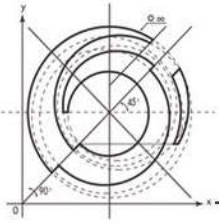




# Generator Protection

**ALSTOM**

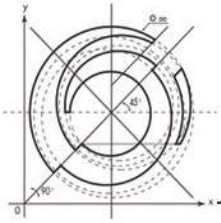


# Generator Protection



The extent and types of protection specified will depend on the following factors :-

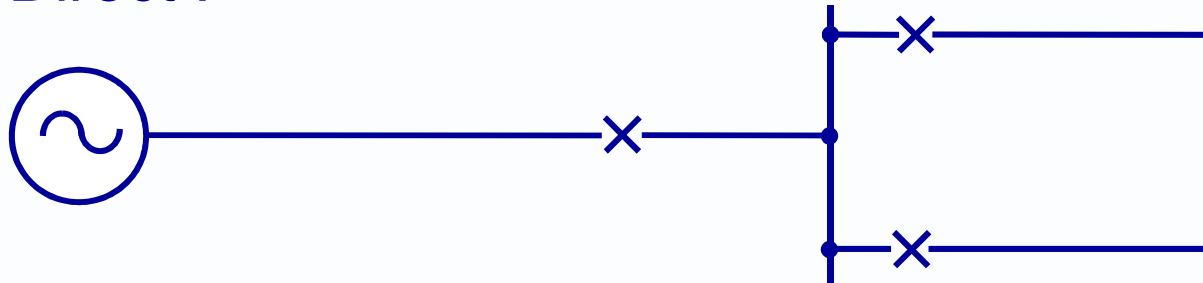
- Type of prime mover and generator construction
- MW and voltage ratings
- Mode of operation
- Method of connection to the power system
- Method of earthing



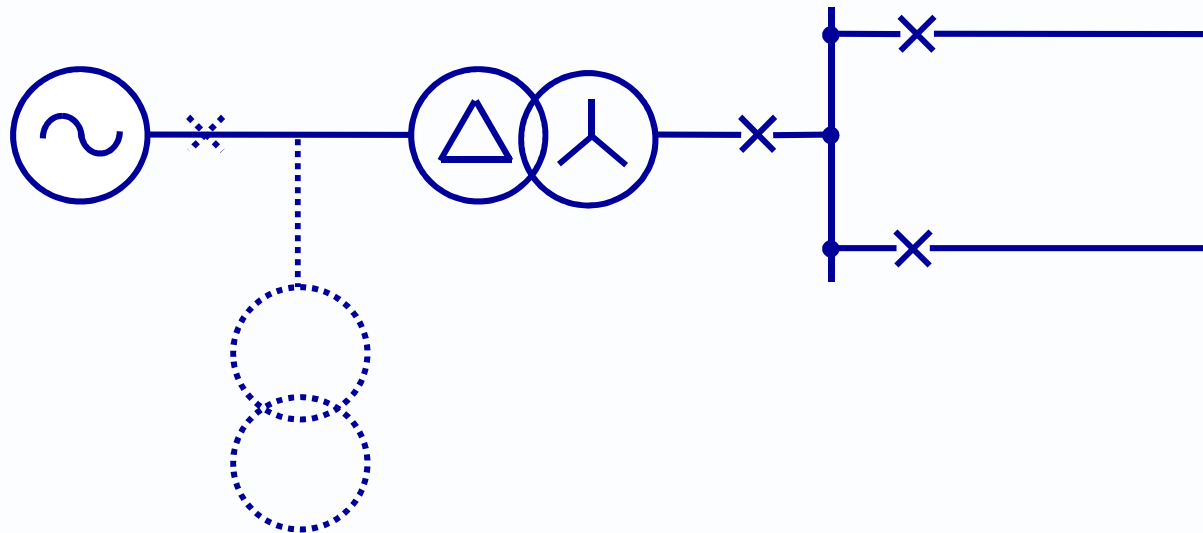
# Connection to the Power System

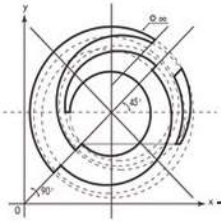


1. Direct :

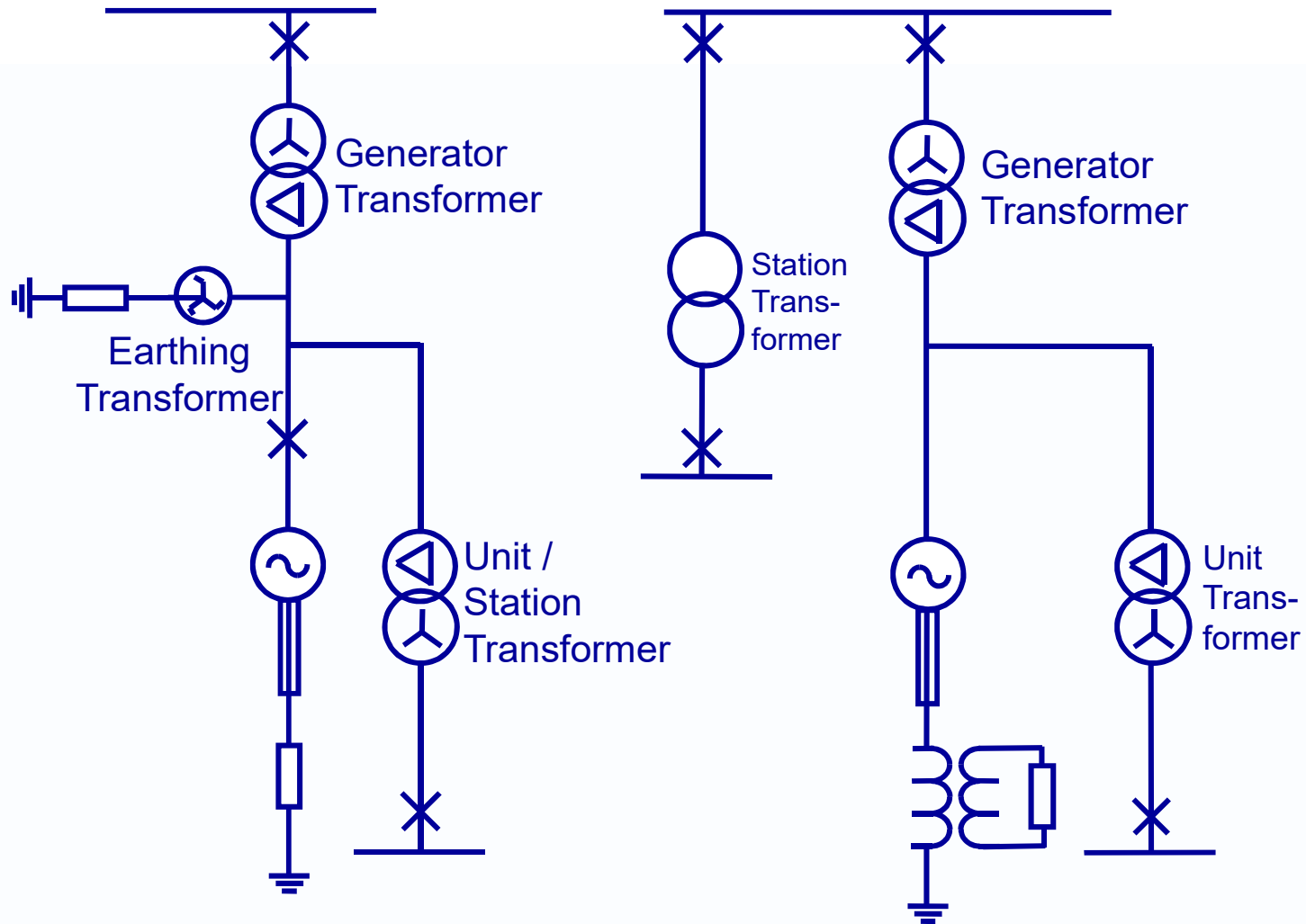


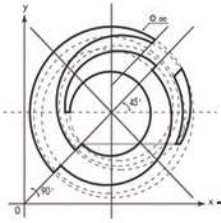
2. Via Transformer :





# Typical Generator Installations





# Generator Protection Requirements

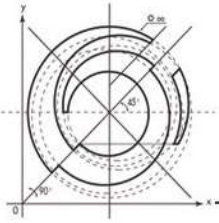


- To detect faults on the generator
- To protection generator from the effects of abnormal power system operating conditions
- To isolate generator from system faults not cleared remotely

Action required depends upon the nature of the fault.

Usual to segregate protection functions into :

- Urgent
- Non-urgent
- Alarm



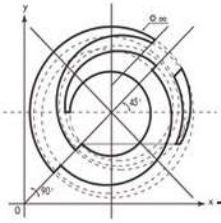
# Generator Faults



Mixture of mechanical and electrical problems.

Faults include :-

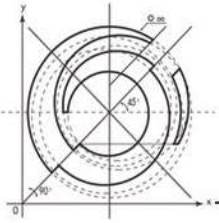
- Insulation Failure
    - Stator
    - Rotor
  - Excitation system failure
  - Prime mover / governor failure
  - Bearing Failure
  - Excessive vibration
  - Low steam pressure
- etc.



# System Conditions

**ALSTOM**

- Short circuits
- Overloads
- Loss of load
- Unbalanced load
- Loss of synchronism



# Stator Earth Fault Protection



Fault caused by failure of stator winding insulation

Leads to burning of machine core  
welding of laminations

Rebuilding of machine core can be a very expensive process

Earth fault protection is therefore a principal feature of any generator protection package

TYPE OF PROTECTION

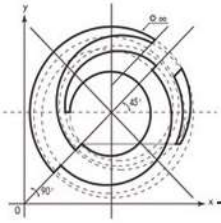


METHOD OF EARTHING



METHOD OF CONNECTION

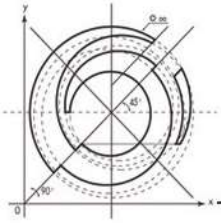




## Method of Earthing



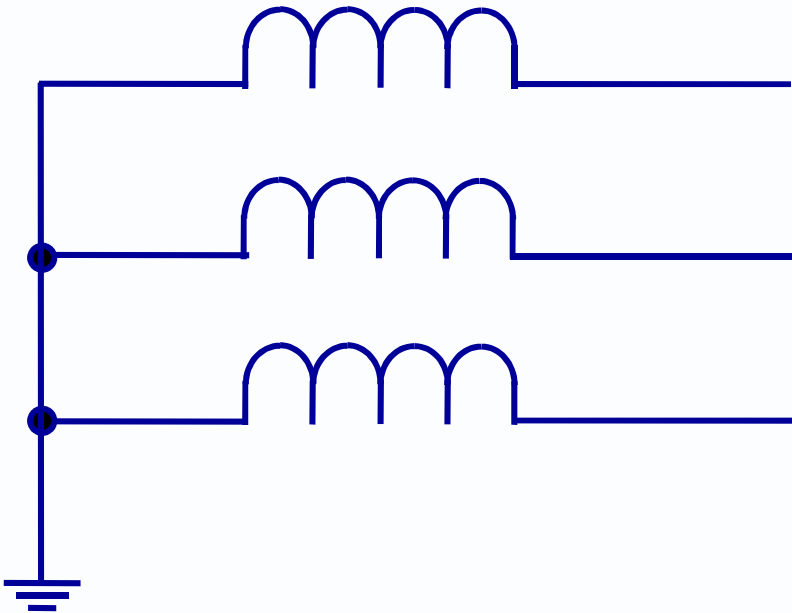
- Machine stator windings are surrounded by a mass of earthed metal
- Most probable result of stator winding insulation failure is a phase-earth fault
- Desirable to earth neutral point of generator to prevent dangerous transient overvoltages during arcing earth faults
- Several methods of earthing are in use
- Damage resulting from a stator earth fault will depend upon the earthing arrangement



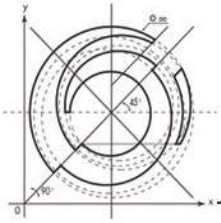
# Method of Earthing



## Solidly Earthed Machines :



- Fault current is high
- Rapid damage occurs
  - burning of core iron
  - welding of laminations
- Used on LV machines only



## Method of Earthing

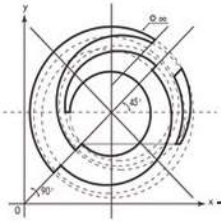
ALSTOM

Desirable to limit earth fault current :

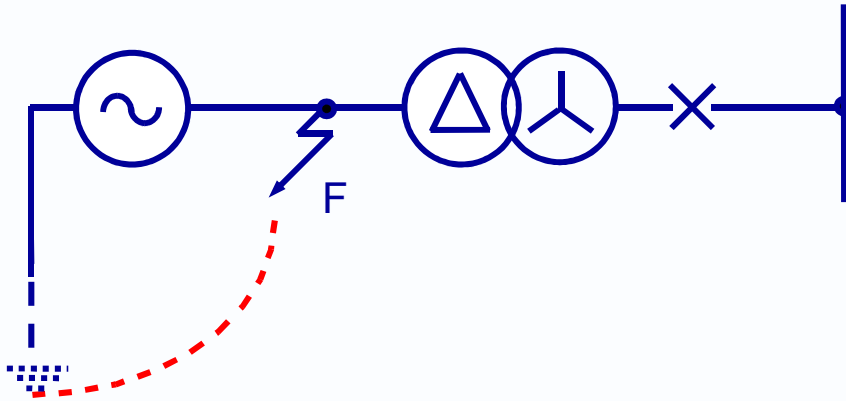
- limits damage
- reduces possibility of developing into phase-phase fault

Degree to which fault current is limited must take into account :

- detection of earth faults as near as possible to the neutral point
- ease of discrimination with system earth fault protection (directly connected machines)

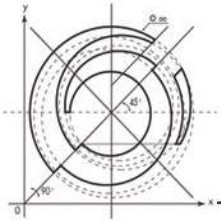


## Method of Earthing : Limitation of Earth Fault Current



Earth faults on the power system are not seen by the generator earth fault protection.

Discrimination not required  $\therefore$  can limit current to very low value. Sometimes down to 5A

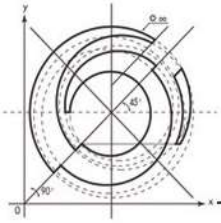


## Method of Earthing : Limitation of Earth Fault Current

**ALSTOM**

### Limit To Generator Full Load Current

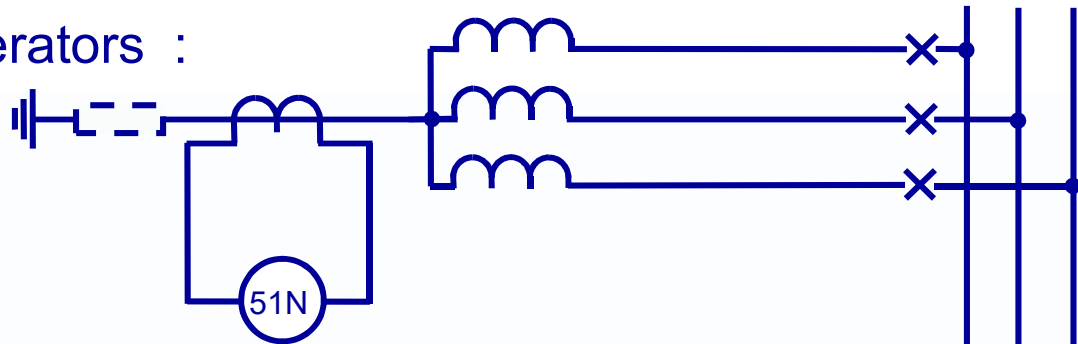
- Most popular.
- Used for ease of fault detection and discrimination.
- Residual connection of CTs can be used
- Can result in serious core damage.



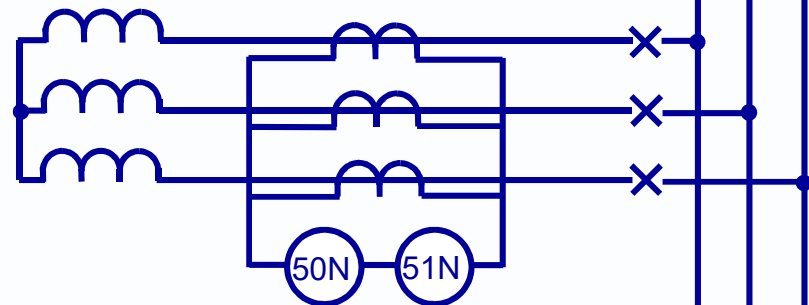
# Stator Earth Fault Protection



Directly Connected Generators :

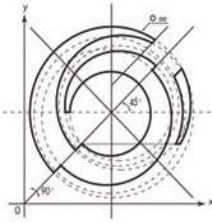


Earthed Generator : Earth fault relay must be time delayed for co-ordination with other earth fault protection on the power system.



Unearthed Generators : Other generators connected in parallel will generally be unearthed.

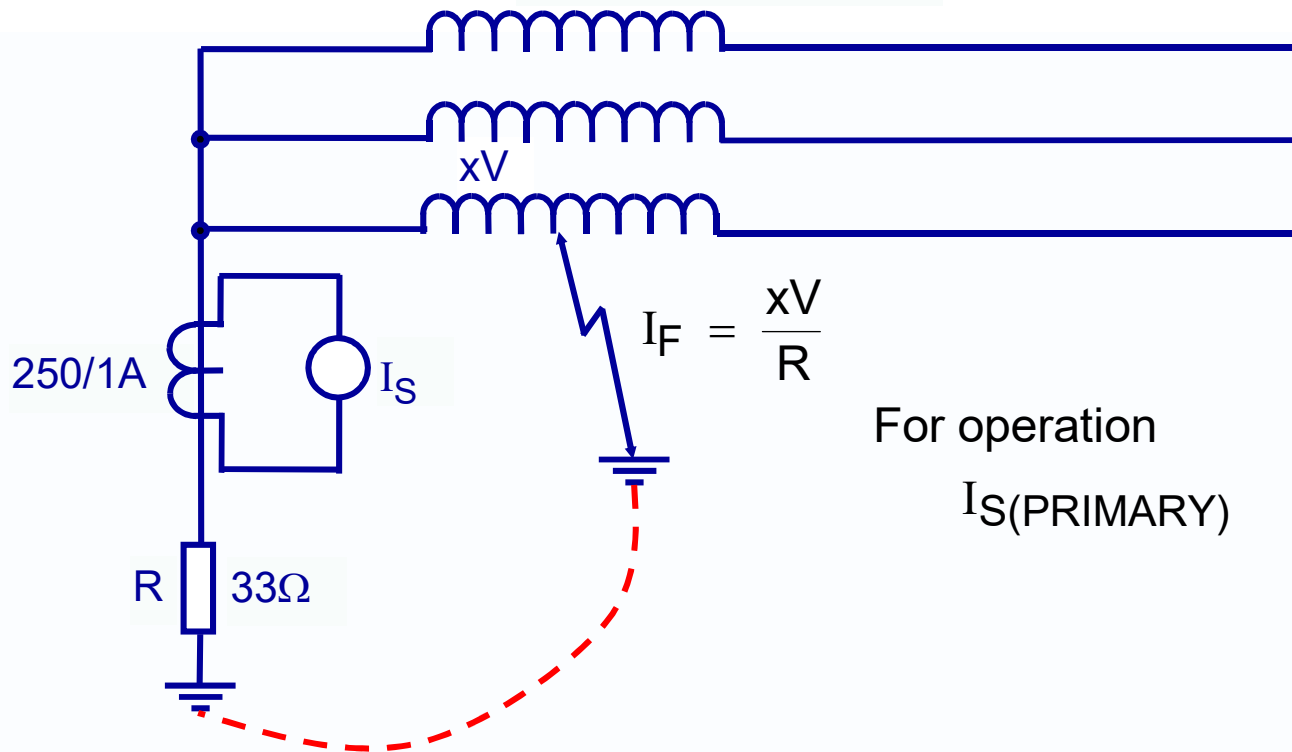
Protection is restricted to faults on the generator, grading with power system earth fault protection is not required. A high impedance instantaneous relay can be used (Balanced Earth Fault protection).



# Percentage Winding Protected



11.5kV; 75,000KVA



For operation

$$I_S(\text{PRIMARY}) < I_F$$

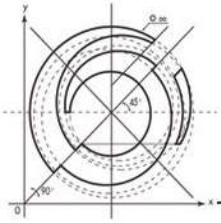
$$< \frac{xV}{R}$$

$$< \frac{x.6600}{33} < x.200$$

$$I_S(\text{SECONDARY}) < x.200 \times \frac{1}{250} < 0.8x$$

∴ For protection of 90% of winding;  $x = 1 - 0.9 = 0.1$

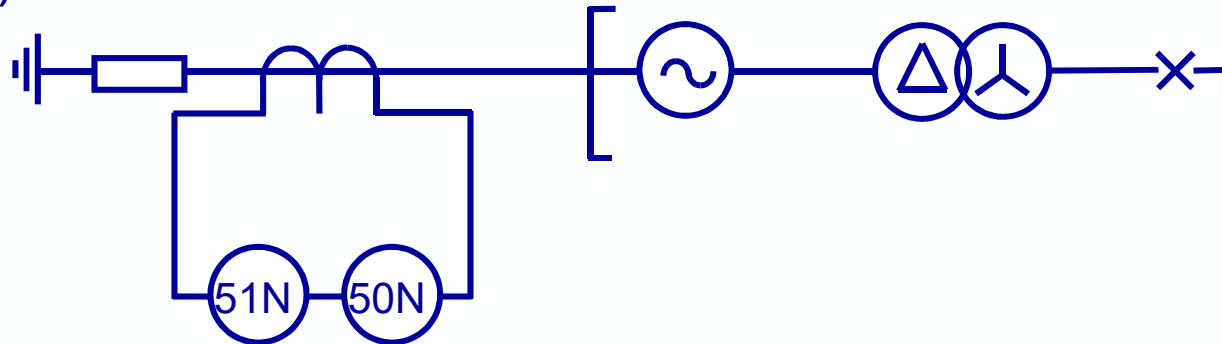
Relay setting =  $0.8 \times 0.1 = 0.08\text{A} = 8\%$  of 1A



# Stator Earth Fault Protection



Generators connected via step-up transformer (resistance earthed) :



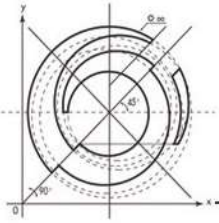
Instantaneous protection (50N) :

System earth faults ARE not seen by generator earth fault protection  $\therefore$  instantaneous relay may be used.

Set to 10% of resistor rating (avoids operation due to transient surges passed through generator transformer interwinding capacitance).

**Advantage** : Fast





# Stator Earth Fault Protection



Time delayed protection (51N) :

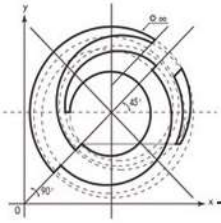
Time delay prevents operation on transient surges.

A more sensitive current setting may be used.

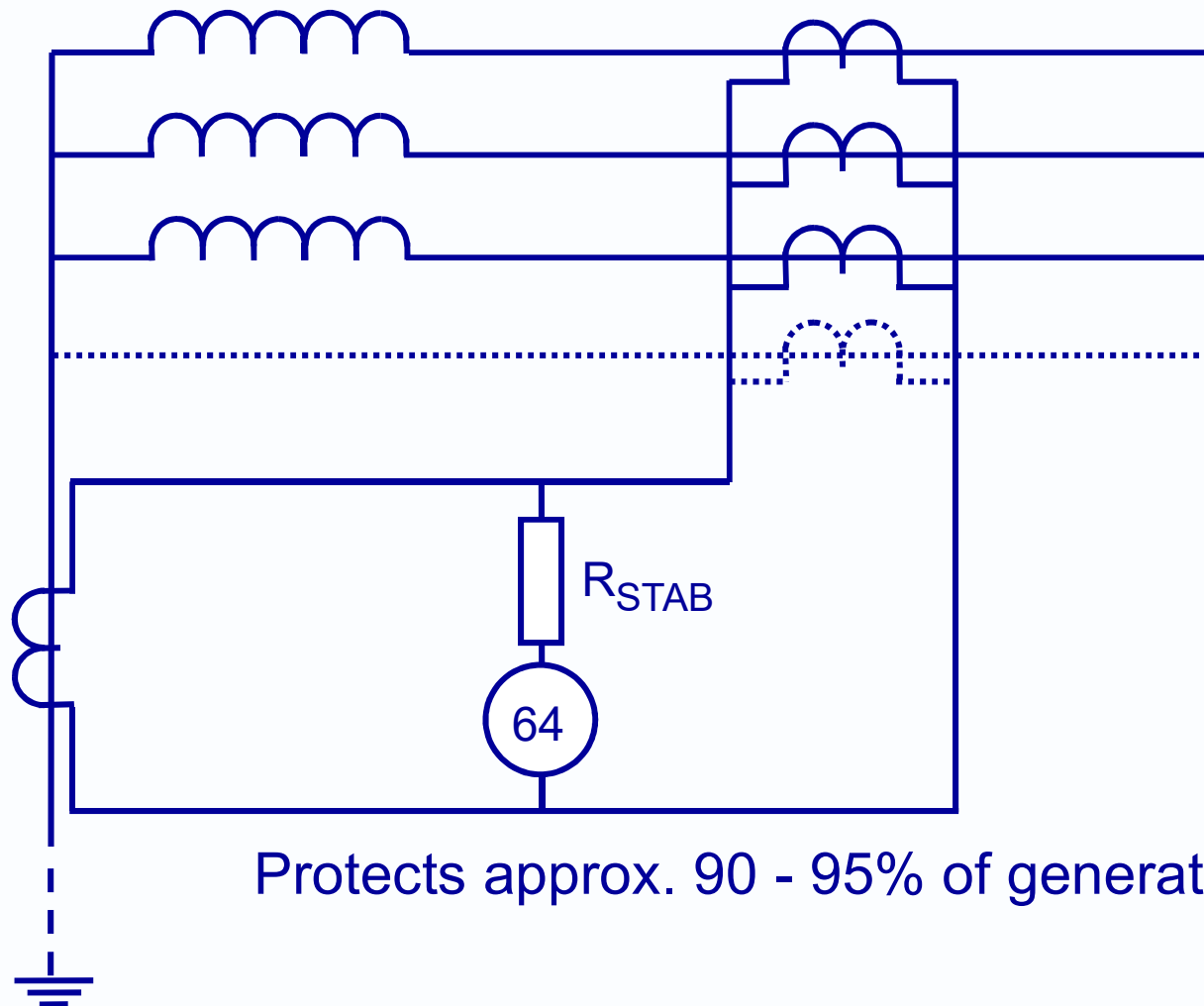
Set to 5% of resistor rating.

**Advantage** : Sensitive

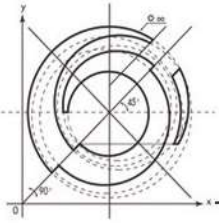
On large machines considered worthwhile to use both instantaneous and time delayed.



## Restricted Earth fault Protection



Protects approx. 90 - 95% of generator winding.



# Stator Earth Fault Protection



## **100% Stator Earth Fault Protection :**

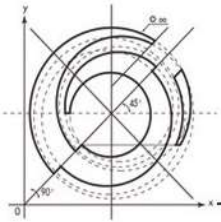
Standard relays only cover 95% of winding.

Probability of fault occurring in end 5% is low.

On large machines 100% stator earth fault protection may be required.

Two methods :

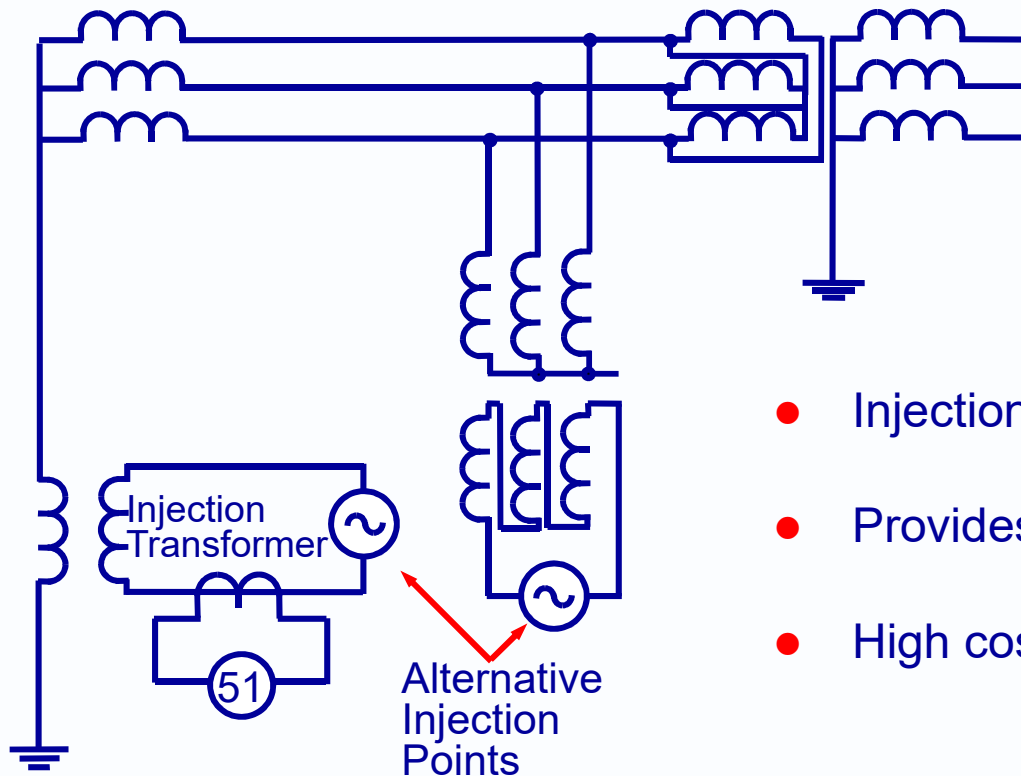
- \* Low Frequency Injection
- \* Third Harmonic Voltage Measurement



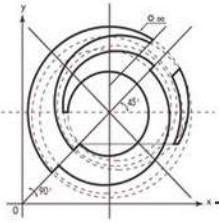
# 100% Stator Earth Fault - Low Frequency Injection



## For Large Machines Only

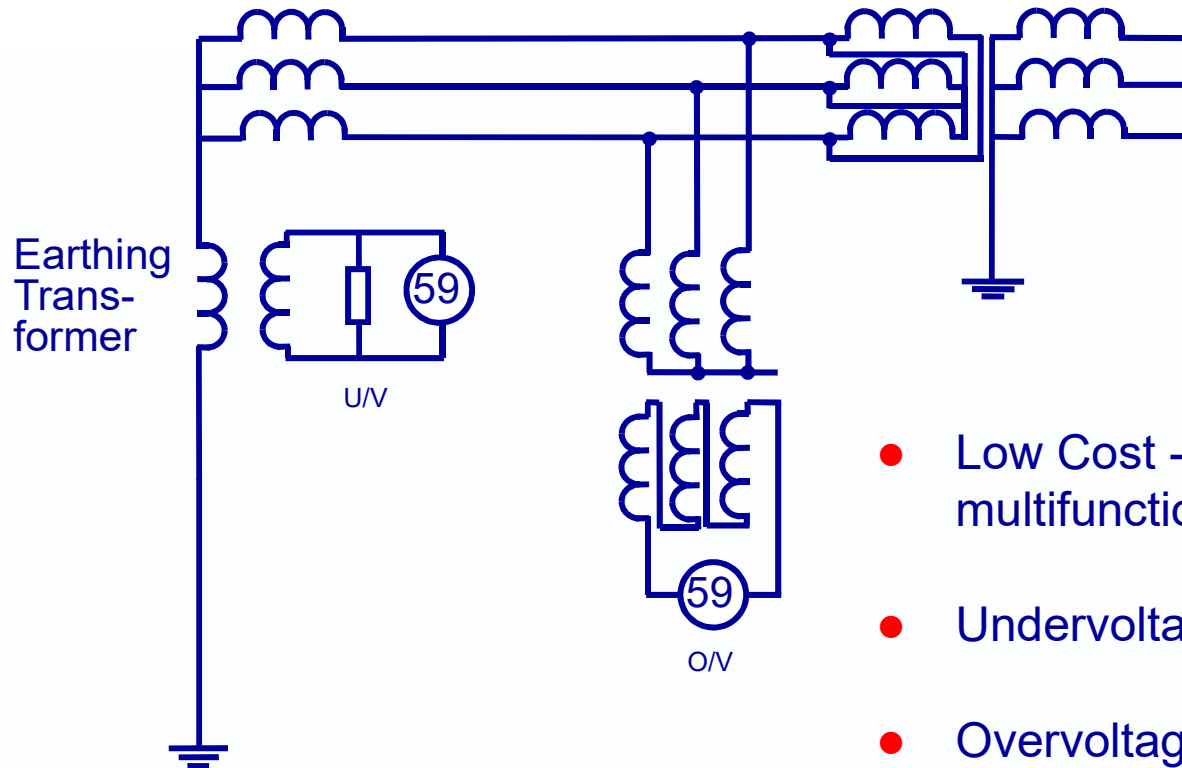


- Injection Frequency 12.5 - 20Hz
- Provides protection during run up
- High cost due to injection equipment.

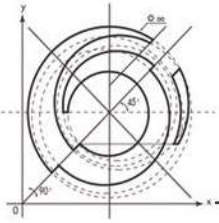


# 100% Stator Earth Fault - 3rd Harmonic Voltage

ALSTOM



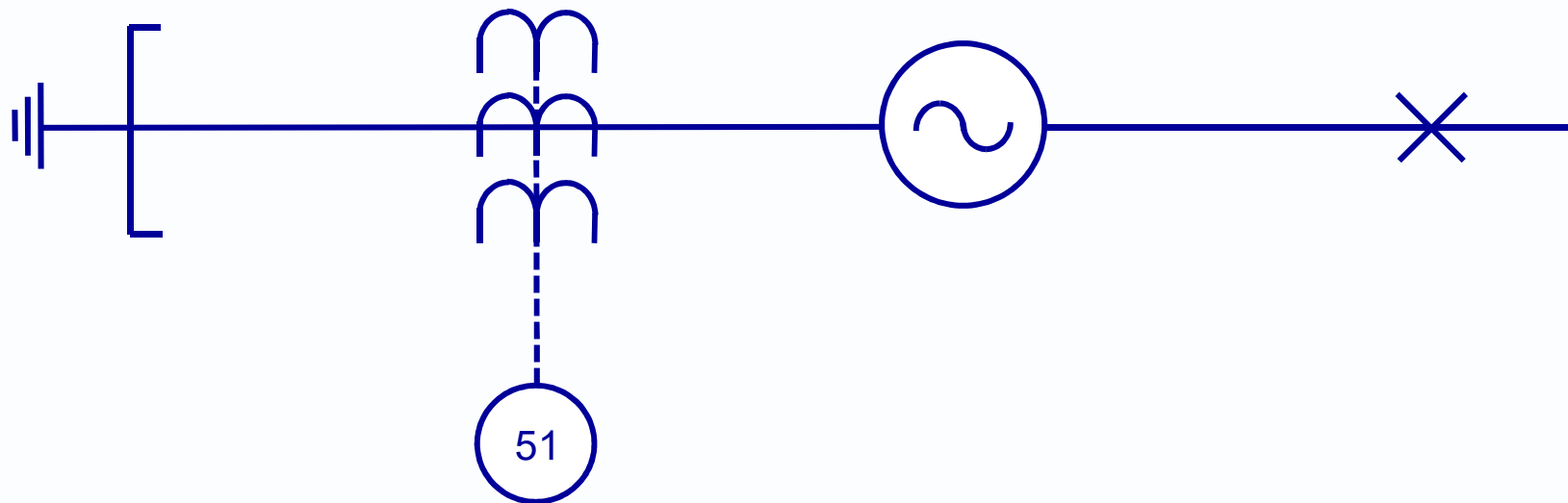
- Low Cost - Can be integrated into multifunction relay
- Undervoltage measurement at neutral
- Overvoltage measurement at terminals
- No protection during run up - need to be on load.
- 3rd harmonic voltage maybe limited due to design of machine

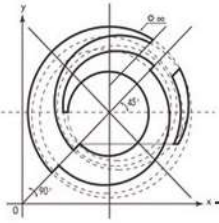


# Overcurrent Protection



- For small generators this may be the only protection applied.
- With solid earthing it will provide some protection against earth faults.
- For a single generator, CTs must be connected to neutral end of stator winding.

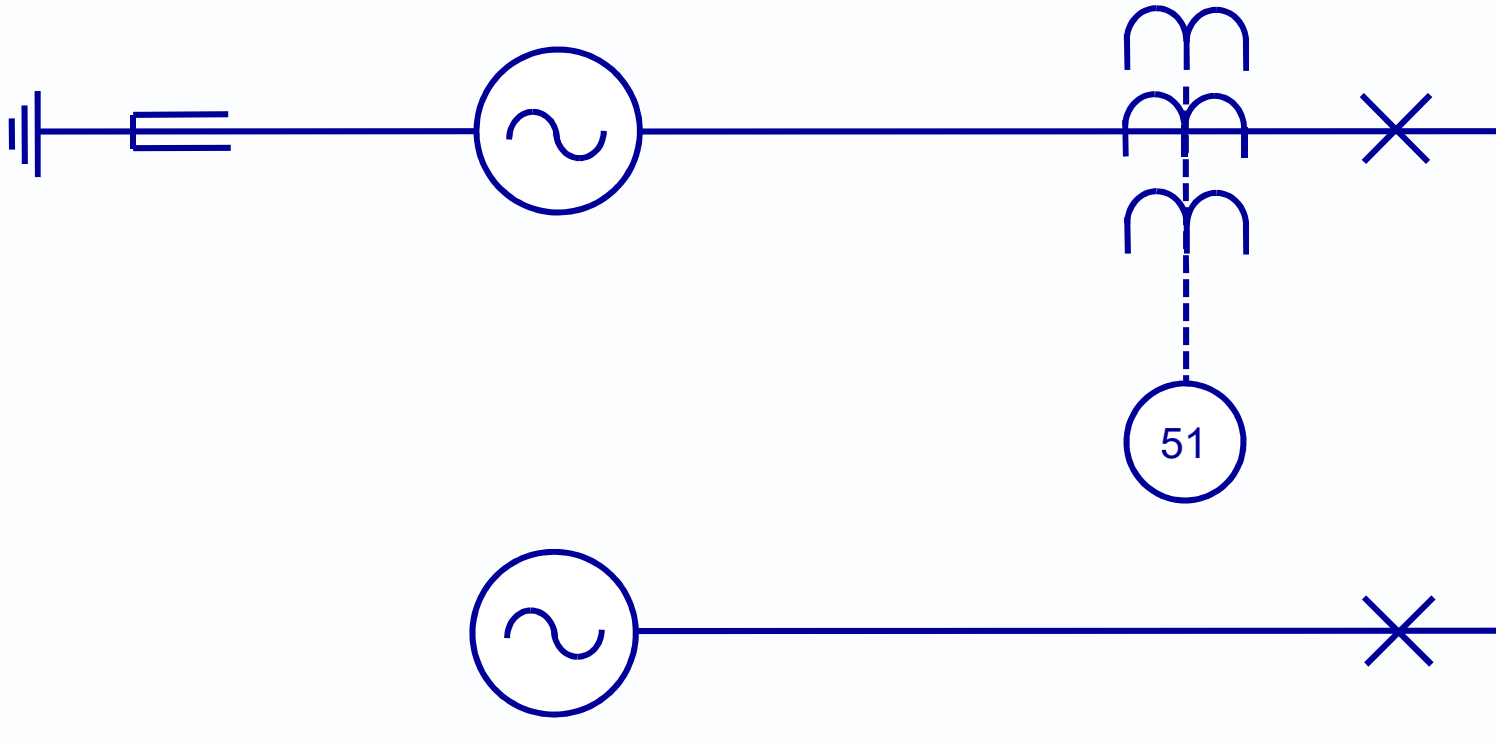


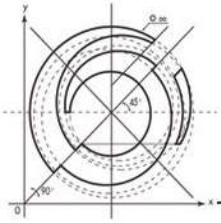


# Overcurrent Protection



- For parallel generators, CTs can be located on line side.



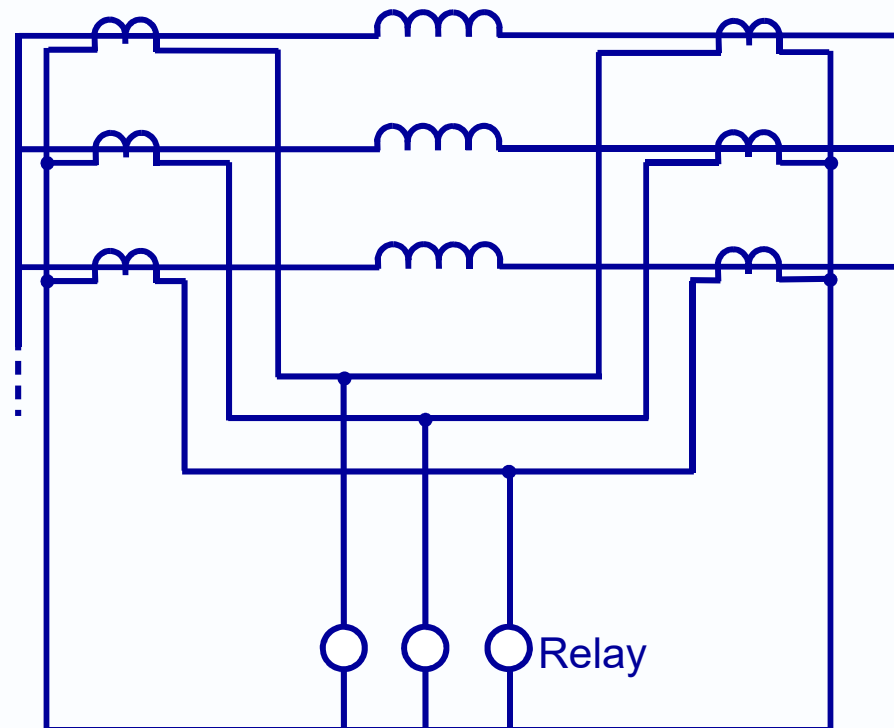


# Differential Protection

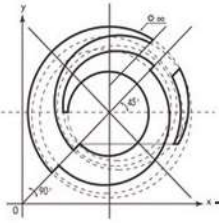


- Provides high speed protection for all fault types
- May be : High impedance type  
: Biased (low impedance) type

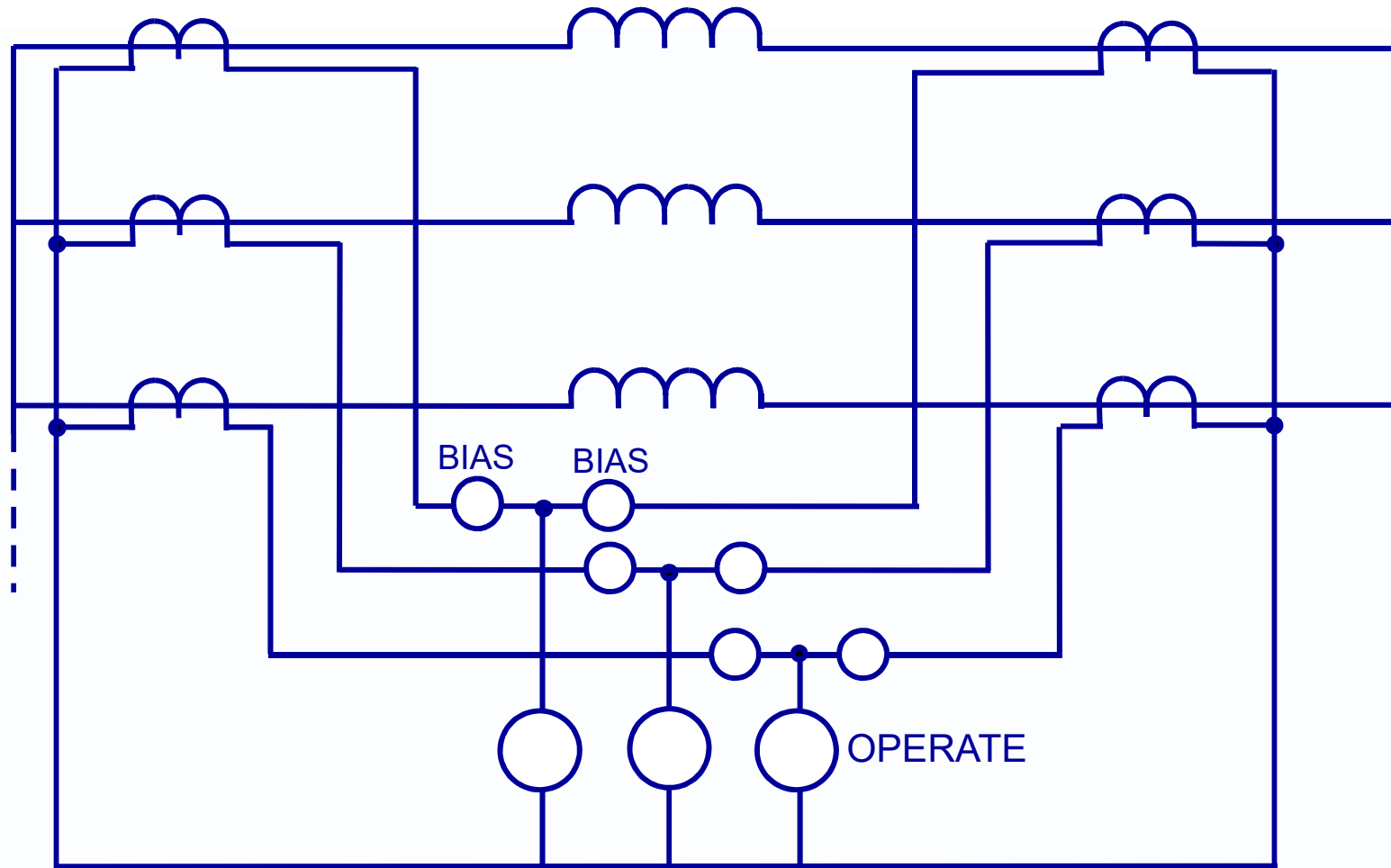
CT's required in neutral end of winding



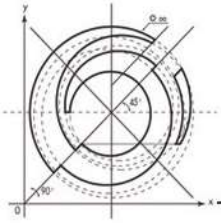




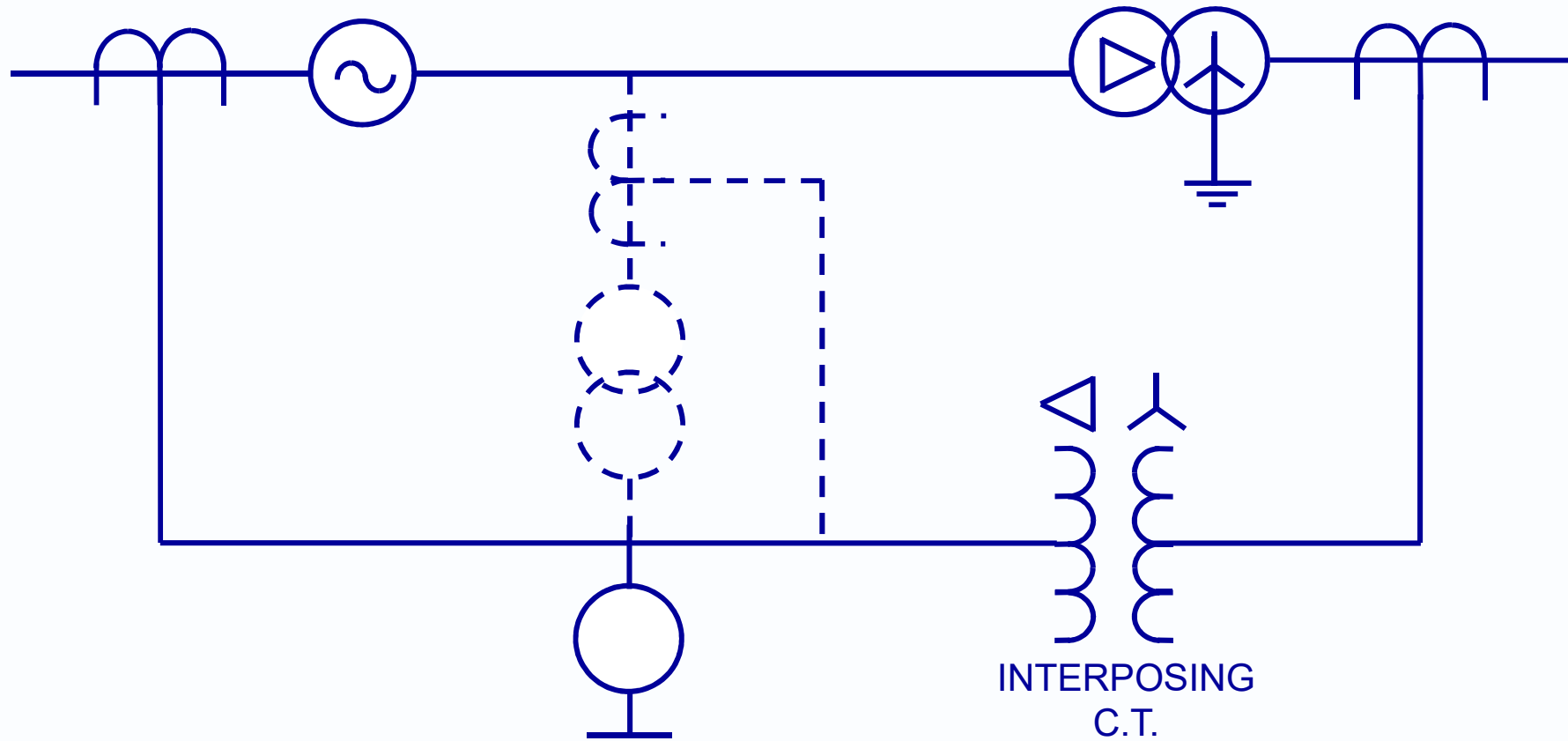
# Differential Protection - Biased



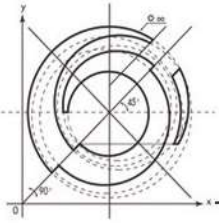
Biased Differential Scheme



# Differential Protection



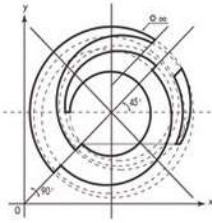
Overall Differential Scheme



# Stator Interturn Fault Protection



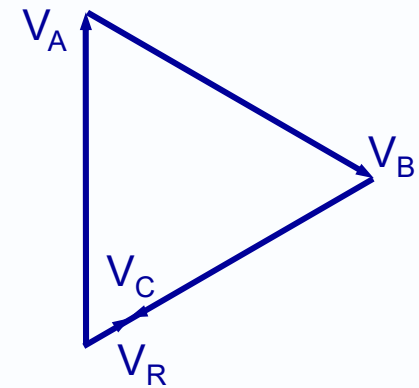
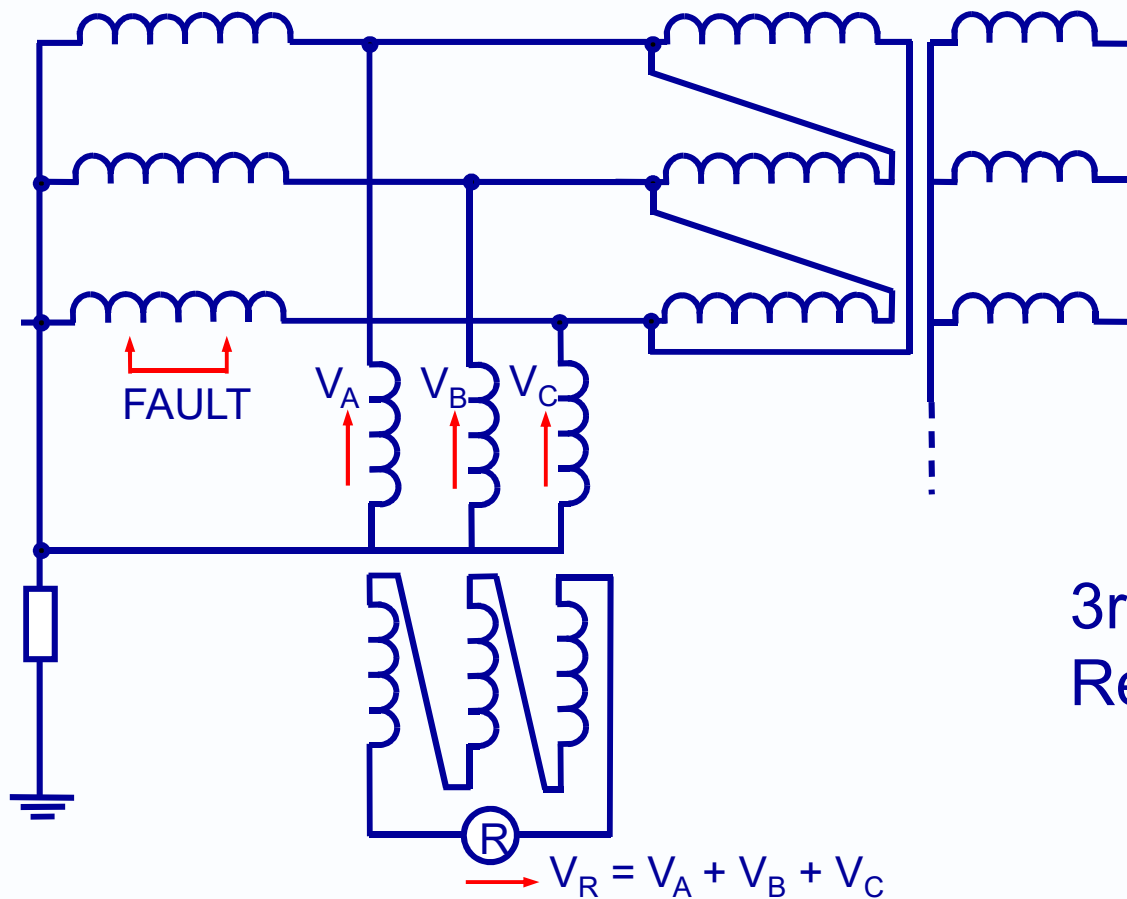
- Longitudinal differential system does not detect interturn faults
- Interturn fault protection not commonly provided because :
  - Fault rare
  - Even if interturn fault occurs, will develop into earth fault
- Possible that serious damage can occur before fault is detected



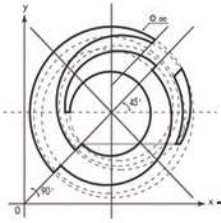
# Stator Interturn Fault Protection



Zero Sequence Voltage Method :



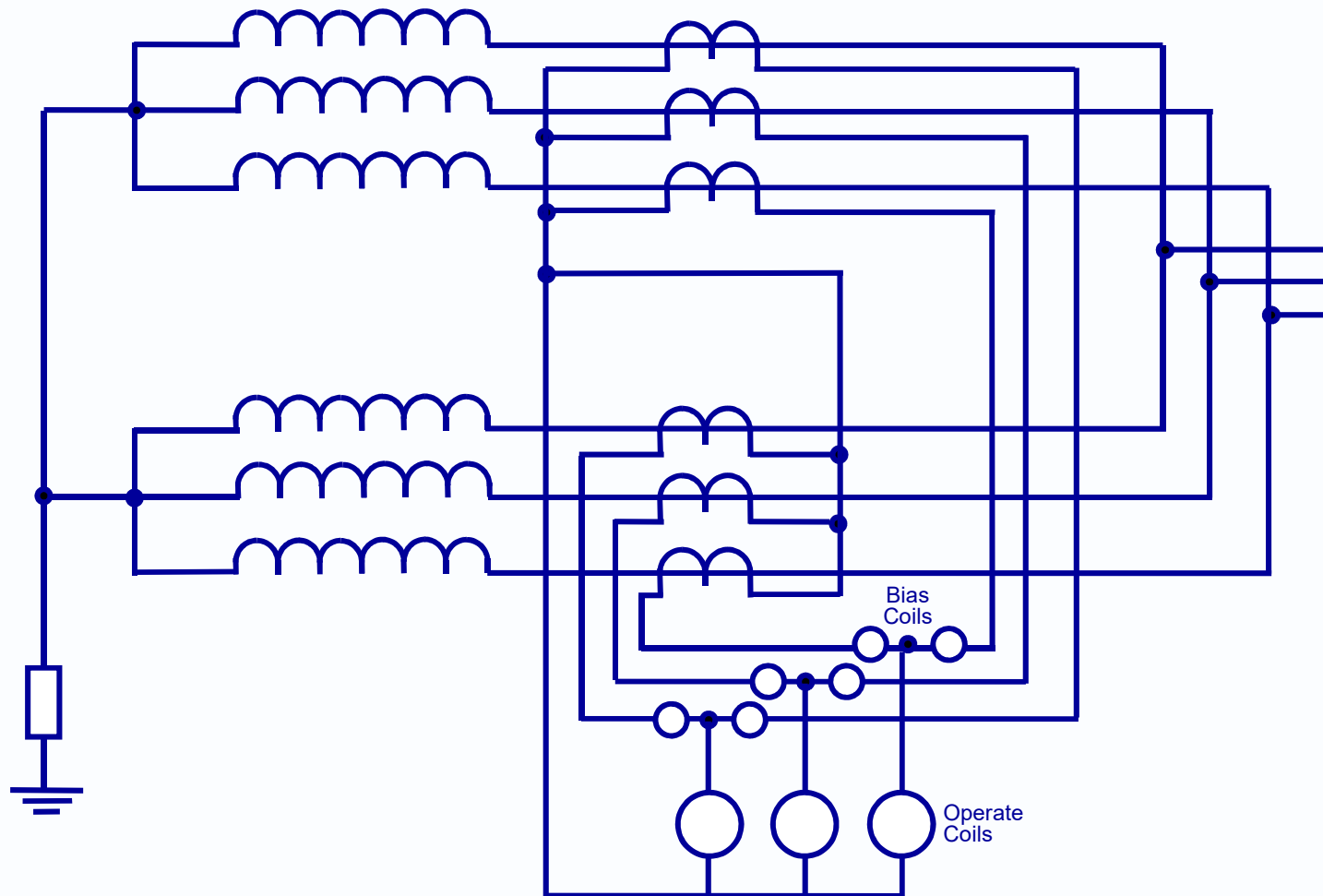
3rd Harmonic Rejection  
Required

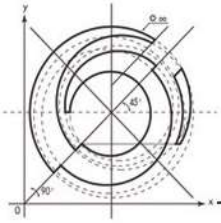


# Stator Interturn Fault Protection



Transverse Differential Protection  
(Double Wound Machines) :





# Prime Mover Failure



## **Isolated Generators :**

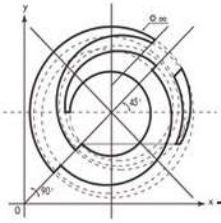
Machine slows down and stops. Other protection initiates shut down.

## **Parallel Sets :**

System supplies power - generator operates as a motor.  
Seriousness depends on type of drive.

## **Steam Turbine Sets :**

Steam acts as a coolant.  
Loss of steam causes overheating.  
Turbulence in trapped steam causes distortion of turbine blades.  
Motoring power 0.5% to 6% rated.  
Condensing turbines, rate of heating slow. Loss of steam instantly recognised.



# Prime Mover Failure



## **Diesel Driven Sets :**

Prime mover failure due to mechanical fault.

Serious mechanical damage if allowed to persist.

Motoring power from 35% rated for stiff machine, to 5% rated for run in machine.

## **Gas Turbines :**

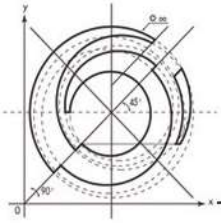
Motoring power 100% rated for single shaft machine, 10% to 15% rated for double shaft.

## **Hydro Sets :**

Mechanical precautions taken if water level drops.

Low head types - erosion and cavitation of runner can occur.

Additional protection may be required.



## Prime Mover Failure



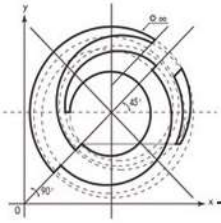
### **Reverse Power Protection :**

Reverse power measuring relays used where protection required.

Single phase relay is sufficient as prime mover failure results in balanced conditions.

Sensitive settings required - metering class CTs required for accuracy.





# Loss of Excitation



## Effects

### **Single Generator :**

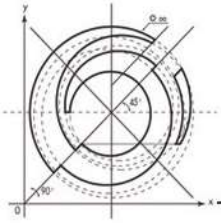
- Loses output volts and therefore load.

### **Parallel Generators :**

- Operate as induction motor ( $>$  synch speed)
- Flux provided by reactive stator current drawn from system-leading pf
- Slip frequency current induced in rotor - abnormal heating

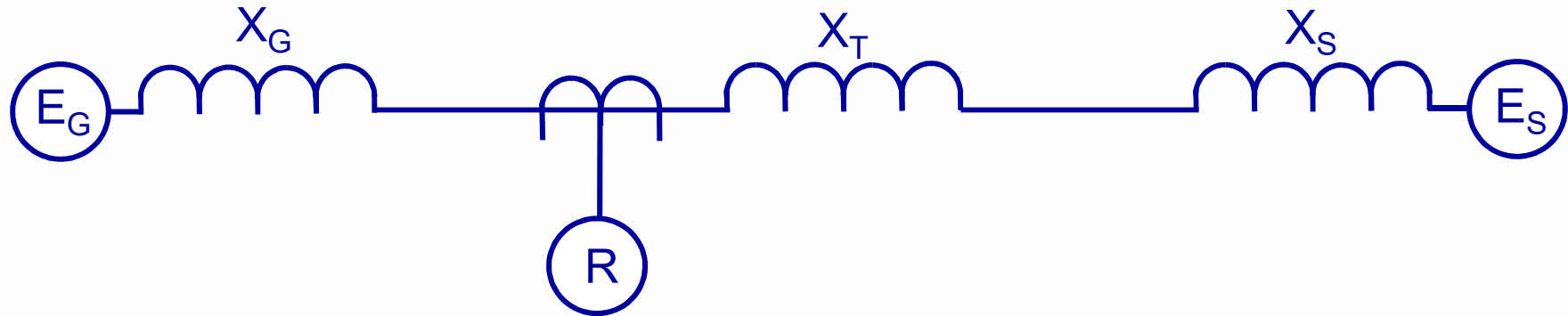
Situation does not require immediate tripping,  
however,

large machines have short thermal time constants -  
should be unloaded in a few seconds.



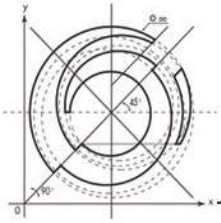
## Loss of Excitation

ALSTOM

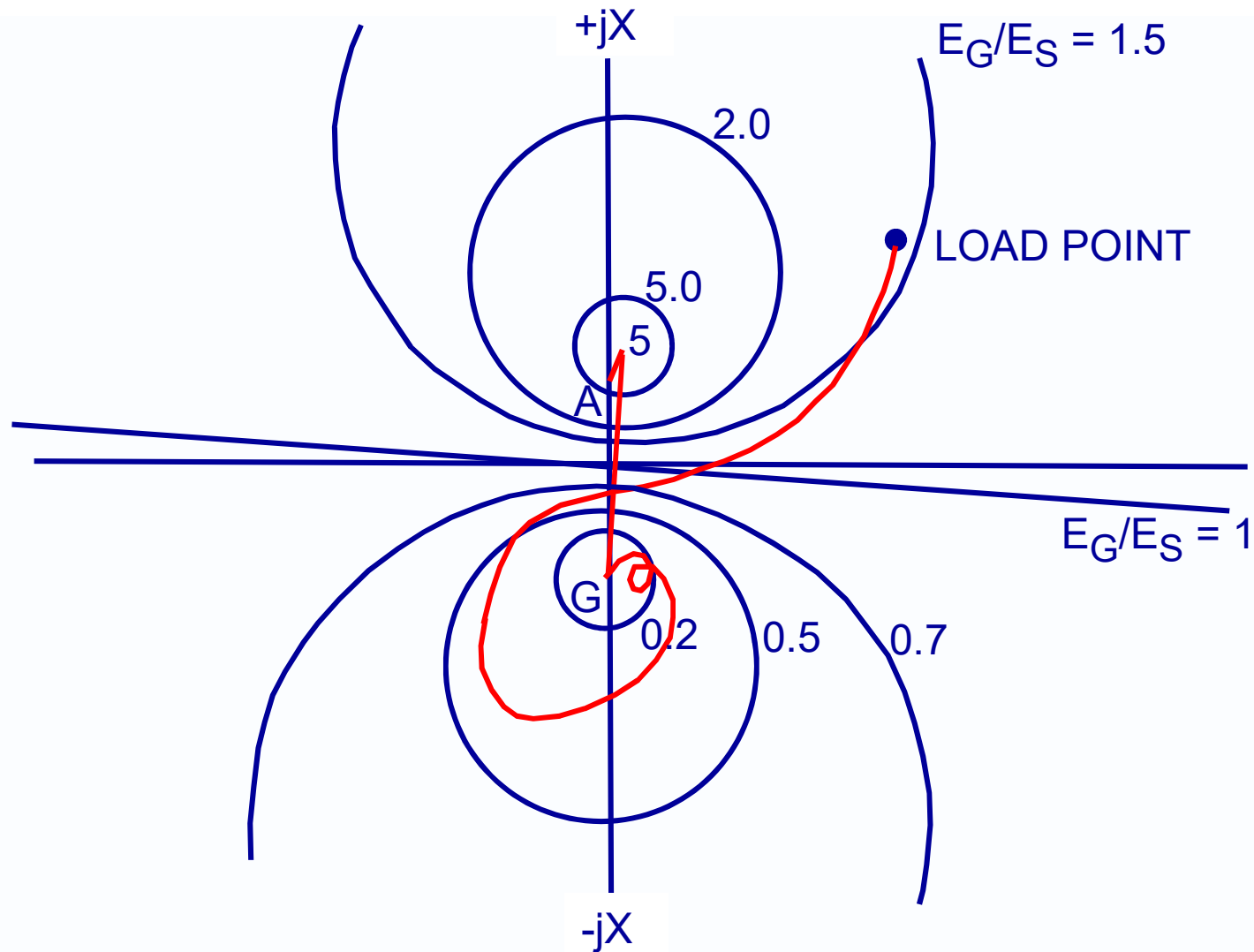


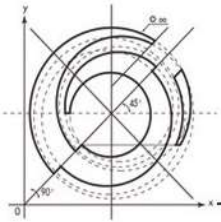
On field failure ratio  $E_G / E_S$  decreases and rotor angle increases.

Machine starts to pole slip with decaying internal EMF.



# Impedance Locus of Generator Operating Out of Synchronism

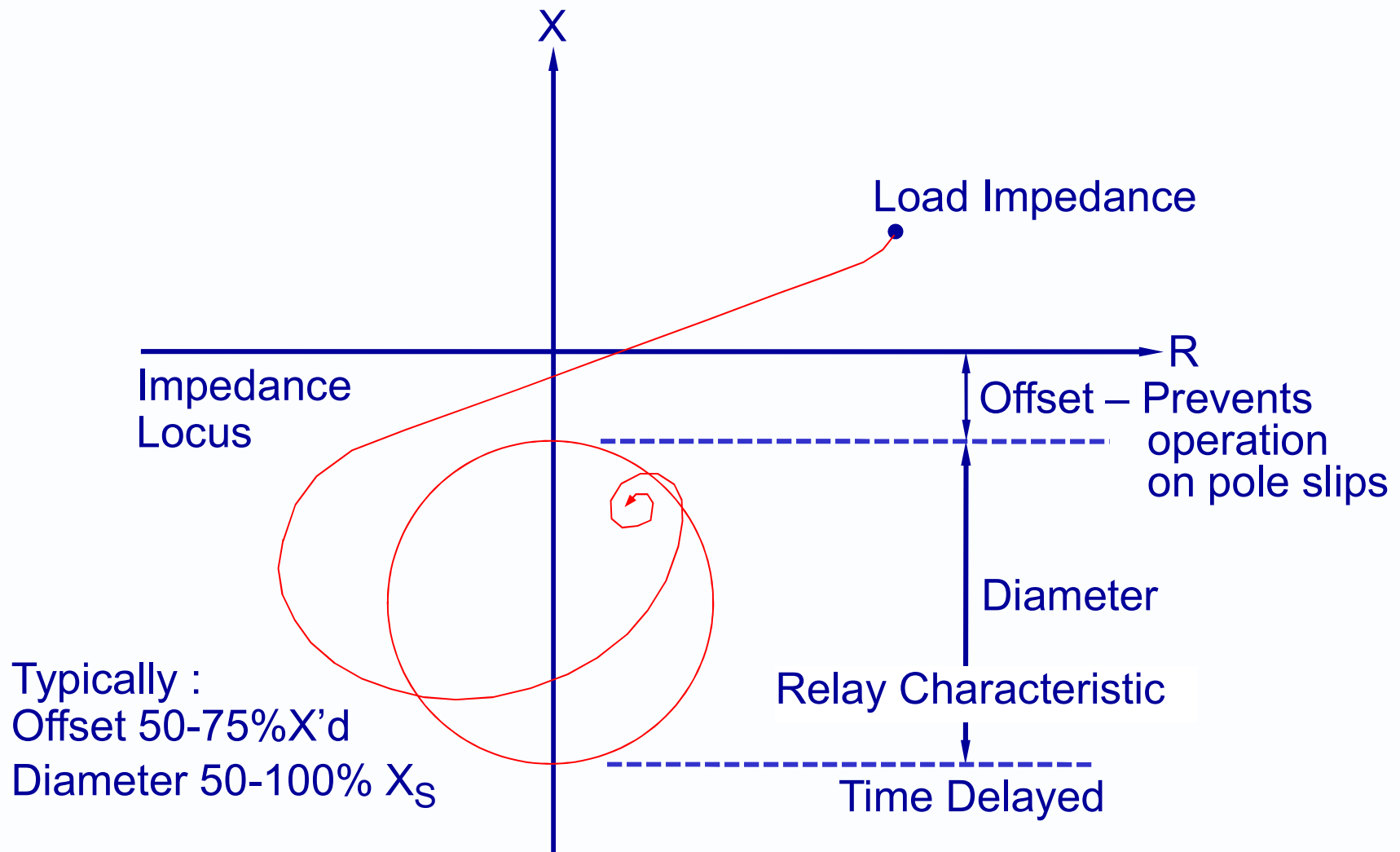


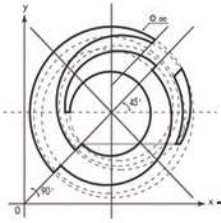


# Loss of Excitation



Impedance seen by relay follows locus shown below :

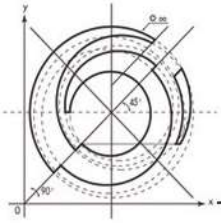




## Unbalanced Loading



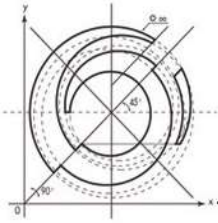
- Gives rise to negative phase sequence (NPS) currents - results in contra-rotating magnetic field.
- Stator flux cuts rotor at twice synchronous speed.
- Induces double frequency current in field system and rotor body.
- Resulting eddy currents cause severe over heating.
  - Use negative sequence overcurrent relay.
  - Relay should have inverse time characteristic to match generator  $I_2^2t$  withstand.



## Unbalanced Loading

ALSTOM

- Machines are assigned NPS current withstand values :
  - \* Continuous NPS rating,  $I_2R$
  - \* Short time NPS rating,  $I_2^2t$
- If possible level of system unbalance approaches machine continuous withstand, protection is required.

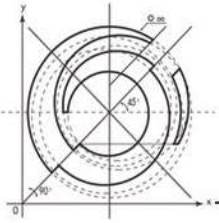


# Unbalanced Loading



## Machine NPS Withstand Values

TYPE OF MACHINE	ROTOR COOLING	$I_2^2R$ (PU CMR)	$I_2^2t = K$
Typical Salient Pole	Conventional Air	0.40	60
Cylindrical Rotor	Conventional Hydrogen 0.5 PSI	0.20	20
Cylindrical Rotor	Conventional Hydrogen 15 PSI	0.15	15
Cylindrical Rotor	Conventional Hydrogen 30 PSI	0.15	12
Cylindrical Rotor	Direct Hydrogen 40 - 60 PSI	0.10	3



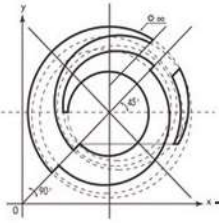
# Rotor Earth Fault Protection



Field circuit is an isolated DC system.

- Insulation failure at a single point :
  - No fault current, therefore no danger
  - Increase chance of second fault occurring
- Insulation failure at a second point :
  - Shorts out part of field winding
  - Heating (burning of conductor)
  - Flux distortion causing violent vibration of rotor
- Desirable to detect presence of first earth fault and give an alarm.

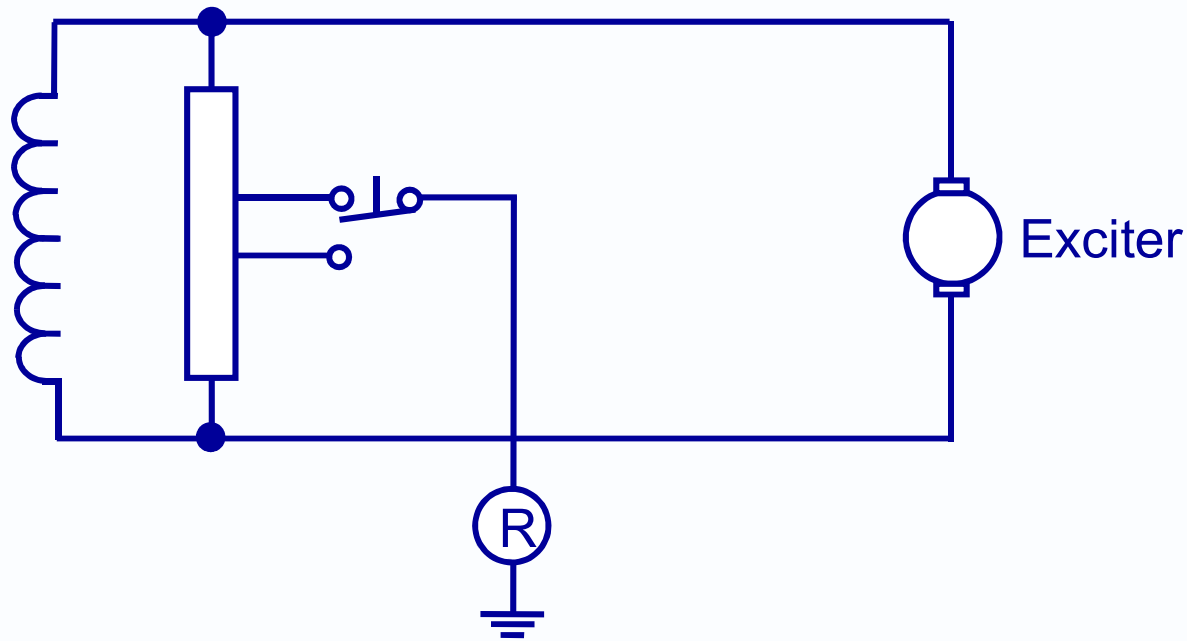




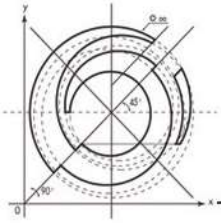
# Rotor Earth Fault Protection



## Potentiometer Method



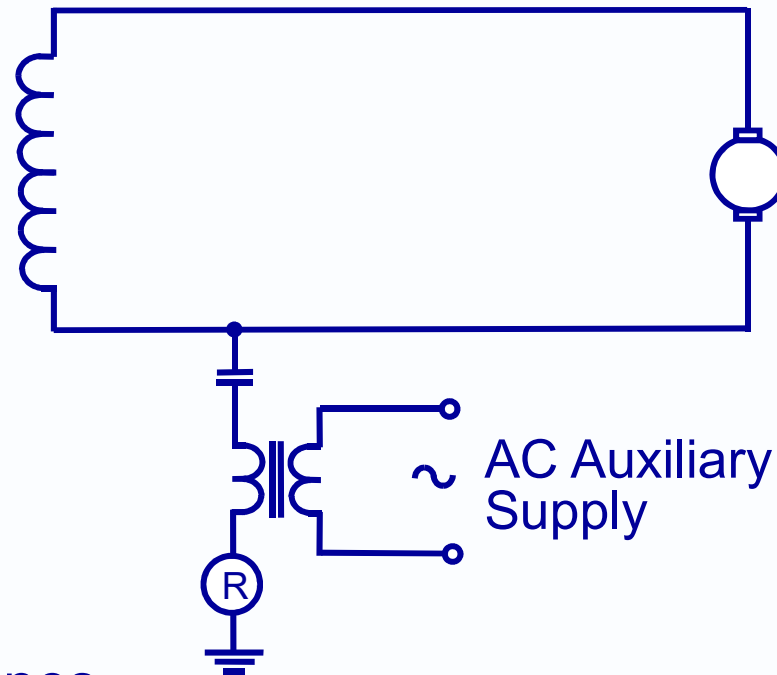
- Required sensitivity approximately 5% exciter voltage.
- No auxiliary supply required.
- “Blind spot” - require manually operated push button to vary tapping point.



# Rotor Earth Fault Protection

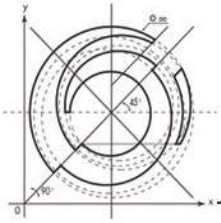


## AC Injection Method



### Brushless Machines

- No access to rotor circuit
- Require special slip rings for measurement
- If slip rings not present, must use telemetering techniques (expensive)



## Overload Protection



**high load current**



**heating of stator and rotor**

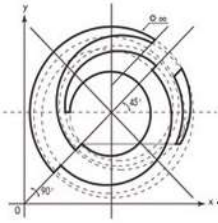


**insulation failure**

### Governor Setting

Should prevent serious overload automatically.

Generator may lose speed if required load can not be met by other sources.



# Overload Protection



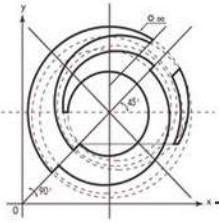
## Direct Temperature Measuring Devices

Resistance temperature detectors (RTDs), thermocouples etc., embedded in windings.

Provide alarm and/or trip via auxiliary relays.

## Thermal Replica Relays

Current operated. May have ambient temperature compensation.



# Generator Back-Up Protection

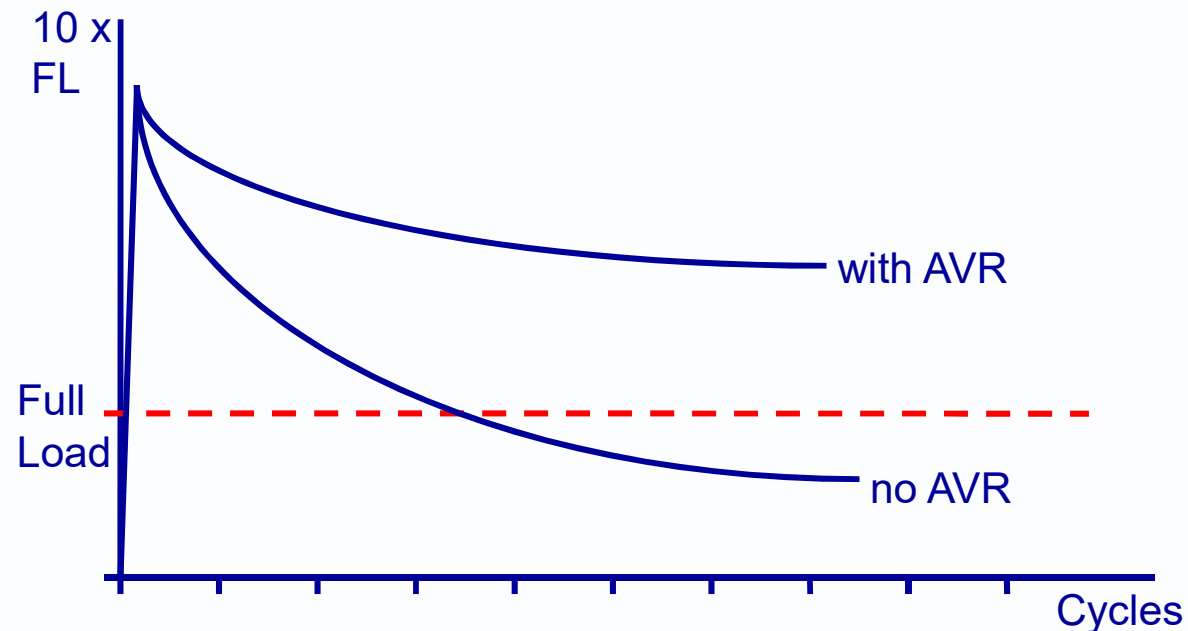


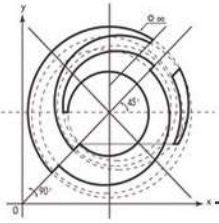
## Overcurrent Protection

Typical use :

- Very or extremely inverse for LV machines
- Normal inverse for HV machines

Must consider generator voltage decrement characteristic for close-in faults.  
With reliable AVR system, “conventional” overcurrent relays may be used.  
Otherwise, voltage controlled / restrained relays are required.





# Generator Back-Up Protection



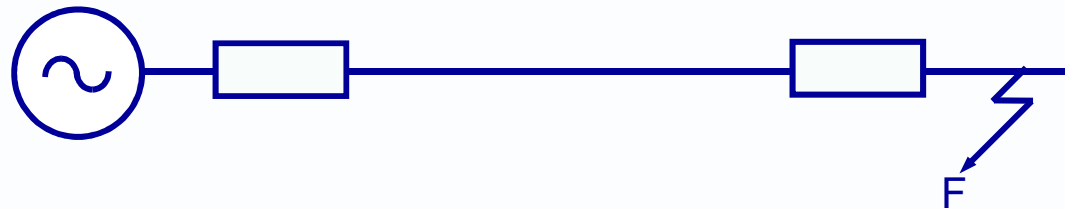
## Overcurrent Protection

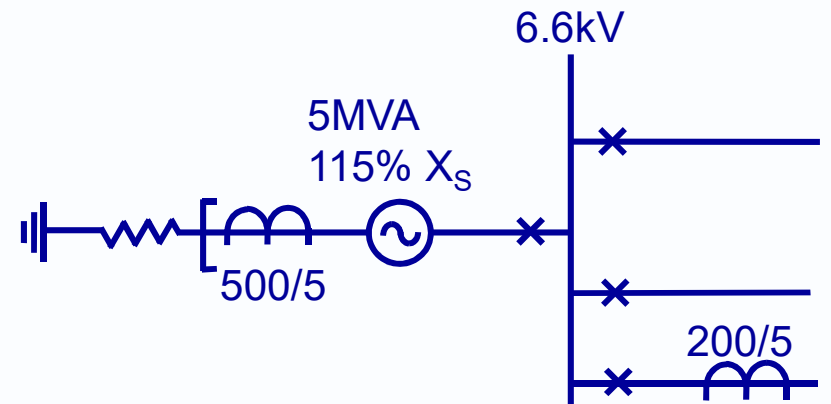
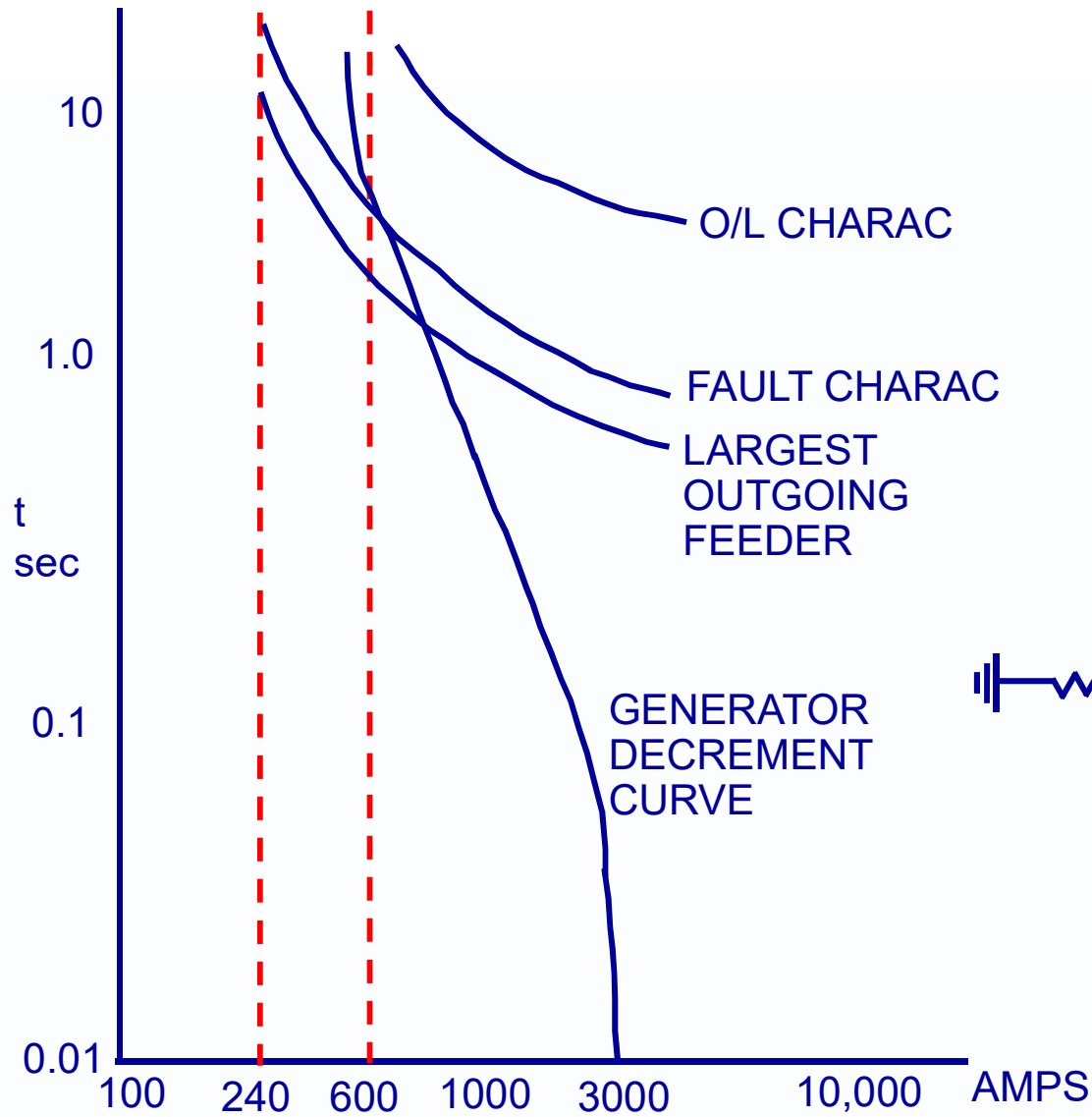
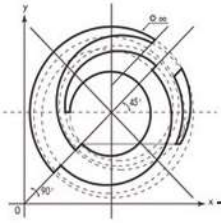
### Voltage Restrained

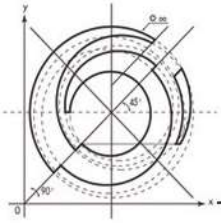
- Operating characteristic is continuously varied depending on measured volts.
- Alternatively, use impedance relay.

### Voltage Controlled

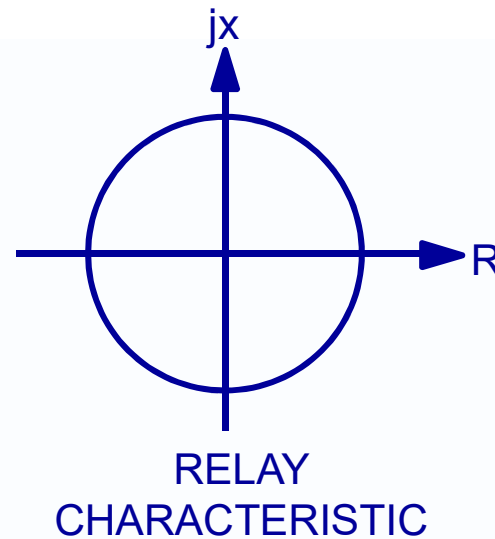
- Relay switches between fault characteristic and load characteristic depending on measured volts.





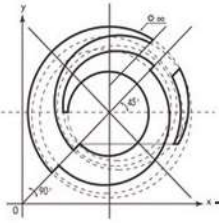


# Impedance Relay



Set to operate at 70% rated load impedance when voltage drops to zero, current required to operate relay is 10% rated current. Built-in timer for co-ordination purposes.



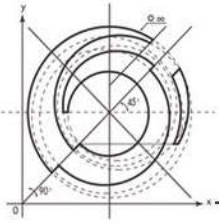


# Under & Over Frequency Conditions



## Over Frequency

- Results from generator over speed caused by sudden loss of load.
- In isolated generators may be due to failure of speed governing system.
- Over speed protection may be provided by mechanical means.
- Desirable to have over frequency relay with more sensitive settings.

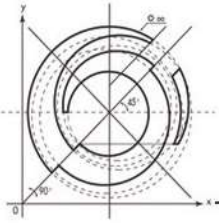


# Under & Over Frequency Conditions



## Under Frequency

- Results from loss of synchronous speed due to excessive overload.
- In isolated generators may be due to failure of speed governing system.
- Under frequency condition gives rise to:
  - Overfluxing of stator core at nominal volts
  - Plant drives operating at lower speeds - can affect generator output
  - Mechanical resonant condition in turbines
- Desirable to supply an under frequency relay.
- Protection may be arranged to initiate load shedding as a first step.

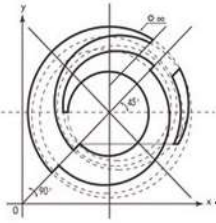


# Under & Over Voltage Conditions



## Protection

- Under & over voltage protection usually provided as part of excitation system.
- For most applications an additional high set over voltage relay is sufficient.
- Time delayed under and over voltage protection may be provided.



# Under & Over Voltage Conditions

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## Over Voltage

- Results from generator over speed caused by sudden loss of load.
- May be due to failure of the voltage regulator.
- An over voltage condition :
  - Causes overfluxing at nominal frequency
  - Endangers integrity of insulation

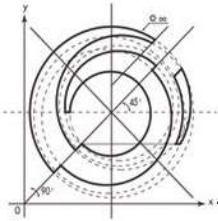
## Under Voltage

- No danger to generator. May cause stalling of motors.
- Prolonged under voltage indicates abnormal conditions.

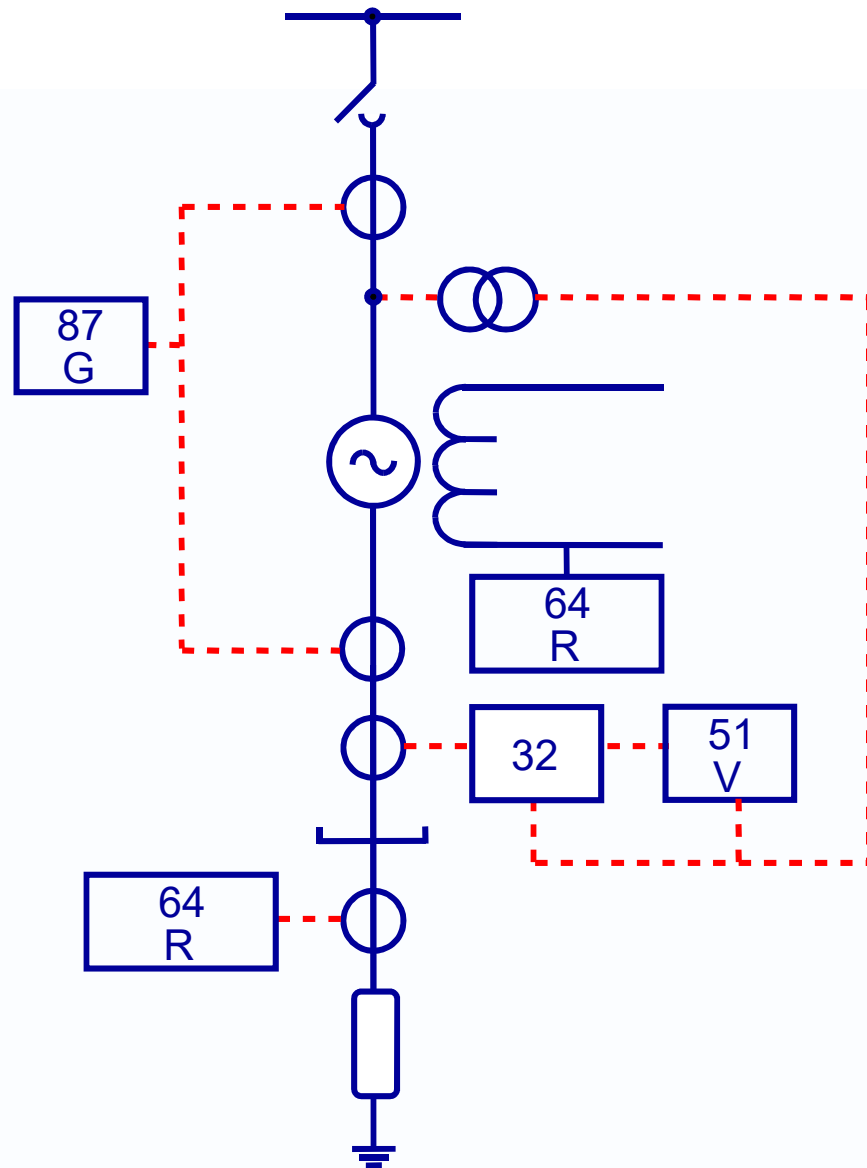


# Typical Schemes

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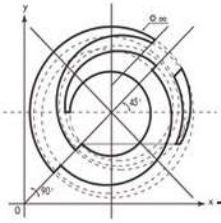


## Protection Package for Diesel Generator

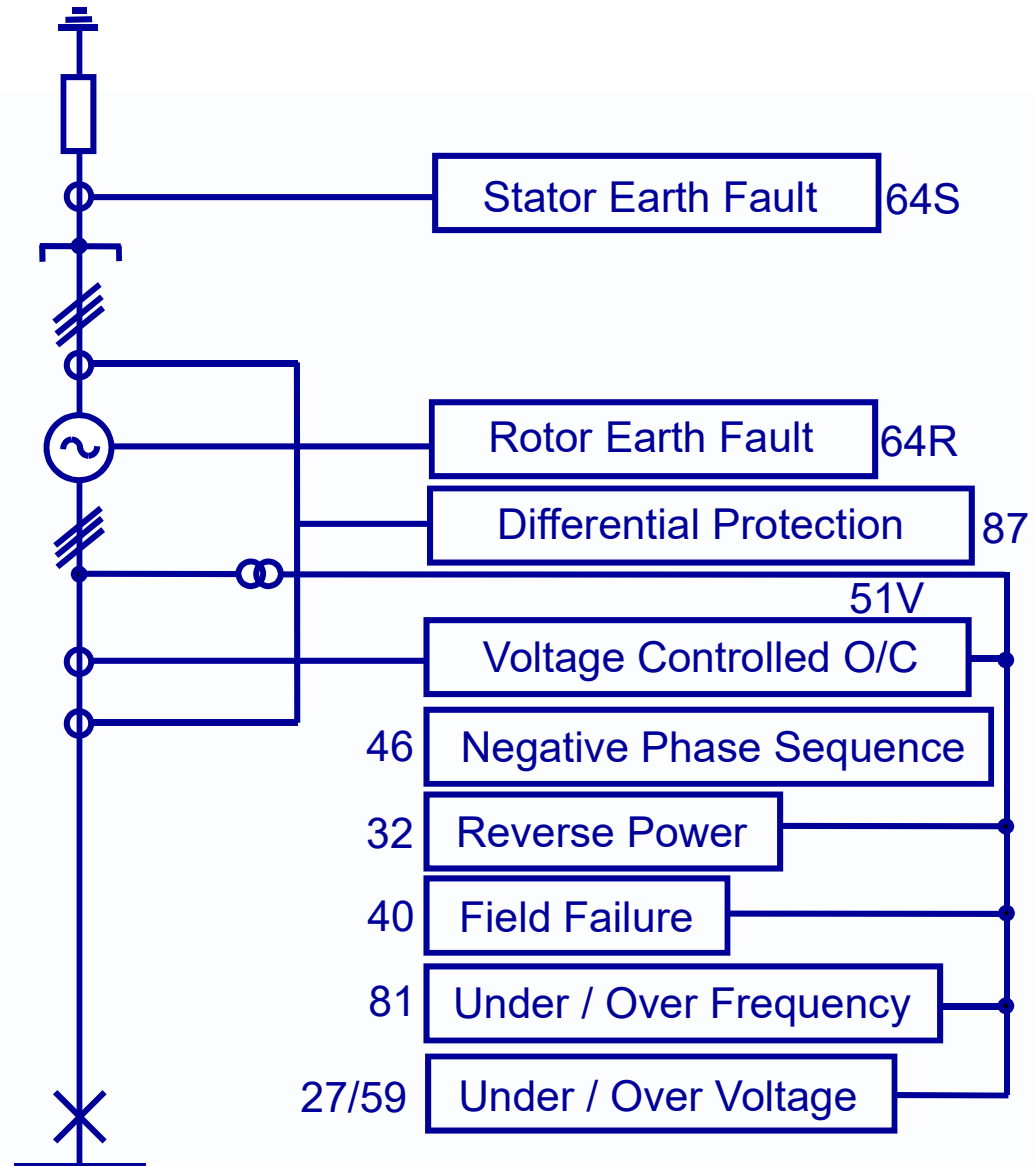


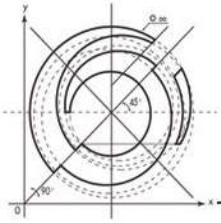
- 32 Reverse Power
- 64R Rotor Earth Fault
- 64S Stator Earth Fault
- 51V Voltage Dependent Overcurrent
- 87G Generator Differential

Protection P343

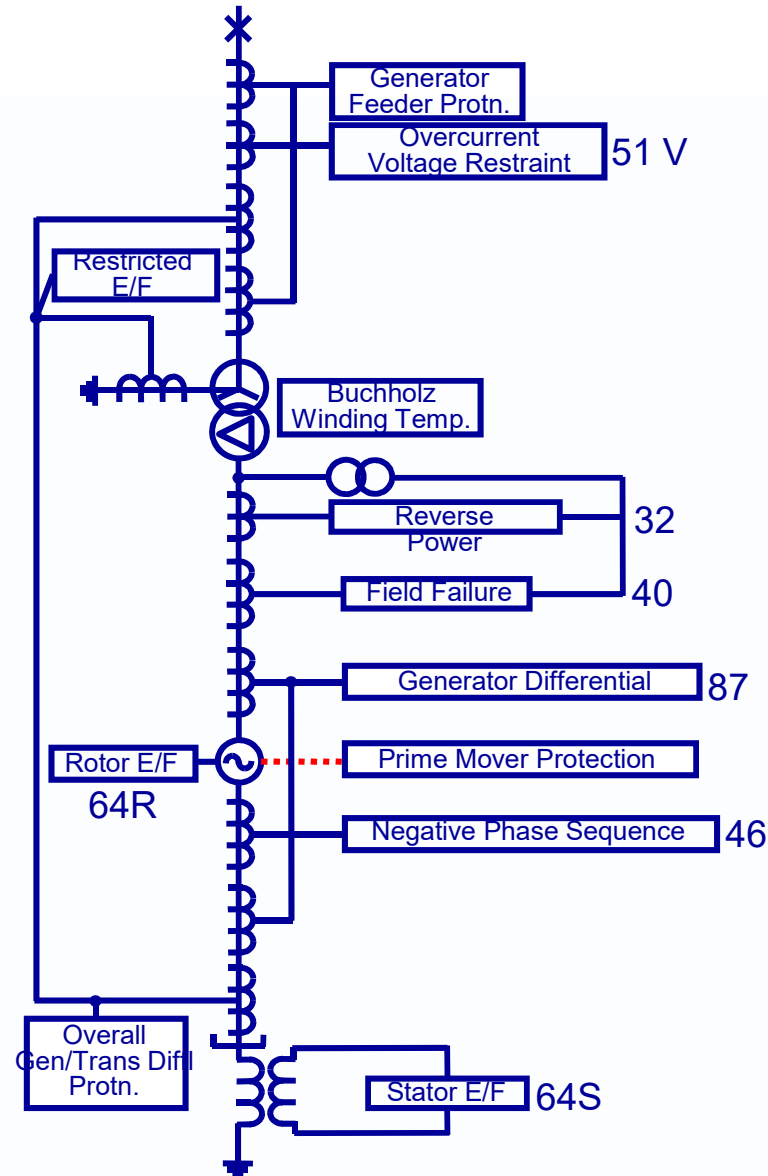


# Overall Protection of Directly Connected Generator Installation

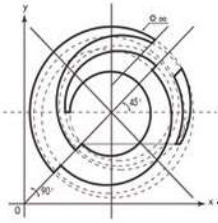




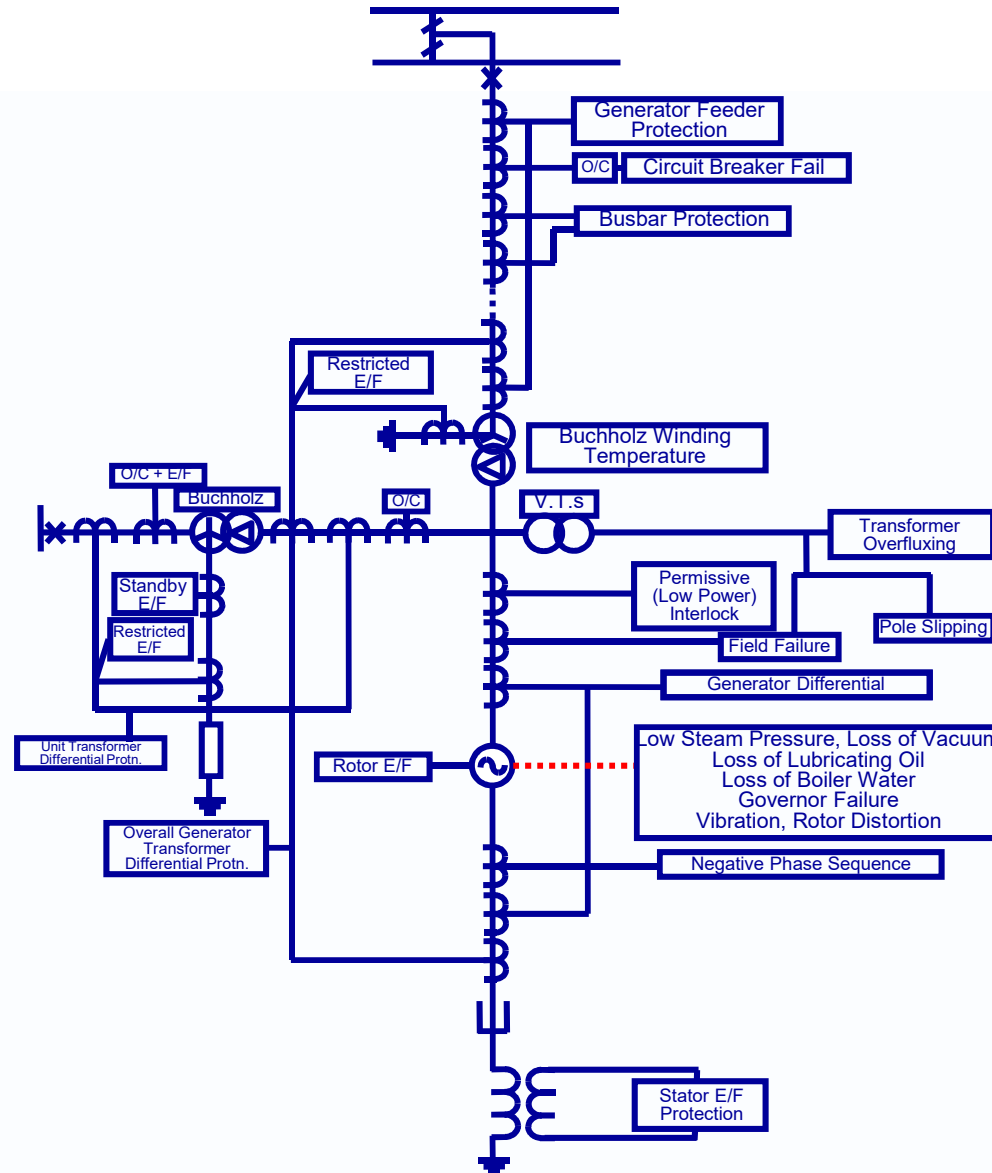
# Overall Protection of Generator Installation







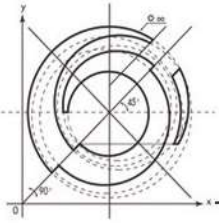
# Overall Protection of Generator Installation





# Embedded Generation

**ALSTOM**

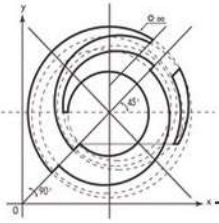


# Embedded Generation



## USED TO PROVIDE:

- Emergency Power Upon Loss Of Main Supply
- Operate In Parallel To Reduce Site Demand
- Excess Generation May Be Exported Or Sold

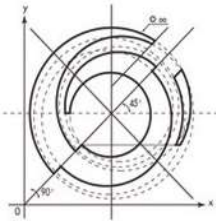


# ENGINEERING RECOMMENDATION G59

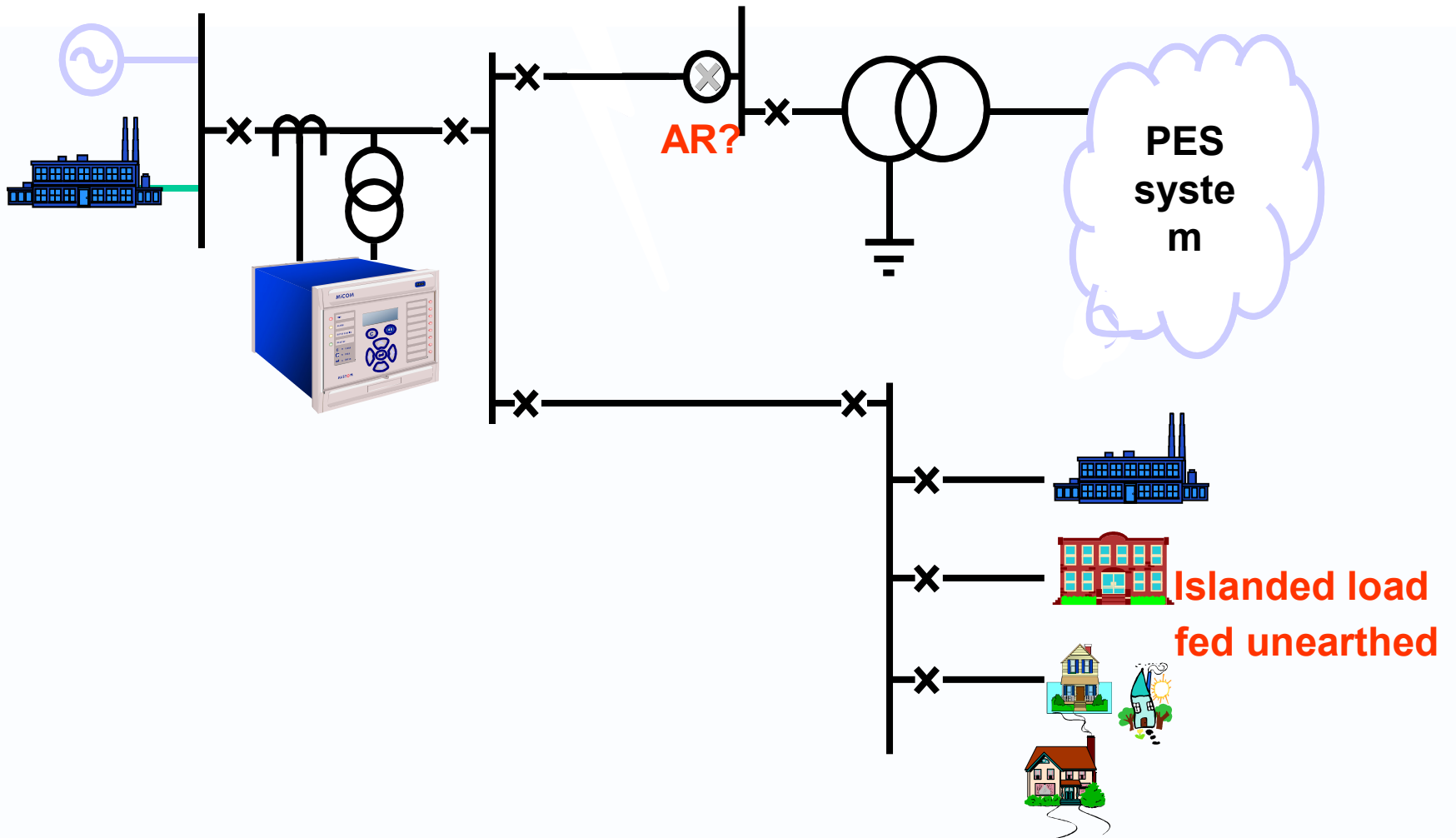
ALSTOM

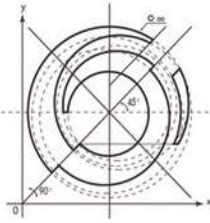
Relates To The Connection Of Privately Owned  
Generators & Generating Systems To Regional  
Electricity Companies

- **COVERS:**
  - Safety Aspects
  - Legal Requirements
  - Operation
  - Protection



# Co-generation/Embedded Machines

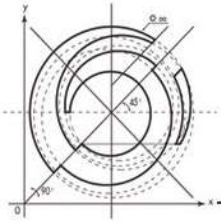




## Islanded Operation Must Be Avoided To Ensure:



- Unearthed Operation Of Main Supply Network
- Automatic Reclosure Of CB Will Not Result In Connecting Unsynchronised Supplies
- Staff Cannot Attempt Unsynchronised Manual Closure Of An Open CB
- Faults On Electricity Supply Companies Network Being Undetected Due To Low Fault Supplying Capability Of Embedded Generator
- Voltage & Frequency Supplied To Customers Remains Within Statutory Limits



## PROTECTION

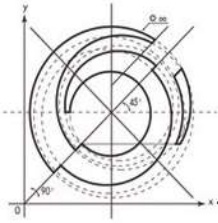
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- Under/Over Voltage & Under/Over Frequency

Keep Voltage & Frequency Within Statutory Limits

- Directional Power / Overcurrent

Used When Generator Does Not Export Power During Normal Operation



# PROTECTION

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- Loss Of Mains

Used Where Generating Capacity Is Closely Matched To Load Or Where Normal Operation Requires The Export Of Power

- Two Types Are Used:

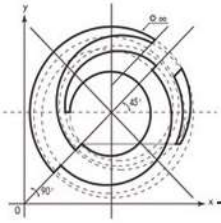
- Rate Of Change Of Frequency

- Sensitive
- Possible Nuisance Tripping

- Voltage Vector Shift

- Requires Higher Change In load
- More Stable





# PROTECTION

ALSTOM

- **ADDITIONAL PROTECTION**

- NEUTRAL VOLTAGE DISPLACEMENT
- OVERCURRENT
- EARTHFAULT

The background features a large, stylized graphic consisting of a thick red curved band that arches across the top and sides of the page. The interior of this arch is white, creating a large, open space for the text. The top corners of the page are filled with a blue-to-purple gradient, suggesting a sky or a modern architectural design.

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