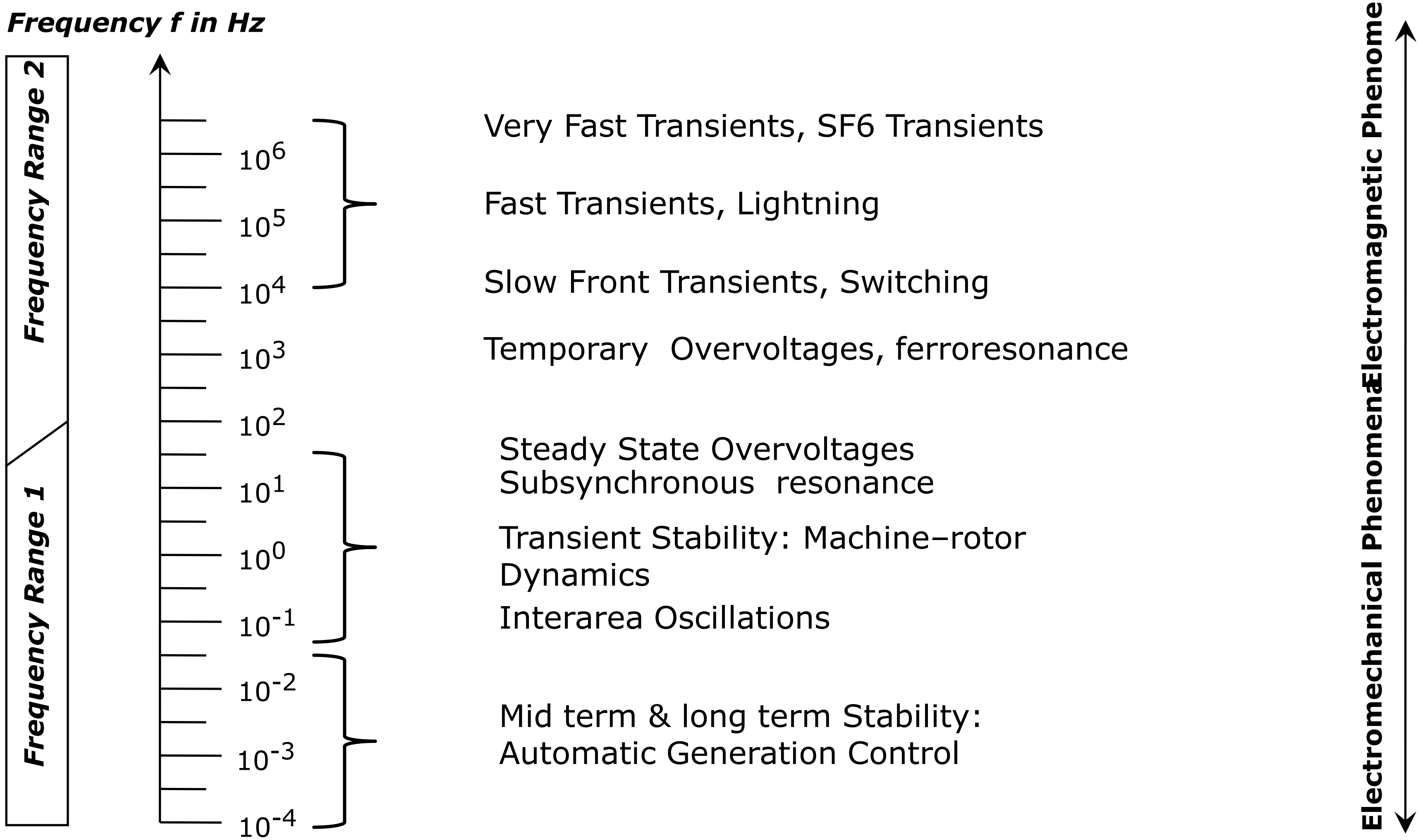
1.Power flow solutions

2. Short circuit studies

3.Transient stability analysis

4.Electromagnetic Transient Analysis (ETA)

Transients in power Systems



Transients in power Systems

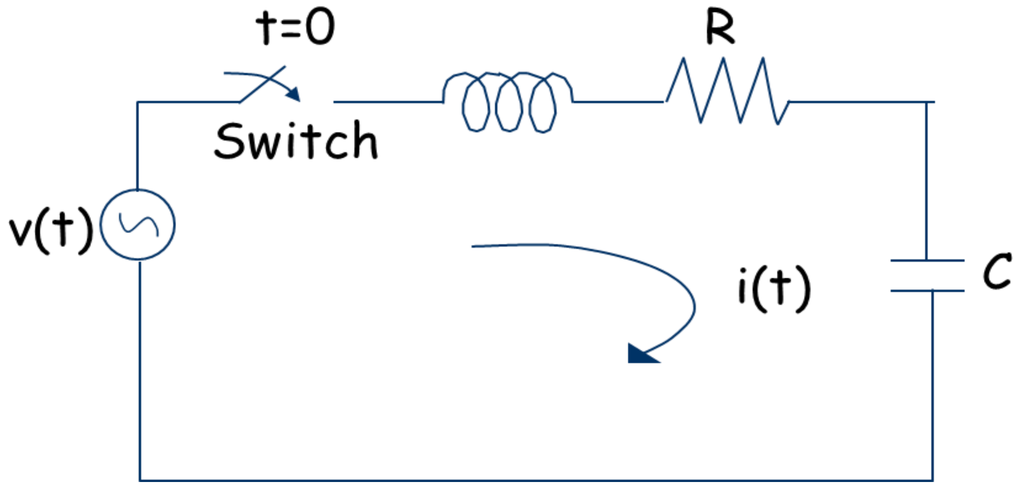
Electromagnetic Transients in Power Systems

Impulsive Transient

- Nanosecond 5ns rise
- Microsecond 1μs rise
- Millisecond 0.1ms rise

Oscillatory Transients

- Slow transient <5 kHz
- Medium transient 5-500 kHz
- Fast transient 0.5-5 MHz
- Very fast transient 5-50MHz



The differential equation for the circuit shown

$$Ri(t) + L\frac{di(t)}{dt} + \frac{1}{C}\int i(t)dt = V_m \sin(wt + \alpha)$$

Linear system ⟶ Laplace Transforms

The closed form solution is

$$I(s)\left[R + sL + \frac{1}{sC}\right] = V(s)$$

Polyphase and several loops → Not possible to use Laplace Transforms

Numerical methods → Time discretization

$$(\Delta T, 2\Delta T, \ldots\ldots)$$

$L\&\,C$ → Storage elements; transients

Convert all L & C to Resistances and solve only resistive networks

Trapezoidal Rule

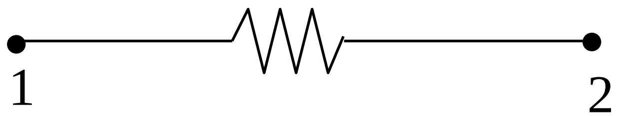
Differential Equation ⟶ Difference Equation

$$\frac{di(t)}{dt} = \frac{\Delta i(t)}{\Delta T} = \frac{i(t) - i(t - \Delta T)}{\Delta T}$$

$i(t)$ ⟶ To be computed

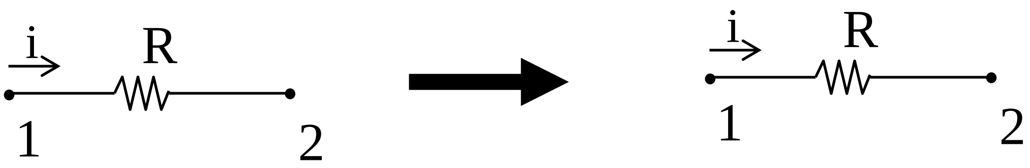
$i(t - \Delta T)$ ⟶ known as past history term

Resistor

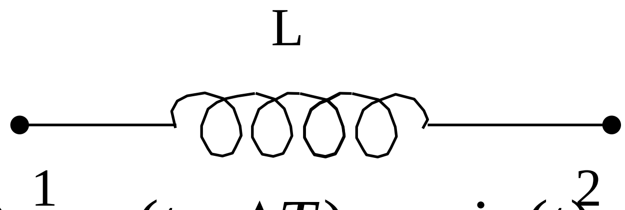


$$i_{12}(t) = \frac{v_1(t) - v_2(t)}{R}$$

$$i_{12}(t) = G_{12}\left[v_1(t) - v_2(t)\right]$$



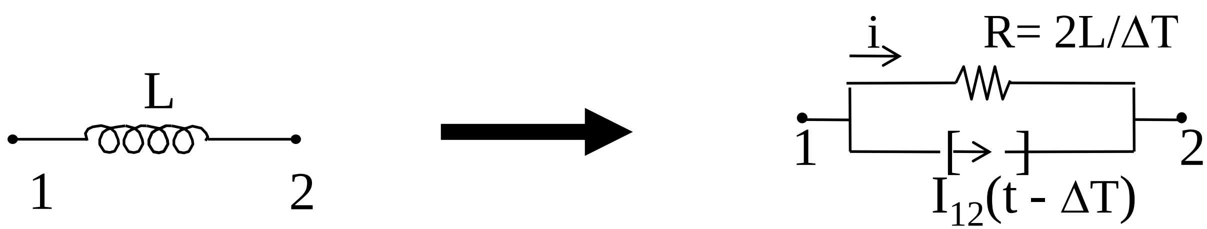
Inductor



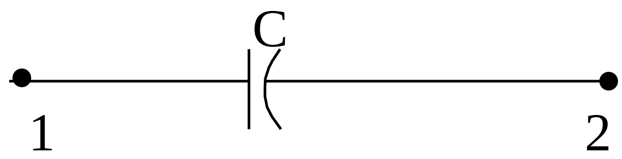
$$\frac{v_{12}(t)+v_{12}(t-\Delta T)}{2} = L\frac{i_{12}(t)-i_{12}(t-\Delta T)}{\Delta T}$$

$$v(t) = L\frac{di(t)}{dt}$$

$$i_{12}(t) = \frac{\Delta T}{2L}\left[v_1(t)-v_2(t)\right]+I_{12}(t-\Delta T)$$



Capacitor

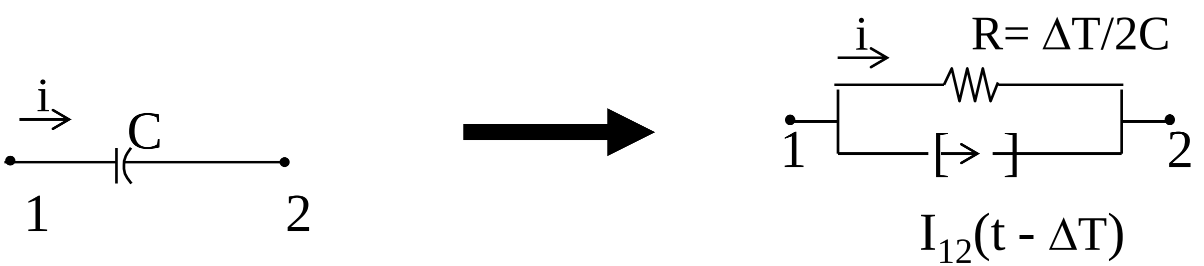


$$i_{12}(t) = C\frac{dv(t)}{dt}$$

$$\frac{i_{12}(t) + i_{12}(t-\Delta T)}{2} = C\frac{v_{12}(t) - v_{12}(t-\Delta T)}{\Delta T}$$

$$i_{12}(t) = \frac{2C}{\Delta T}\left[v_1(t) - v_2(t)\right] - \frac{2C}{\Delta T}\left[v_1(t-\Delta T) - v_2(t-\Delta T)\right] - i_{12}(t-\Delta T)$$

$$i_{12}(t) = \frac{2C}{\Delta T}\left[v_1(t) - v_2(t)\right] + I_{12}(t-\Delta T)$$



Inductor with series Resistor:

$$i_{12}(t) = G\left[v_1(t) - v_2(t)\right] + I_{12}(t - \Delta T)$$

where

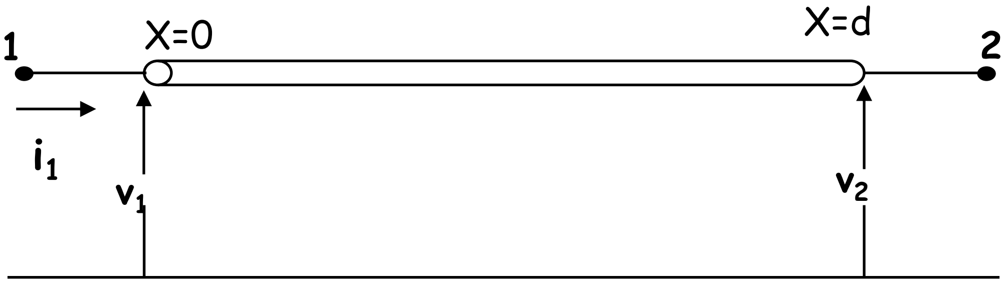
$$G = \frac{1}{R + \dfrac{2L}{\Delta T}}$$

$$I_{12}(t - \Delta T) = G\left[v_1(t - \Delta T) - v_2(t - \Delta T)\right] + H i_{12}(t - \Delta T)$$

where

$$H = \frac{\dfrac{2L}{\Delta T} - R}{R + \dfrac{2L}{\Delta T}}$$

Distributed Elements: Transmission line



R' = Resistance Ω/unit length

L' = Inductance H/unit length

C' = Capacitance F/unit length

d = line length

$$-\frac{\partial v(x,t)}{\partial x} = L'\frac{\partial i(x,t)}{\partial t}$$

$$-\frac{\partial i(x,t)}{\partial x} = C'\frac{\partial v(x,t)}{\partial t}$$

$$i(x,t) = f_1(x-ct) - f_2(x+ct)$$

$$v(x,t) = Z_o f_1(x-ct) + Z_o f_2(x+ct)$$

where

$$Z_o = \sqrt{\frac{L'}{C'}} \;; \quad c = \frac{1}{\sqrt{L'C'}}$$

$$v(x,t) + Z_o i(x,t) = 2Z_o f_1(x-ct)$$

$$v_1(t) - Z_o i_{12}(t) = v_2(t-\tau) + Z_o i_{21}(t-\tau)$$

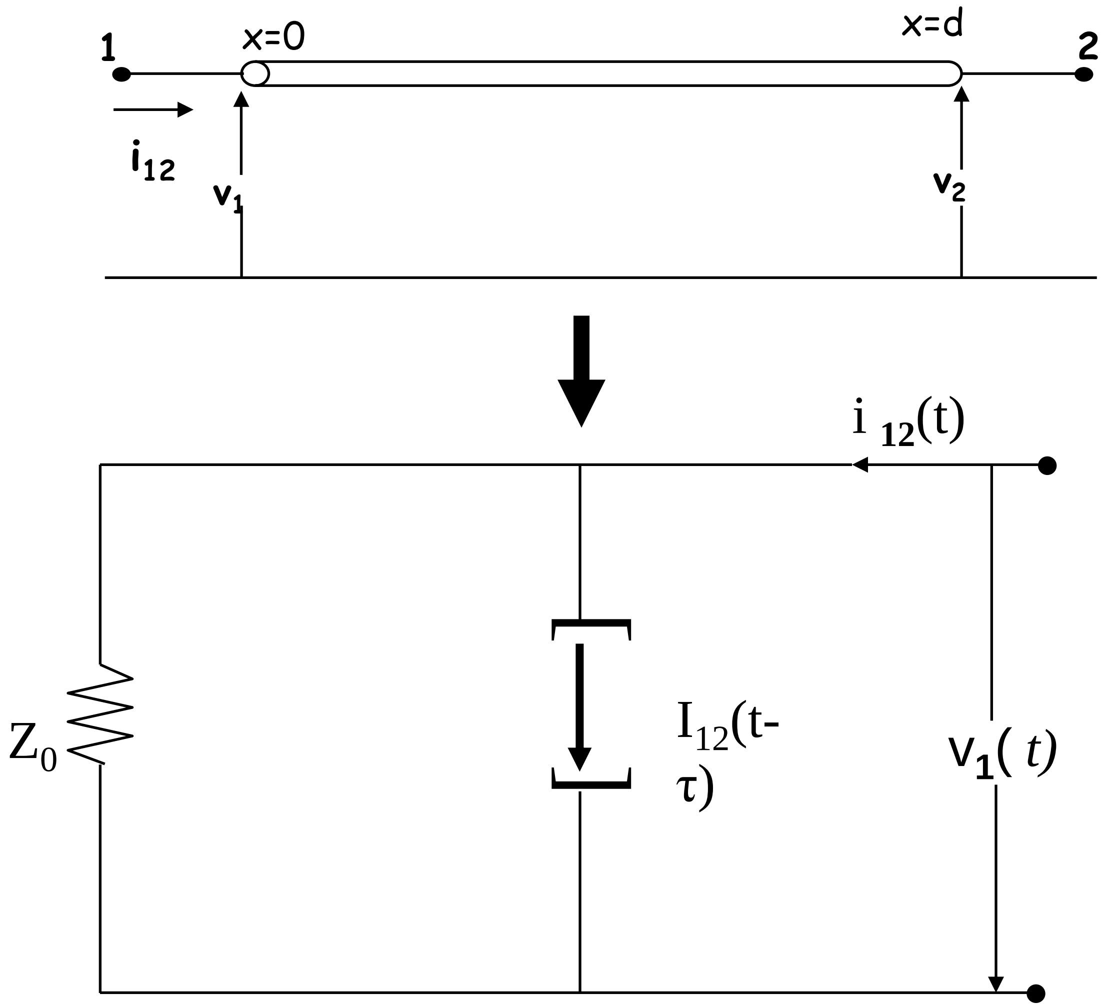
$$i_{12}(t) = \frac{v_1(t)}{Z_o} - \frac{v_2(t-\tau)}{Z_o} - i_{21}(t-\tau)$$

$$i_{12}(t) = \frac{v_1(t)}{Z_o} + I_{12}(t-\tau)$$

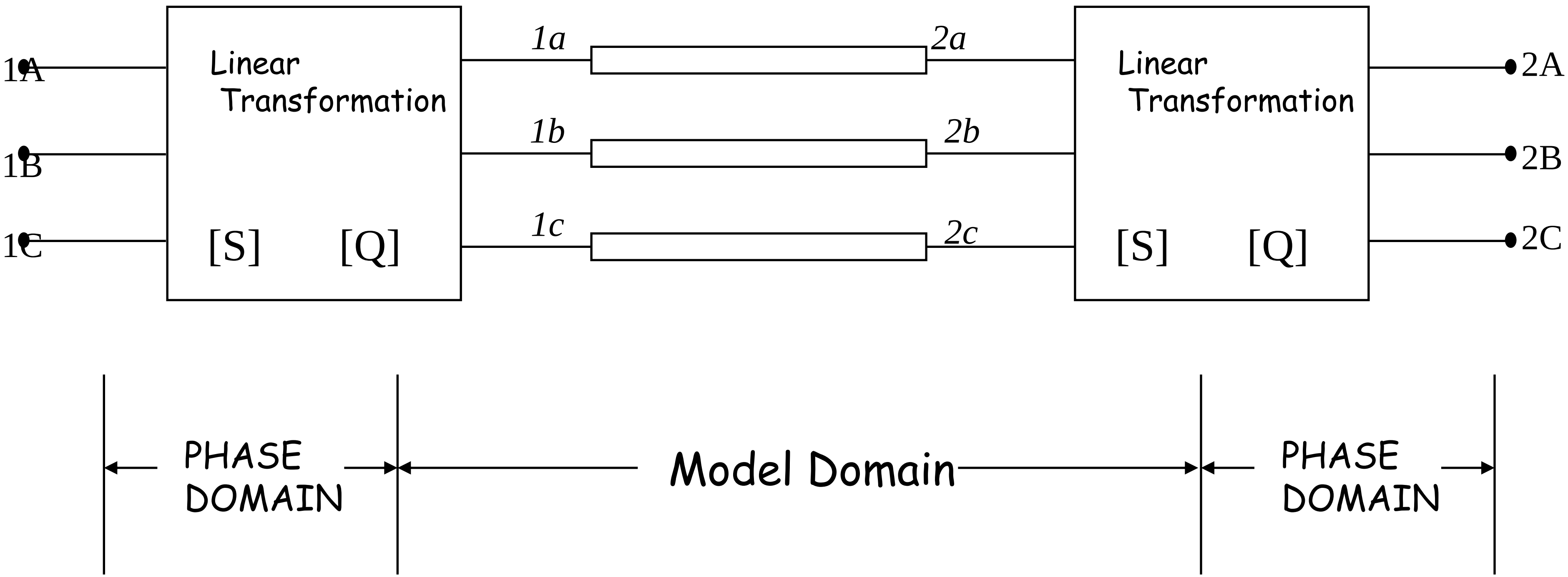
where

$$travel\ time = \frac{d}{c}$$

Resistive Equivalent for Single Phase Line:



Extension to Three – Phase Networks:



Transformation of Three-phase Line
From Phase to Model Domain

Extension to 3-*phase* network

$$V^{mode} = SV^{phase}; V^{phase} = QV^{mode} \quad where\ S\ is\ model\ matrix\ of\ [ZY]\ and\ Q = S^{-1}$$

$$i_{1a2a}(t) = \frac{v_{1a}(t)}{Z_{ao}} + I_{1a2a}(t-\tau_a) \ where\ I_{1a2a}(t-\tau_a) = -\frac{v_{2a}(t-\tau_a)}{Z_{ao}} - i_{2a1a}(t-\tau_a)$$

$$i_{1b2b}(t) = \frac{v_{1b}(t)}{Z_{bo}} + I_{1b2b}(t-\tau_b) \ where\ I_{1b2b}(t-\tau_b) = -\frac{v_{2b}(t-\tau_b)}{Z_{bo}} - i_{2b1b}(t-\tau_b)$$

$$i_{1c2c}(t) = \frac{v_{1c}(t)}{Z_{co}} + I_{1c2c}(t-\tau_c) \ where\ I_{1c2c}(t-\tau_c) = -\frac{v_{2c}(t-\tau_c)}{Z_{co}} - i_{2c1c}(t-\tau_c)$$

$$\left[i_{12}^{phase}\right] = \left[Z_{phase}\right]^{-1}\left[V_1^{phase}\right] + \left[I_{12}^{phase}\right]$$

$$\left[Z_{phase}\right]^{-1} = [S][Z_{mode}]^{-1}[Q]$$

$$[I_{12}^{phase}] = [Q][I_{12}^{mode}]$$

$$S = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \quad Q = \frac{1}{3}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 0 \\ 1 & 0 & -1 \end{bmatrix}$$

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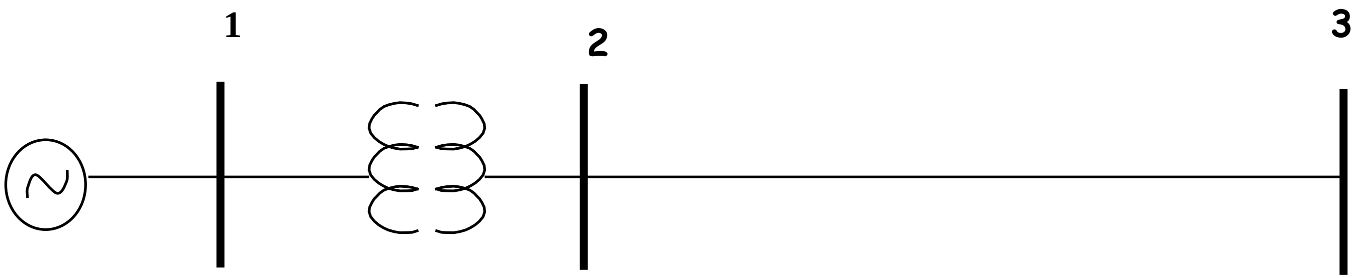
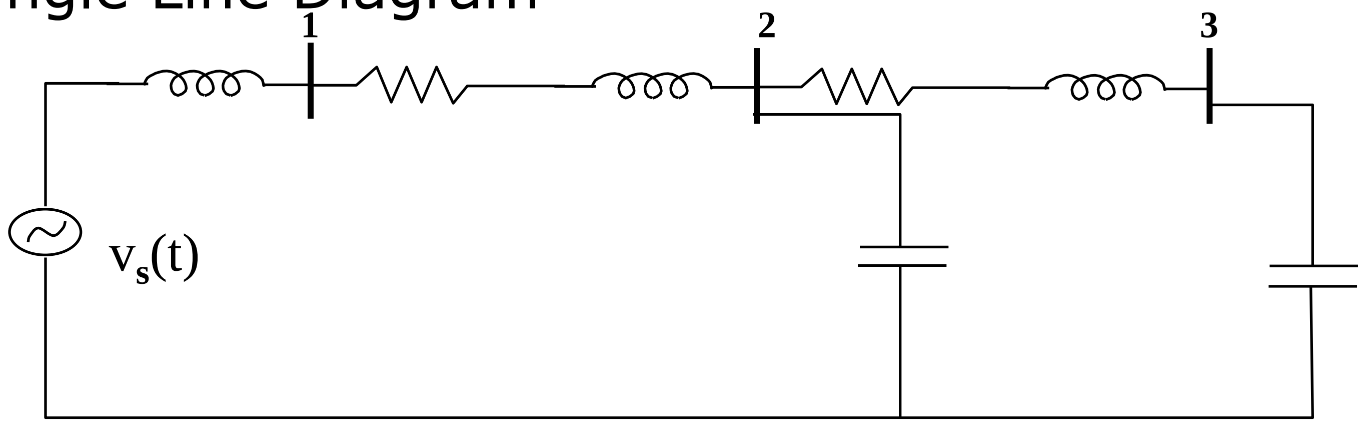
Illustration

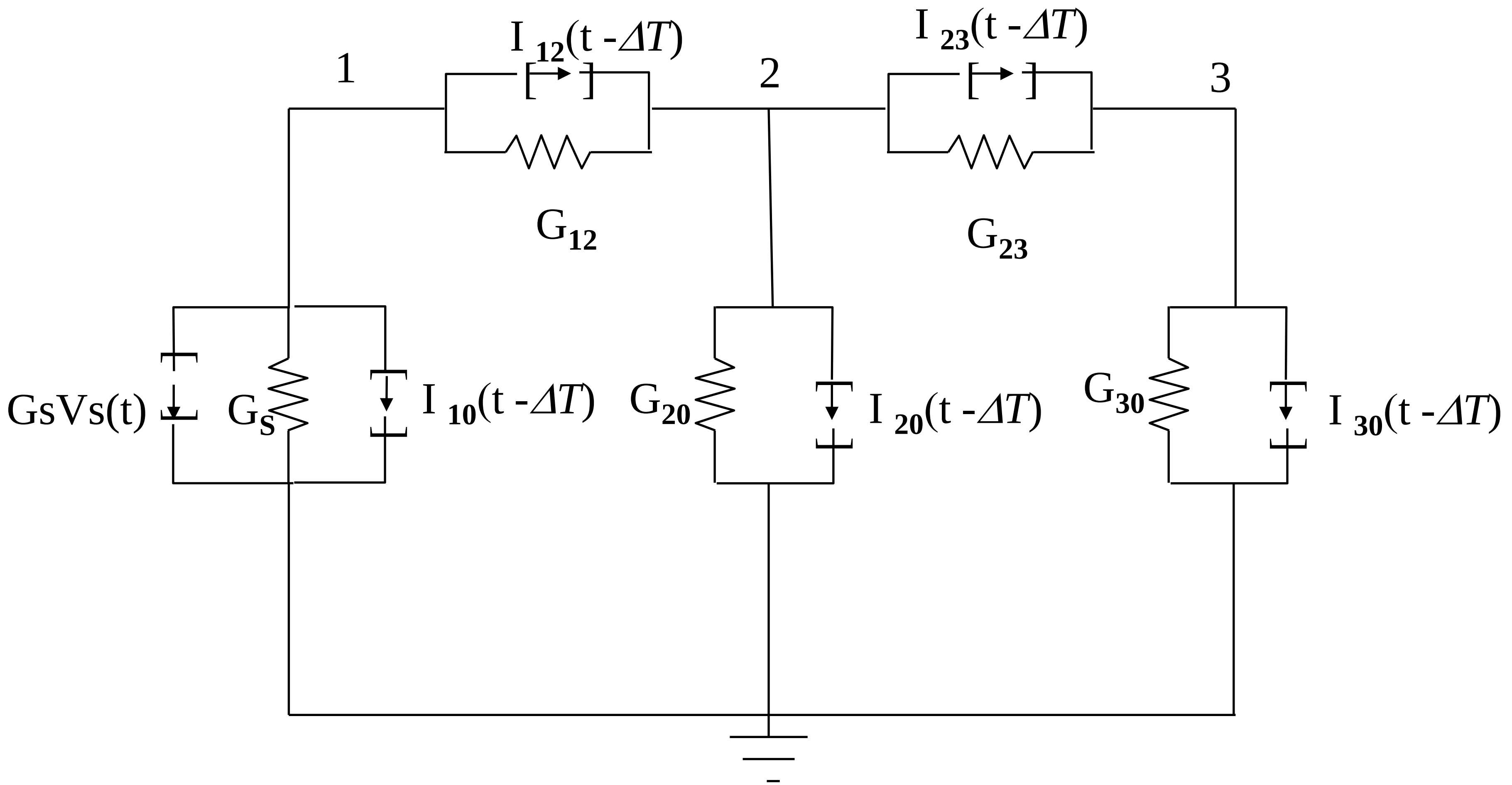
System:



Single Line Diagram



Associated Equivalent Circuit



Nodal equations for the illustration network

$$node1$$

$$G_{12}[v_1(t)-v_2(t)]+I_{12}(t-\Delta T)+G_s[v_1(t)-v_s(t)]+I_{10}(t-\Delta T)=0$$

$$node\ 2$$

$$G_{12}[v_2(t)-v_1(t)]+I_{12}(t-\Delta T)+G_{23}[v_2(t)-v_3(t)]+I_{23}(t-\Delta T)+G_{20}v_2(t)+I_{20}(t-\Delta T)=0$$

$$node\ 3$$

$$G_{23}[v_3(t)-v_2(t)]+I_{23}(t-\Delta T)+G_{30}v_3(t)+I_{30}(t-\Delta T)=0$$

$$\begin{bmatrix} G_{12}+G_S & -G_{12} & 0 \\ -G_{12} & G_{12}+G_{23}+G_{20} & -G_{23} \\ 0 & -G_{23} & G_{23}+G_{30} \end{bmatrix} \begin{bmatrix} v_1(t) \\ v_2(t) \\ v_3(t) \end{bmatrix} =$$

$$\begin{bmatrix} G_{1s}\, v_s(t) \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} -\ I_{12}(t-\Delta T) - I_{10}(t-\Delta T) \\ -\ I_{21}(t-\Delta T) - I_{20}(t-\Delta T) - I_{23}(t-\Delta T) \\ -\ I_{32}(t-\Delta T) - I_{30}(t-\Delta T) \end{bmatrix}$$

$$[G][v(t)] = [i(t)] - [I_{history}]$$

where

$[G]$ = conductance matrix

$[i(t)]$ = column vector of current sources(specified)

$[I_{history}]$ = column vector of past history current sources

$[v(t)]$ = column vector of n node voltages (to be computed at instant 't')

$$\begin{bmatrix} G_{AA} & G_{AB} \\ G_{BA} & G_{BB} \end{bmatrix} \begin{bmatrix} v_A(t) \\ v_B(t) \end{bmatrix} = \begin{bmatrix} i_A(t) \\ i_B(t) \end{bmatrix} - \begin{bmatrix} I_{Ahistory} \\ I_{Bhistory} \end{bmatrix}$$

$$part\ A : representing\ nodes\ unknown\ voltages$$

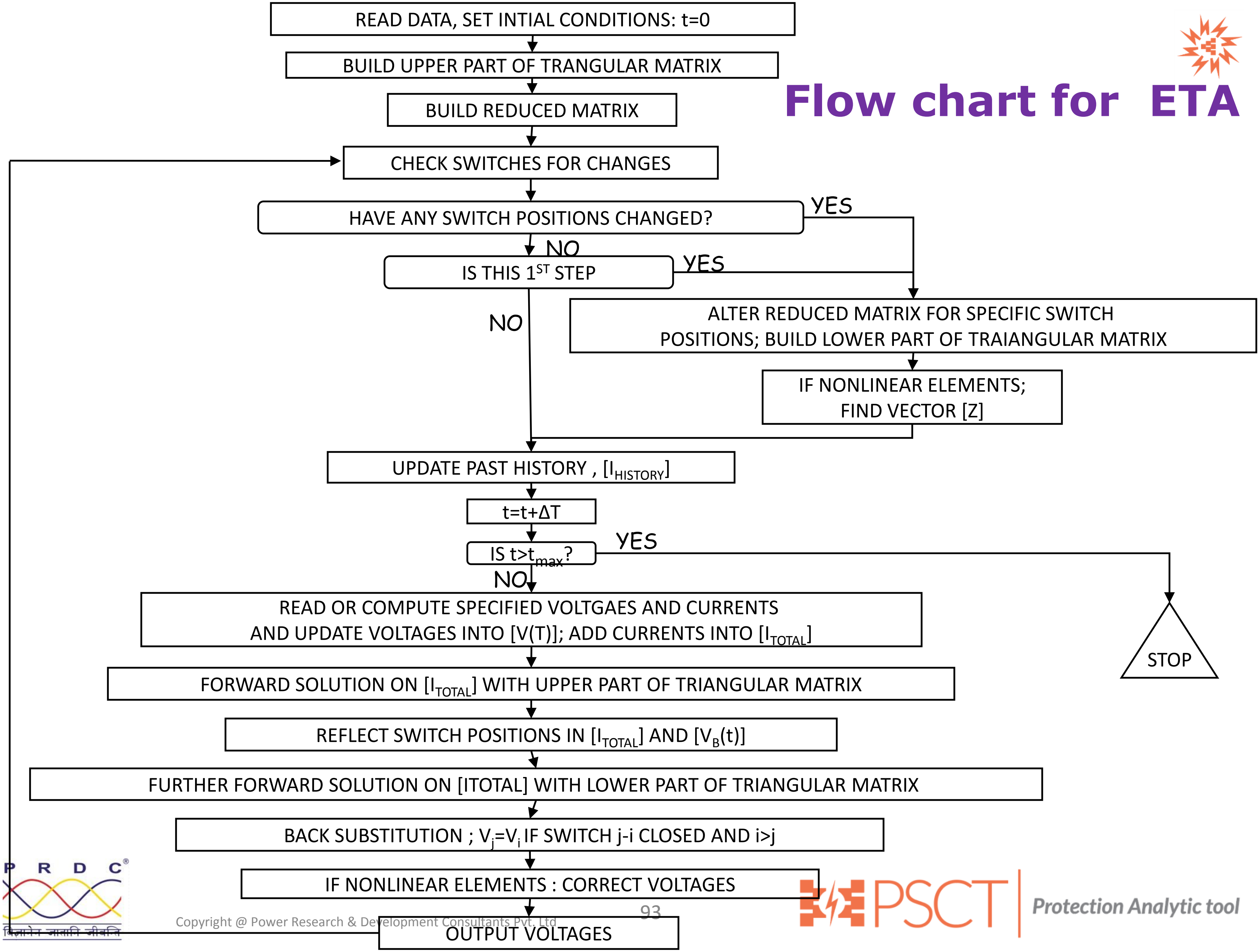
$$part\ B : representing\ nodes\ known\ voltages$$

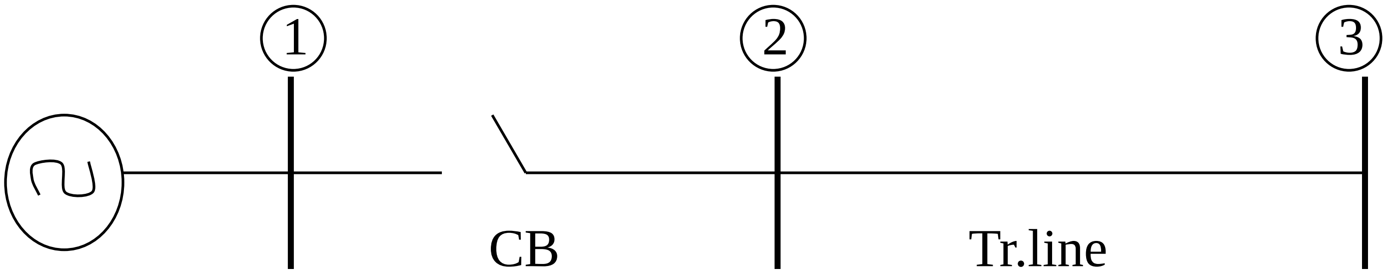
$$[G_{AA}][v_A(t)] = [I_{total}] - [G_{AB}][v_B(t)]$$

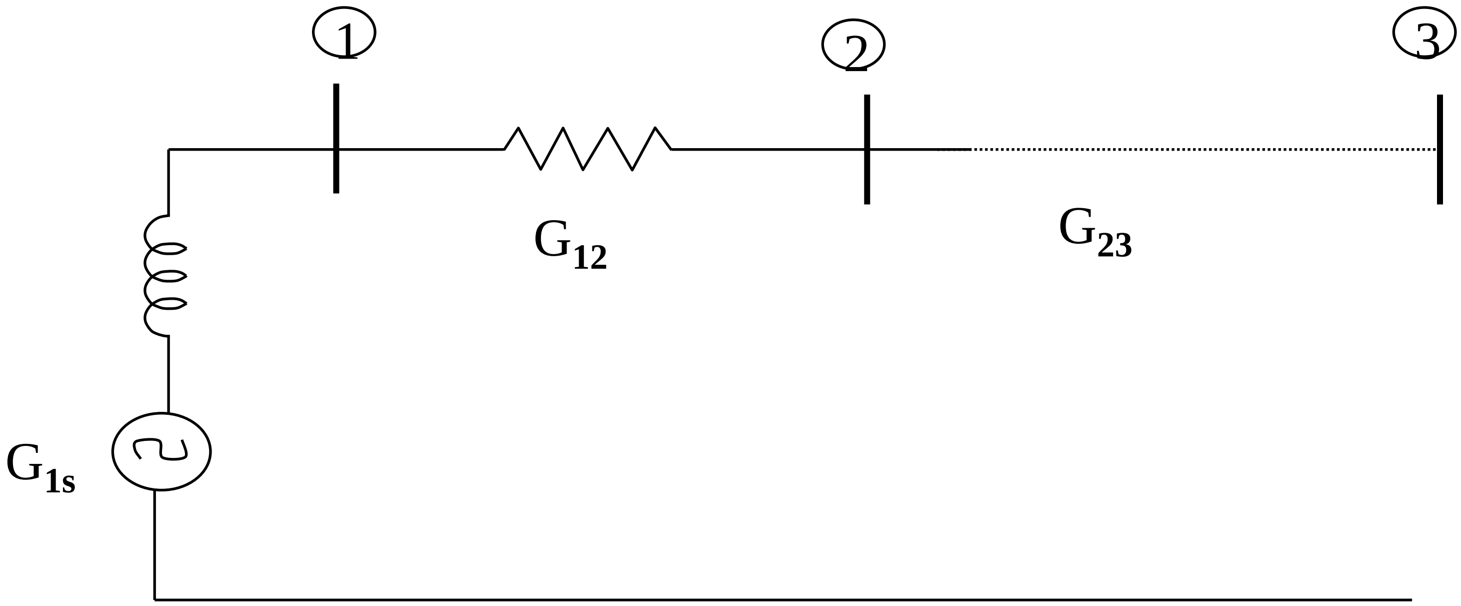
$$where$$

$$[I_{total}] = [i_A(t)] - [I_{Ahistory}]$$

Flow chart for ETA

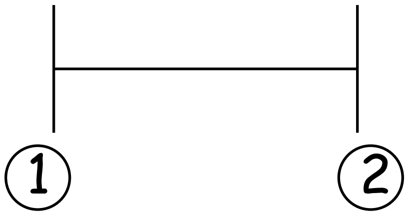



1
2
3
CB
Tr.line

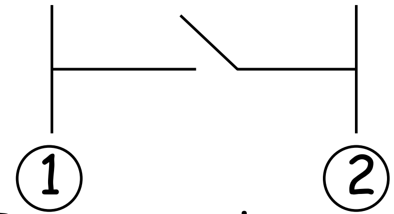

1
2
3
G_{12}
G_{23}
G_{1s}

Representation

① Switch / Circuit breaker

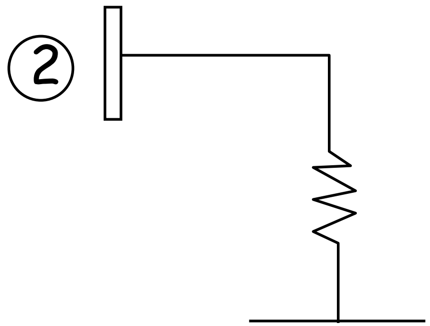


R_{12}= very small



R_{12}= very large

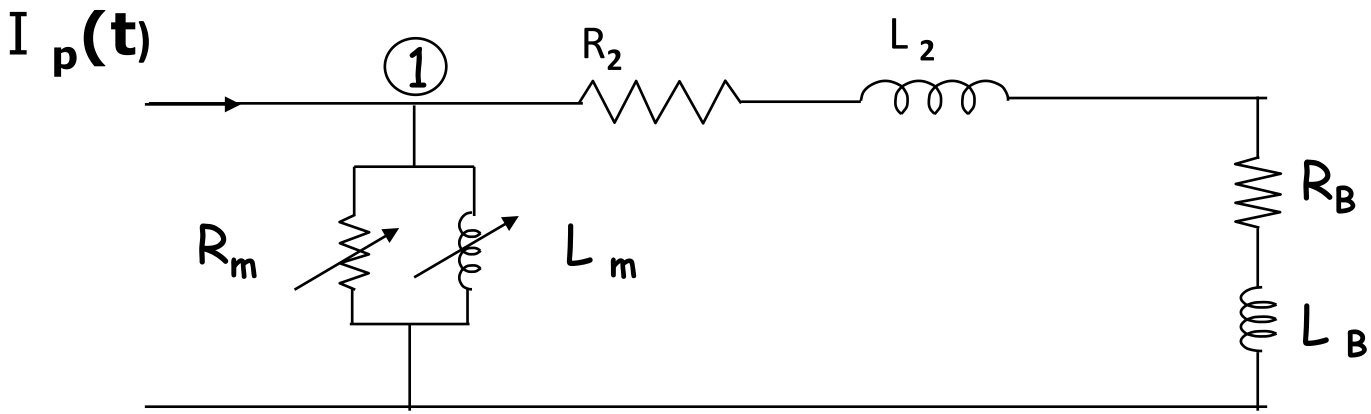
② Creation of fault



③ Non linearity

f (V, I, time)

PSCT Protection Analytic tool

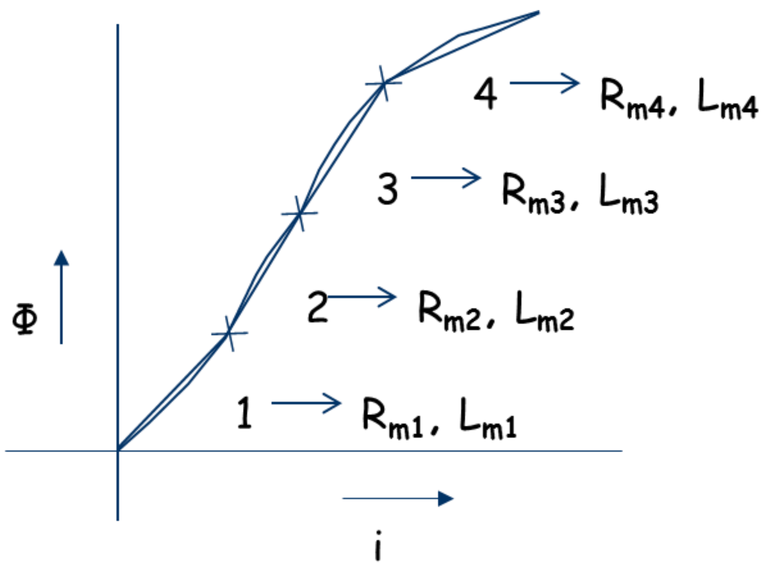


$$node1$$

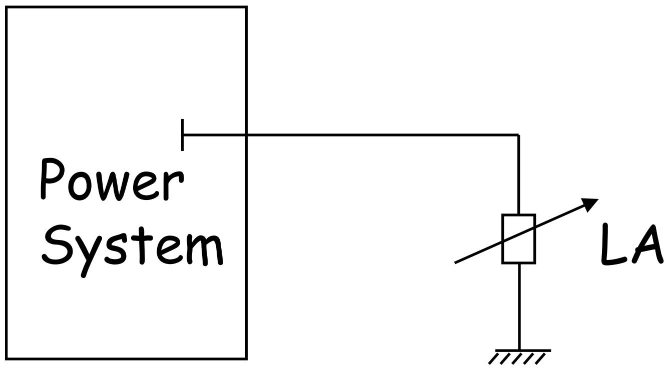
$$I_p(t) = G_{12}[v_1(t) - v_2(t)] + I_{12}(t - \Delta T) + G_{1m} v_1(t) + I_{1m}(t - \Delta T)$$

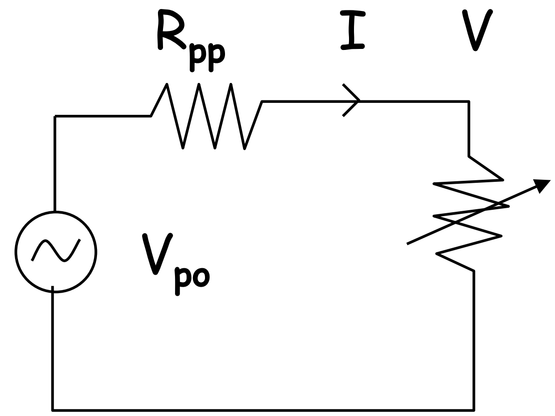
$$node2$$

$$G_{12}[v_2(t) - v_1(t)] + I_{21}(t - \Delta T) + G_{2B} v_2(t) + I_{2B}(t - \Delta T) = 0$$



Surge Arrestor model:





Current for SA $I = KV^n$

K, n are specified for ranges of v

$f(v) = V_{po} - R_{pp} I - V$

$f(v) = V_{po} - R_{pp} KV^n - V$

Taylors Series $\longrightarrow$

$$f(v_0 + \Delta v) = f(v_0) + \Delta v\, f'(v)\big|_{v_0} + \ldots\ldots\ldots\ldots\ldots = 0$$

$f'(v) = -R_{pp} KnV^{n-1} - 1.0$

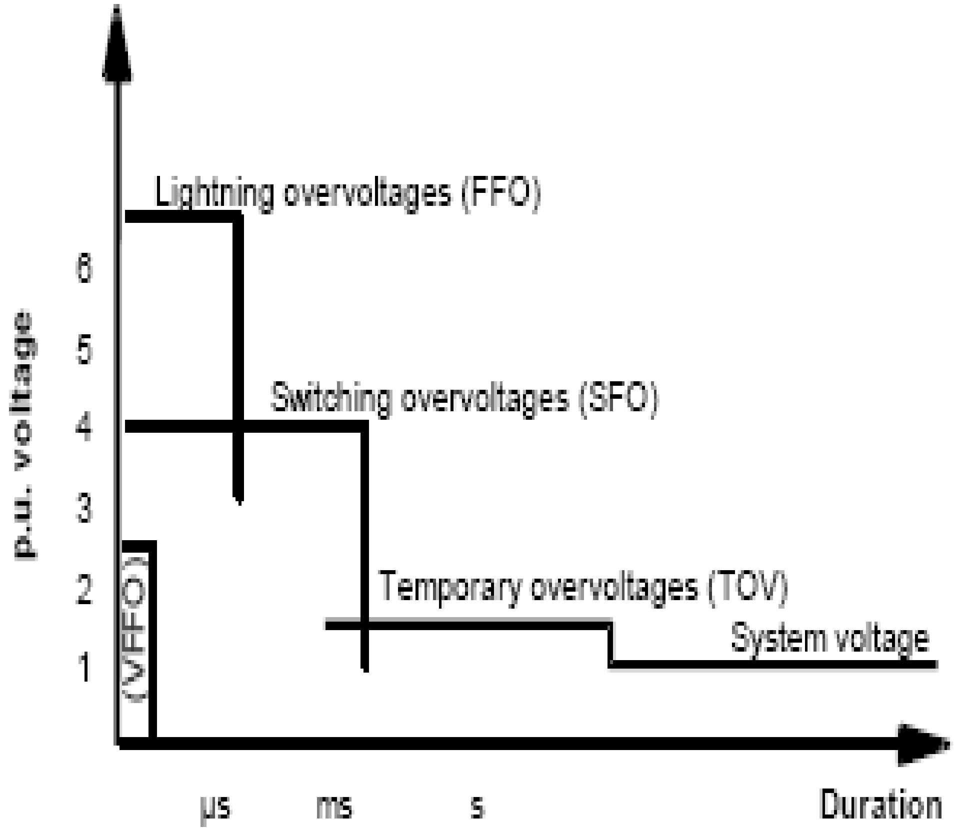
$f'(v_0) = -R_{pp} KV_0^{n-1} - 1.0$

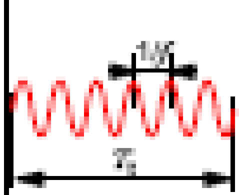
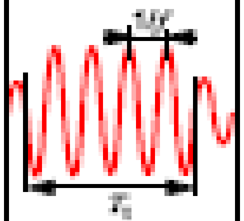
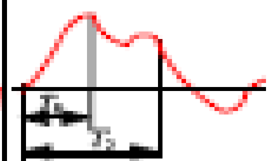
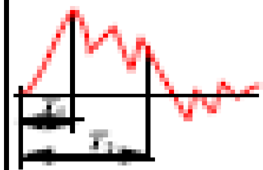
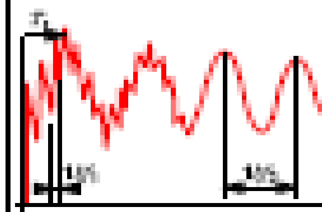
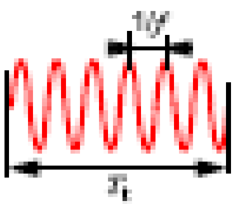
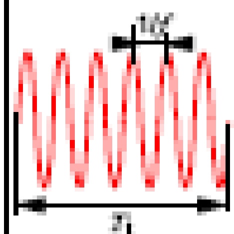
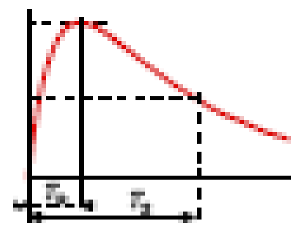
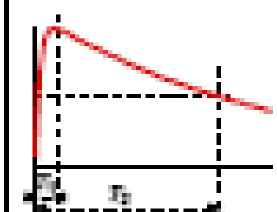
Need of Overvoltage studies

- Design issues
- Protecting equipment from Insulation failures
- Preventing Overheating of equipment
- Avoid the Mal-operation of protective device
- To find optimum location of Lightning Arrestors
- To find the energy class of arrestors
- Protection against high-touch voltages and internal flashover in GIS enclosures.

Classification of O/V

- Steady state
- Temporary
- Slow front
- Fast front
- Very fast front



Class	Low frequency		Transient		
	Continuous	Temporary	Slow-front	Fast-front	Very-fast-front
Voltage or over-voltage shapes					
Range of voltage or over-voltage shapes	f = 50 Hz or 60 Hz T_t ≥3 600 s	10 Hz < f < 500 Hz 0,03 s ≤ T_t ≤ 3 600 s	20 µs < T_p ≤ 5 000 µs T_2 ≤ 20 ms	0,1 µs < T_1 ≤ 20 µs T_2 ≤ 300 µs	3 ns < T_f ≤ 100 ns 0,3 MHz < f_1 < 100 MHz 30 kHz < f_2 < 300 kHz
Standard voltage shapes	 f = 50 Hz or 60 Hz T_t [1]	 48 Hz ≤ f ≤ 62 Hz T_t = 60 s	 T_p = 250 µs T_2 = 2 500 µs	 T_1 = 1,2 µs T_2 = 50 µs	[1]

Protection Analytic tool

Events Causing Overvoltages

	TOV	Transient Over Voltages		
		SFO	FFO	VFFO
Load rejection	×			
Transformer energisation	×	×		
Parallel resonance	×			
Uneven breaker poles	×			
Line fault application	×	×		
Fault clearing	×	×		
Line energisation	×	×		
Line re-energisation	×	×		
Line dropping	×	×		
AIS busbar switching			×	◆
Switching of inductive and capacitive current	×	×	×	
Back flash over			×	
Direct lightning stroke			×	
Switching inside GIS station				×
SF6 CB inductive and capacitive current switching	×	×	×	◆
Flash over in GIS station				×
Vacuum circuit breaker switching			×	×

Steady state overvoltages

- The highest r.m.s phase-to-phase voltage that occurs on the system under normal operating conditions.

- These are preceded by those of transient and dynamic periods.

- This investigation must be done in advance so that if necessary, modification in basic system could be done so that these over voltages remain within the capabilities /rating of the equipments.

Temporary Overvoltages

- Oscillatory phase-to-ground or phase-to-phase overvoltage of relatively long duration (seconds, even minutes) at a given location and that is undamped or only weakly damped.
- Temporary overvoltages usually originate from switching or fault clearing operations or from non-linearities.
- Temporary overvoltages are of importance when determining stresses on equipment related to power-frequency withstand voltage in particular for the energy capability of MOA.

Ferroresonance (FR) TOV

- An oscillating phenomena occurring in an electric circuit which must contain at least:

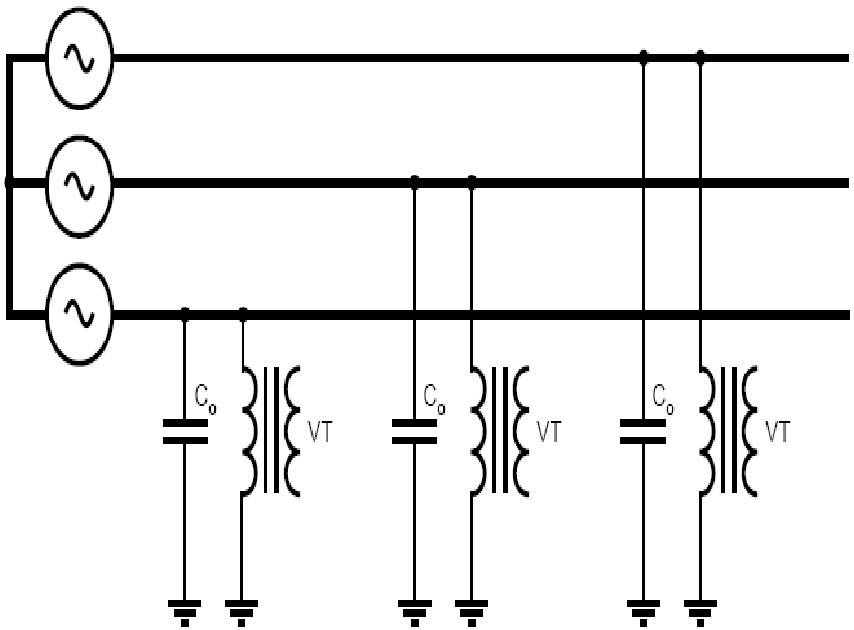
1. a non-linear inductance
2. a capacitor,
3. a voltage source (generally sinusoidal),
4. low losses.

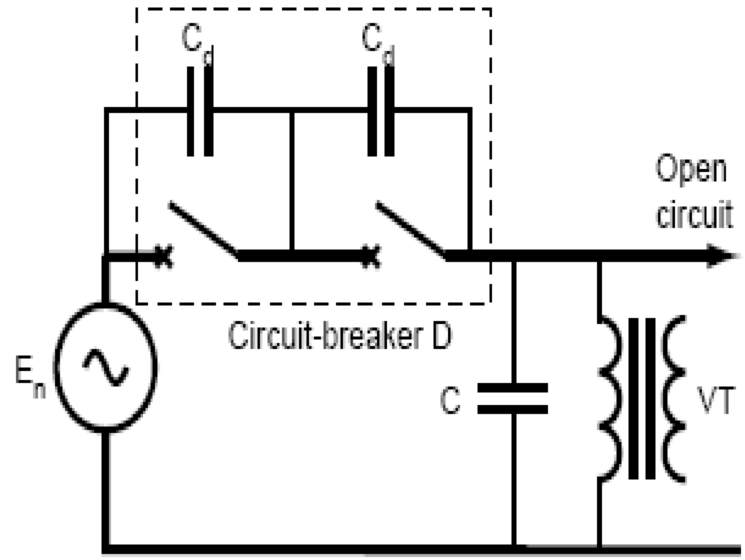
- Transients, lightning overvoltages, energizing or deenergizing transformers or loads, occurrence or removal of faults, etc...may initiate ferroresonance.
- The main feature of this phenomenon is that more than one stable steady state response is possible for the same set of the network parameters.

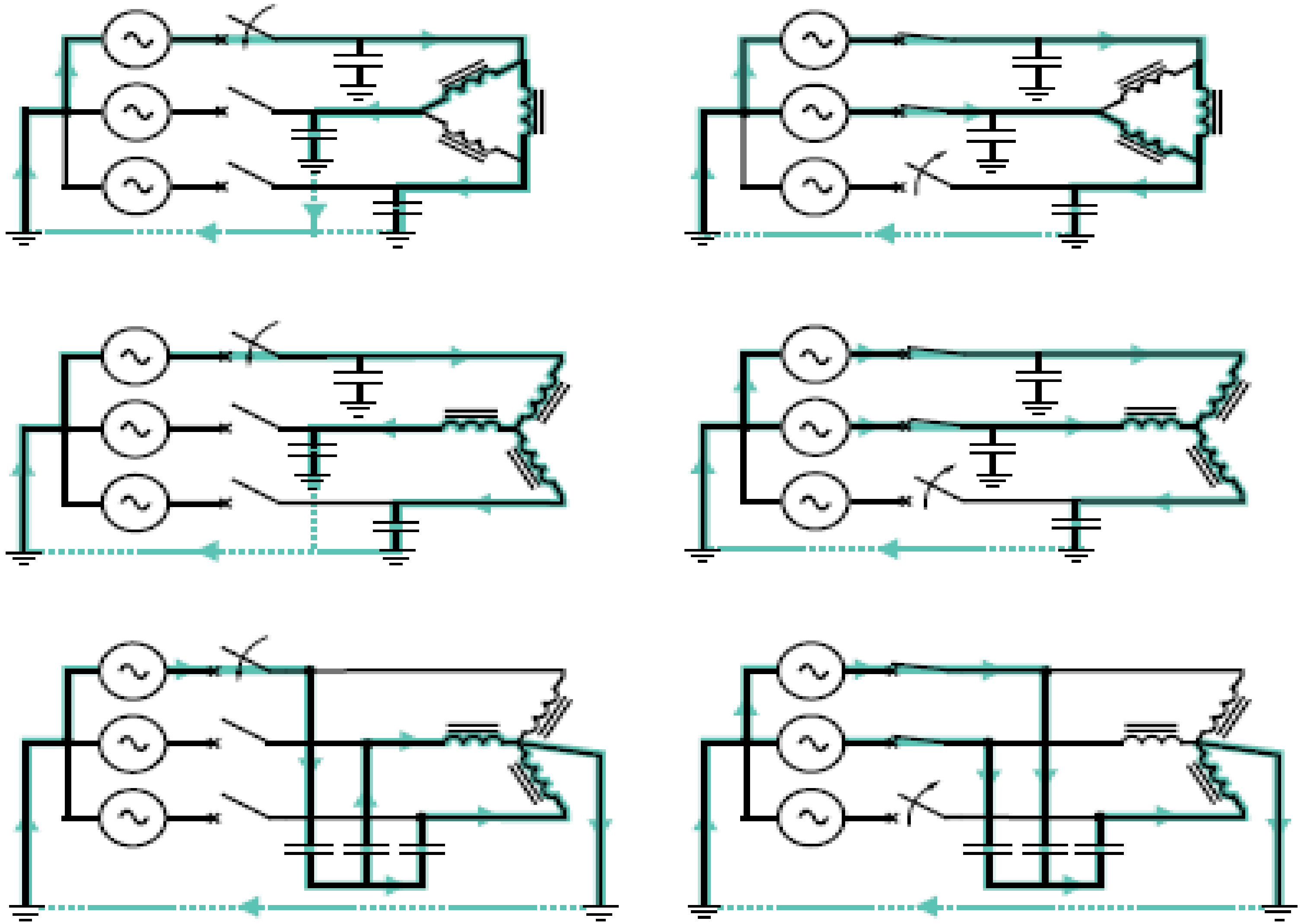
Comparison of LR and FR

- Its (FR) resonance possibility in a wide range of values of Capacitances.
- In case of FR, the frequency of the voltage and current waves which may be different from that of the sinusoidal voltage source.
- The existence of several stable steady state responses for a given configuration and values.
- In case of LR the voltages and currents are linear and they are frequency dependent.

Examples of systems at risk from ferroresonance.







Ferroresonance Prediction

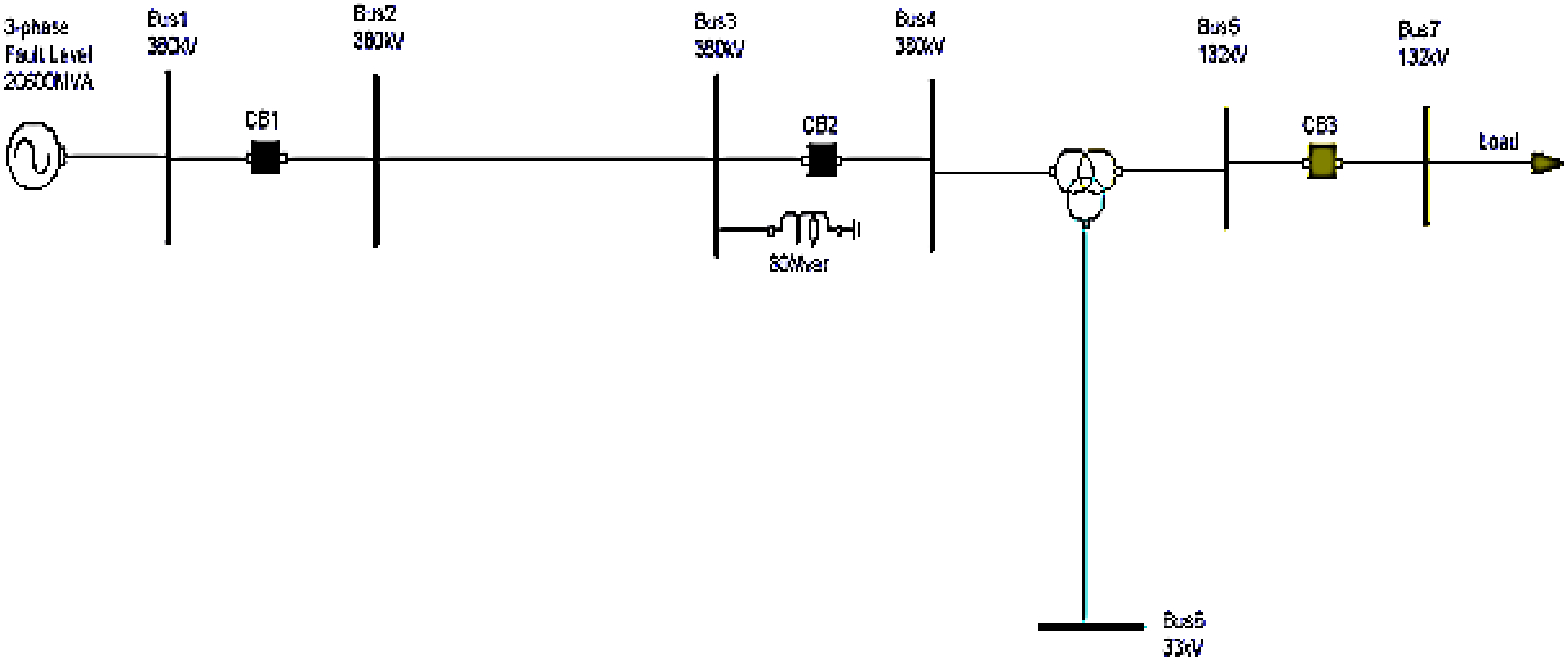
- High permanent overvoltages of differential mode (phase-to-phase) and/or common mode (phase-to-earth)
- High permanent over currents, high permanent distortions of voltage and current waveforms.
- Displacement of the neutral point voltage, transformer heating (in no-load operation)
- Continuous, excessively loud noise in transformers and reactors,
- Apparent untimely tripping of protection devices.

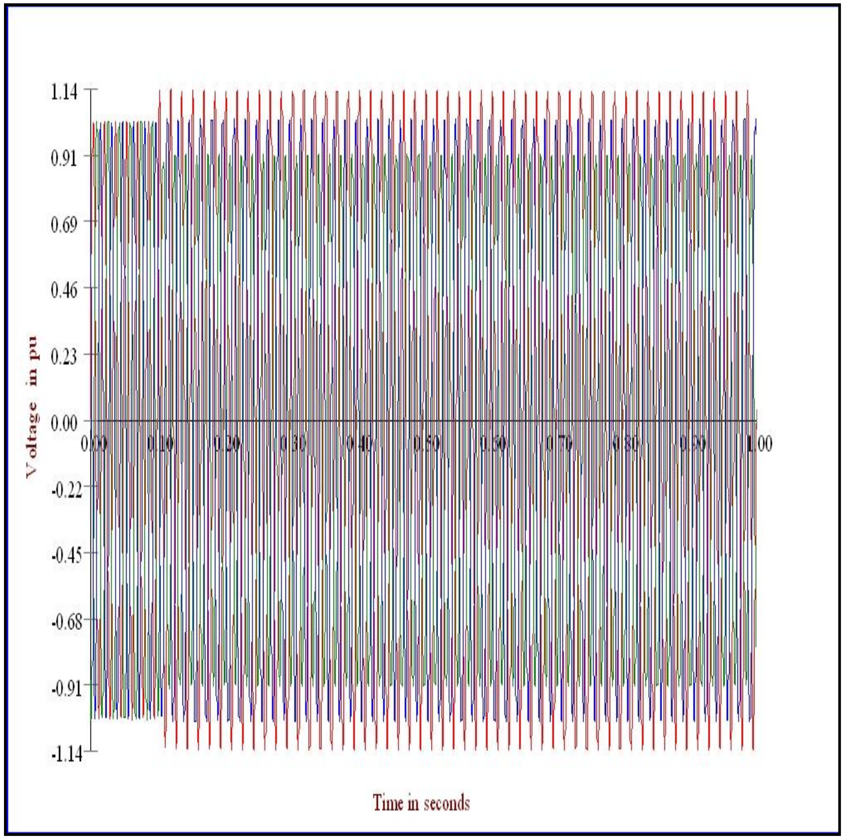
Preventing or Damping FR

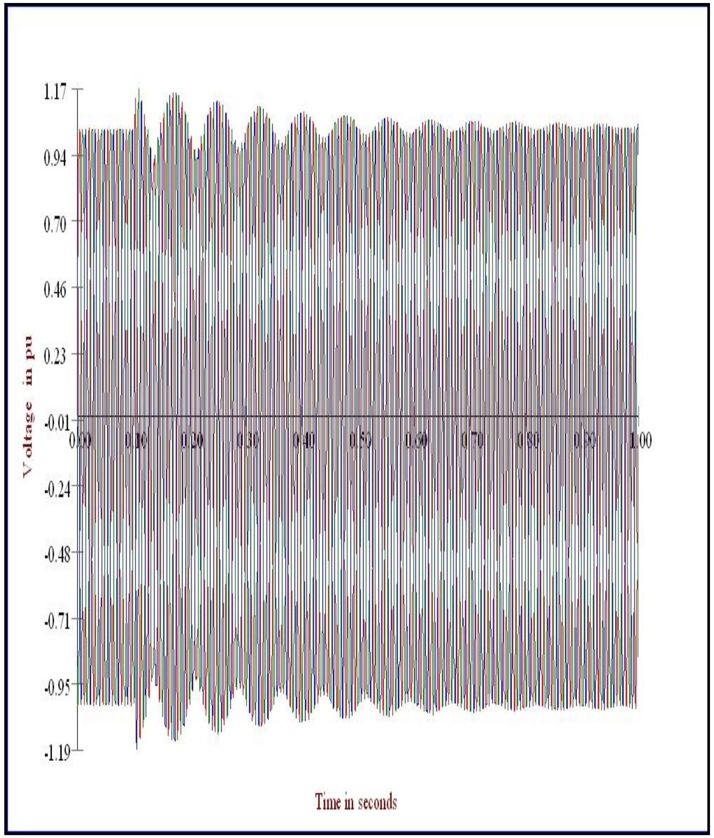
Avoid or by proper design and/or switching operations, configurations suspectable to ferroresonance

Ensure that the energy supplied by the source is not sufficient to sustain the phenomenon.

Sample study results for predicting and understanding of TOV and FR







1-pole

2-pole

HT side LR by opening CB2

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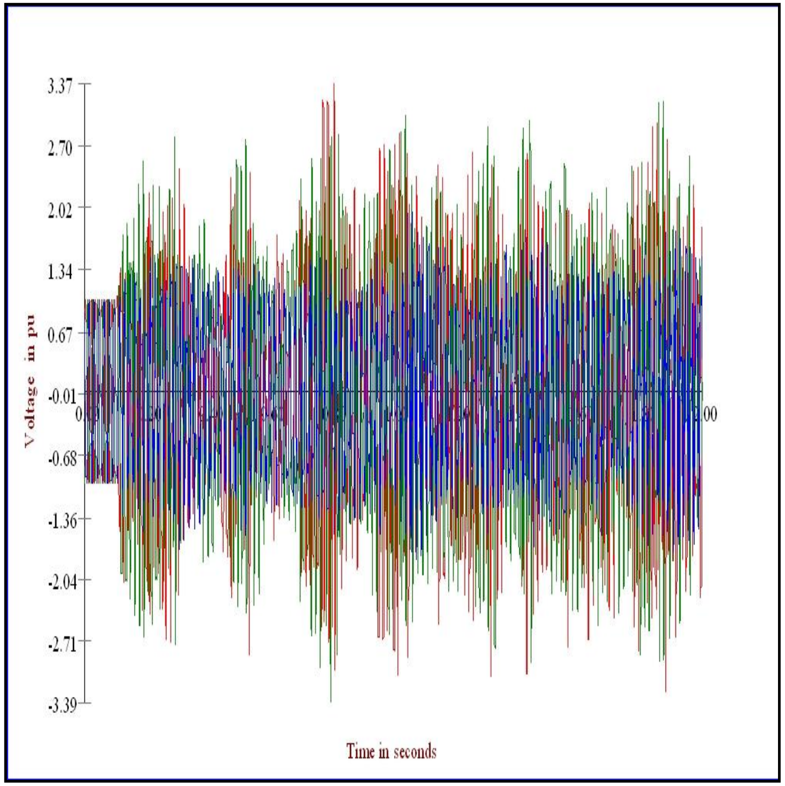
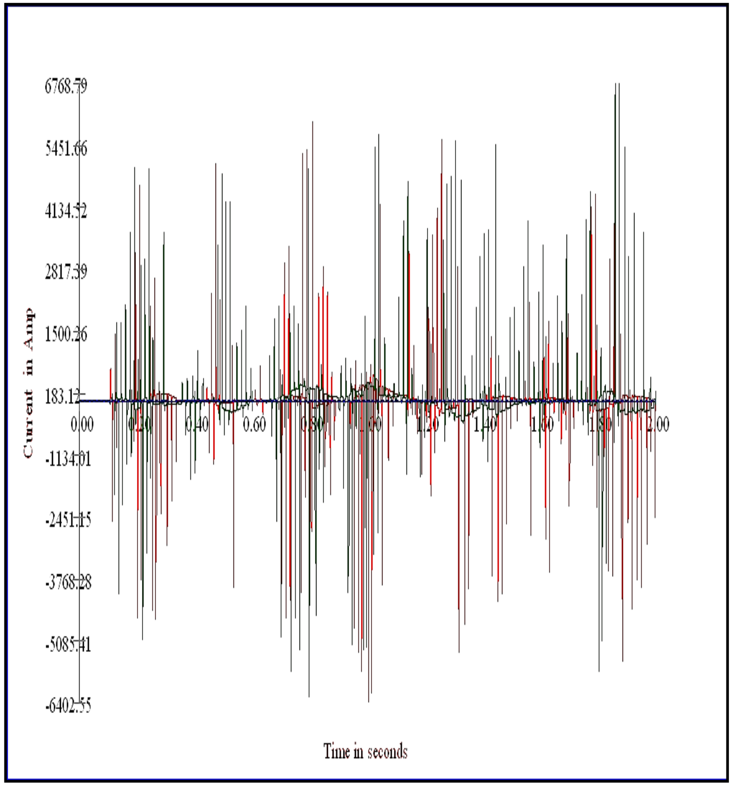


Voltage

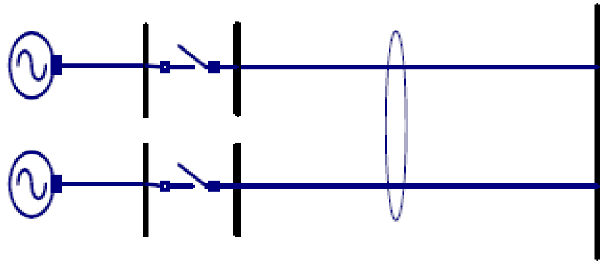


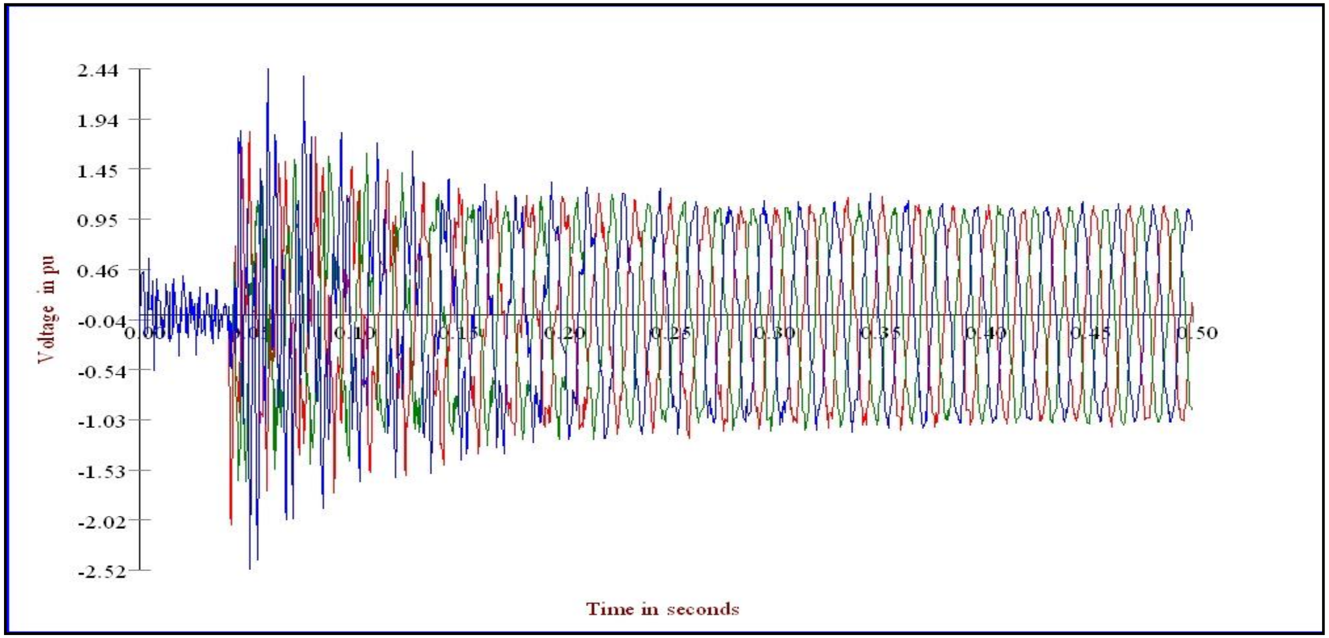
Current

FR existence when 2-poles opening of CB1

Slow front overvoltages

- When a circuit is energized, re-energized or opened, transient over voltages termed as switching surges are generated due to associated traveling wave phenomena.
- Line energisation
- Transformer energisation and de-energisation
- Shunt reactor switching
- Shunt capacitor switching





Line energisation

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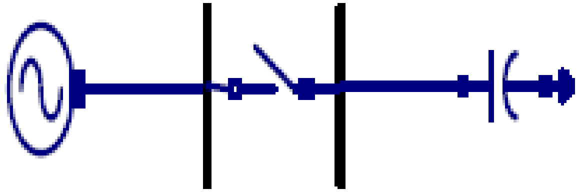
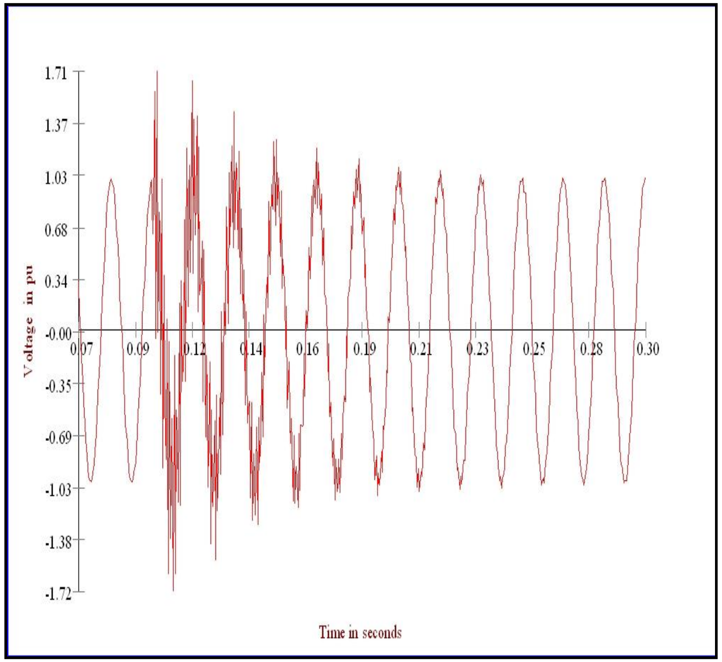
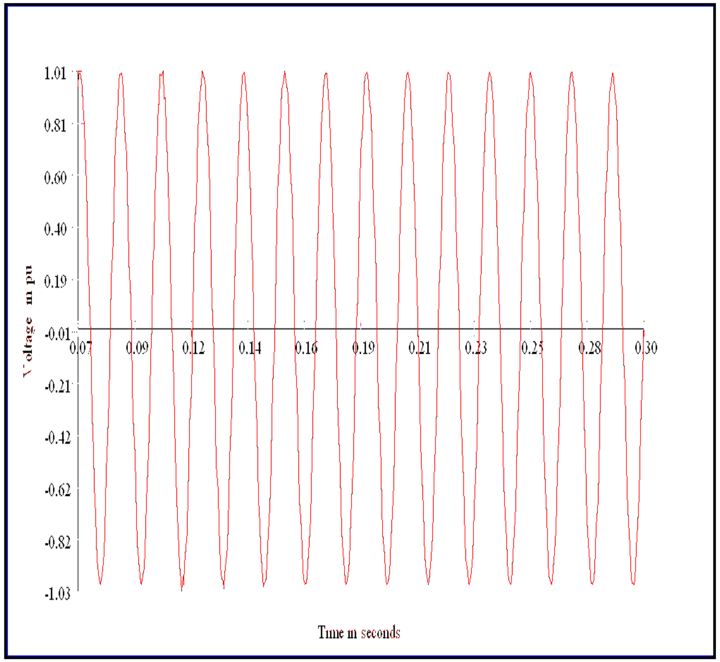
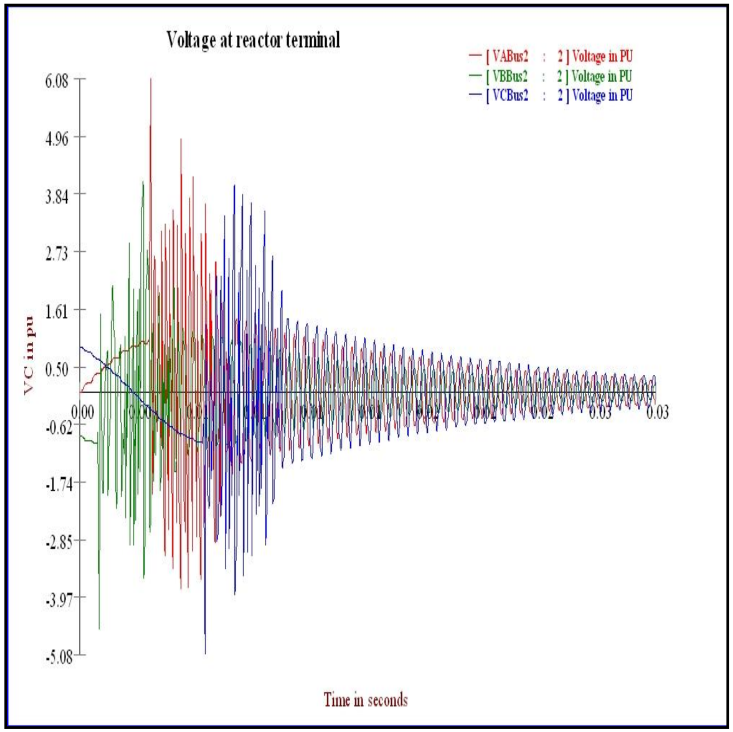
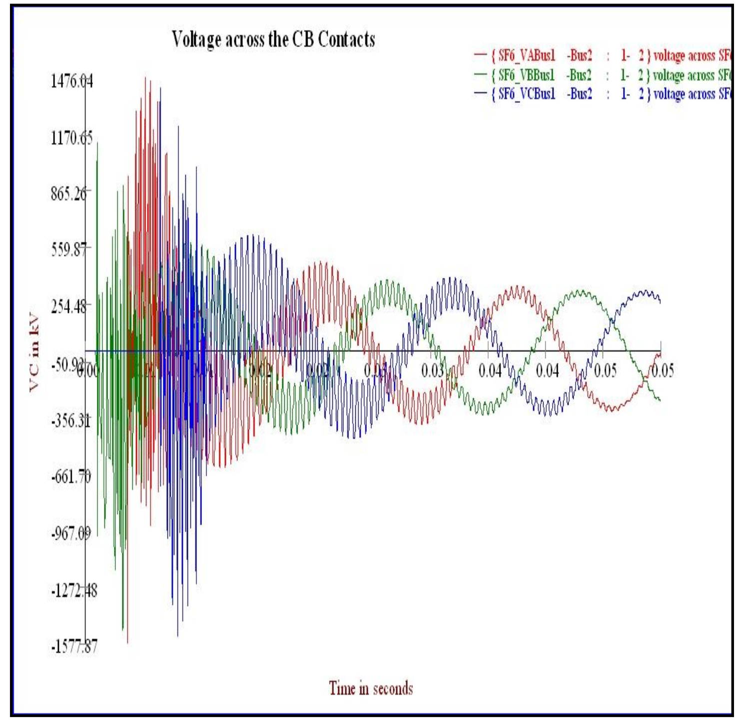




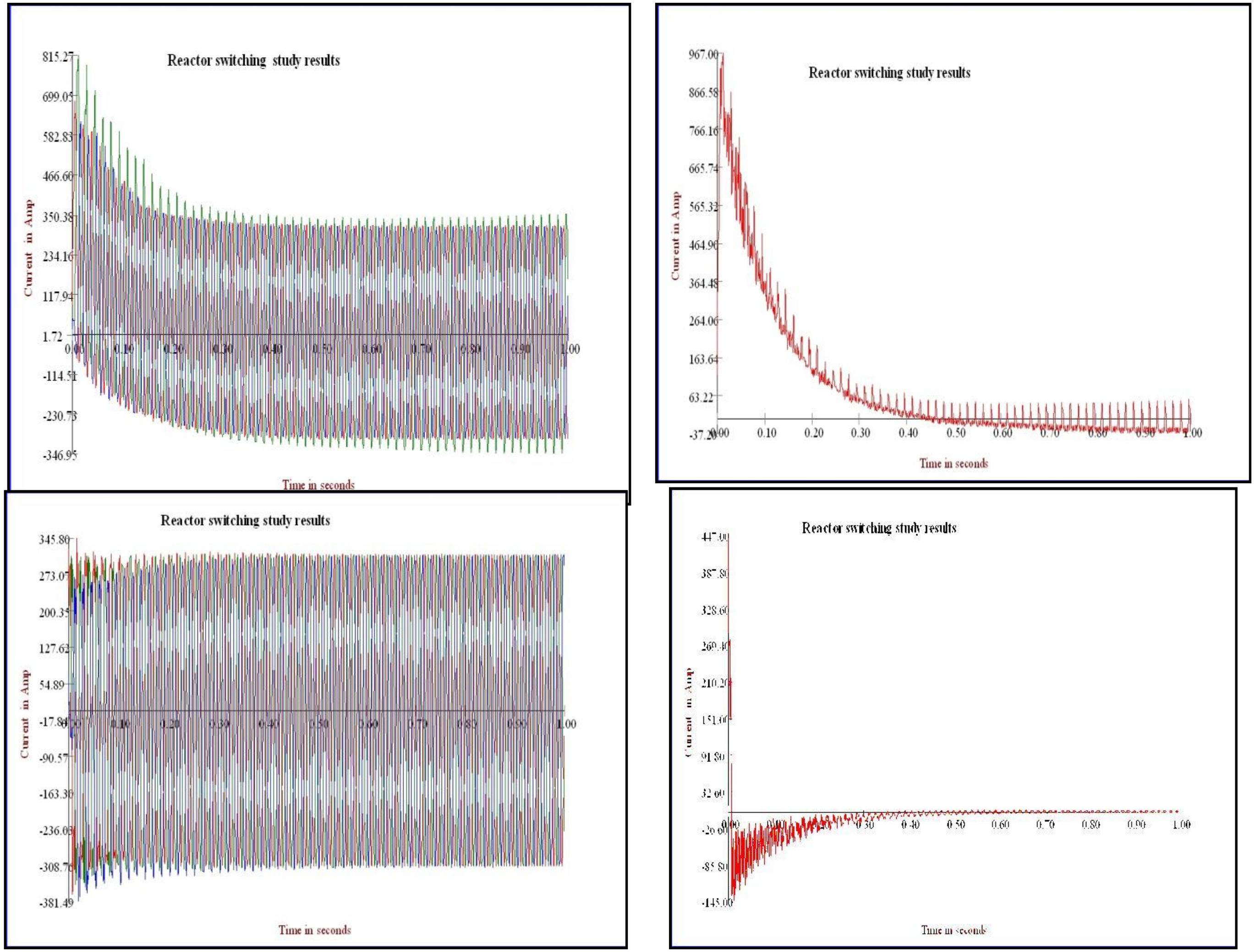


Capacitor switching





Shunt reactor De-energisation



Reactor energisation

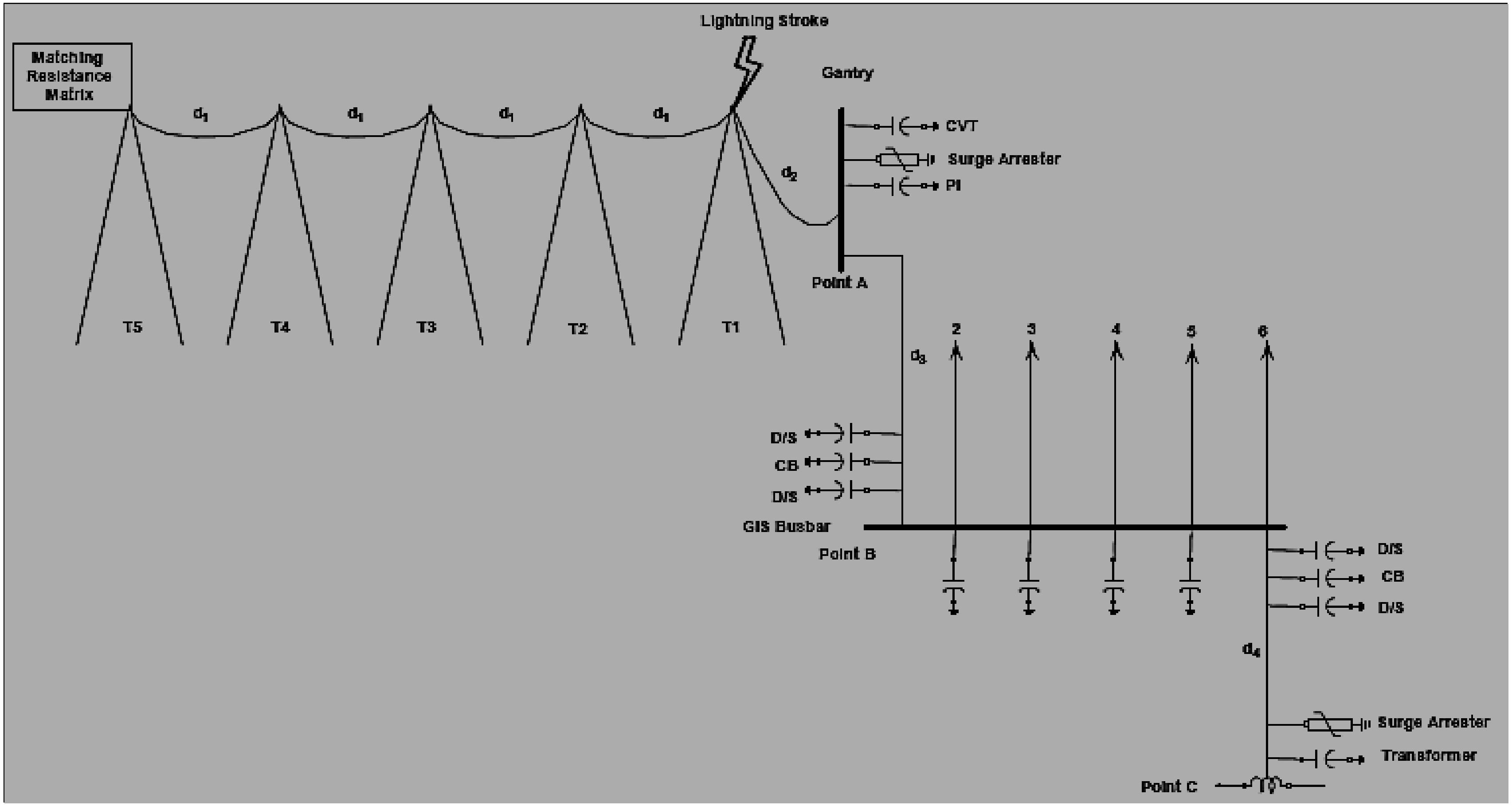
Fast front Overvoltages

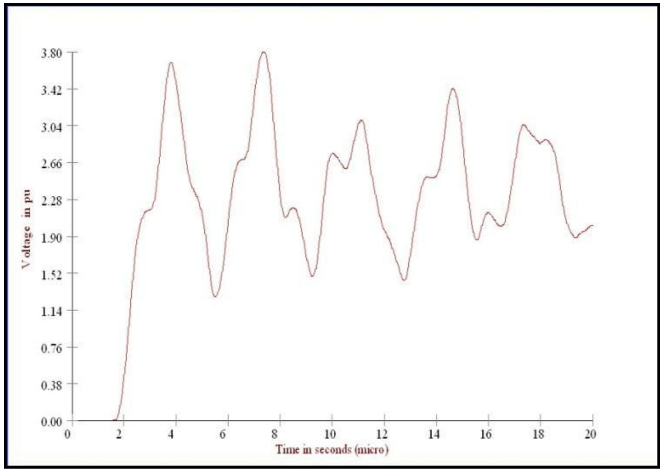
- One of the primary causes of fast transients (frequency range 0.5-5MHz) is the due to lightning stroke to the transmission line.

- Direct strokes to power conductors

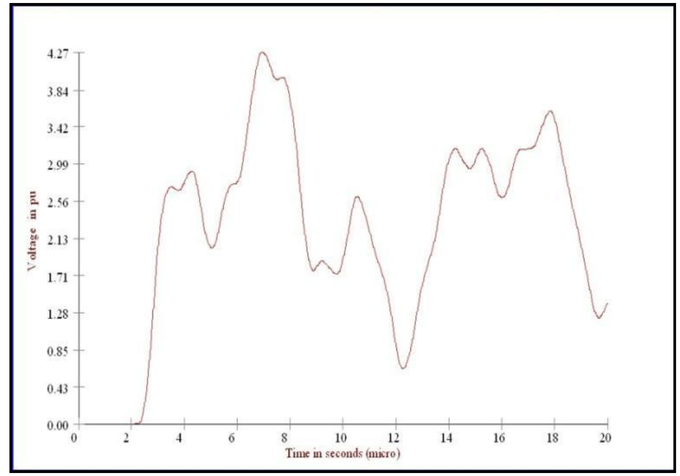
- Back flashovers

Sample study results of FFO

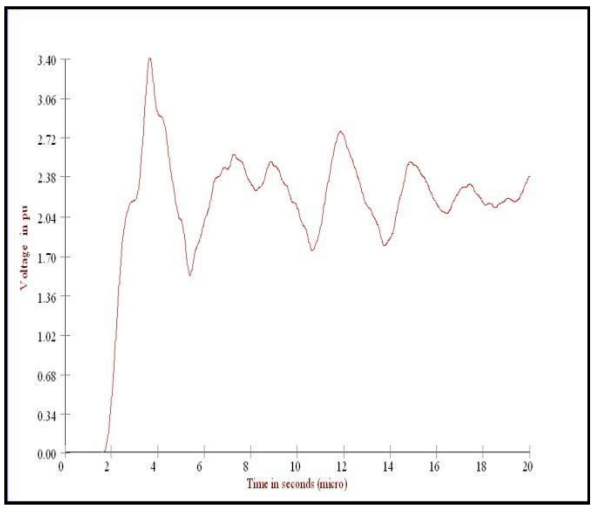




V_{busbar} with 1LA

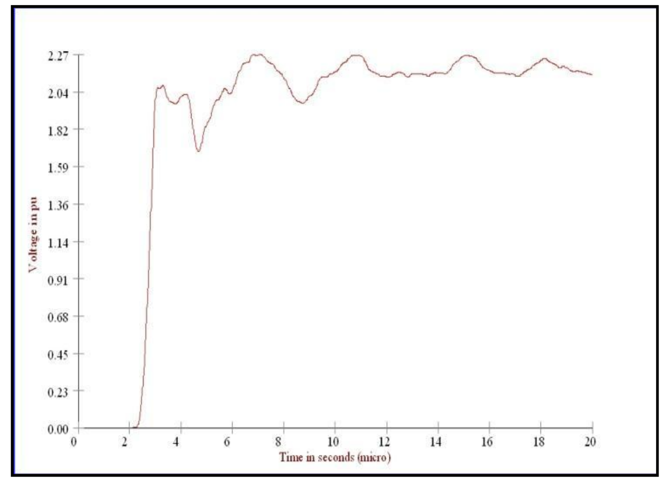


$V_{transformer}$ with 1LA

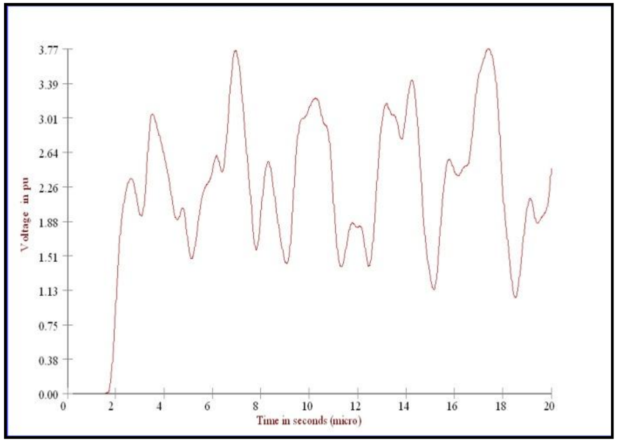


V_{busbar} with 2LAs

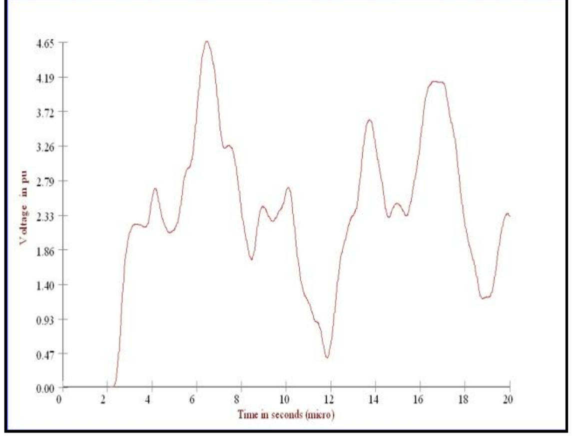
Direct stroke



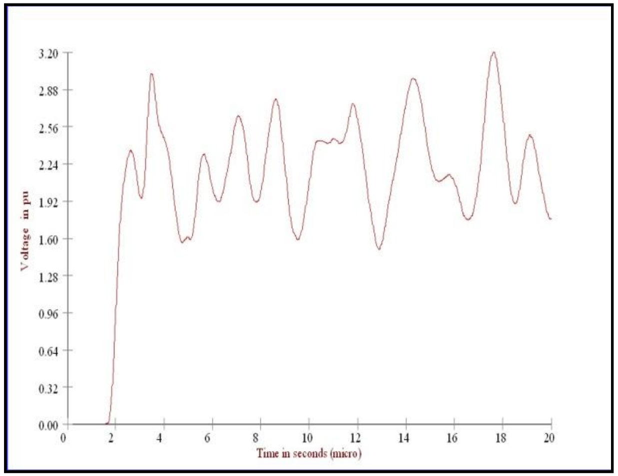
$V_{transformer}$ with 2LAs



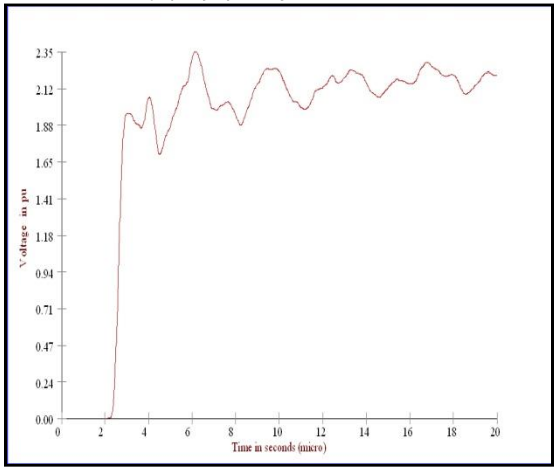
V_{busbar} with 1LA



$V_{transformer}$ with 1LA



V_{busbar} with 2LAs

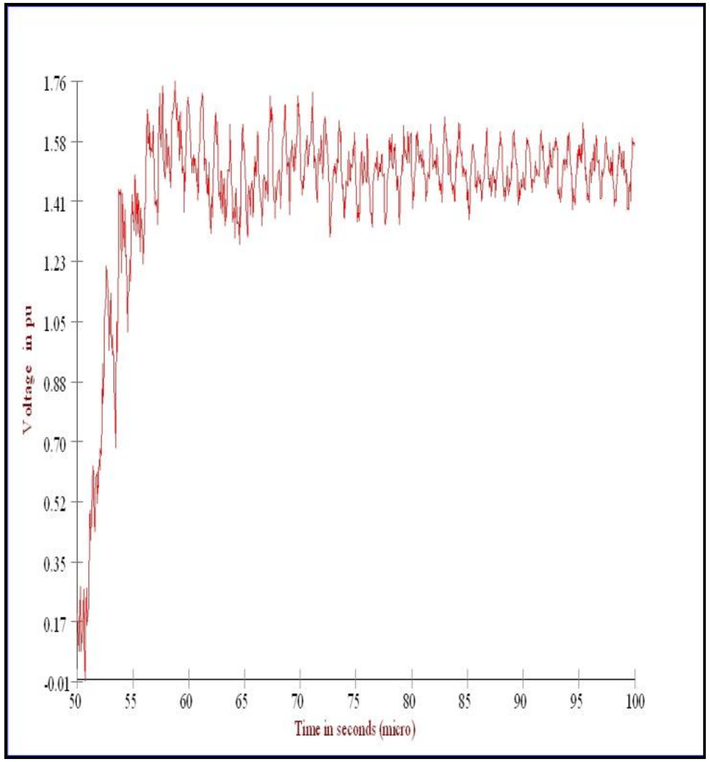


$V_{transformer}$ with 2LAs

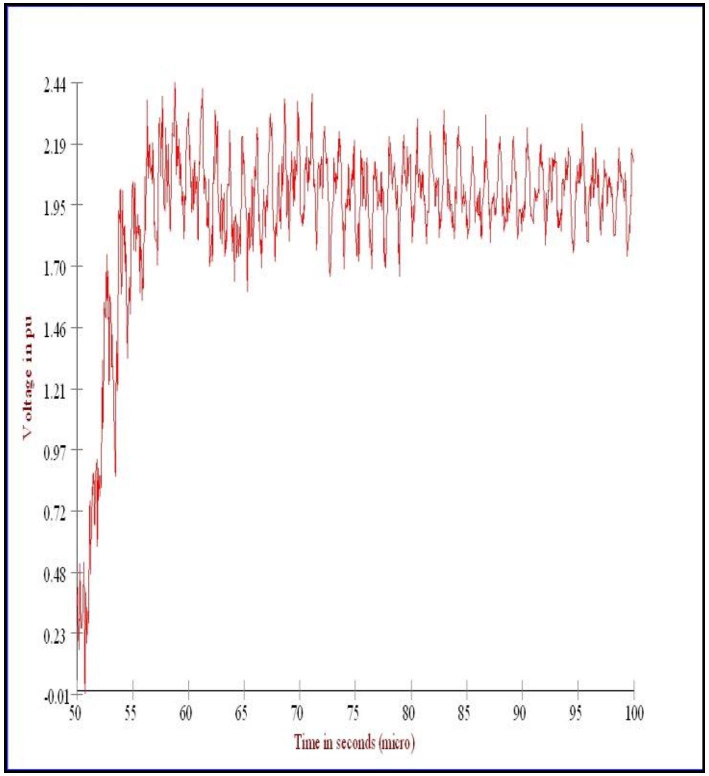
Back flashovers

Very Fast Front Overvoltages

- VFFOs appear under switching conditions in GIS or when operating vacuum circuit-breakers in medium-voltage systems.
- Pre-striking or GIS disconnector and SF6 circuit-breaker re-ignition would produce VFFO.
- VFFO in GIS can be divide into internal transient and external transient overvoltages,
- These VFFOs can be avoided by point-on-cycle (POC) switching



Trapped charge=0.5p.u



Trapped charge=1.0p.u

VFFOs in GIS

Overvoltage protection

Steady state overvoltages

-Transformer taps
-AVRs of Generators
-Neutral grounding of system
-Reactors
  -Line reactors
  -Bus reactors
  -Tertiary reactors

Overvoltage Protection for SFO,FFO, and VFTO

-Resistor Insertion

-Controlled switching

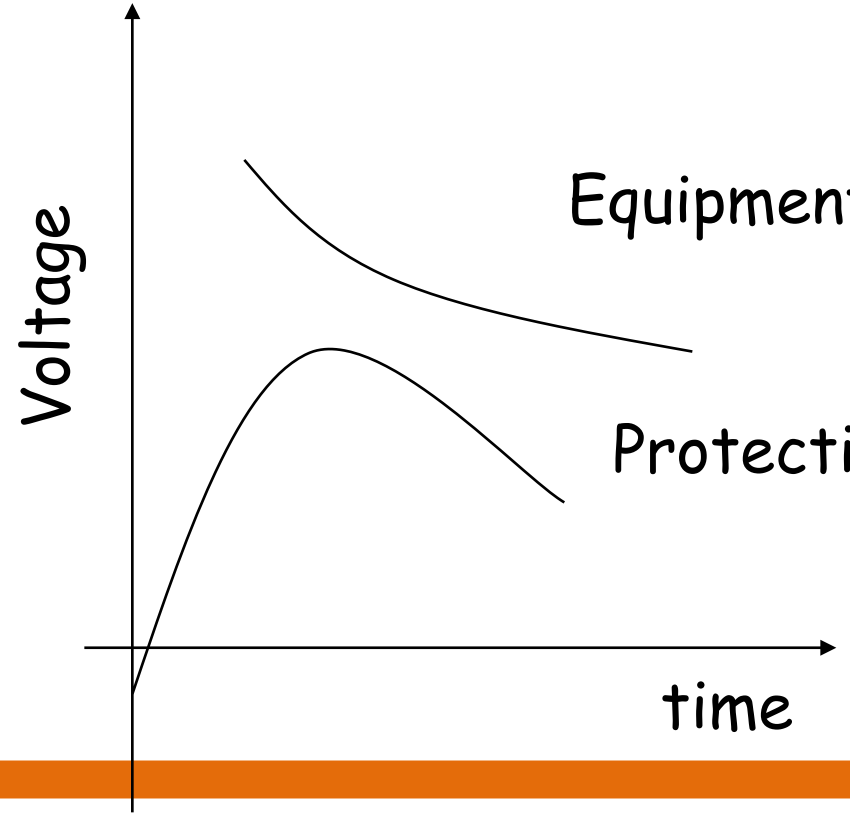
-Draining trapped energy

-Shielding methods

-Lightening Arresters

Conclusion

Based on these different overvoltage studies, we will do the insulation coordination of system equipment and protective device



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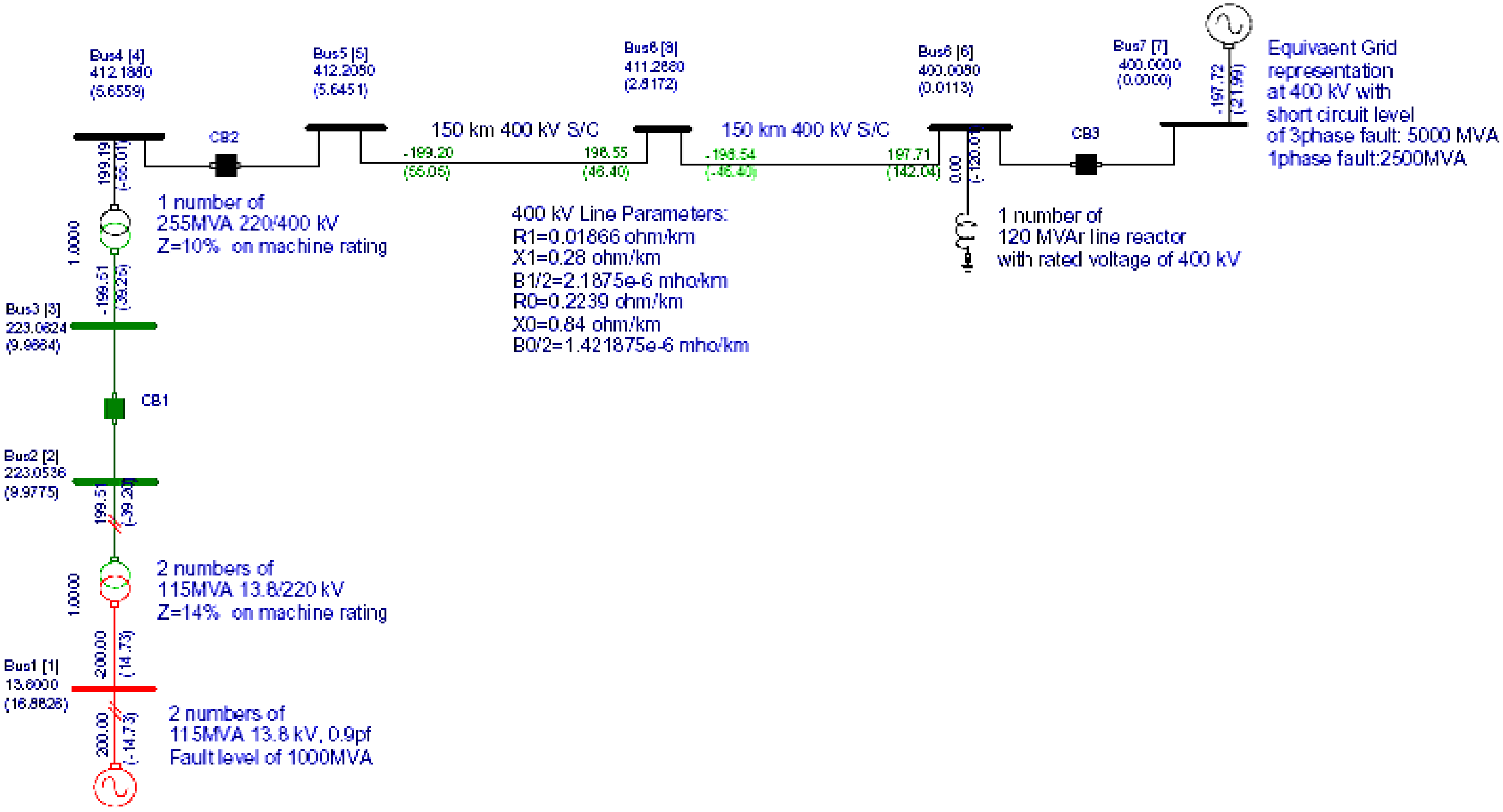
Case study on Overvoltages

Insulation coordination for 400kV S/S by conducting following overvoltage studies.

- Steady state Overvoltages
- Temporary Overvoltages
- Switching Overvoltages
- Lightning Overvoltages

Temporary Overvoltage studies



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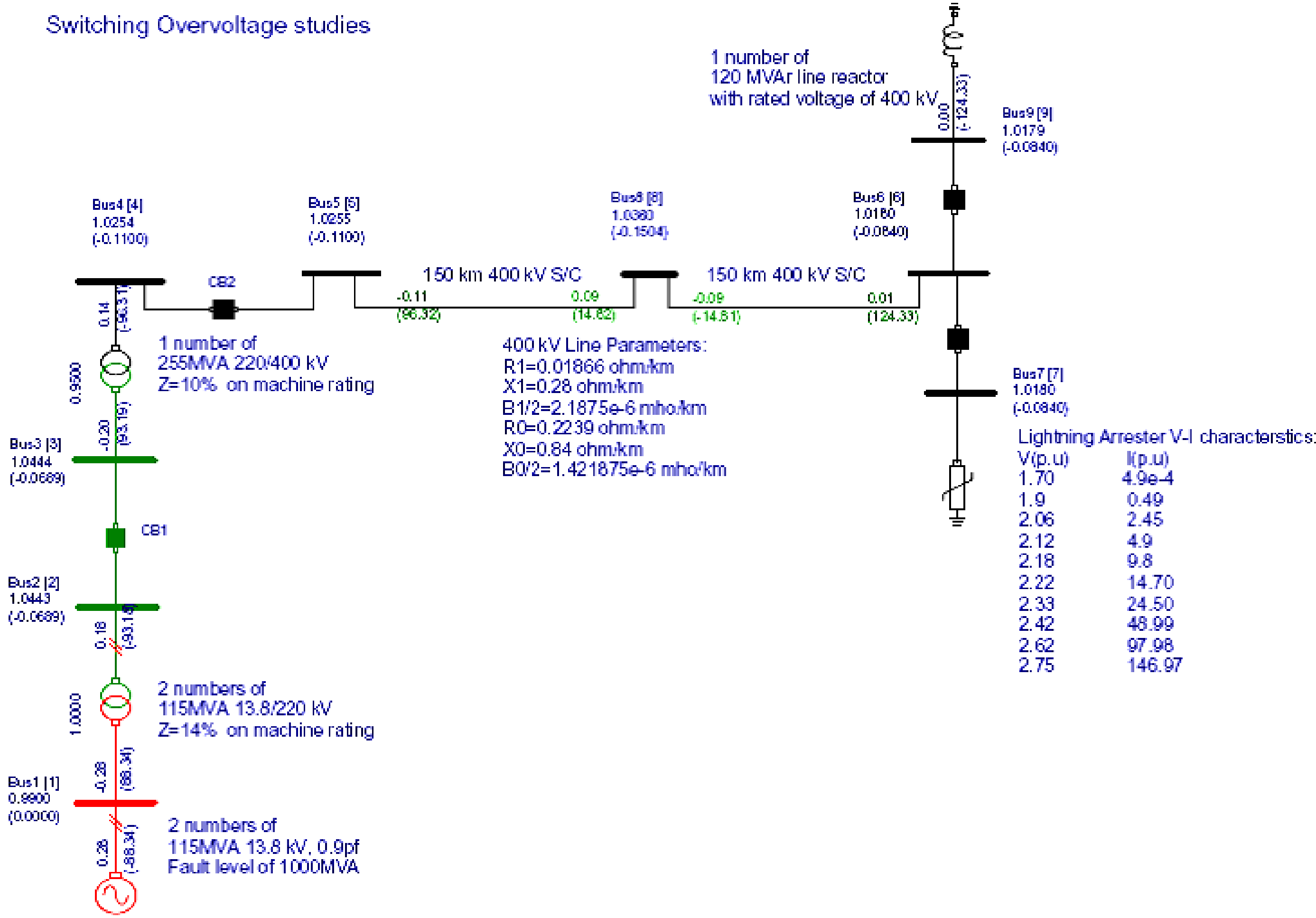
Switching Overvoltage studies



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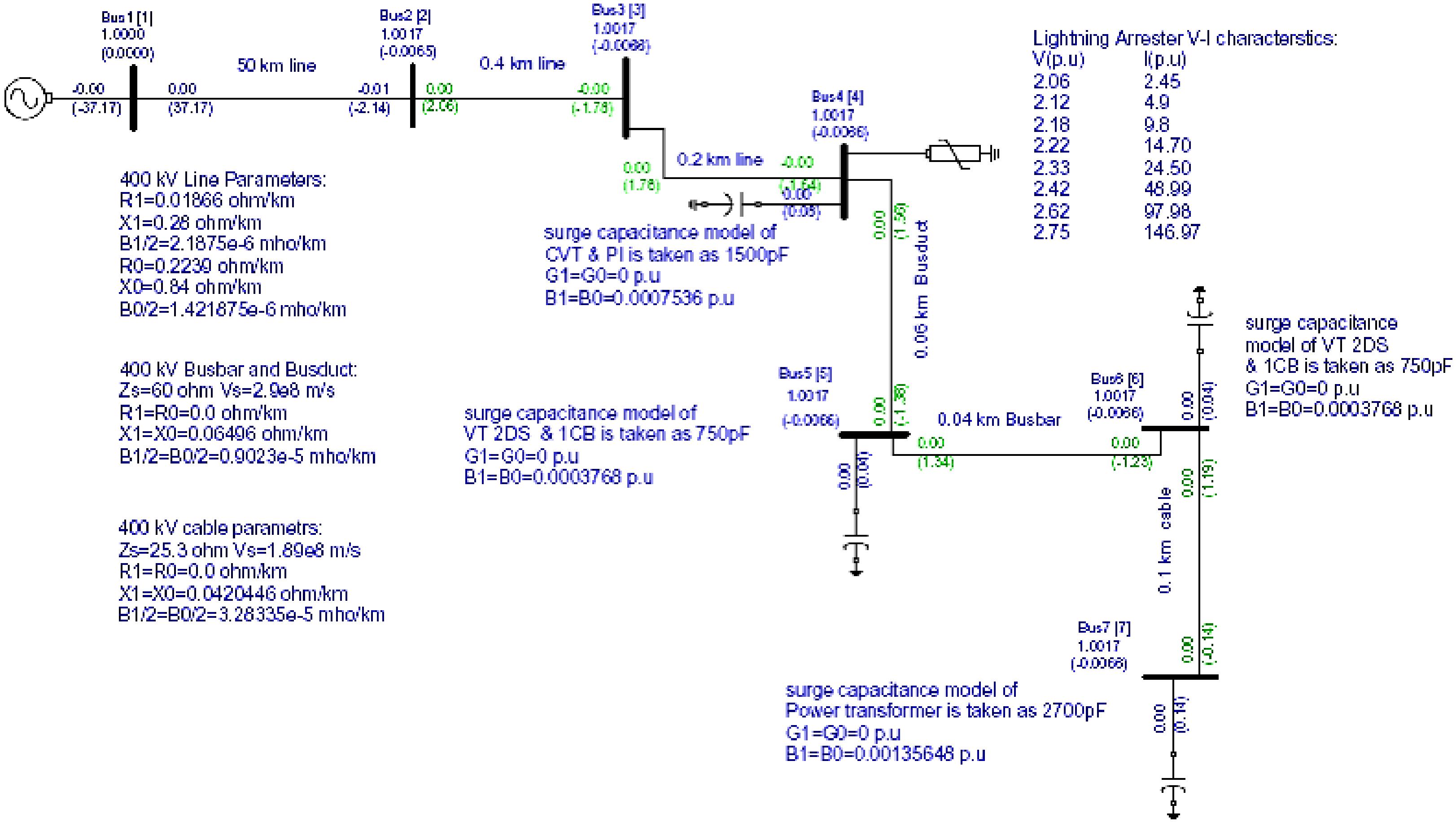
Fast Transient Analysis : Lightning stroke to phase wire (Direct stroke)



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Queries & Discussions

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COMTRADE
File Analysis

Contents

- Introduction
- Exploring Standard
- Types of files
- Difference between standard 1999 and 1991
- Exercise

Introduction

- Successful implementation of AFAS requires handling variety of recording equipments.
- The data available will be mostly in proprietary format which is a critical issue to handle.
- The problem can be solved by converting it into a standard format such as COMTRADE file format.
- Data need to be analyzed by implementing various algorithms.

Exploring standard

- IEEE Std C37.111 is dedicated to Common Format for Transient Data Exchange (COMTRADE) for Power Systems.
- A common format for data files and exchange medium used for the interchange of various types of fault, test or simulation data for electrical power systems is defined in the standard.
- There are two versions initial came in 1991 and revision is made in 1999.

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IEEE Std C37.111-1999

- Each COMTRADE record has set of four files which carries a different class of information.
- The four files are as follows :
  - Header
  - Configuration
  - Data
  - Information

Header file (xxx.HDR)

- The header file is an optional ASCII text file
- The header file can include any information in any order desired by the creator.
- The content of file is not intended to be manipulated by any application and it can be
  - Description of the power system prior to disturbance
  - Name of the station
  - Length of the faulted line; etc..

Configuration file (xxx.CFG)

- The configuration file is an ASCII text file intended to be read by a computer program
- It contains information needed by a computer program in order to properly interpret the data (.DAT) file
- One field in the first line of the configuration file identifies the year of the COMTRADE standard revision with which the file complies (e.g. 1991, 1999, etc.)

Configuration file (xxx.CFG)

- The configuration file shall have the following information:
  - Station name, identification of the recording device, and COMTRADE Standard revision year
  - Number and type of channels
  - Channel names, units, and conversion factors
  - Line frequency
  - Sample rate(s) and number of samples at each rate
  - Date and time of first data point
  - Date and time of trigger point
  - Data file type
  - Time Stamp Multiplication Factor.

Sample configuration file

An, ch_id, ph, ccbm, uu, a, b, skew, min, max, primary, secondary, PS

```
400kV UDUMALPET1,1,2001
40,8A,32D
1,VA              ,,,V,31.7,0,0,-32768,32767,1,1,S
2,VB              ,,,V,31.7,0,0,-32768,32767,1,1,S
3,VC              ,,,V,31.7,0,0,-32768,32767,1,1,S
4,VN              ,,,V,31.7,0,0,-32768,32767,1,1,S
5,IA              ,,,A,2.762,0,0,-32768,32767,1,1,S
6,IB              ,,,A,2.762,0,0,-32768,32767,1,1,S
7,IC              ,,,A,2.762,0,0,-32768,32767,1,1,S
8,IN              ,,,A,2.762,0,0,-32768,32767,1,1,S
1,D1 M-CB RPH OPEN,,,0
2,D2 M-CB YPH OPEN,,,0
3,D3 M-CB BPH OPEN,,,0
|
|
|
|
30,R4 RPH CONT MULT,,,0
31,R5 YPH CONT MULT,,,0
32,R6 BPH CONT MULT,,,0
50
0
1194,1800
07/08/2011,04:25:21.936000
07/08/2011,04:25:22.117000
ASCII
1
```


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Data file (xxx.DAT)

- The data file contains the value for each input channel for each sample in the record.
- The data file contains the sample number, time stamp, and data values of each channel for each sample in the file.
- In the event that the total storage space required for the file set exceeds 1.44 MB, the data file may be segmented into multiple files, each of less than 1.44 MB having file extension from .D00 to .D99, thus allowing a maximum of 100 data files.

Data file (xxx.DAT)

- All data in data files are in the integer format.
- The contents of the file are:
  - The first column contains the sample number.
  - The second column is the time stamp for the data of that sample number.
  - The third set of columns contain the data values that represent analog information.
  - The fourth set of columns contain the data for the status channels.
  - Format : **n, timestamp, A1, A2,···Ak, D1, D2,···Dm**

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Sample Data File

```
1,         0,    -2254, -7796, 10211,   162,   55, 27, -77, 4,0,-------,0,0
2,       838,     541, -9544,  9073,    69,   38, 45, -79, 3,0,-------,0,0
3,      1676,    3164,-10444,  7267,   -13,   12, 60, -73,-1,0,-------,0,0
|                                |                           |
|                                |                           |
|                                |                           |
|                                |                           |
1799,   1506724,   65, -1663, -1548, -3146,   14,   6,    3, 22,1,-------,1,1
1800,   1507562,   63, -1714, -1614, -3265,   15,   5,    2, 21,1,-------,1,1
```


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Obtaining Instantaneous Value

- The constants are available in XXX.CFG file
- The value is available in XXX.DAT file
- The conversion can be as follows :

  Let x be the value of a quantity in data file

  Let a and b the constants given in configuration file

Then, instantaneous value *x* is given as

$$x = ax + b$$

Example: if x=100, a = 10 and b=1

$$x = 10*100 + 1 = 1001$$

Information File (xxx.INF)

- The information file (.INF) is an optional file.
- The information file is an ASCII text file that is in a computer readable specified format.
- File contains two type of information which are classified as public and private respectively.
- Public sections contain information in a form that can be used by equipment and/or software made by more than one manufacturer.
- Private sections contain manufacturer specific information that is only useful with a specific vendor

Difference Between Standard of 1999 and 1991

- The Header (.HDR) file is explicitly defined as optional.
- The Configuration (.CFG) file has been modified.
  - A field containing standard revision year has been added.
  - A field for a Time Stamp Multiplication Factor has been added.
  - To assist in conversion of the data, three new scaling fields (primary, secondary, and primary-secondary) are added.
  - Configuration fields for Status (Digital) Channel Information have been expanded to five fields.
  - Support for Event Triggered data has been added by the addition of a new mode for sampling rate Information
  - The Date/Time Stamps format has been modified
  - i.e. mm/dd/yy in 1991 to dd/mm/yyyy in 1999

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Difference Between Standard of 1999 and 1991

- A new format for a binary data (.DAT) file has been specified .
- A new optional Information file (.INF) has been added to provide for transmission of extra public and private information in computer-readable form
- All field descriptions are explicitly defined with respect to: criticality, format, type, minimum/maximum length, and minimum/maximum value.

Exercise

```
KAIGA LINE 2,34,1999
25,8A,17D
1,VA,,, V, 31.702786,0.0,0.0,-32767,32767,,,
2,VB,,, V, 31.702786,0.0,0.0,-32767,32767,,,
|
|
8,IN,,, A,  2.762230,0.0,0.0,-32767,32767,,,
1,TRIP-R-MAIN-GR-B,,,0
2,TRIP-Y-MAIN-GR-B,,,0
|
|
17,SOTF/TOR Trip,,,0
49.000000
1
2000.0000,5972
18/06/2011,12:18:55.610001
18/06/2011,12:18:56.210000
ASCII
1
```

```
REL521,0
58,10A,48D
1,VA,,,kV,0.018043,0,0,-32768,32767
2,IA,,,A,5.000000,0,0,-32768,32767
|
|
9,U5,,,kV,0.018043,0,0,-32768,32767
10,I5,,,A,10.000000,0,0,-32768,32767
1,LINE-CB-OPN-R,0
2,LINE-CB-OPN-Y,0
|
|
47,Time-Sync     ,0
48,Input48       ,0
50.000000
1
1000,1605
3/30/10,11:44:48.96000
3/30/10,11:44:48.196000
ASCII
```

Solution

- Exercise 1 :
  - Ans 1: 1999 Ans 1: 1991
  - Ans 2: Analog = 8 Ans 2: Analog = 10

    Digital =17 Digital = 48
  - Ans 3: 5972 Ans 3: 1605
  - Ans 4: Time Stamp - Ans 4: 1000 Hz

    -Multiplication Factor
- Exercise 2 :

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Tripping Analysis - Methodology

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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 Analys

- 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

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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

Adobe Acrobat Document

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.

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Queries & Discussions

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