



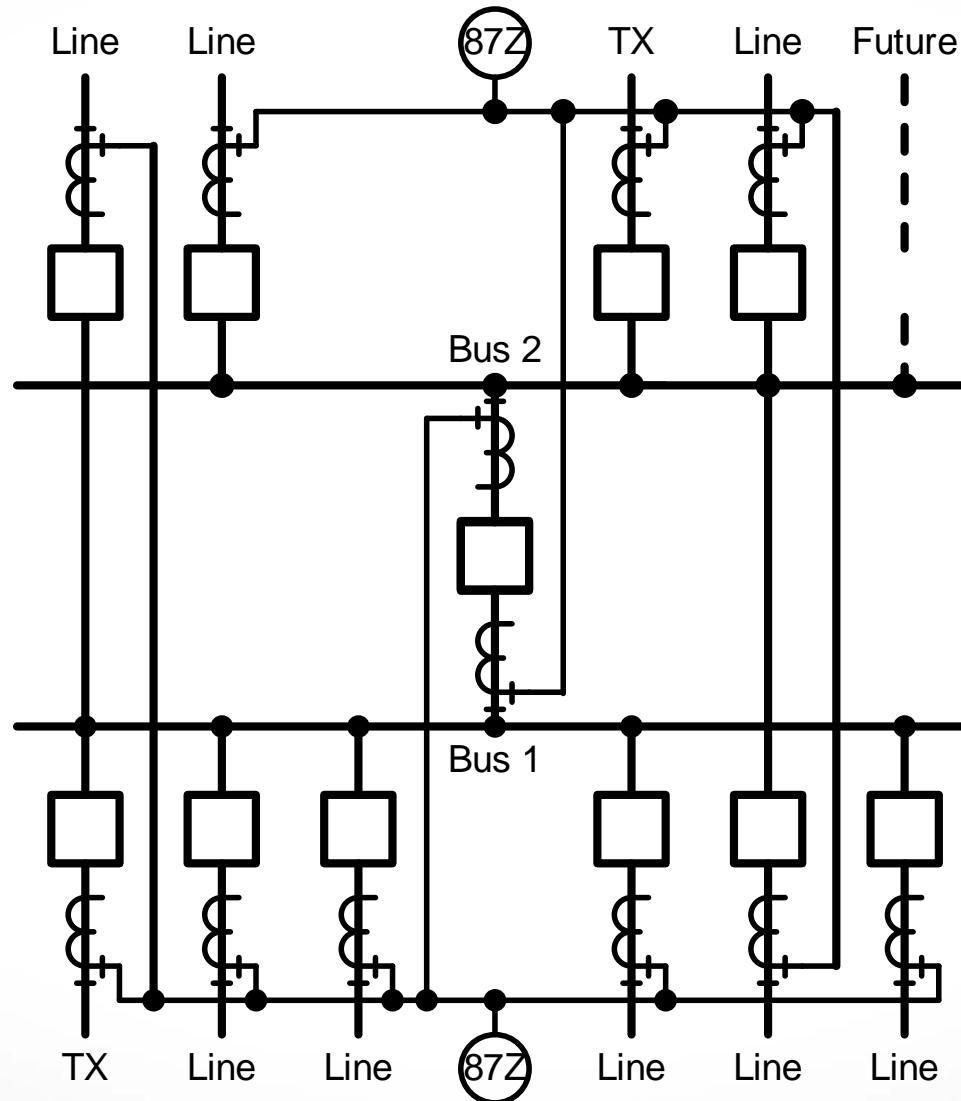
Redundant Bus Protection Using High-Impedance Differential Relays

Josh LaBlanc

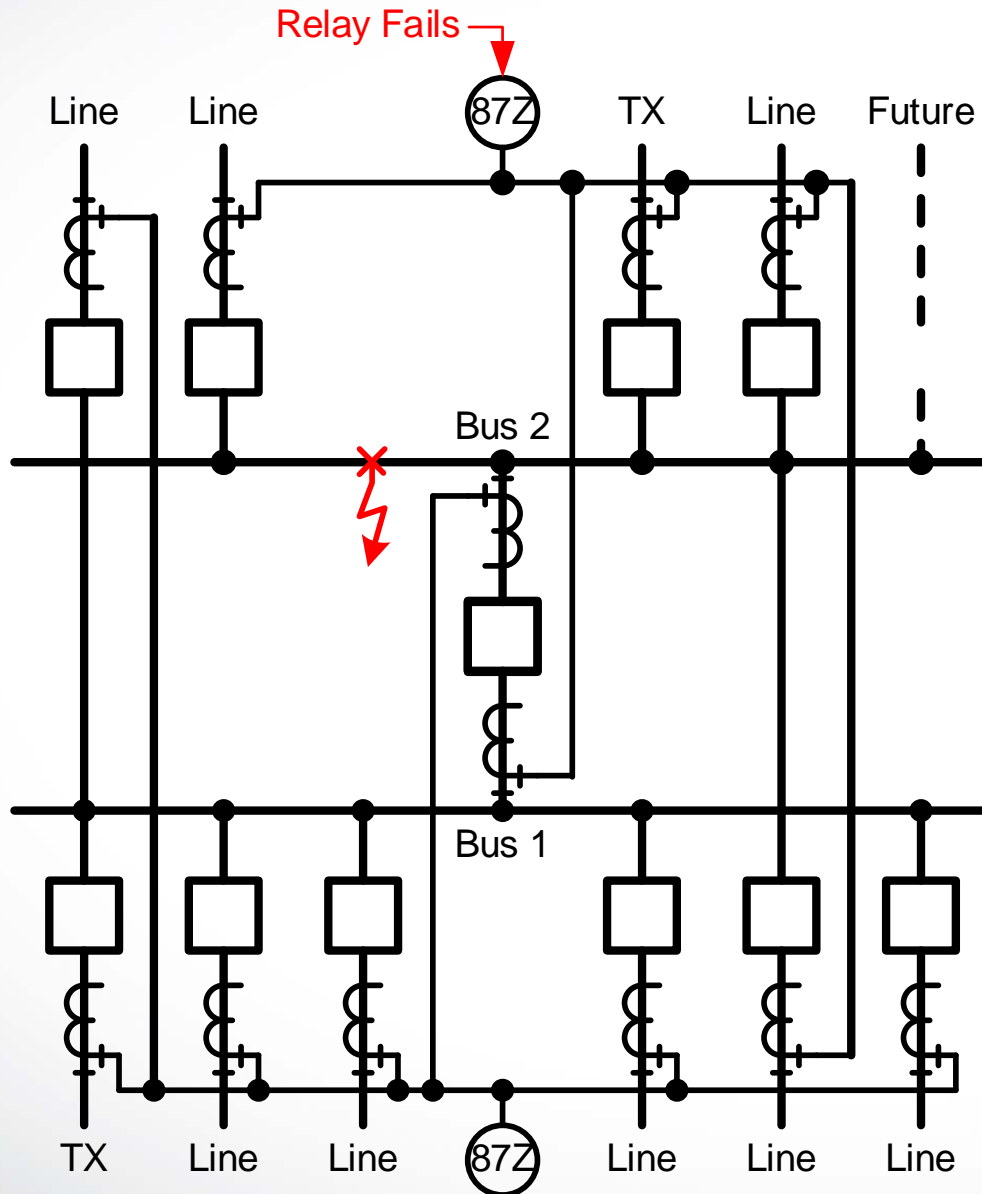
Purpose

- Discuss the configuration of the bus under study, and touch on the needs for redundant protection on the bus.
- Briefly discuss redundant bus protection applications other than high impedance based protection.
- Discuss the different methods in applying redundancy to a high impedance bus protection circuit.
- Discuss the pros and cons of each bus protection application.
- Discuss Minnesota Power's selection of redundant bus protection.

Original Bus Configuration

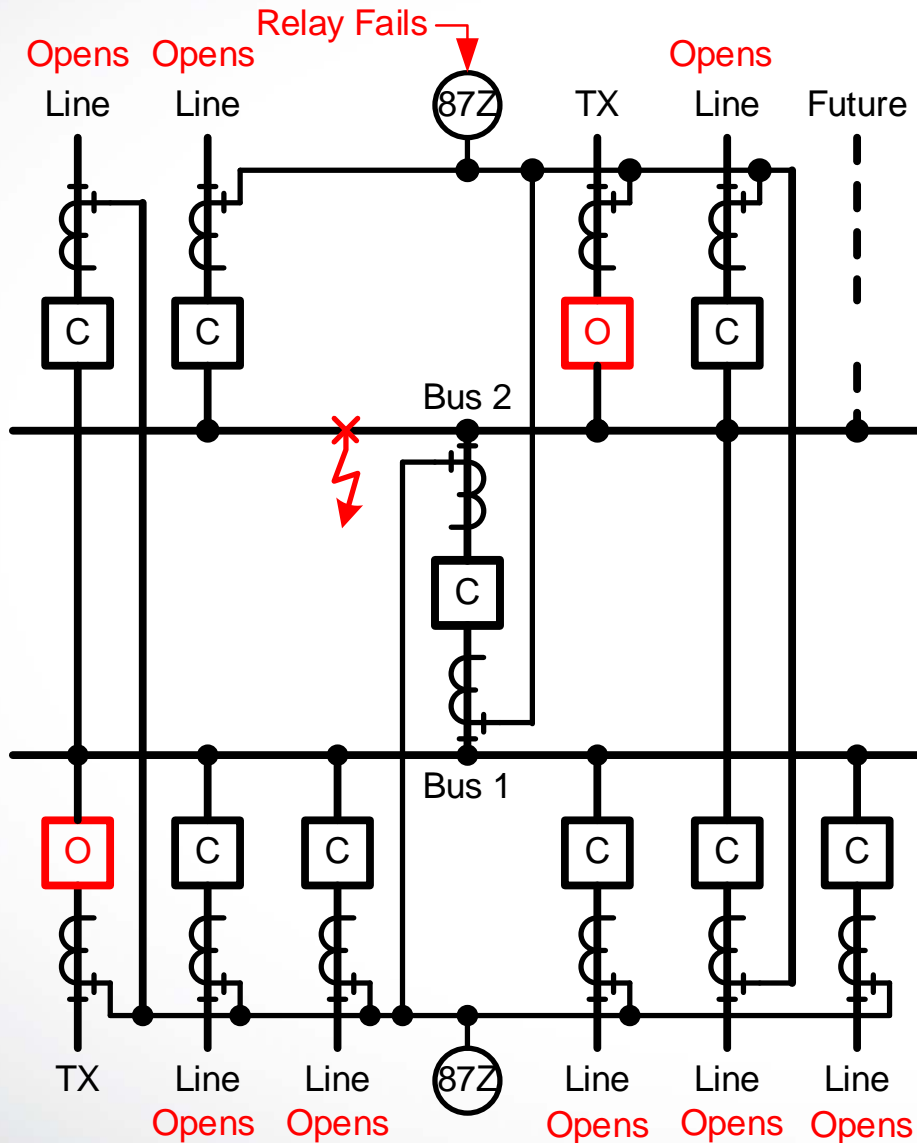


Relaying Issue



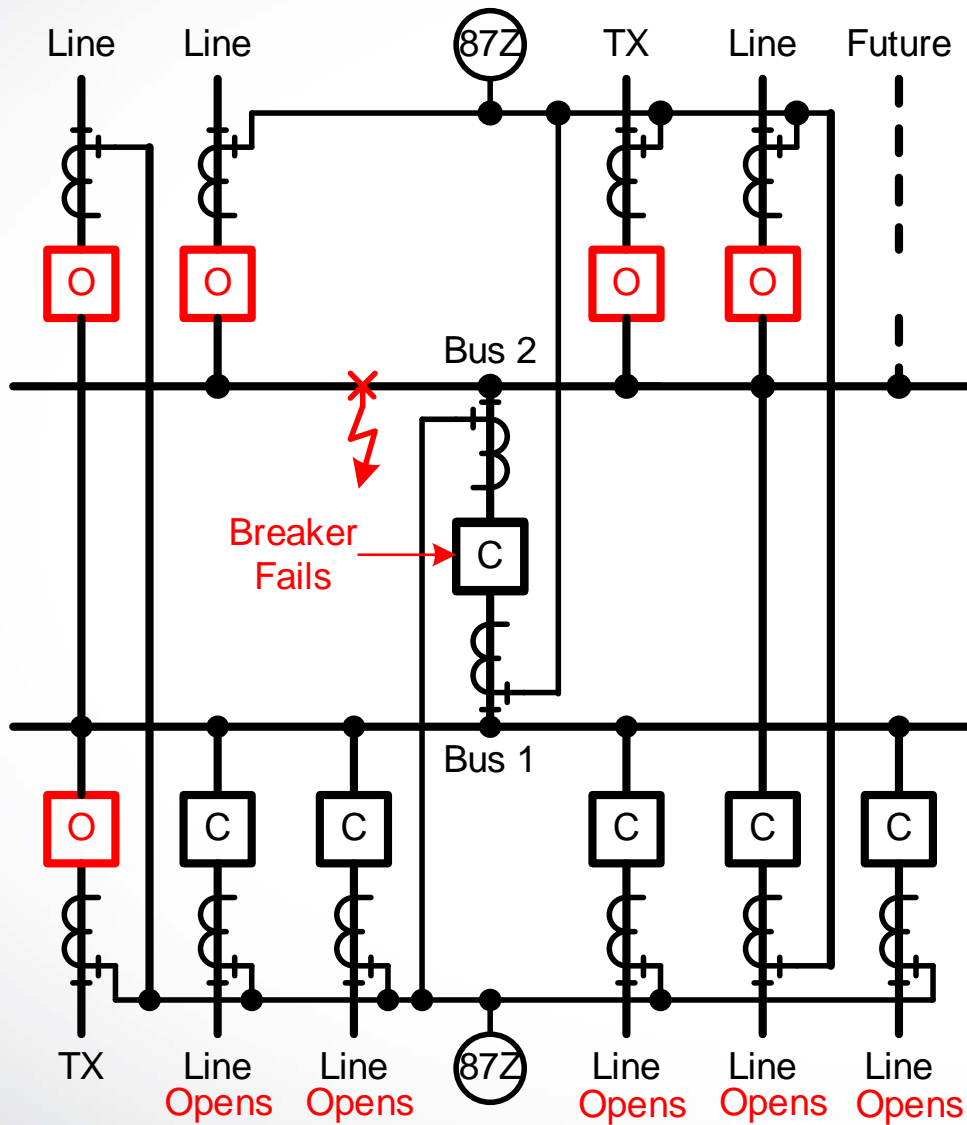
- Issue is applicable for a single line to ground type fault only.

Relay Failure Clearing Zone

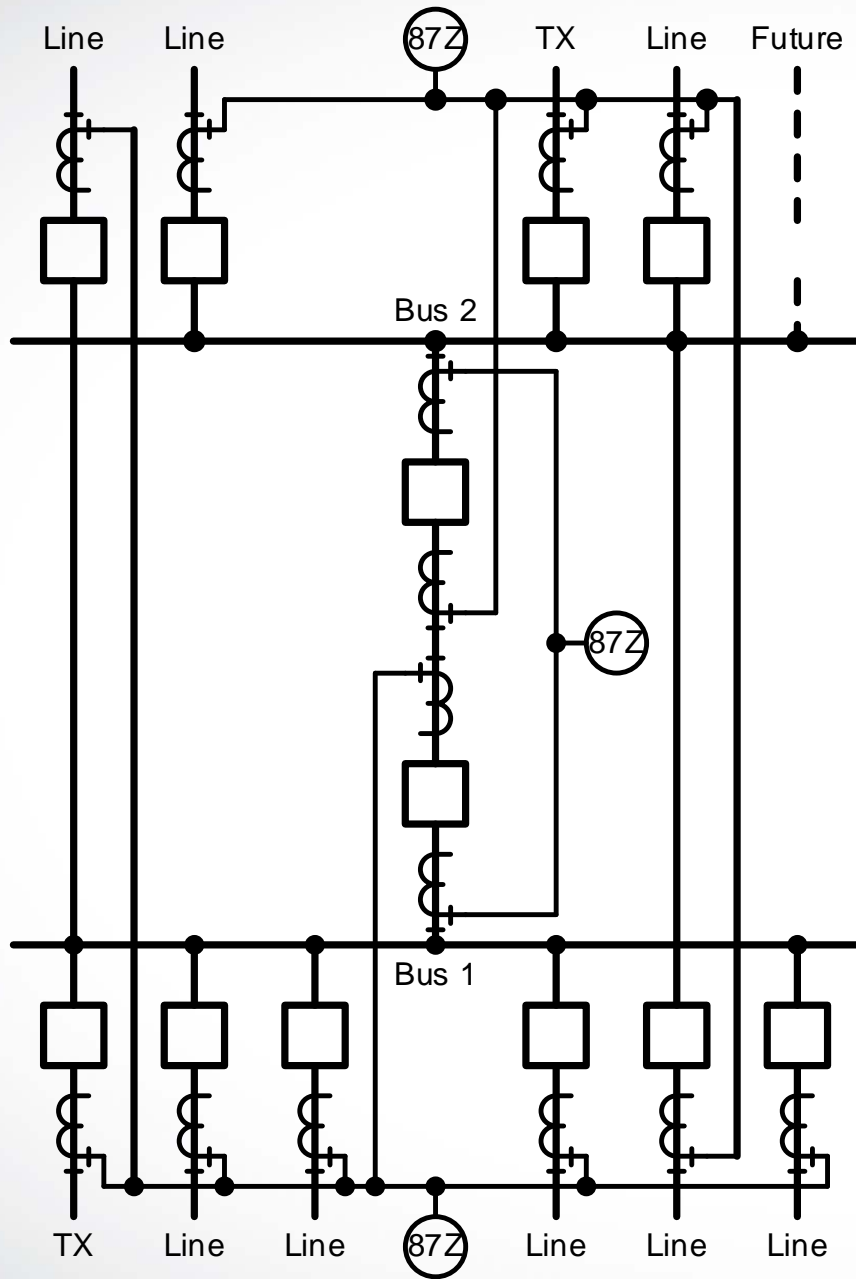


- All line ends open.
- Transformer breakers open on overcurrent protection.
- The widespread outage is likely to cause other lines to overload.

Tie Breaker Issue



- Issue is applicable for any fault type.



New Single-Line Diagram

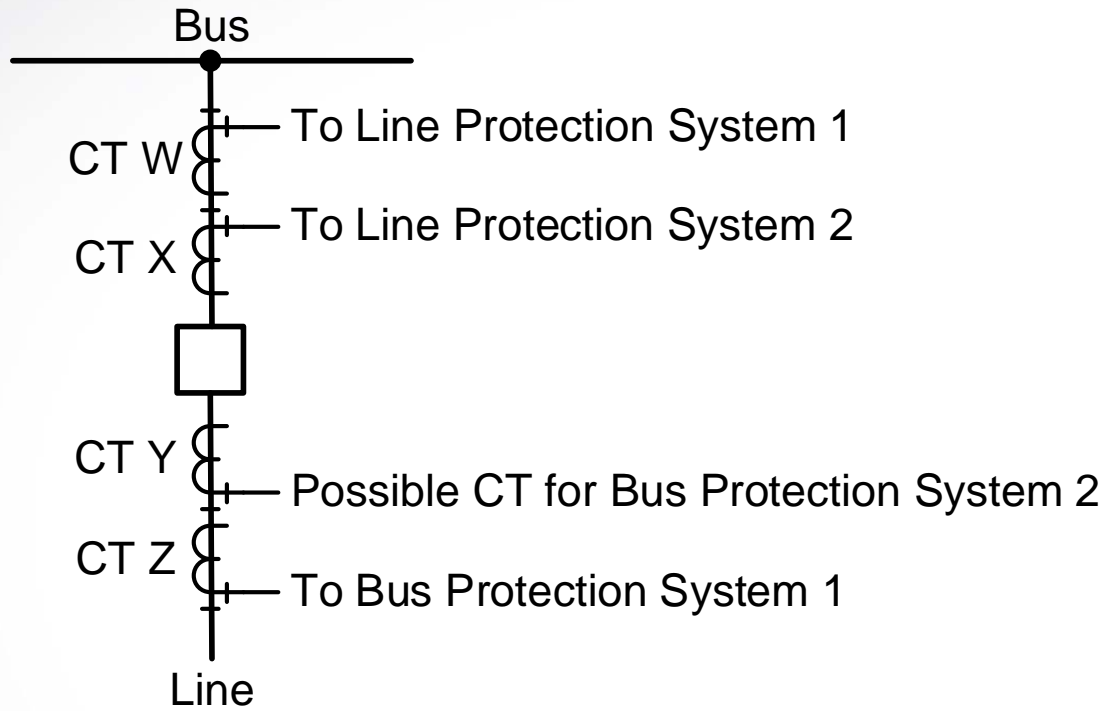
- Two tie breakers were placed in series to alleviate the concern of a major contingency from a tie breaker failure.
- This leaves the question, how do we apply relaying redundancy?

Protection Redundancy Characteristics

- Includes redundant:
 - Relaying schemes,
 - Control circuits, and
 - CT circuits.

Is it feasible to apply these concepts to the substation under study?

CT Circuits



- All the breakers attached to the bus have an unused CT Z circuit, however three different full tap CT ratios exist.
- None of the CTs are currently wired into the control house.

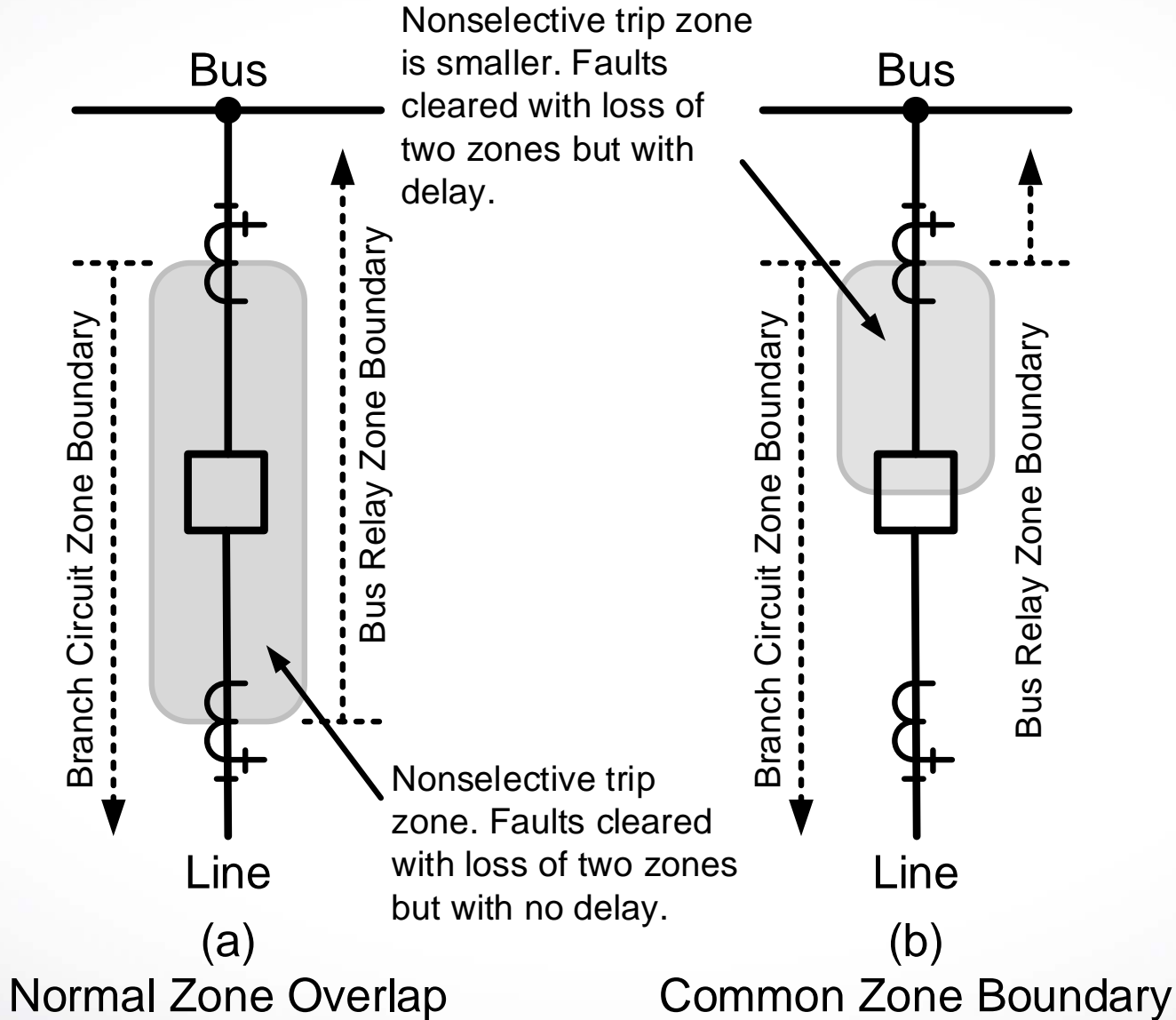
Relaying Schemes

- Dual High Impedance Relays
 - Possible, though not an option in this application without replacing CTs.
- High Impedance Primary, Restrained Differential Secondary Relaying Scheme
 - Fully redundant scheme.
 - No need for CT replacement.
 - An additional relaying panel and control building is needed.
 - Outage constraints.

Percentage Restrained Bus Differential Applied to Line CT Circuit

- Advantages:
 - CTs are already supplied within the control house.
- Disadvantages:
 - The scheme doesn't solve the problem of panel and control building space.
 - The scheme requires sharing CT circuits between line and differential protection, adding complexities to technicians jobs.
 - The scheme includes a nonselective tripping zone.

Nonselective Tripping Zone Explained



Zone Interlock Directional Blocking Scheme

- Scheme can only be applied to a straight bus
- There are a couple of ways to apply this scheme
 - Trip if all the line relays on the connected bus see a reverse looking fault, or
 - Trip if none of the relays on the connected bus see a forward looking fault.

Zone Interlock Directional Blocking Scheme

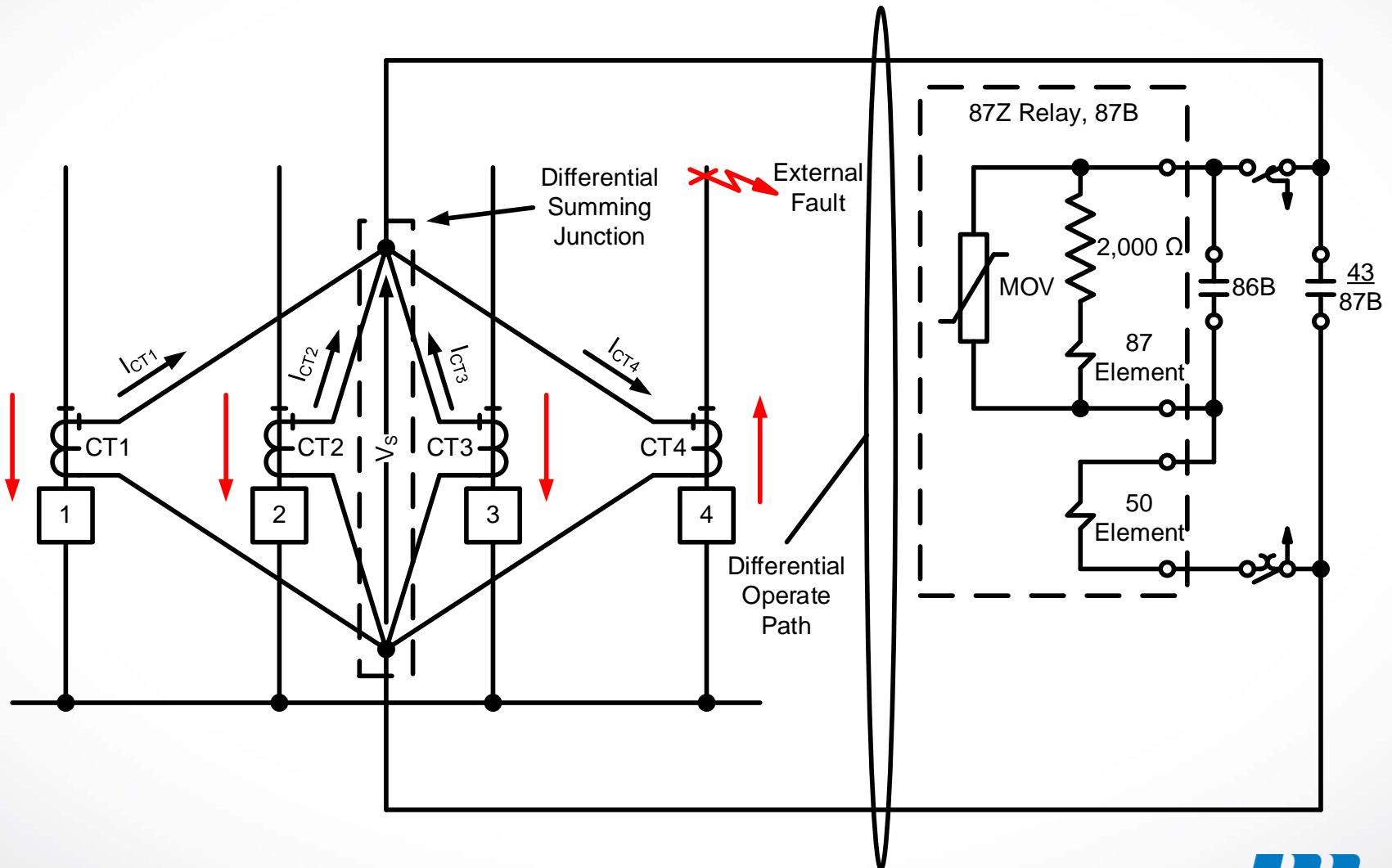
- Advantages:

- Takes advantage of existing relays on the protected bus.

- Disadvantages:

- The scheme gets really complex especially when you consider the affects of a single relay outage.
- The probability of a failure with the scheme is greater than a single relay application.
- Would require directional relays applied to both the tie breaker and the transformer breakers.
- Would be a very complicated protection scheme for technicians to work with.
- Included in the scheme is a non-selective tripping zone.
- Testing....

High Impedance Bus Differential Application

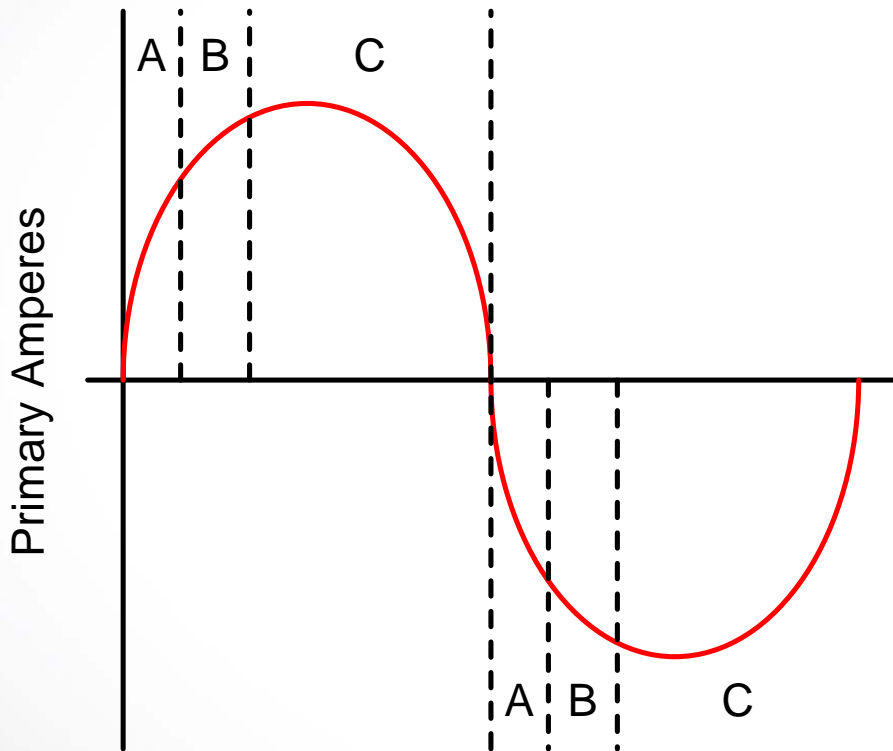


High Impedance Bus Differential Modes of Operation for an Internal Fault

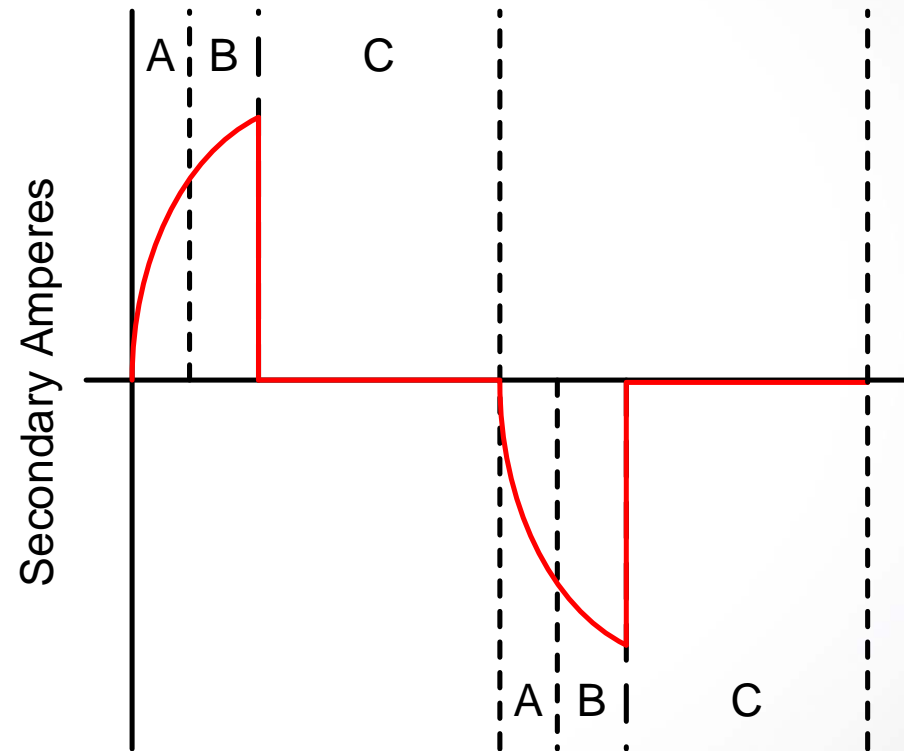
1. Upon fault inception, a high voltage raises nearly instantaneously.
2. This voltage rises to a point where a metal-oxide varistor clamps the voltage to a safe level. This MOV clamps the voltage until a single CT saturates. Waveform width is dependent on the lowest accuracy class of all the CTs in the differential circuit.
3. A CT saturates and shunts the differential current through the saturated CT.
4. After the next zero crossing on the waveform the process repeats itself.

Current Waveform during Internal Faults

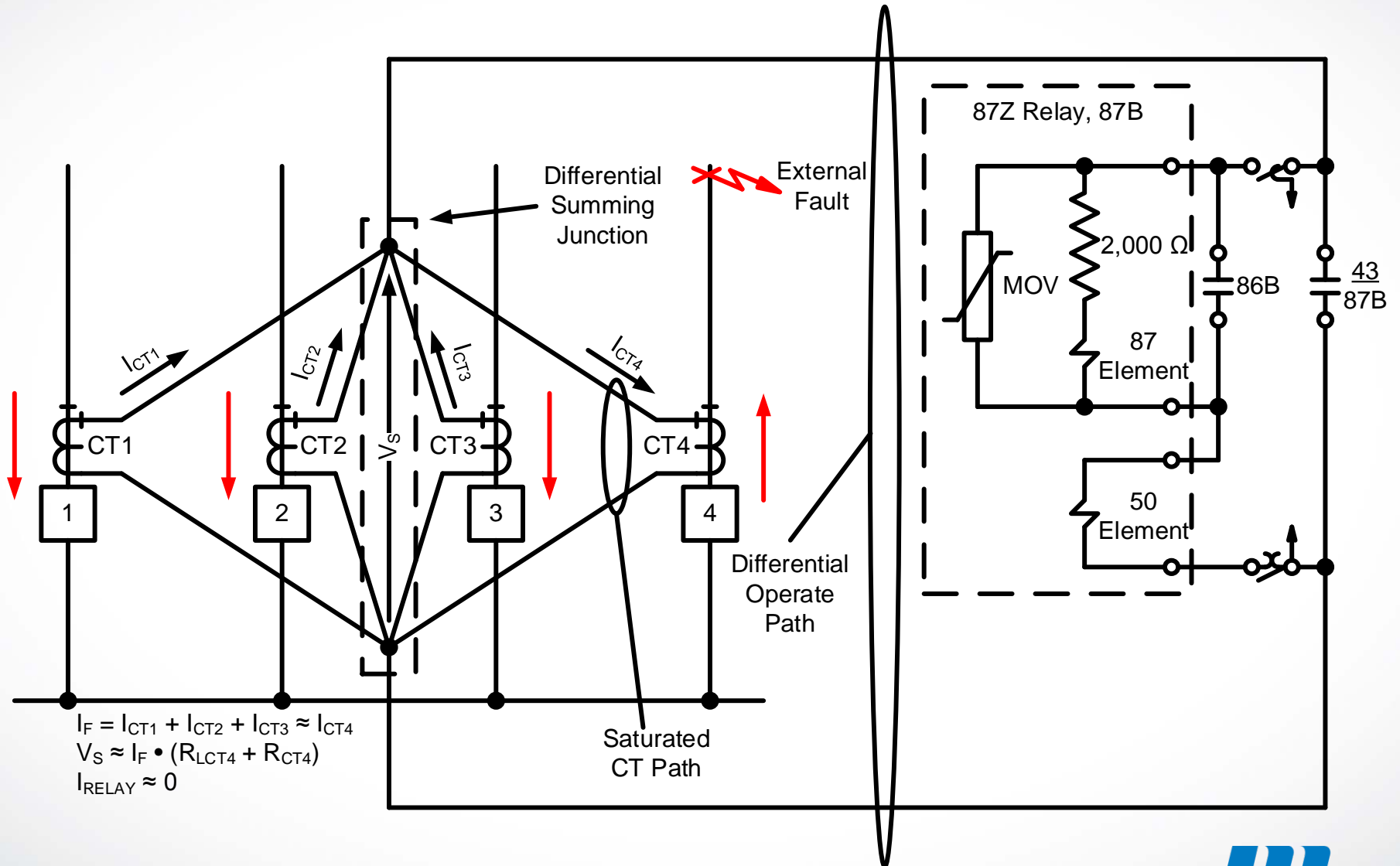
Total Fault Current in Primary Circuit



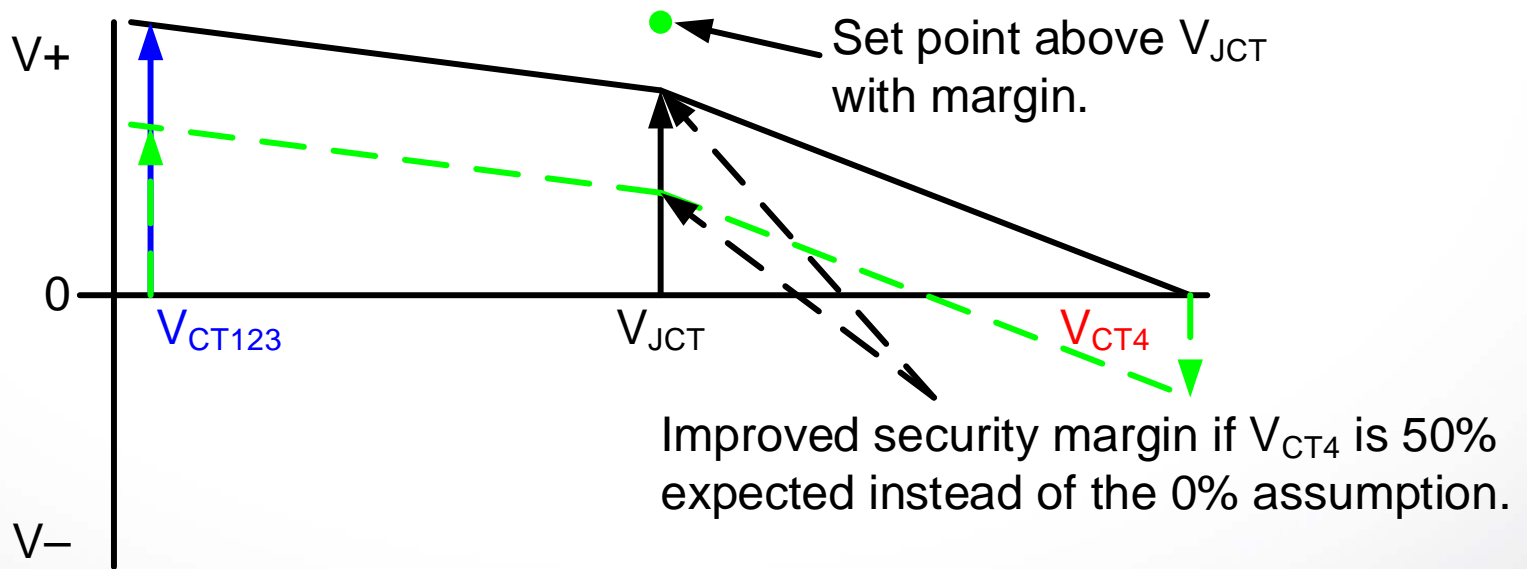
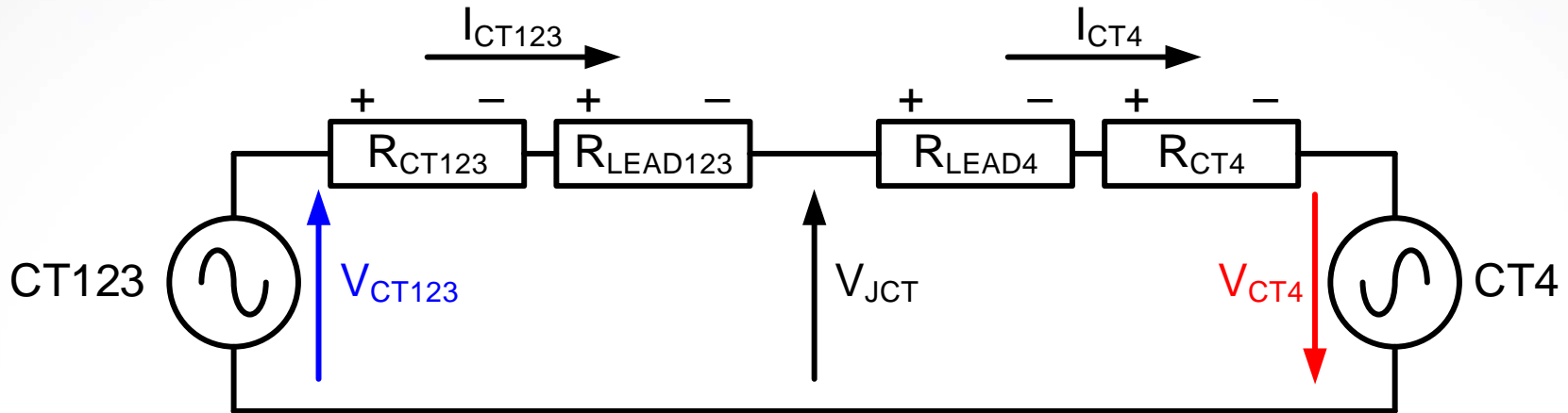
Relay Current



CT Saturation for an External Fault



Relay Voltage during Saturation



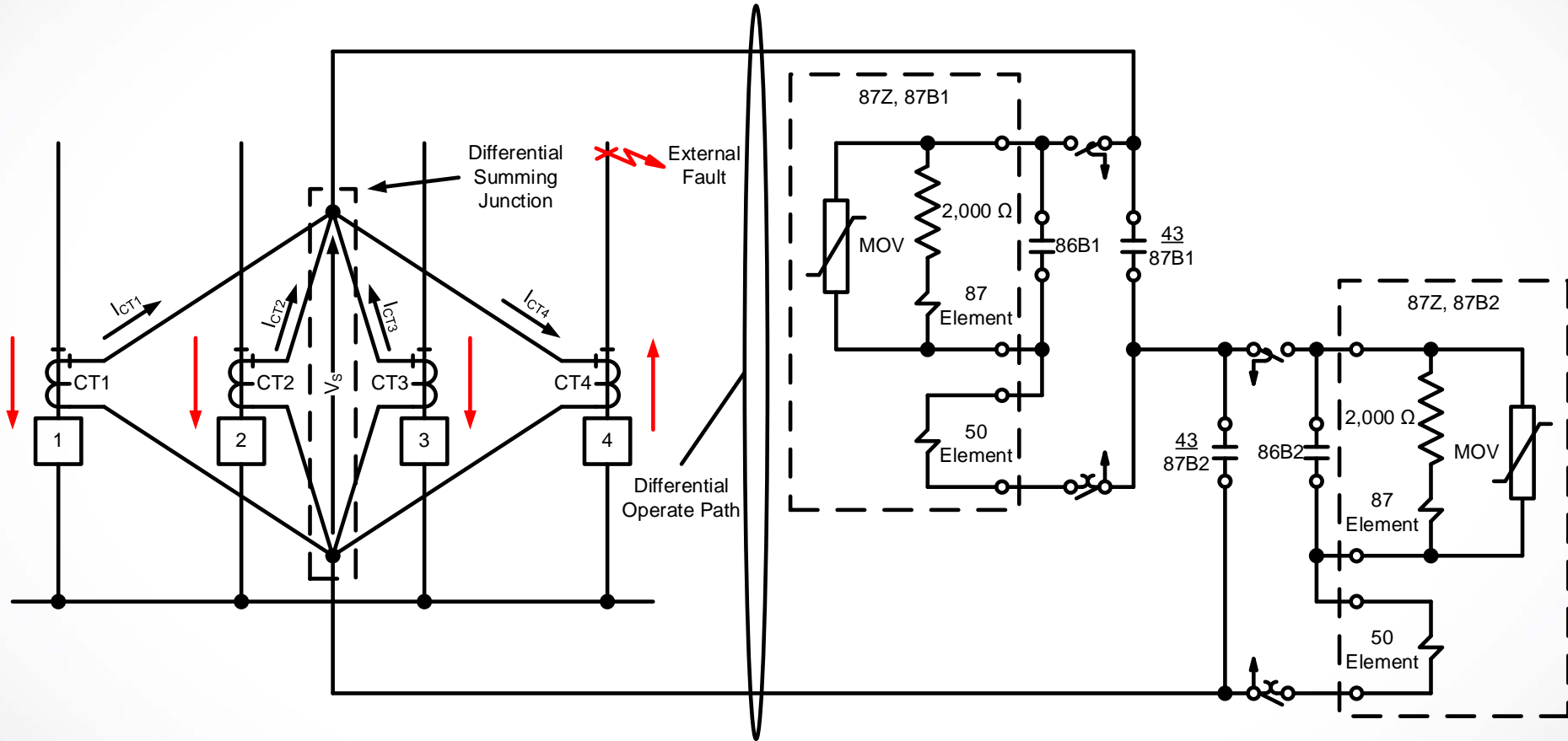
Other Security Considerations

- In zone surge arrestors
 - Common when using transformer bushing current transformers in the protection scheme.
 - Intentional time delays must be added to relay tripping elements.
 - Time delay is dependent on the relay's filter.
- In zone station service or voltage transformers
 - Coordination with the transformer secondary fuses must be evaluated.

Redundant High Impedance Differential Relay Applications

- Series Configuration
 - Consists of two high impedance bus differential relays connected in a series configuration.
- Parallel Configuration
 - Consists of two high impedance bus differential relay voltage elements connected in a parallel configuration.
- Differential Connected Overcurrent Backup Configuration
 - Consists of a high impedance bus differential relay and an overcurrent relay connected in a series configuration.

Series Configuration



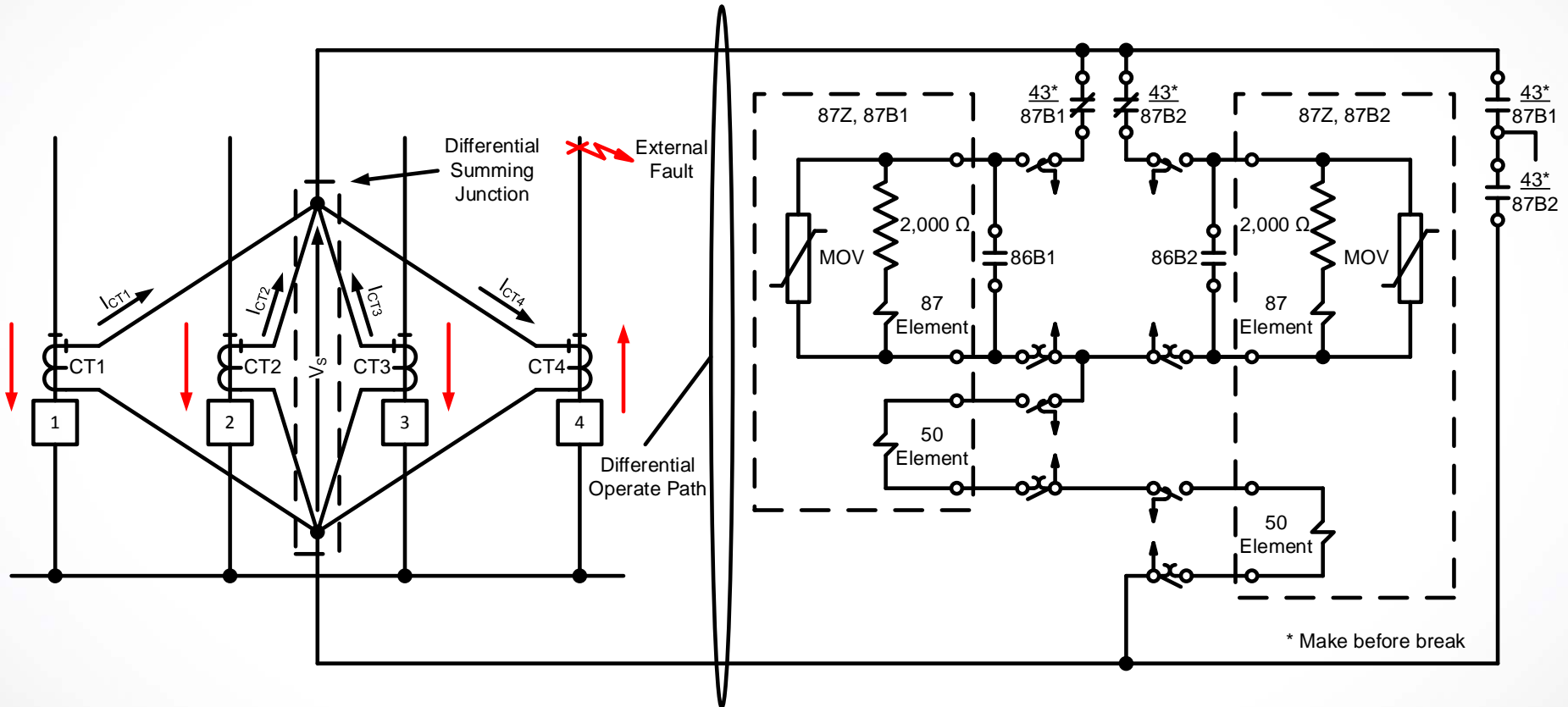
Series Configuration Details

- Relay Sensitivity Considerations
 - Clamping voltage doubles causing earlier CT saturation.
 - Voltage pulse width reduction by about half as seen by the relay.
 - Voltage pulse width is a function of the volt-time area of the CTs.

Series Configuration Details

- CT Insulation Impacts
 - Due to overall MOV clamping voltage doubling, the voltage on the circuit impresses greater stress on the turn-to-turn and turn-to-ground insulation of circuits.
 - Refer to the type test described in Clause 12.3 of IEEE Std. C57.13-2016, IEEE Standard Requirements for Instrument Transformers.
 - The interturn voltage test is limited to 3500V.
 - If a 1500V clamping voltage MOV is used, this type test compares favorably to the theoretical 3000V impressed on the cable.
 - However, it must be verified that all of the CT circuit equipment underwent this type test.

Parallel Configuration



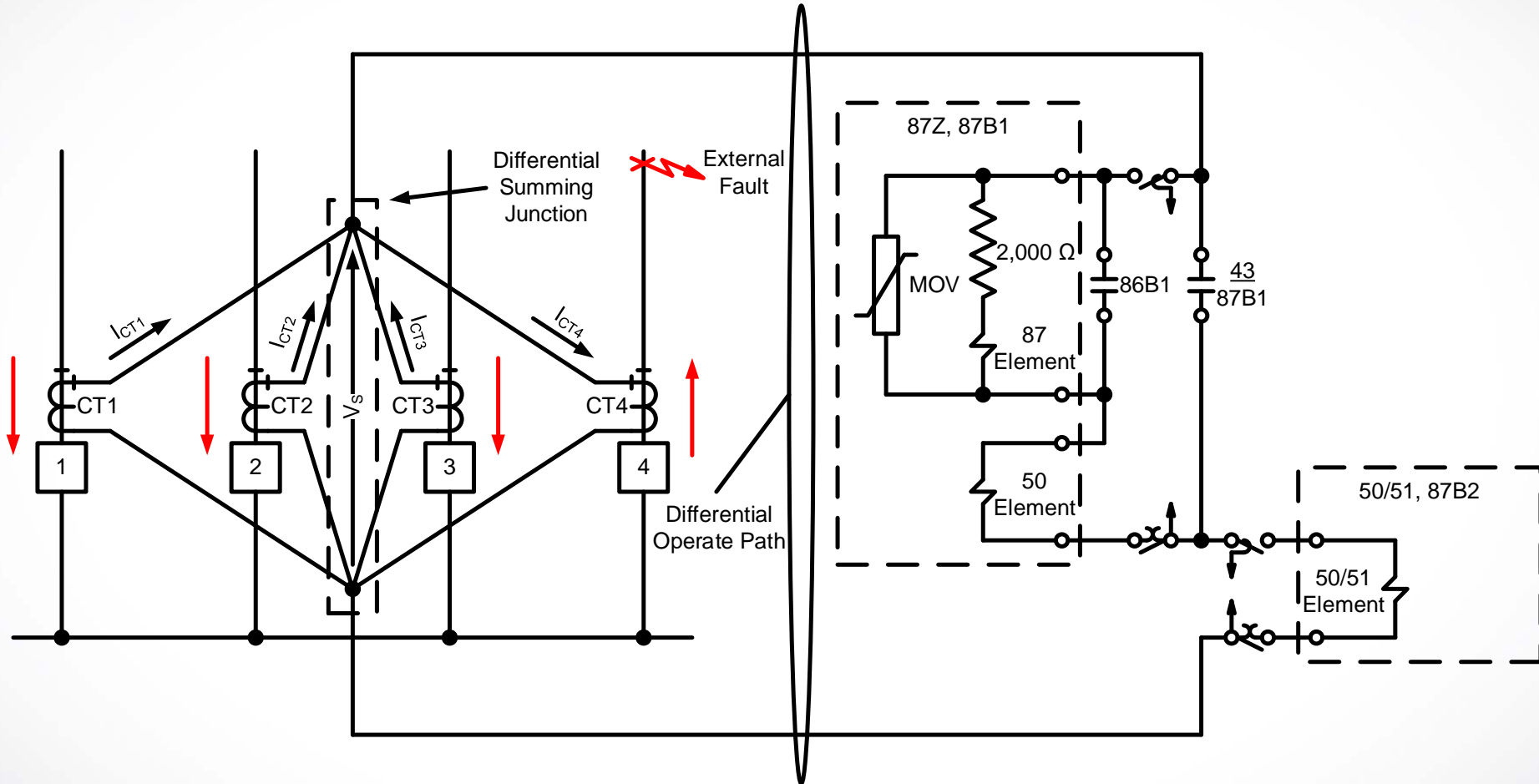
Parallel Configuration Details

- Relay Sensitivity Considerations
 - The MOV clamping voltage impressed upon the CT circuit is no different than the single relay application.
 - Thus the parallel configuration has no additional impact to the sensitivity of the relay.
 - However, the I^2T heat buildup in the MOVs is reduced by half because the current splits equally between the two MOVs in the parallel configuration.
- CT Insulation Impacts
 - Because the MOV clamping voltage impressed on the circuit is no different than the single relay application, the parallel configuration has no impact on the voltage withstand capability of the CT circuit.

Parallel Configuration Details

- CT Circuit Considerations
 - The CT circuit in the parallel configuration has some added complexities.
 - The 43/87B shunting path must be applied using make before break contacts.
 - Required to alleviate safety concerns if both relays are disabled.

Differentially Connected Overcurrent



Unrestrained Overcurrent Setting Considerations

- This scheme is only used when the primary relay is disabled by the 43/87B switch.
- Overcurrent element should be set per IEEE Std. C37.234-2009, IEEE Guide for Protective Relay Applications to Power System Buses.
- Pickup should be set to a five times margin for N-0 conditions and a three times margin for N-1 conditions.
- A short-time inverse curve is desired for security purposes.

Differential Overcurrent Configuration Details

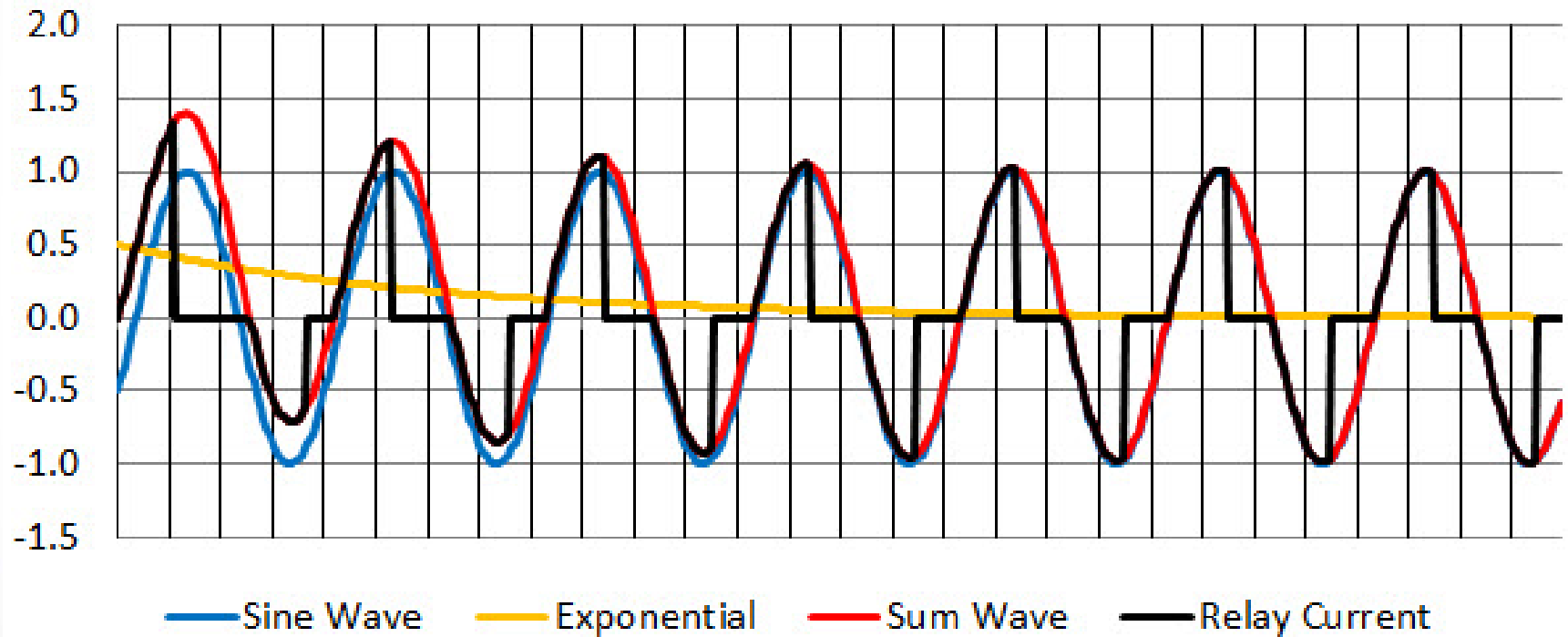
- CT Performance when MOVs are Shorted
 - When an MOV is shorted, the system acts as a unrestrained differential overcurrent scheme.
 - CTs should be evaluated for performance under worst case faulted conditions.
- 43/87B Switch Status
 - The 43/87B switch status can be mapped to an overcurrent relay input to switch between overcurrent elements depending on whether the high impedance relay's resistor is in the circuit or not.

Attenuation with MOV In-Service

- With MOVs in service, the current signal is attenuated due to the three stages of the high impedance relay's performance as described earlier.
- The degree of attenuation is dependent on:
 - The maximum and minimum internal fault current levels,
 - X/R ratio of the faults, and
 - The point on wave or DC offset of the fault.

Attenuation Example

© 2010 Minnesota Power



Application of Alarms

- CT Open Circuit Detection
 - Low set overvoltage with a long intentional time delay.
- MOV Failure
 - Low set overcurrent with a short intentional time delay.
- CT Saturation Detection
 - Can only be detected for external faults.

Minnesota Power's Selection

- For the following reasons, the differentially connected overcurrent relay as bus protection backup was selected:
 - The cost of applying a truly redundant bus protection scheme.
 - Concerns of damage to CT circuits in the series application.
 - The simplicity of the protection circuit and scheme as compared to the other options for backup.
 - The primary goal of installation was to prevent tripping line remote ends in the case of a bus fault. Therefore security could be gained by adding slightly longer time delays to the unrestrained differential O/C protection.
 - The compromise of a shared CT circuit was accepted knowing the probability of CT failure low.

Questions?