# This webinar brought to you by the Relion® product family
## Advanced protection and control IEDs from ABB

### **Relion**. Thinking beyond the box.

Designed to seamlessly consolidate functions, Relion relays are smarter, more flexible and more adaptable. Easy to integrate and with an extensive function library, the Relion family of protection and control delivers advanced functionality and improved performance.


ABB

# ABB Protective Relay School Webinar Series
## Disclaimer

ABB is pleased to provide you with technical information regarding protective relays. The material included is not intended to be a complete presentation of all potential problems and solutions related to this topic. The content is generic and may not be applicable for circumstances or equipment at any specific facility. By participating in ABB's web-based Protective Relay School, you agree that ABB is providing this information to you on an informational basis only and makes no warranties, representations or guarantees as to the efficacy or commercial utility of the information for any specific application or purpose, and ABB is not responsible for any action taken in reliance on the information contained herein. ABB consultants and service representatives are available to study specific operations and make recommendations on improving safety, efficiency and profitability. Contact an ABB sales representative for further information.

ABB Protective Relay School Webinar Series

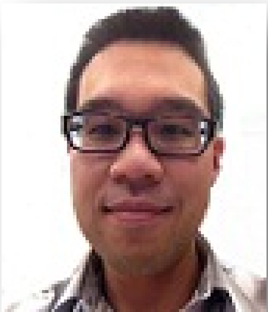
# Bus Protection Fundamentals

Jack Chang, RTM, Western CA

October 1, 2013

Power and productivity for a better world™ ABB

# Presenter



Jack Chang

**Jack Chang** is the regional technical manager for ABB Inc. in the Substation Automation Products BU serving customers in western Canada and northern regions. He provides engineering, commissioning and troubleshooting support to customers applying ABB's high-voltage protective and automation devices. Prior to joining ABB, Jack worked as a substation P&C project engineer in two specialized consulting firms (now ABB and Quanta Services, respectively) and also as an engineering consultant to a public owned utility in their transmission expansion and upgrade projects. Jack is a registered professional engineer in the province of Alberta, Canada.

# Learning objectives

- Types of bus configurations
- Current transformer characteristics and their effect on bus protection
- Types of bus protection schemes
- Modern Numerical Bus Protection Features

- Questions: jack.j.chang@ca.abb.com, 403-923-4028

# Why bus protection?

- Different configuration and design
- Usually very robust, high current faults
- Need to clear quickly
- A Delayed bus trip leads to:
  - Network instability pole slip of nearby generators
  - Possible system collapse
  - Bigger fault related damages & risk to human life or injury
  - Many bus faults caused during maintenance (eg. Arc flash)

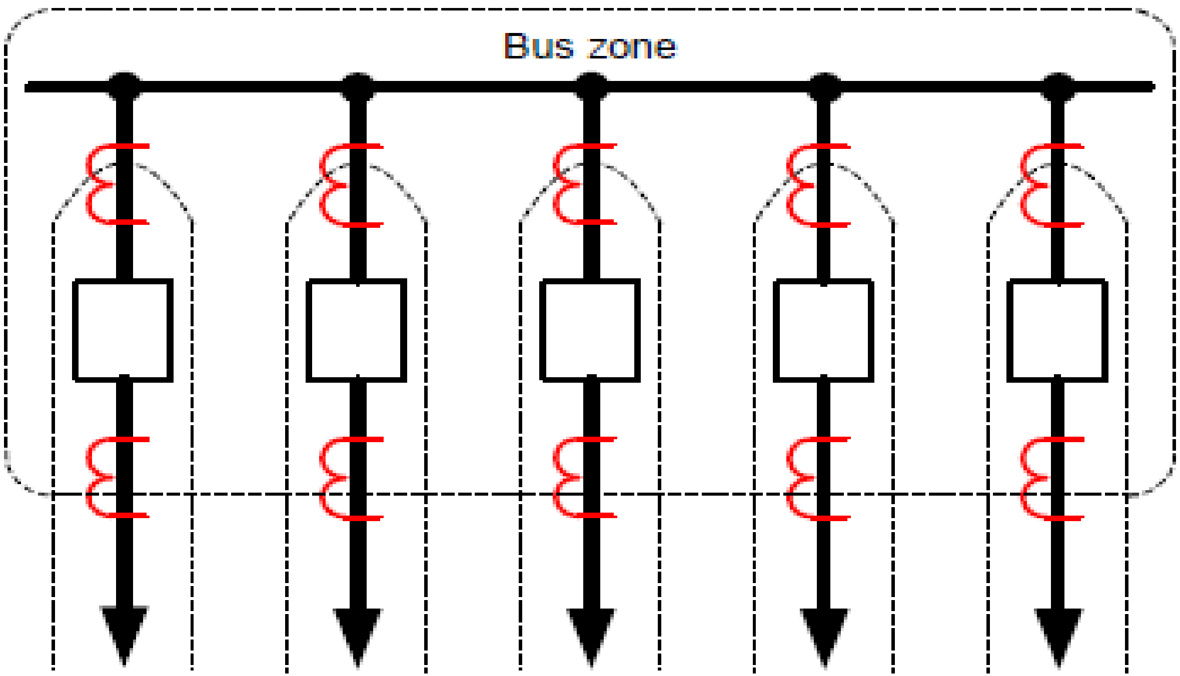
# Bus fault protection

- Easy to detect because of robust nature
- Easy to protect for internal faults (87B)
- Summation of currents not equal to zero for internal fault
- External faults can cause current transformer saturation which results in unwanted differential currents
- Infrequent, but must be cleared with high speed
  - Substation is well shielded
  - Protected environment

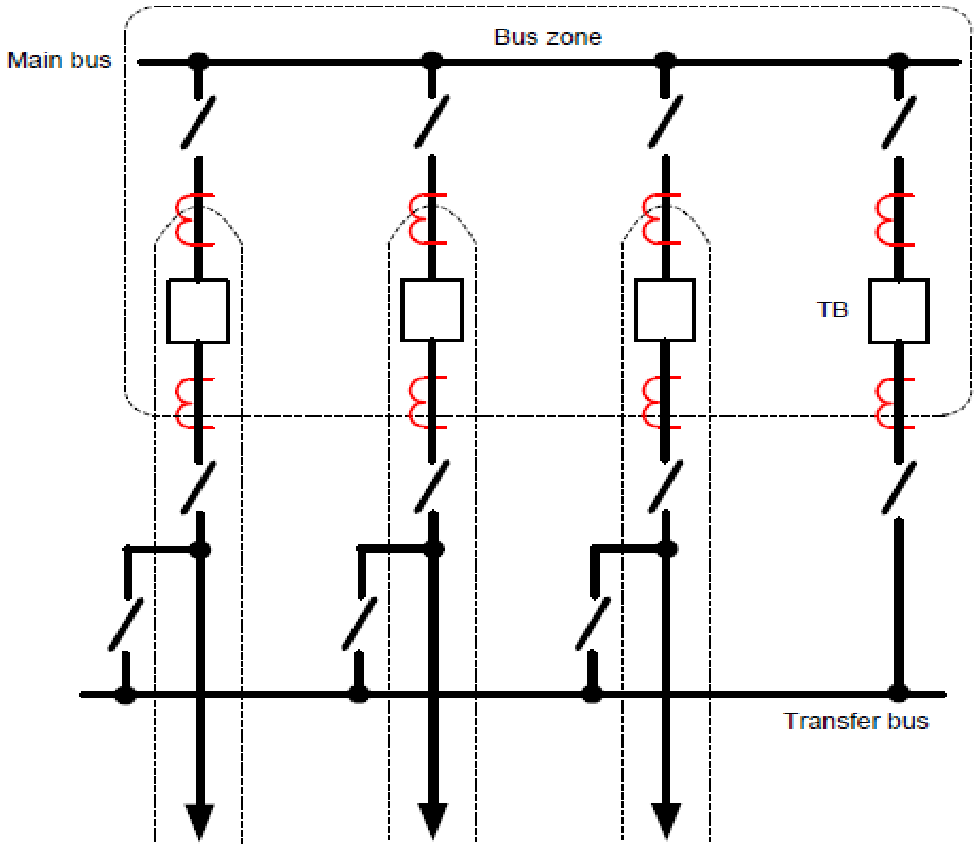
# Bus configurations

- Single bus *
- Main and transfer bus
- Double bus, single breaker *
- Double bus, double breaker
- Breaker and a half *
- Ring bus *

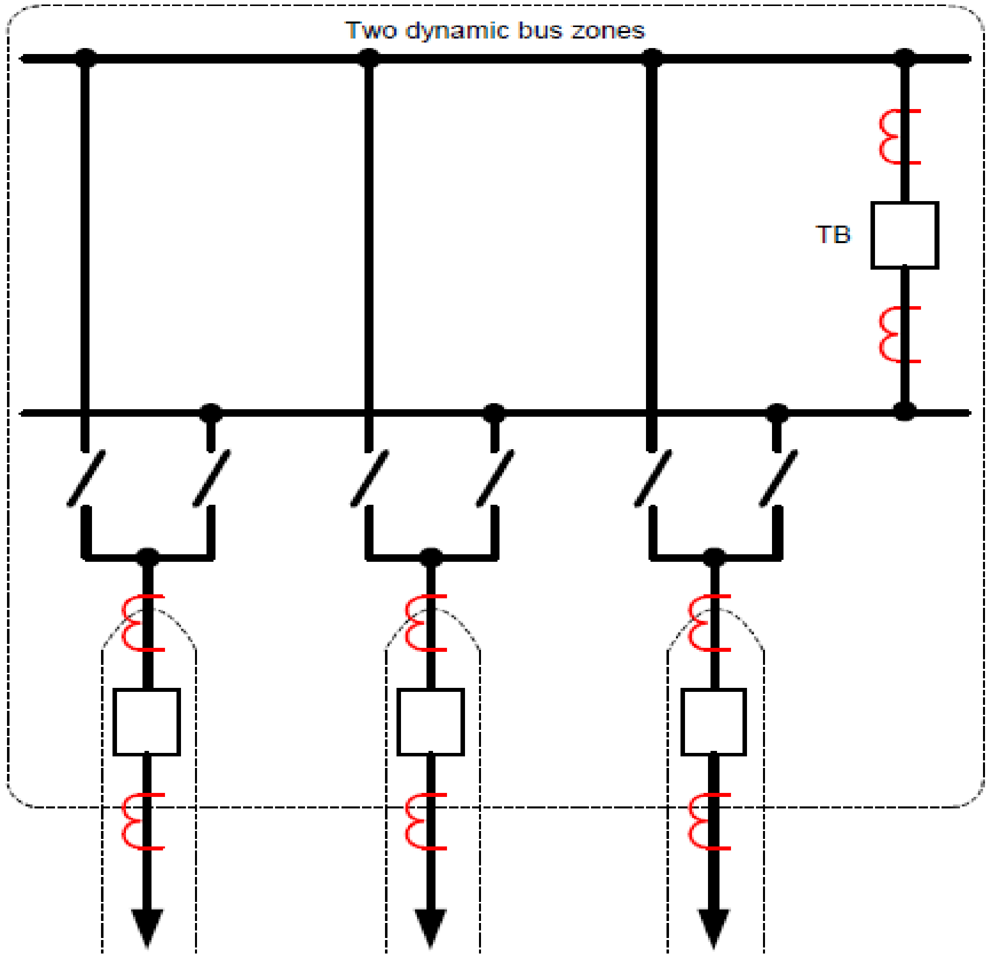
# Single bus



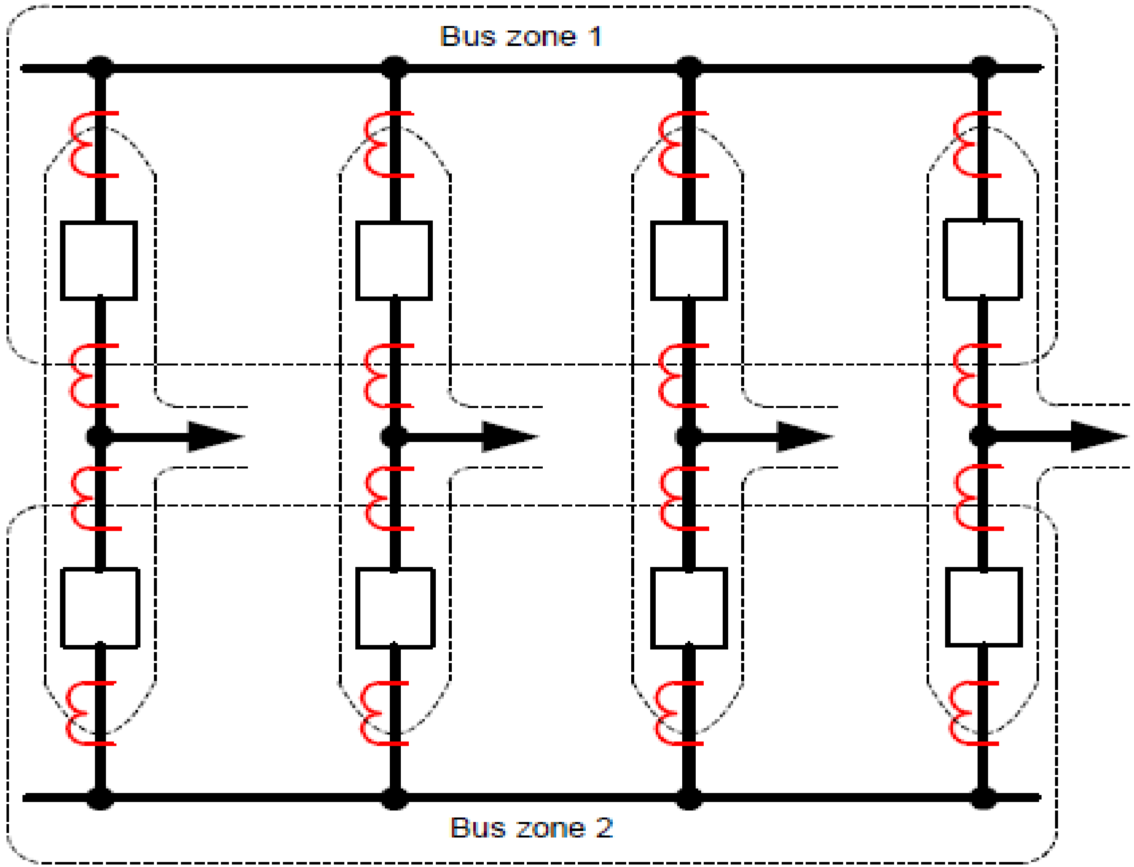
# Main and transfer bus



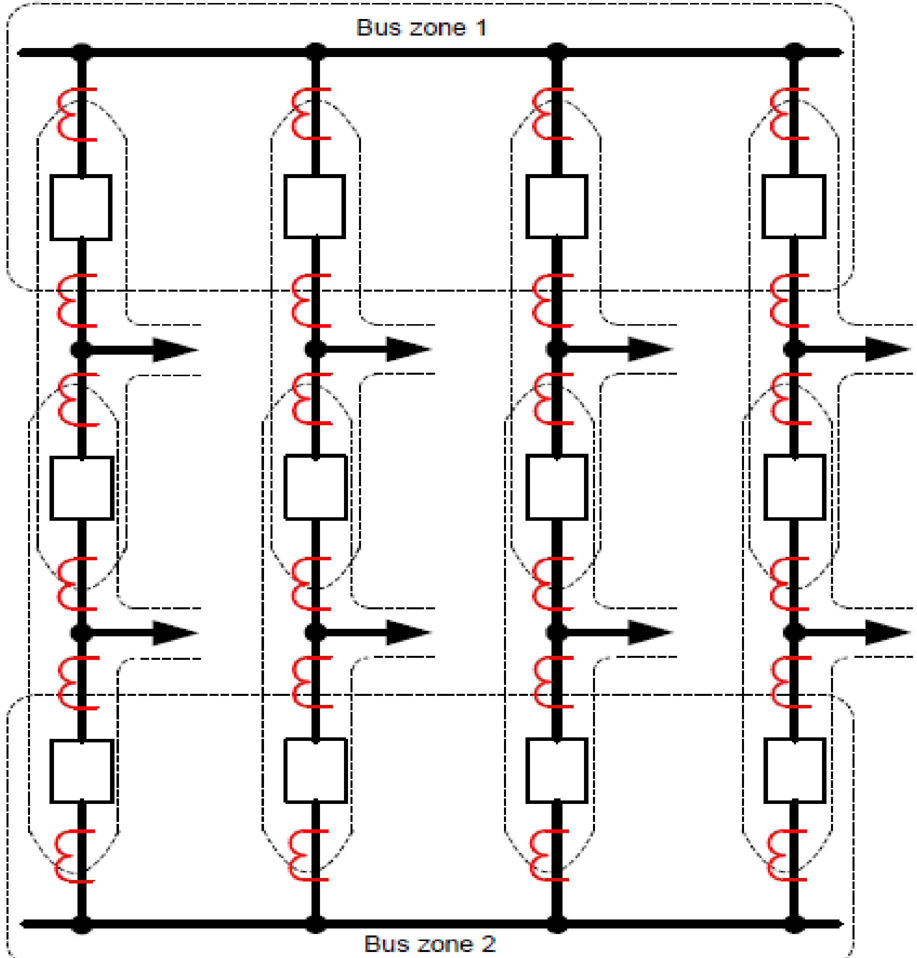
# Double bus single breaker



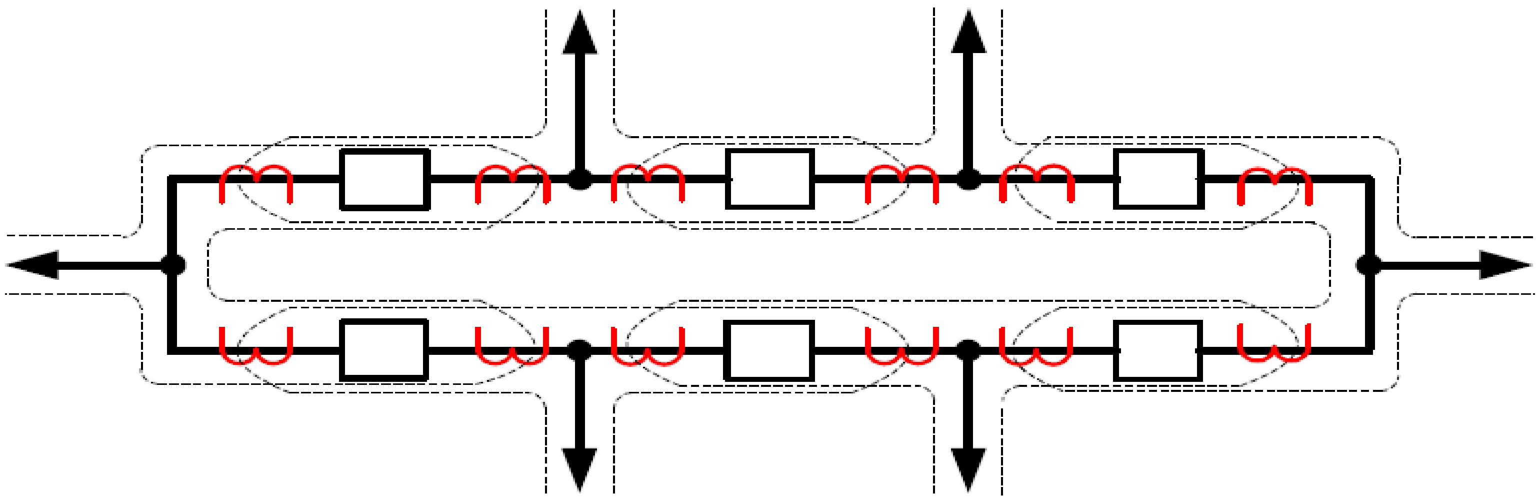
# Double bus, double breaker



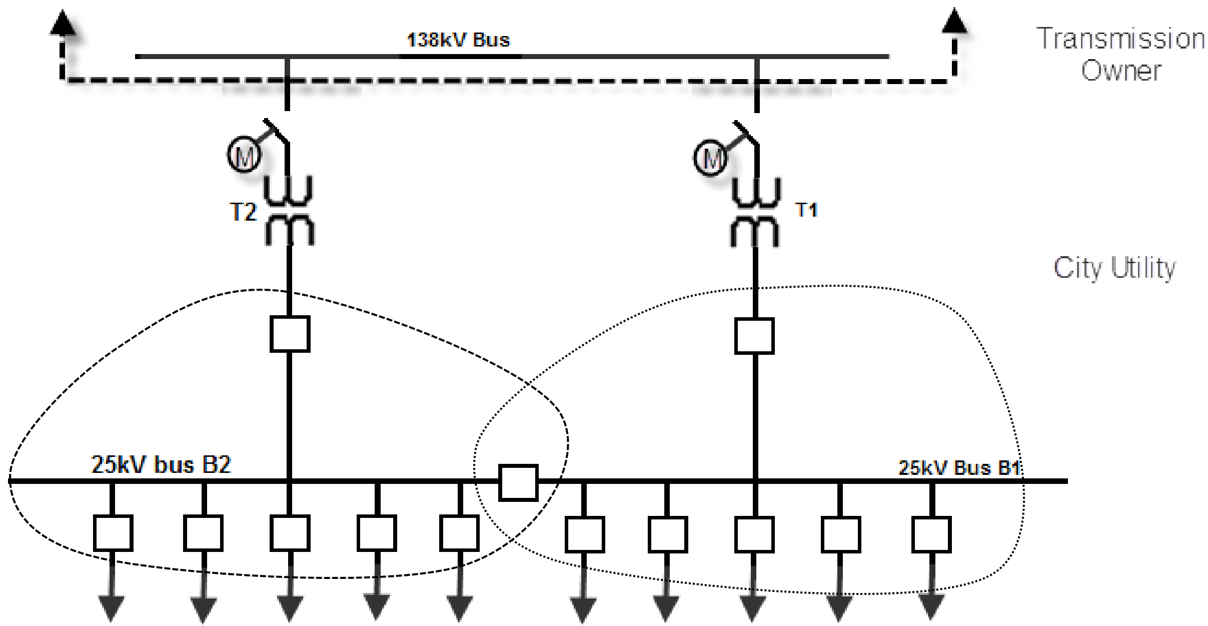
# Breaker and one half



# Ring bus



# Main-Tie-Main



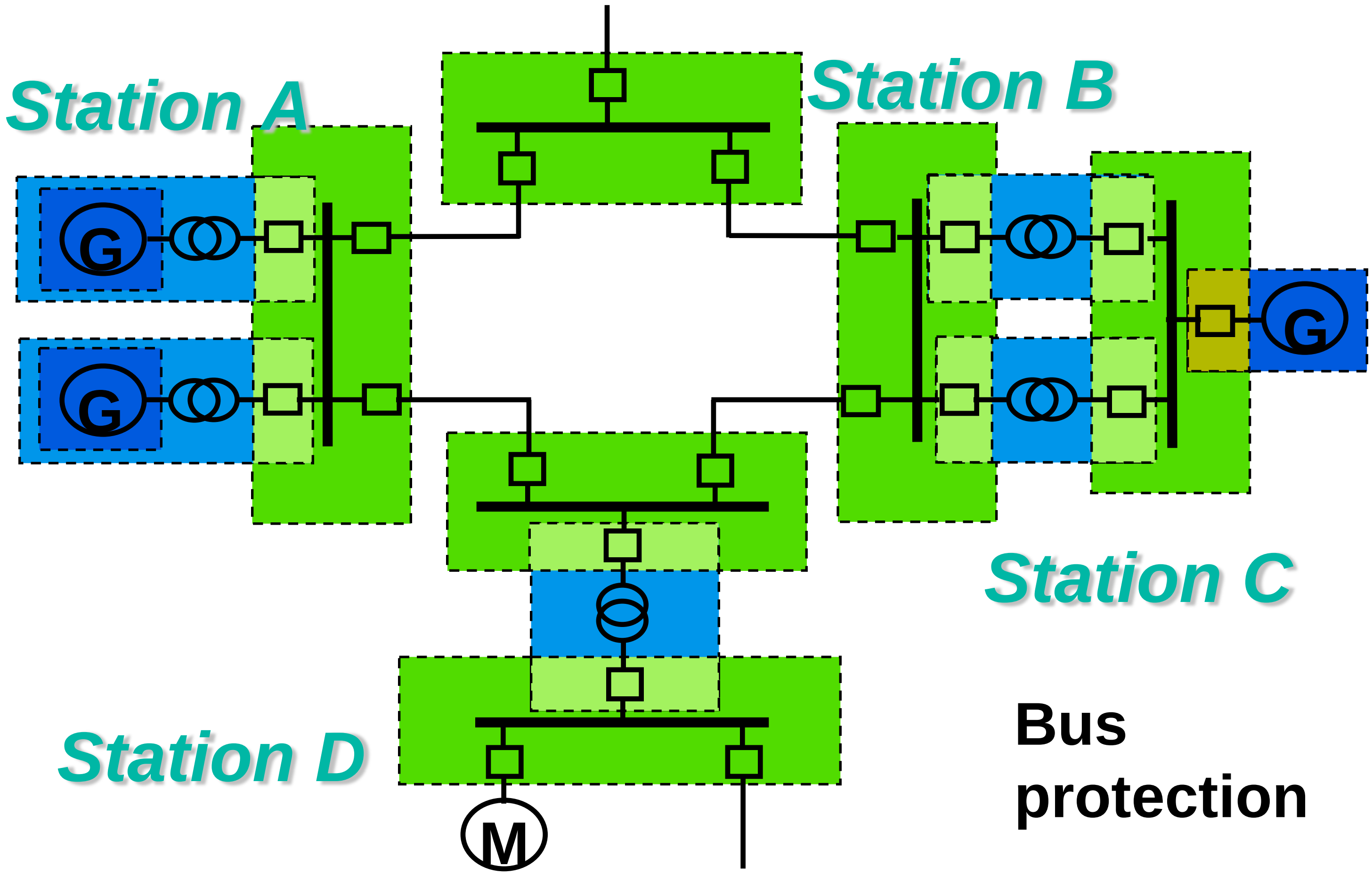

©ABB

# Some issues

- Availability of overlapping protection zones (CTs)
- Blind or end zone protection
- Will loads or sources be switched from one bus to the other
- Current transformer switching from one zone to another
- Open circuit current transformers
- CT Saturation

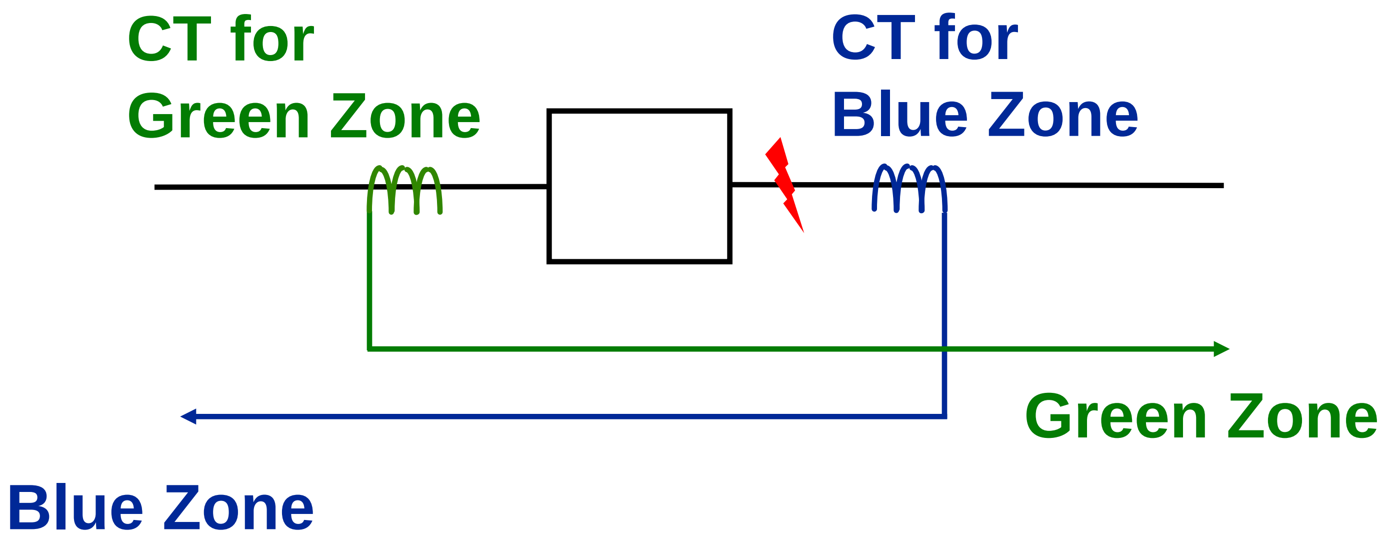
©ABB

# Zones of protection



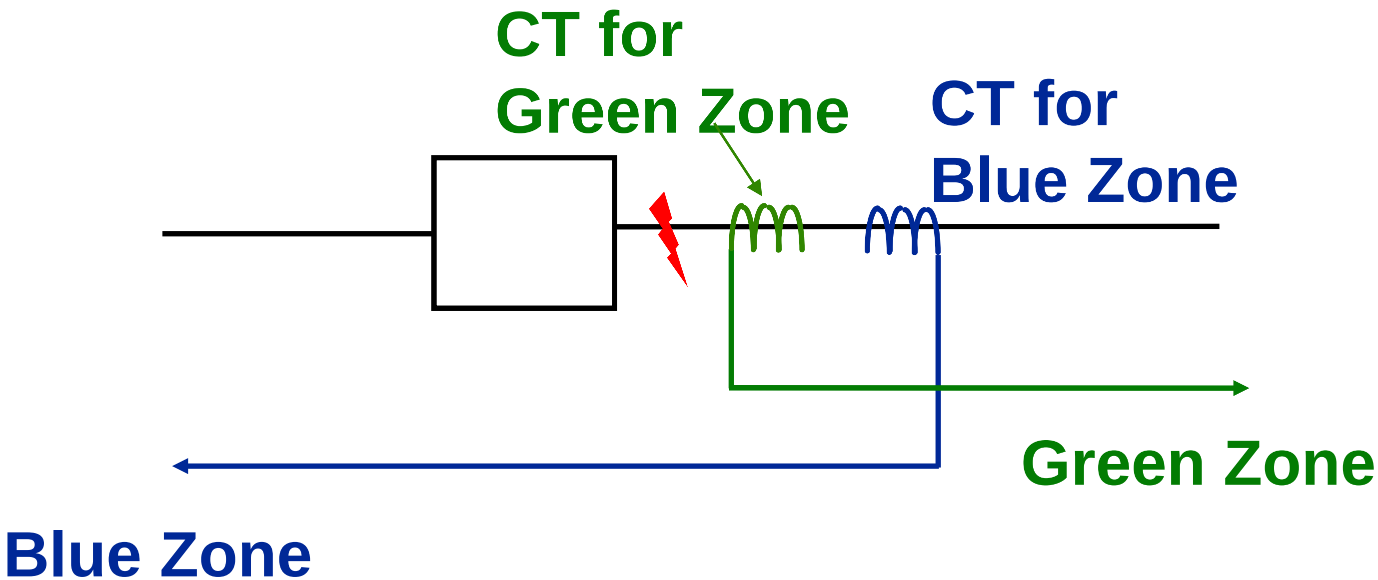

**Bus protection**

# Zones of protection




**Dead tank breaker, two CTs**

# Zones of protection




**Live tank breaker, single CT**

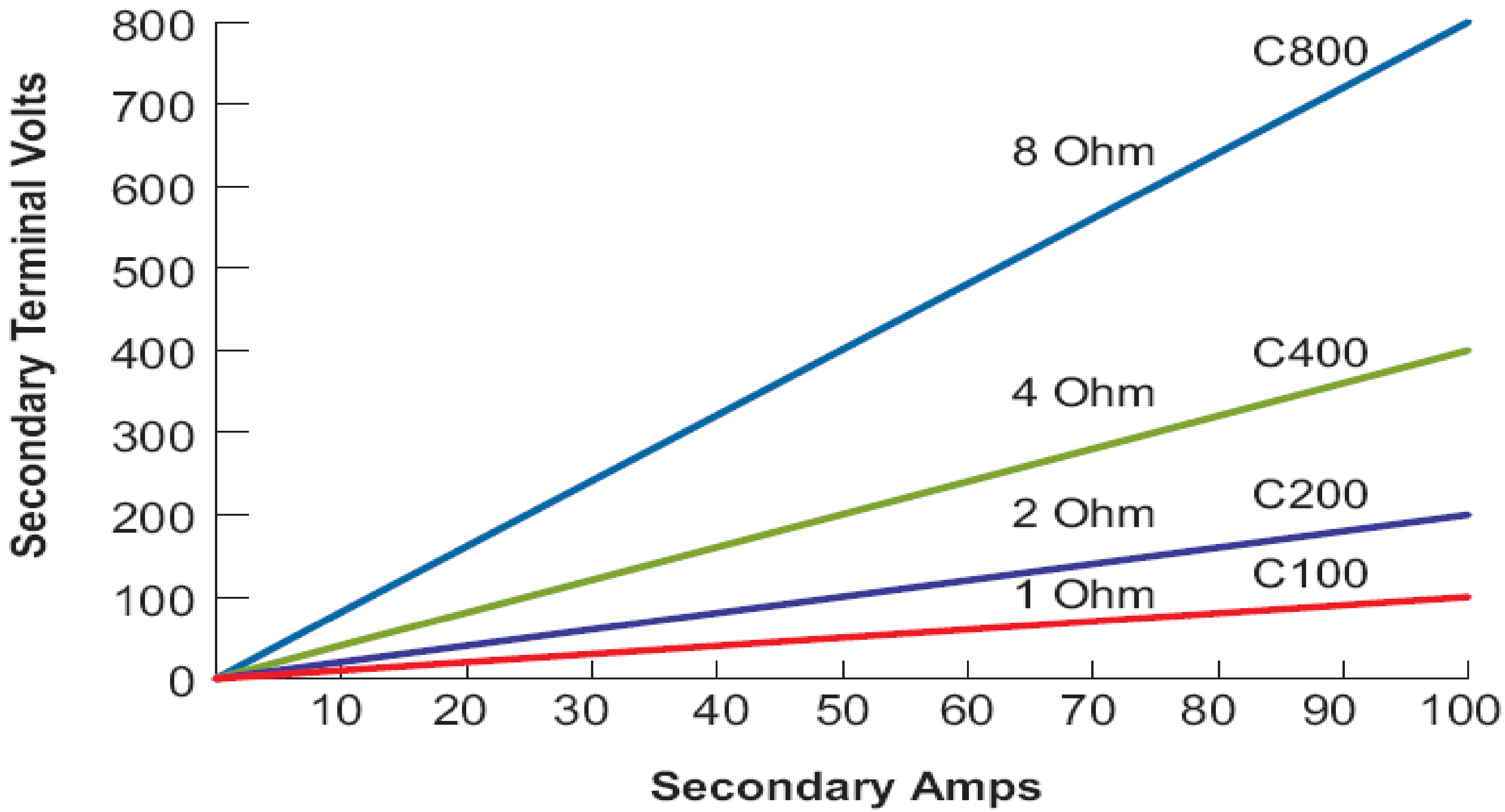
# Current transformer
## Ratings of concern for bus protection

- Ratio: 200/5, 1200/5, …500/1
- Burden capability: VA burden
- Accuracy Class: C800, K200, T400
- Knee point, saturation voltage (can be derived from chart in C class CTs)
- CT availability
- IEEE Standard C57.13-1993 (R2003), IEEE Standard Requirements for Instrument Transformers
- IEEE Standard C37.110-1996, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes

# ANSI current transformer accuracy class

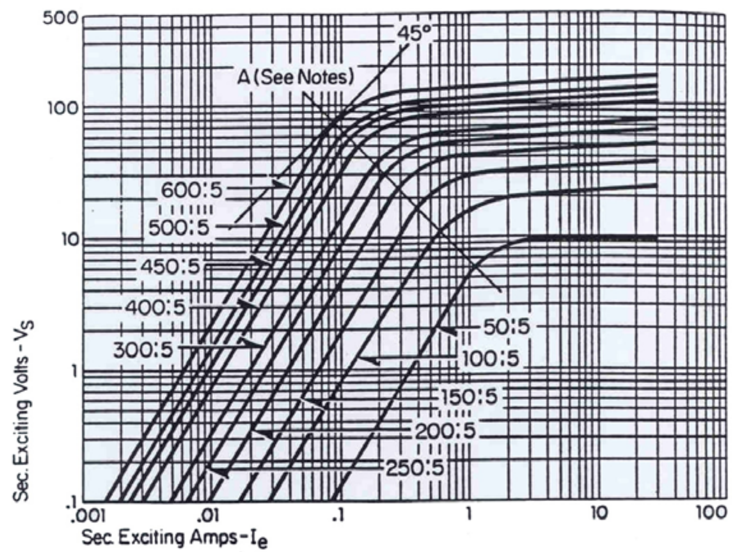
- Example 1200/5 C800
- This current transformer will deliver 800 volts on its secondary when it is connected to a standard burden and 20 times rated current is flowing in the primary winding  without exceeding 10% ratio error.

# ANSI accuracy class
## Standard chart for class C current transformers



# Knee point voltage

- Knee point
  - Log-log plot
  - Square decades
  - I.e. (.01,1) – (.1,10)
  - Tangent 45º line (knee pt)




| Current Ratio | Turn Ratio | Sec. Res. 1 |
|---|---|---|
| 50:5 | 10:1 | .061 |
| 100:5 | 20:1 | .082 |
| 150:5 | 30:1 | .104 |
| 200:5 | 40:1 | .125 |
| 250:5 | 50:1 | .146 |
| 300:5 | 60:1 | .168 |
| 400:5 | 80:1 | .211 |
| 450:5 | 90:1 | .230 |
| 500:5 | 100:1 | .242 |
| 600:5 | 120:1 | .296 |

**Notes:**

1) Above The Line, The Voltage for a Given Exciting Current Will Not be Less Than 95% of The Curve Value.

2) Below The Line, The Exciting Current for a Given Voltage Will Not Exceed The Curve Value by More Than 25%.

# Differential measurement difficulties

- Three measuring conditions
  - normal load flow - no differential current
  - external fault - ideally no differential current
  - internal fault - high differential current
- CT saturation
  - causes false differential current for external  faults

# CT saturation

- CT core may reach saturation flux density due to a combination of dc offset in the fault current, with possibility remnant flux (20-80%, no way to predict, but can be erased by demagenatizing)
- The output current suddenly changes from a proportional signal to zero
- DC saturation depends on
  - system time constant (X/R)- large close to generating stations
  - secondary burden

©ABB

# CT saturation

- CT secondary model
  - a perfect current source (infinite impedance) in parallel with an exciting impedance branch that drives proportional current
- Exciting impedance is normally very high
- At saturation, exciting impedance drops to a very low value
  - the CT appears short-circuited
  - neither delivers nor resists current flow
- Time to saturation is important in low impedance bus protection

# Issues effecting bus protection selection

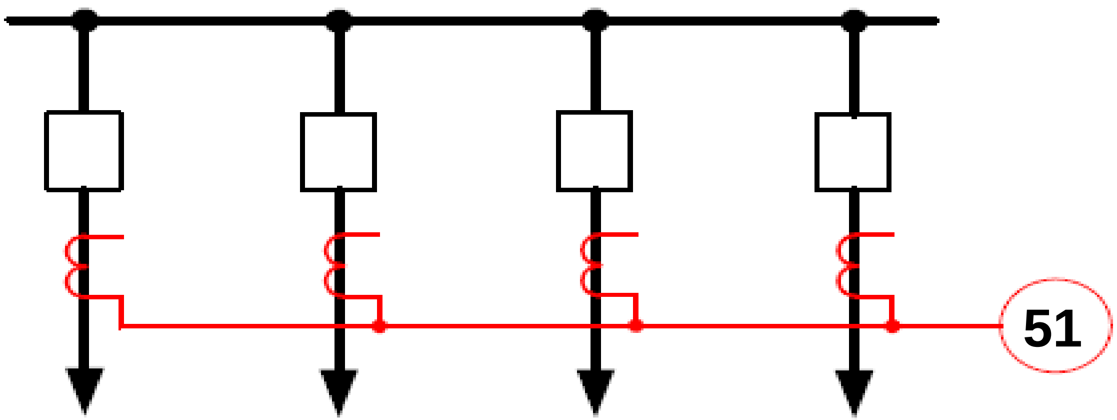
- Bus arrangement
  - Fixed
  - Switchable
- Availability and characteristics of current transformers
- Performance requirements
  - Speed
  - Dependability
  - Security
  - Sensitivity (for high impedance grounded system)

# Types of bus protection

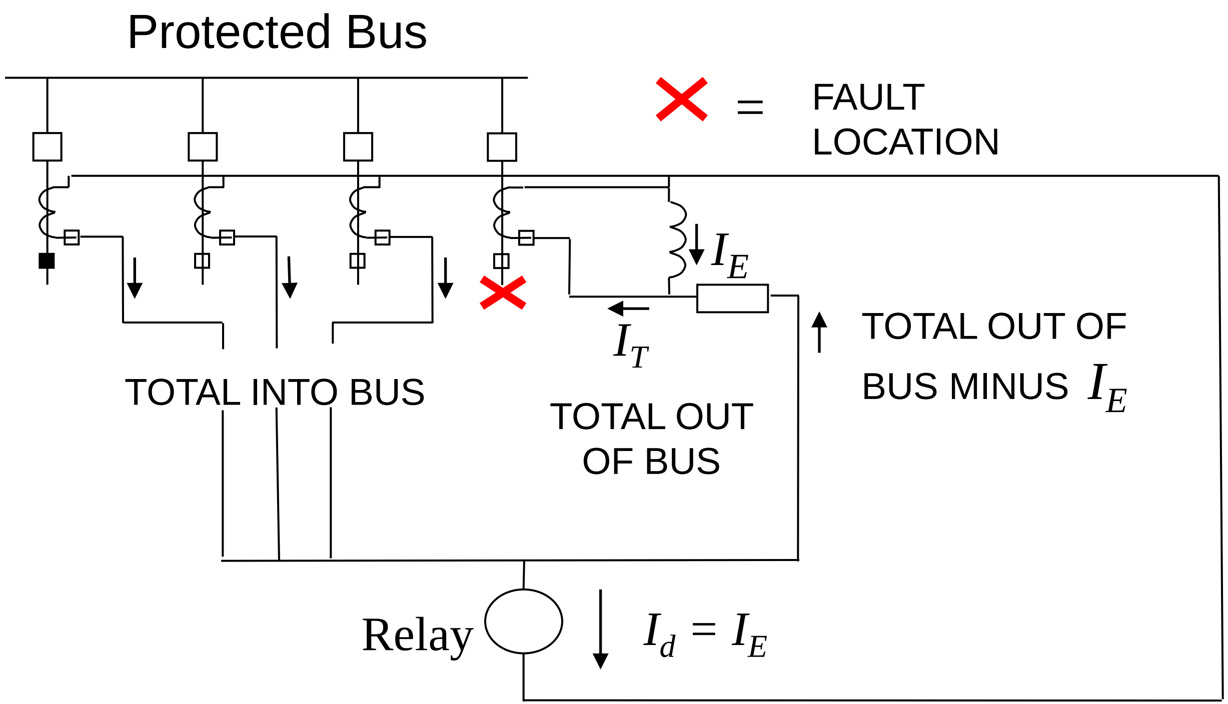
- Differential
  - Differentially connected overcurrent
  - Percentage-restrained differential (low Z)
  - High impedance differential
  - Partial differential
- Zone interlocked scheme
- Back up schemes (eg. remote over-reaching zones)

©ABB

# Differentially connected overcurrent relay

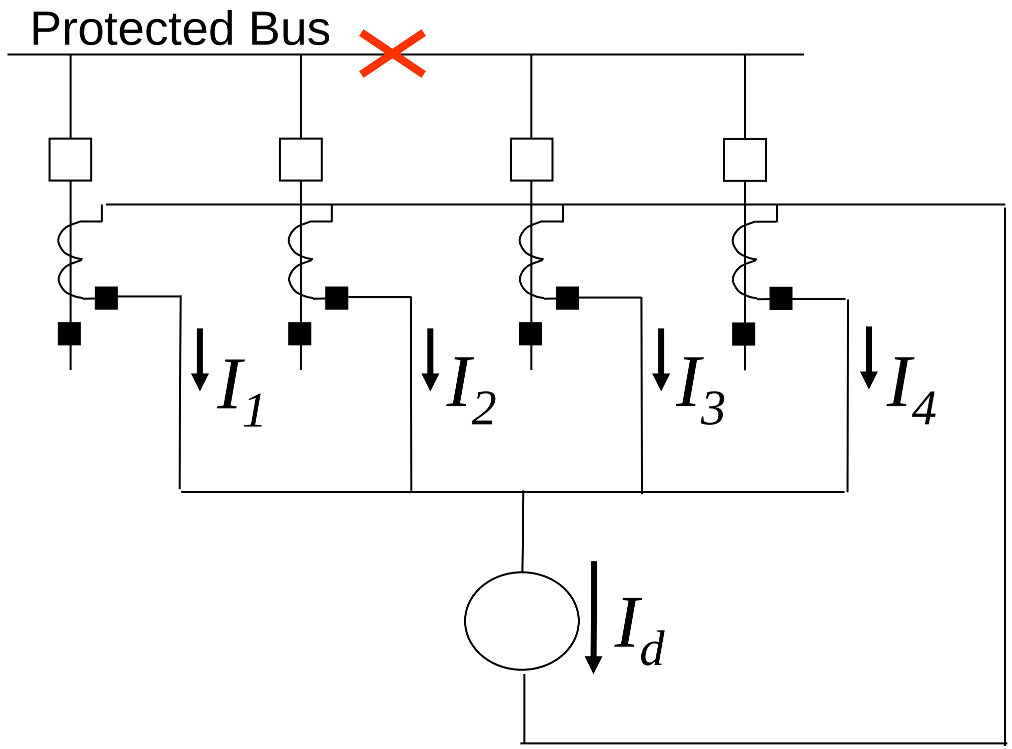


# External fault case




©ABB

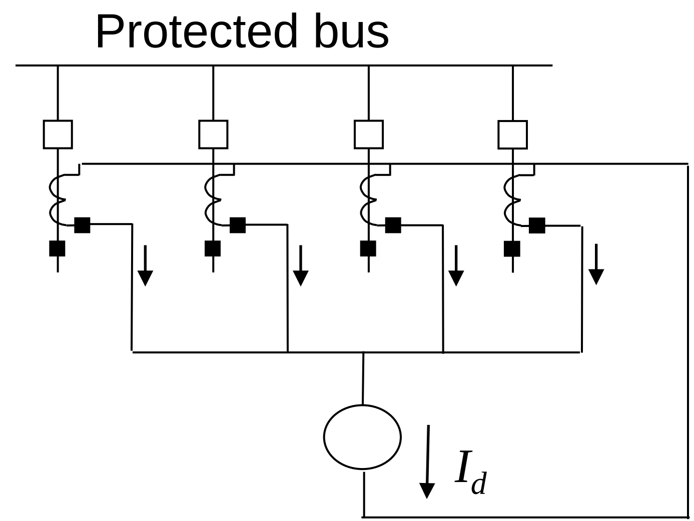
# Internal fault case




$$I_d = I_1 + I_2 + I_3 + I_4$$

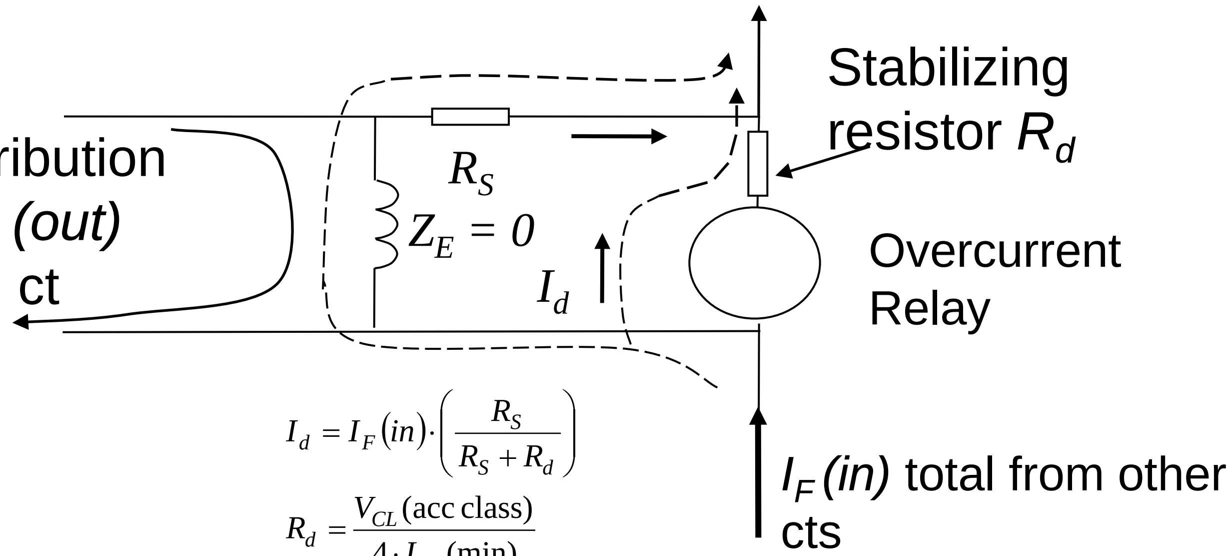
# Overcurrent relay bus differential

- Application OK if:
  - Symmetrical CT secondary current less than 100
  - Burden less than rated
  - Typical pickup setting $I_{PU}$ > 10A
  - Trip delay greater than 3 x primary time constant (L/R)




©ABB

# Resistor added to relay branch
## External fault

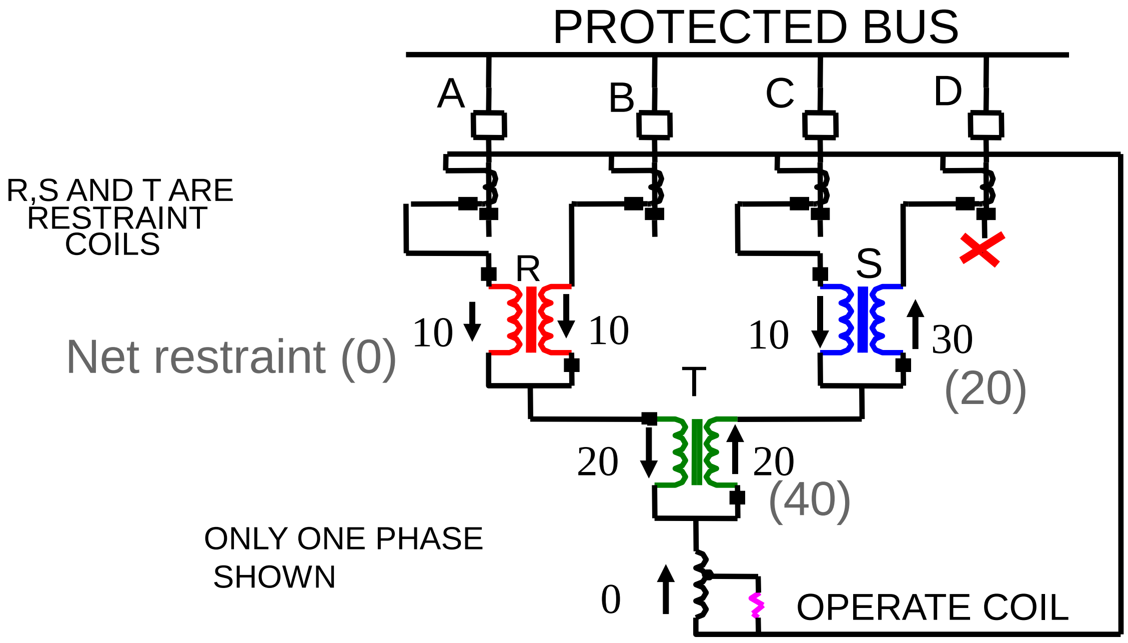



$$I_d = I_F(in) \cdot \left( \frac{R_S}{R_S + R_d} \right)$$

$$R_d = \frac{V_{CL}(\text{acc class})}{4 \cdot I_{pu}(\text{min})}$$

- Resistor reduces current in relay and increases current in $R_S$ (secondary and lead)
- Increases sensitivity to internal faults

# Multiple restraint Percentage Differential (Legacy)

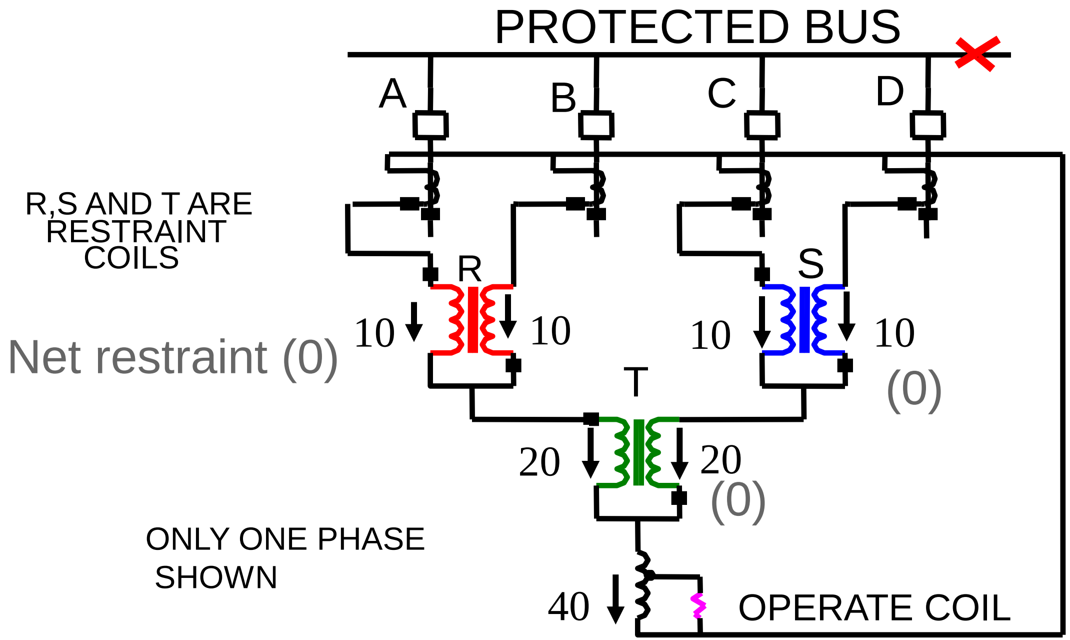



All circuits have 10 Amp contribution

Restraint = 60
Operate = 0

External fault example – 4 circuit connection

# Multiple restraint Percentage Differential (Legacy)

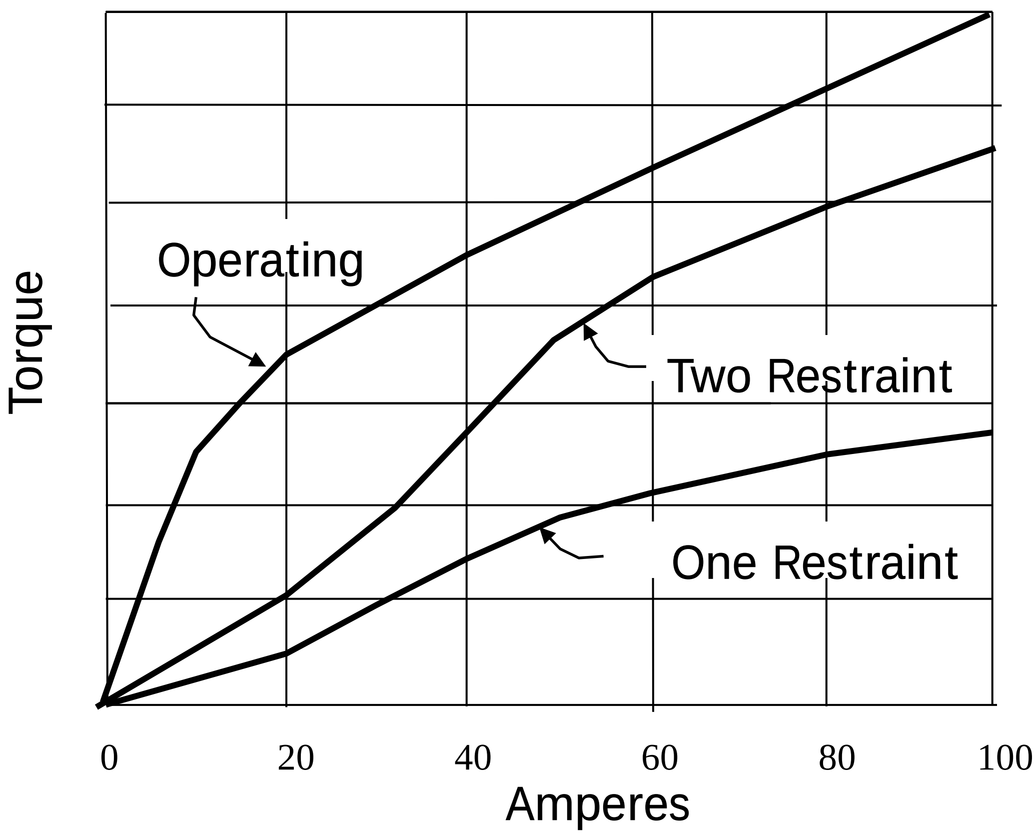



All circuits have 10 Amp contribution

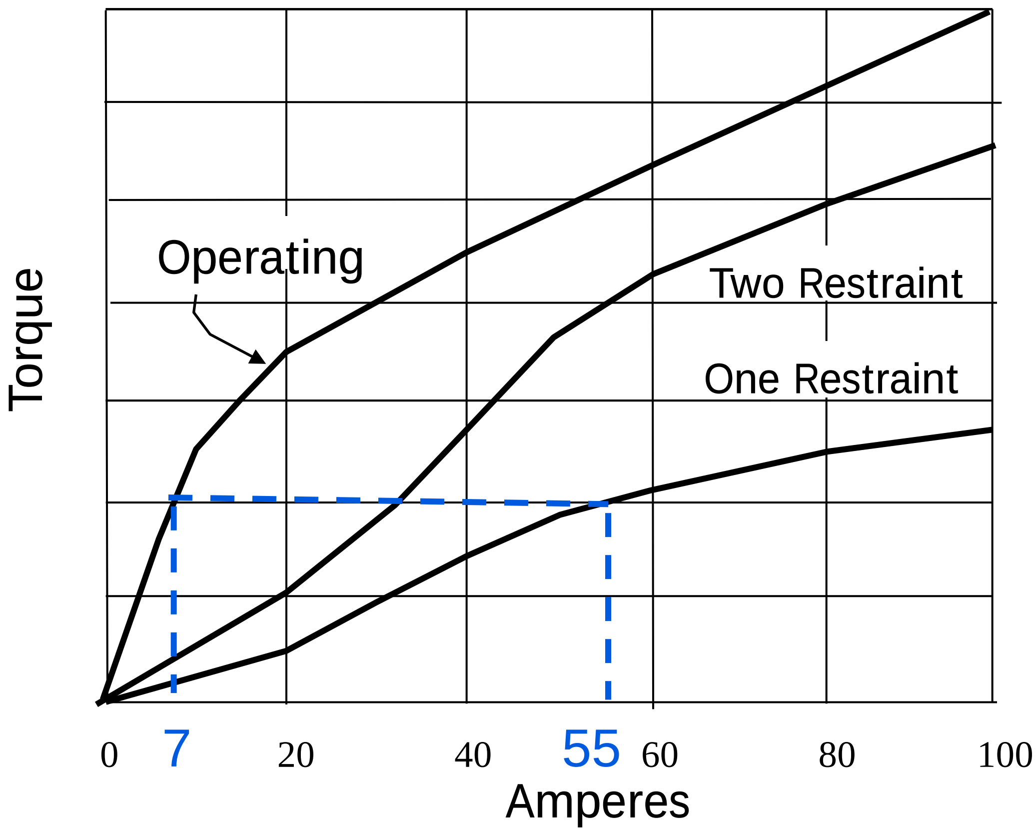
Restraint = 0
Operate = 40

Internal fault example – 4 circuit connection

# Torque for typical multi-restraint relay



# Torque for typical multi-restraint relay



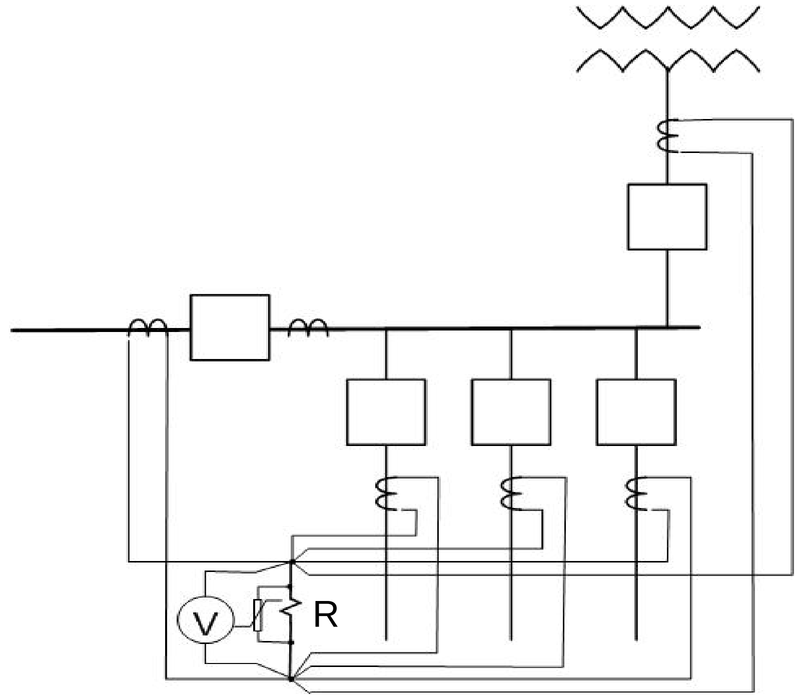

55 A. of restraint overcomes 7 A of operating current with one restraint winding

# Multi-restraint percentage differential

- Good sensitivity
- Good security
- Allows other relays on the same CT core
- Different CT ratios with Aux CTs.
- Slow compared to high impedance
- Number of feeders limited by restraint windings
- Each CT is wired to relay
- Not easily extendable

# High impedance bus protection

- High resistor (R > 1500 ohm) in series with relay coil and a MOV to prevent over-voltages
- High voltage develops for internal faults. lower Voltage will develop on external faults where with ct saturation
- Voltage unit must be set higher than the maximum junction point voltage for any external fault
- The lowest achievable sensitivity must verified for the application
- Proven reliability and very sensitive
- Operating times of less than one cycle for internal faults



# High impedance bus protection

EXTERNAL FAULT - *SECURITY*

Setting $V_R > (I_F / N)(R_L + R_S)$

K = margin factor

$I_F$ = Max external fault current

$R_S$ = Ct secondary resistance

$R_L$ = Lead resistance to junction box

N = ct turns ratio

INTERNAL FAULT - *SENSITIVITY*

$I_{MIN} = (XI_E + I_R + I_V)N$

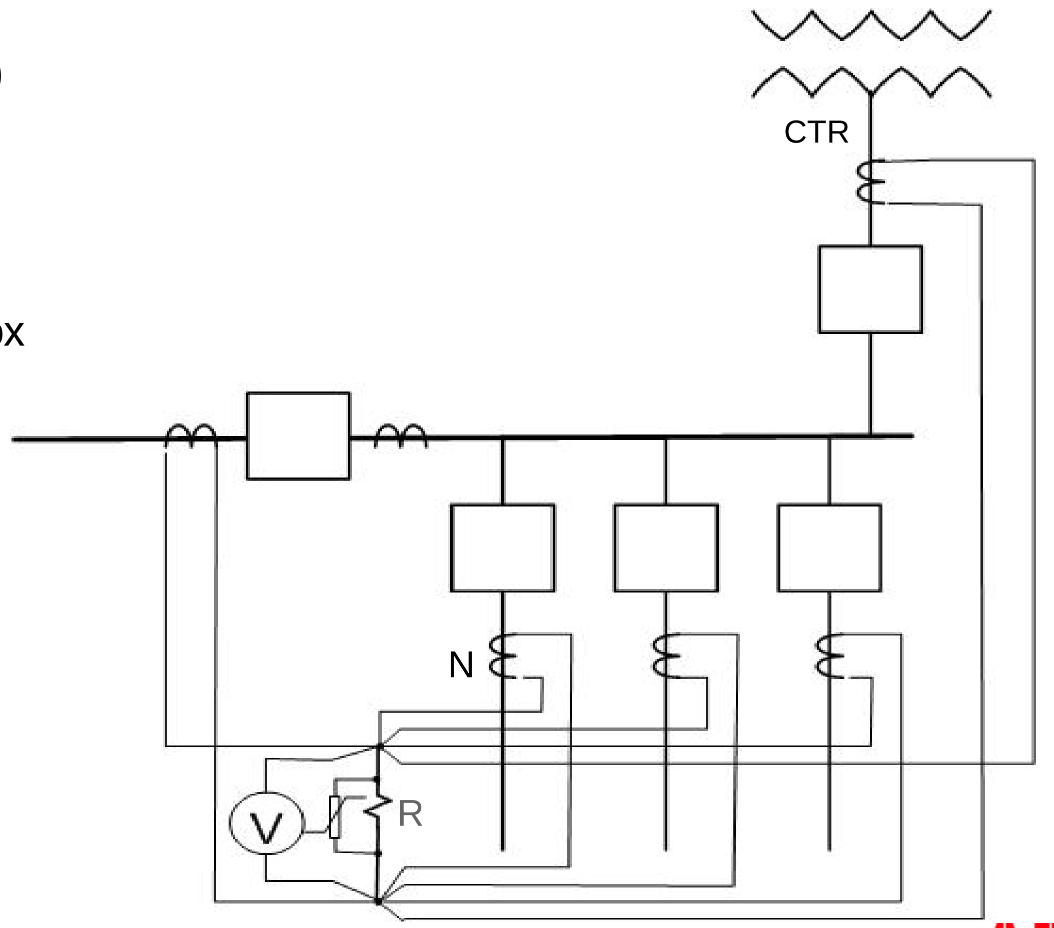
X = number of circuits

$I_E$ = Ct exciting current at $V_R$

$I_R$ = resistor current at $V_R$

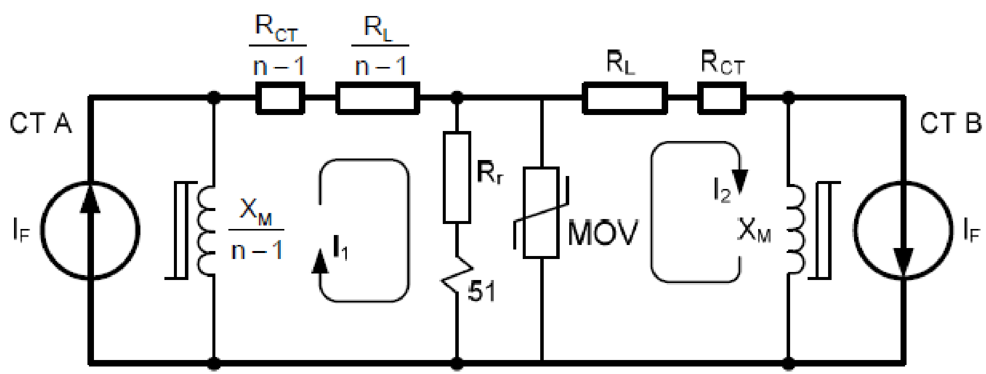
$I_V$ = Varistor current at $V_R$

R > 1500 W



# High impedance bus protection
## Criteria to be met

- Objective: Keep $V_R$ and $I_{min}$ low
  - Ct secondary loop resistance kept low
  - Impedance from junction point to relay is of no consequence so good practice to parallel the CTs as close to the CTs as possible.
  - Theoretically no limitations in the number of parallel CTs but sensitivity reduced.
- All cts should have the same ratio and magnetizing characteristics




©ABB

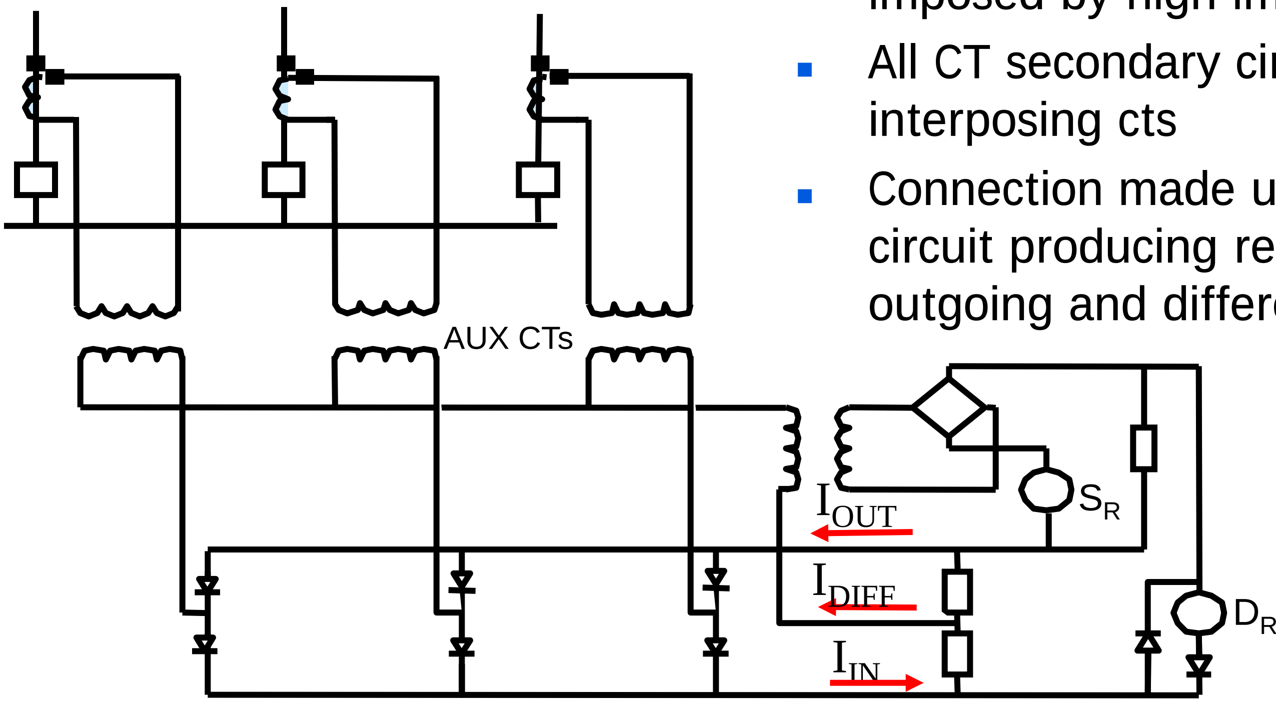
# High impedance bus protection
## Criteria to be met

- Tapped CT's may be interconnected with fixed ratio ct's if attention is given to the autotransformer effect and the overvoltage protective characteristics of the relay
- A voltage setting higher than the lowest of all of the relaying accuracy class voltages of the CT's used in the scheme (400 V for a C400 CT). $I_E$ obtained from the excitation character contains large errors
- Voltage setting can be lowered by reducing CT lead resistance

©ABB

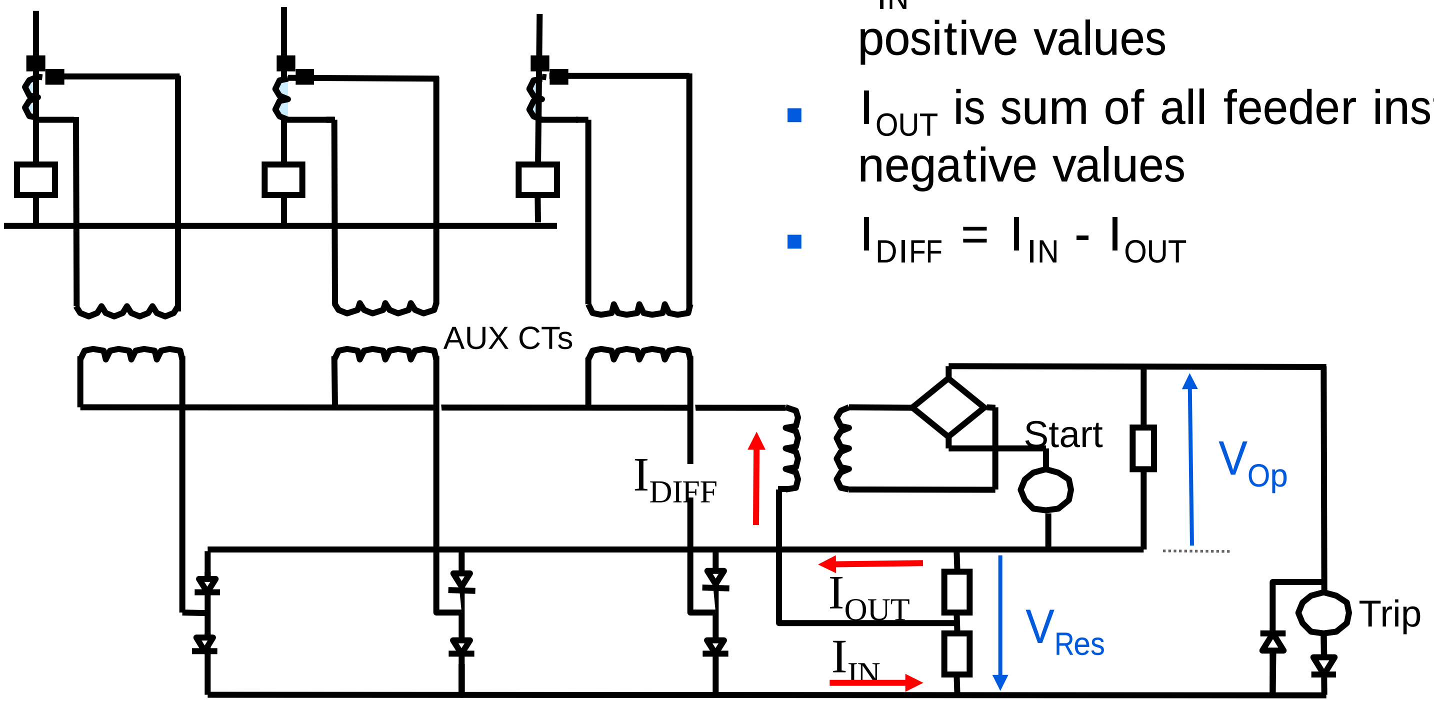
# Differential comparator (Legacy, Static type)
## RADSS/REB103

- Developed to lessen restrictions imposed by high impedance
- All CT secondary circuits connected via interposing cts
- Connection made using a special diode circuit producing rectified incoming, outgoing and differential currents




©ABB

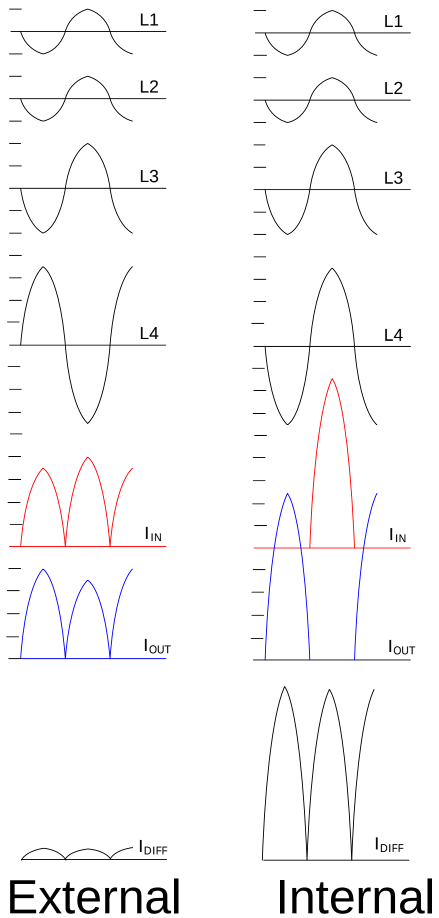
# Differential comparator
## Single phase connection

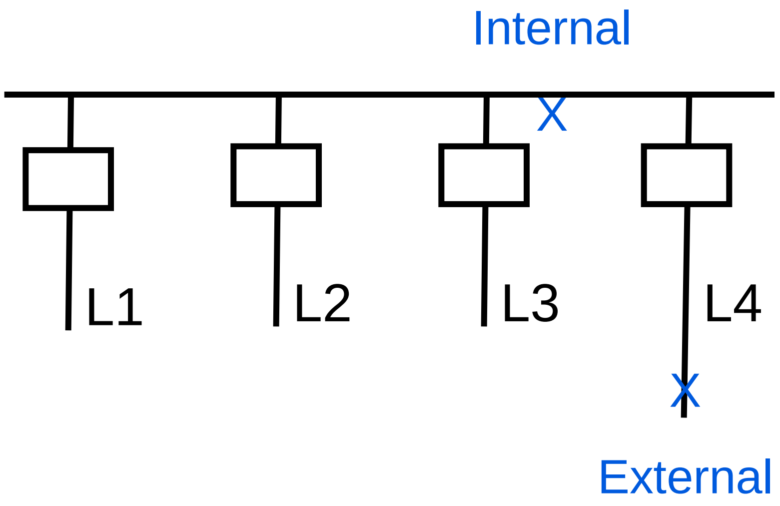



- $I_{IN}$ is sum of all feeder instantaneous positive values
- $I_{OUT}$ is sum of all feeder instantaneous negative values
- $I_{DIFF} = I_{IN} - I_{OUT}$

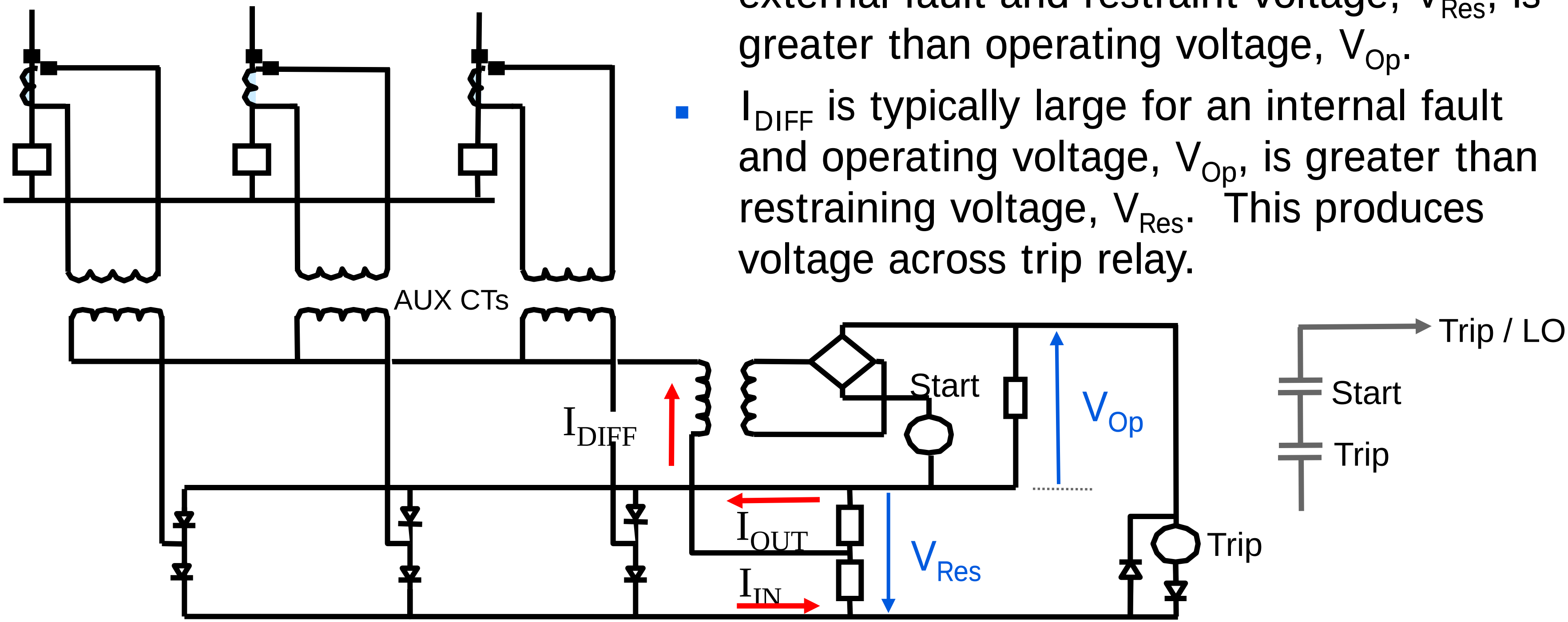
©ABB

# Differential comparator



# Differential comparator
# Single phase connection




- $I_{DIFF}$ is typically small (normally 0) for external fault and restraint voltage, $V_{Res}$, is greater than operating voltage, $V_{Op}$.
- $I_{DIFF}$ is typically large for an internal fault and operating voltage, $V_{Op}$, is greater than restraining voltage, $V_{Res}$. This produces voltage across trip relay.

# Differential comparator

- All measurement decisions based on three quantities
  - $I_{DIFF}$ - difference of input current and output current ($I_{DIFF} = I_{IN} - I_{OUT}$)
  - $I_{IN}$ - total input current
  - S - % differential setting
- $I_{DIFF} > S \times I_{IN}$
  - e.g. for setting S=50%, differential current ≥ 50% of incoming current before operation

# Differential comparator
## Advantages over high impedance differential

- Lower ct requirements
- Allows much higher ct loop resistances
- Accommodate different CT ratios / auxiliary CTs
- Fast operating times for internal faults
  - Detects internal 1 - 3 ms
  - Before ct saturation

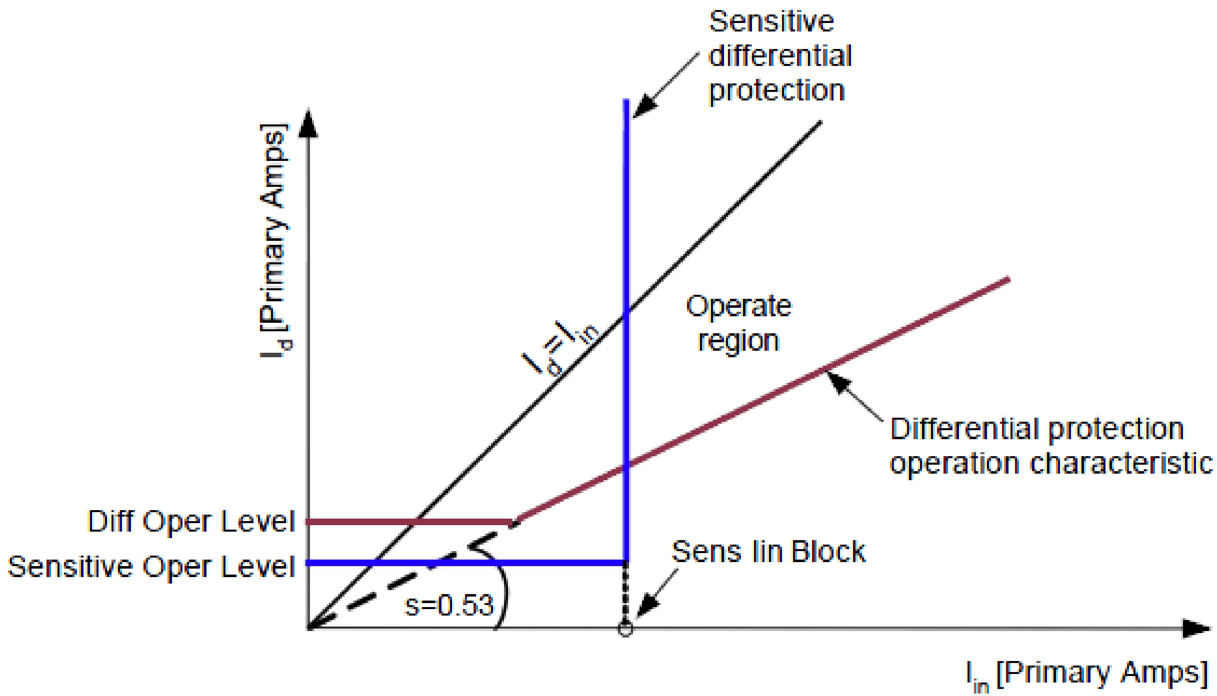
©ABB

# Numerical differential comparator

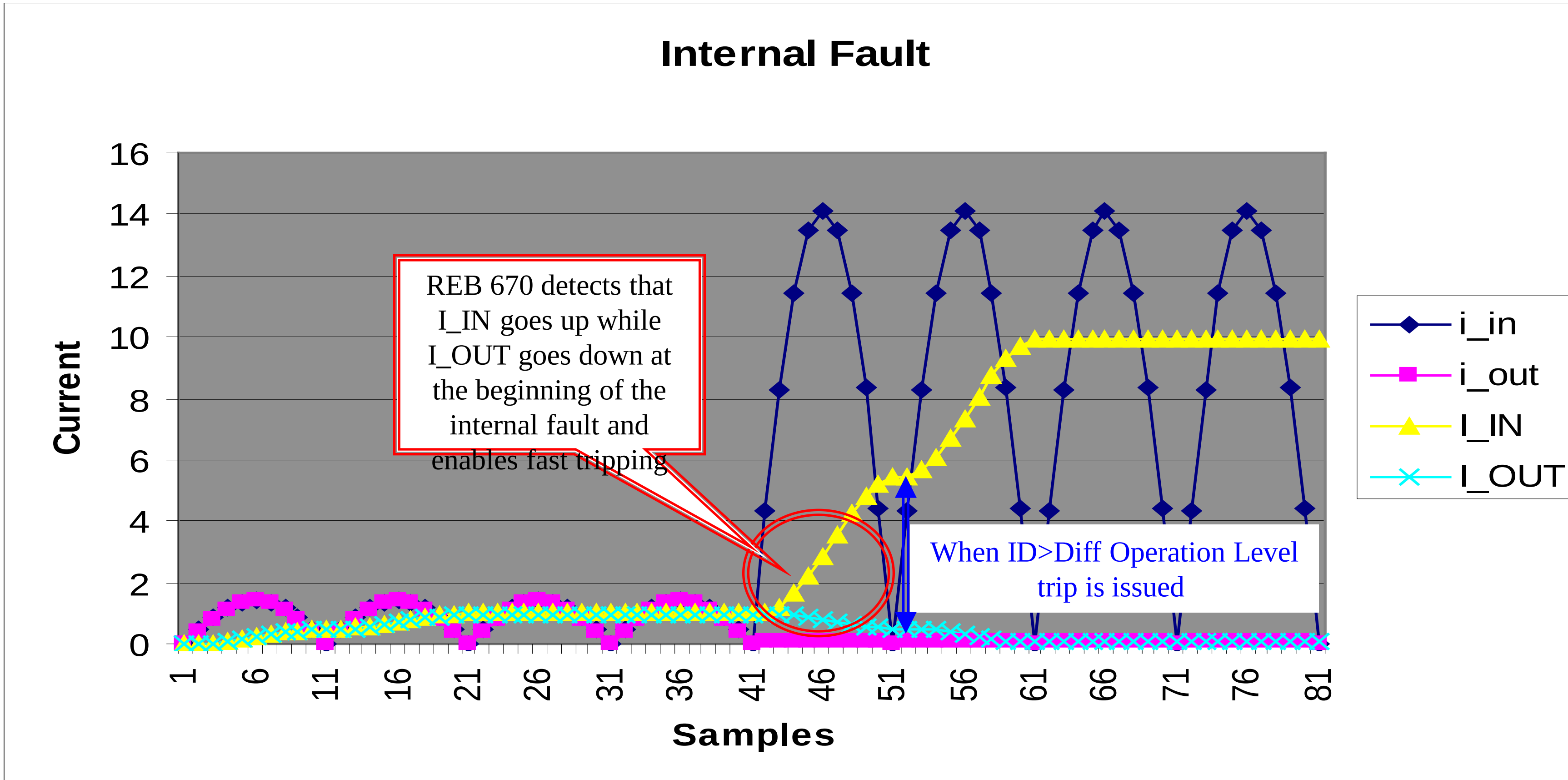
- Analog input currents are instantaneously sampled and quantized to numerical number
- Similar technique to legacy differential comparator, but with measured sampled data
- Secondary circuit loop resistance no longer a critical factor
- Critical factor is time available to make the measurement, i.e. time to saturation.  (only 3ms required to properly restrain for heavy external faults)
- Algorithms for Ct saturation Detection and CT state supervision

©ABB

# Differential comparator

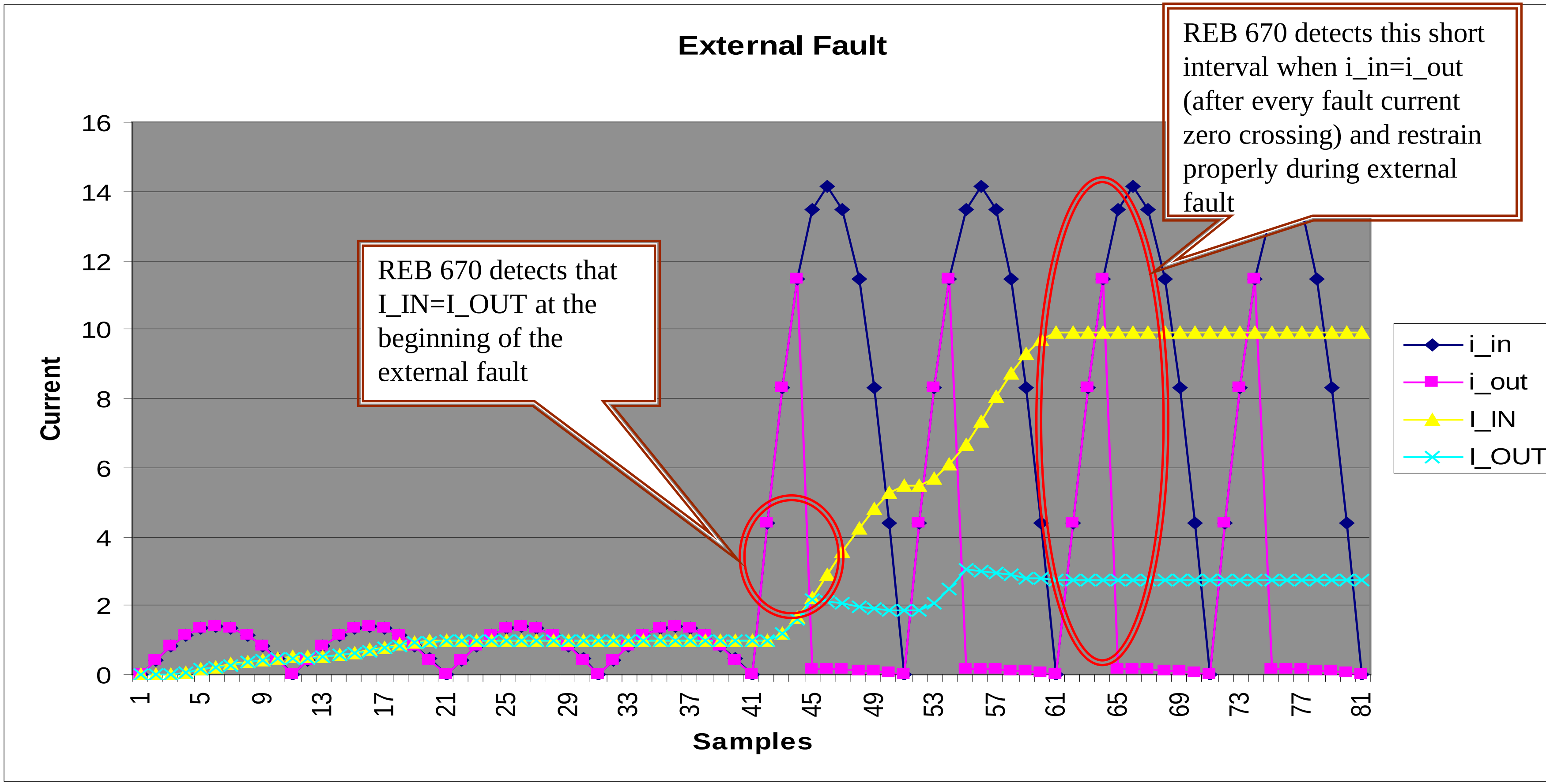


# Quick operation for internal fault

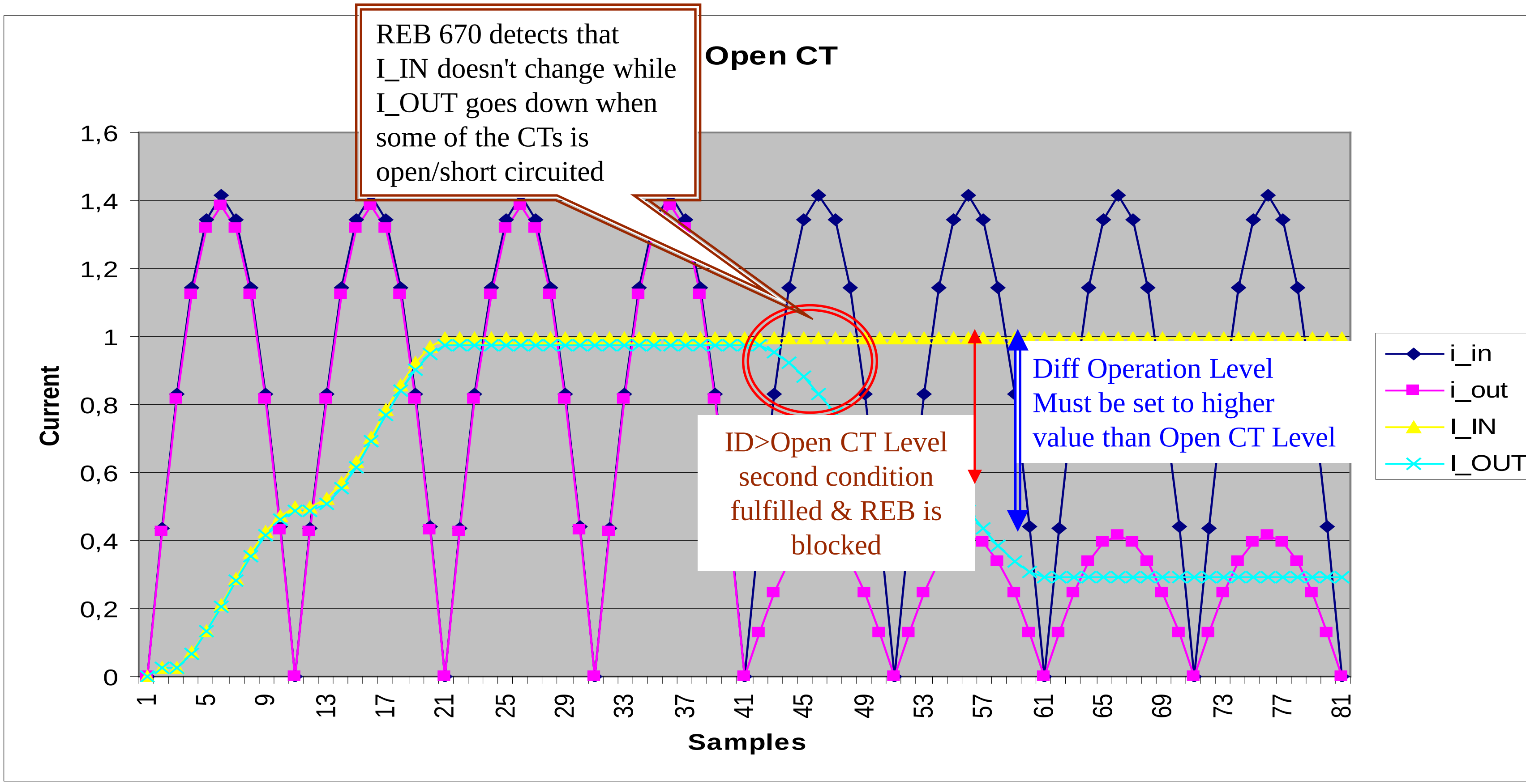



©ABB

# Proper & secure restrain during external fault



# Fast open CT algorithm

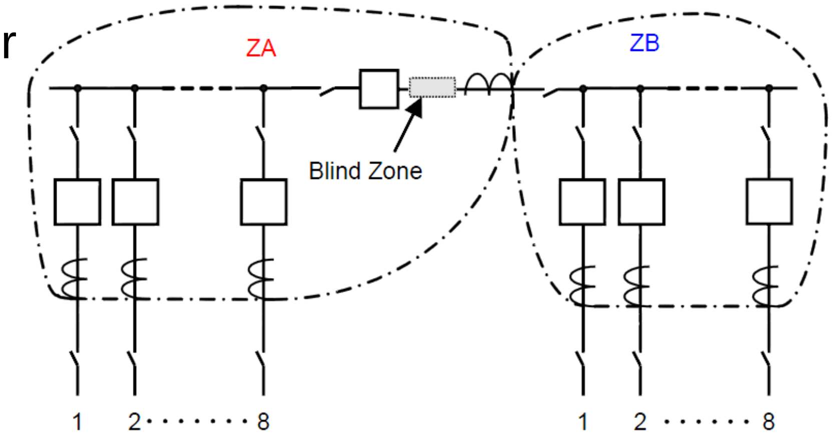


# Other Features in Modern Numerical Bus IEDs

- Each device capable of connecting multiple bays (eg. CTs) in 3-ph or 1-ph design
- Multiple differential zones, dynamic bay switching, zone interconnection, and check zone logics
- External fault/CT saturation detection, open CT detection algorithms
- Blind zone protection (see next 2 slides)
- End zone protection (see next 2 slides)
- Backup protection (eg. 50/51, 50BF) for each connected bay
- Modern substation automation communication (DNP 3.0, IEC61850)

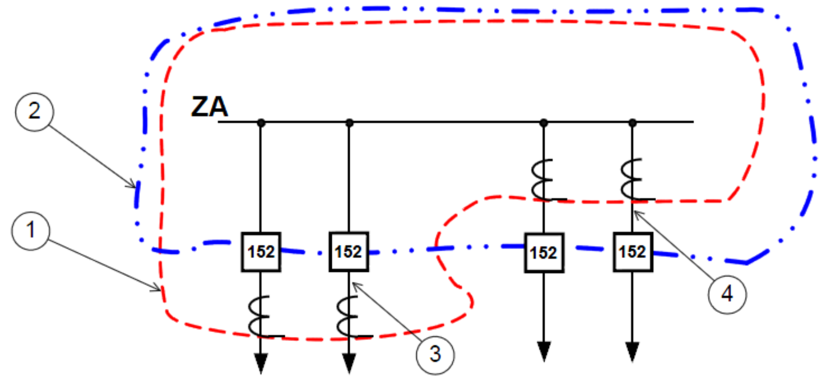
# Blind zone detection

- Blind zone between live tank CT and breaker
- A fault in the blind zone makes operation in ZA unnecessary (tie breaker normally open)
- ZB cannot detect the fault
- Solution: connect BKR NC (open) status to the bay to remove this CT from ZA, ZB (software)
- Remove CT dynamically can force operation of ZB



# End Zone Protection

- Regions not overlapped by both red and blue boundaries are blind zones
- CTs are used for both feeder and bus protection measurement (live tank CTs)
- Common in HV 1-1/2 stations
- Requires local backup (eg. BF) to trigger DTT for 3
- Requires remote back up (eg. zone 2) to open local breaker and disconnect the CT to clear bus zone for 4




where:

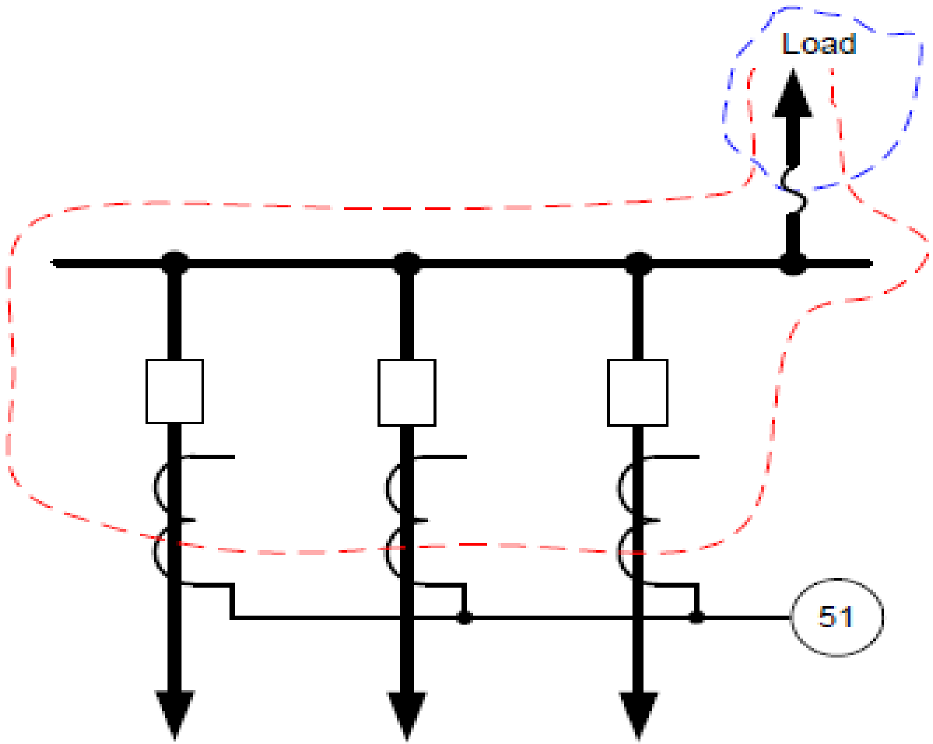
| | |
|---|---|
| 1 | is Busbar Protection measuring boundary determined by feeder CT locations |
| 2 | is Busbar Protection internal fault clearing boundary determined by feeder CB locations |
| 3 | is End fault region for feeders as shown in figure 36/B |
| 4 | is End fault region for feeders as shown in figure 36/C |

©ABB

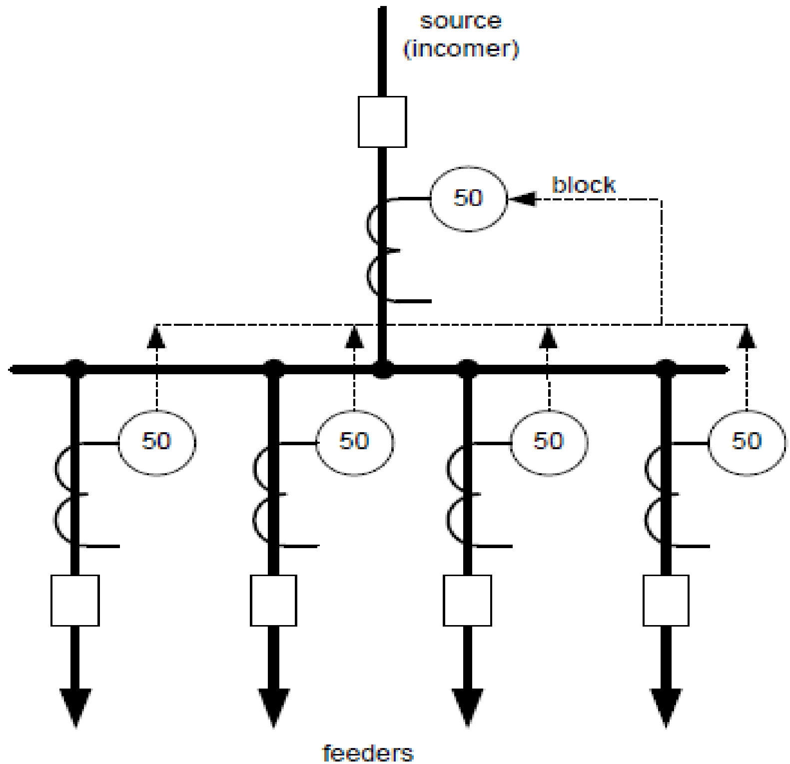
# Other distribution (MV) bus protection methods

- Partial differential
- Blocking on feeder fault

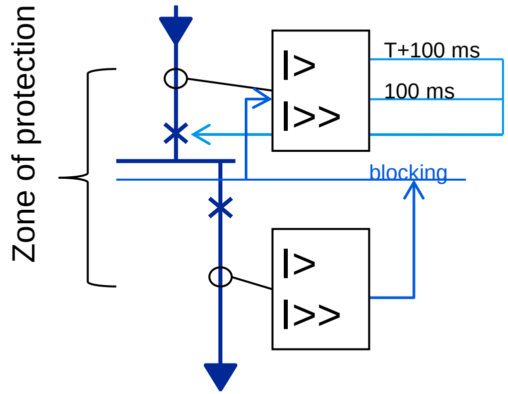
# Partial differential



# Blocking scheme



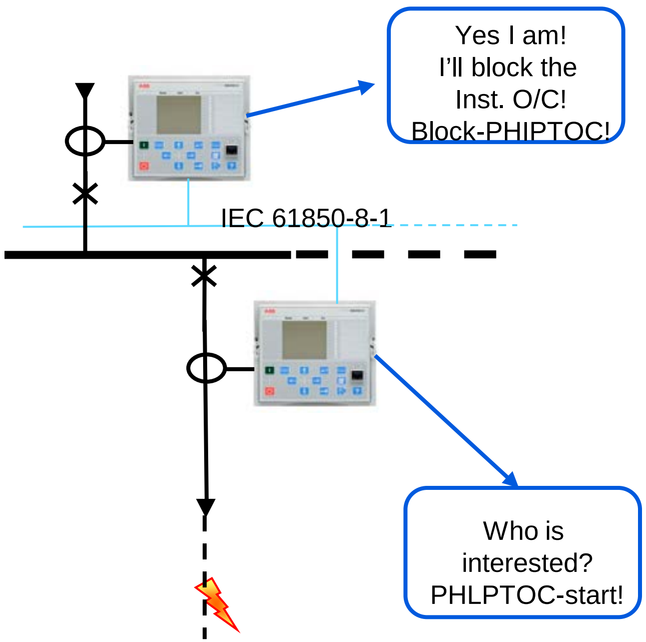
# Conventional Blocking Scheme




| Delay setting with inst. O/C protection (conventional approach) | |
|---|---|
| Safety marginal, e.g. delay in operation due to CT saturation. | **20…40 ms** |
| O/C protection start delay + output relay's delay | **<40 ms** |
| Start delay with receiving relay + retarding time for the blocking signal *) | **<40 ms** |
| **ALL TOGETHER** | **100…120 ms** |

- Traditional busbar protection based on upstream blocking
  - Dedicated hard-wire signal paths needed
  - Signal path delay needs to be considered, input and output delay + auxiliary relays
  - Changes in the protection scheme may require re-wiring
- Typical needed delay in incoming relay is over 100 ms

# Blocking Scheme with IEC-61850 GOOSE




| **Delay setting with inst. O/C protection (REF615 GOOSE approach)** | |
|---|---|
| Safety marginal, e.g. delay in operation due to CT saturation. | **20…40 ms** |
| O/C protection start delay | **20 ms** |
| Retardation time of inst. O/C stage blocking | **5 ms** |
| GOOSE delay (Type 1A, Class P1) | **<10 ms** |
| **ALL TOGETHER** | **55…75 ms** |

# Bus protection comparison chart

| | COST | EASE OF USE | SENSI-TIVITY | DEPEND ABILITY | SECURITY | FLEXI-BILITY | SPEED |
|---|---|---|---|---|---|---|---|
| SIMPLE OVER-CURRENT | LOW | GOOD | POOR | GOOD | GOOD | GOOD | POOR |
| MULTIPLE RESTRAINT | MED | POOR | BEST | GOOD | GOOD | POOR | GOOD |
| HIGH IMPEDANCE | MED | GOOD | GOOD | GOOD | BEST | GOOD | FAST |
| PERCENTAGE RESTRAINED DIFFERENTIAL | HIGH | BEST | GOOD | GOOD | BEST | BEST | BEST |
| PARTIAL DIFFERENTIAL | LOW | GOOD | POOR | GOOD | GOOD | GOOD | POOR |
| BLOCKING | MED | GOOD | POOR | GOOD | GOOD | GOOD | FAST |

# Questions?
## Recommended reading

- ANSI C37.234  Guide for Protective Relay Applications to Power system Buses

# Relion® REB650/670 Advanced Busbar Protection
## Reliable protection and control of busbars

REB650
One IED for a wide range of high impedance differential protection applications

REB670
State of the art protection for medium to extra high voltage levels

- Selective, reliable and fast fault clearance for all types of internal phase-to-phase and phase-to-ground faults in solidly earthed or low-impedance earthed power systems
- Significant savings in configuration and commissioning with  efficient system integration and optimum "off-the-shelf" solutions and settings
- Do more with less - the advanced logic and multipurpose functionality allow you to customize protection schemes for multiple zones with a single IED
- Maximize flexibility and performance with powerful application and communication capabilities that allow you to integrate these IEDs into new or retrofit substation automation systems or use them as stand-alone multifunctional units

# Thank you for your participation

Shortly, you will receive a link to an archive of this presentation.

To view a schedule of remaining webinars in this series, or for more information on ABB's protection and control solutions, visit:

**www.abb.com/relion**

Power and productivity
for a better world™