# Redundant Bus Protection Using High-Impedance Differential Relays

Josh LaBlanc, *Schweitzer Engineering Laboratories, Inc. (formerly of Minnesota Power)*

Michael Thompson, *Schweitzer Engineering Laboratories, Inc.*

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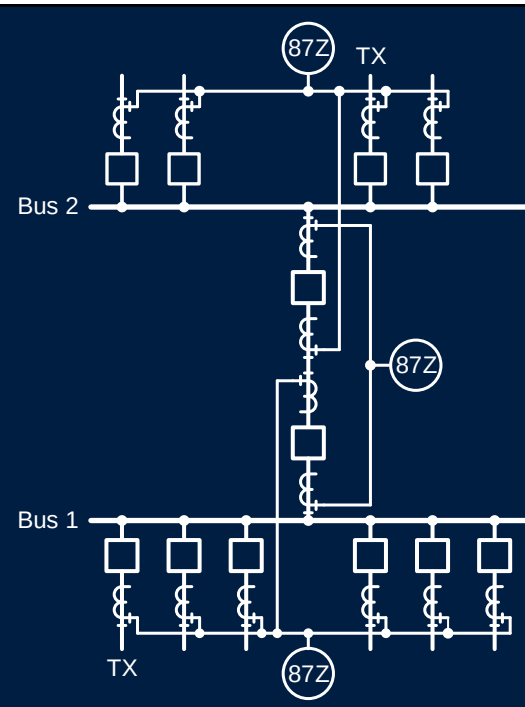
## Introduction

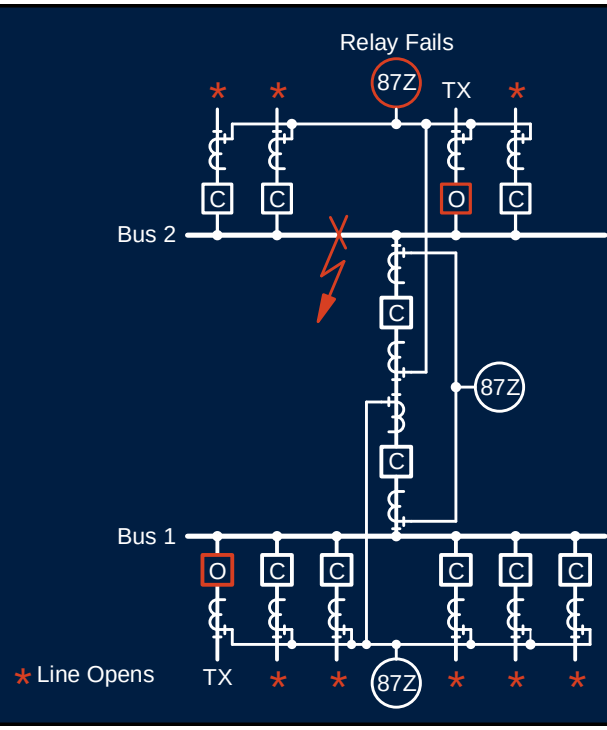
- Configuration of the bus under study
- Redundancy options
- Methods of applying redundancy to a high-impedance bus-protection circuit
- Advantages and disadvantages

## Single-Line Diagram




## Relay Failure Clearing Zone

- All line ends open
- Transformer breakers open on overcurrent protection
- Widespread outage is likely to cause other line overloads



## Protection Redundancy Characteristics

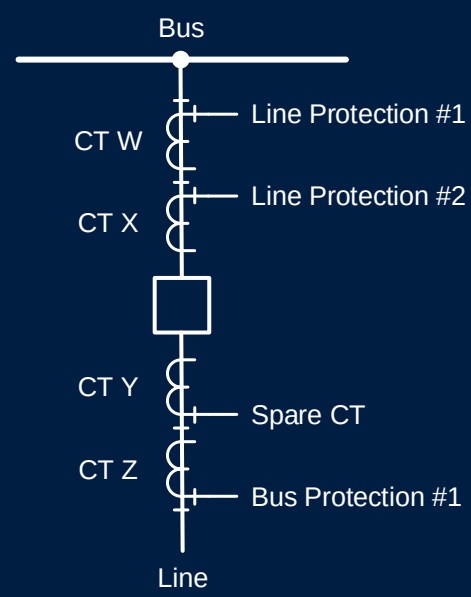
Complete redundancy includes

- Relaying schemes
- Control circuits
- CT circuits

Is complete redundancy feasible?

## CT Circuits

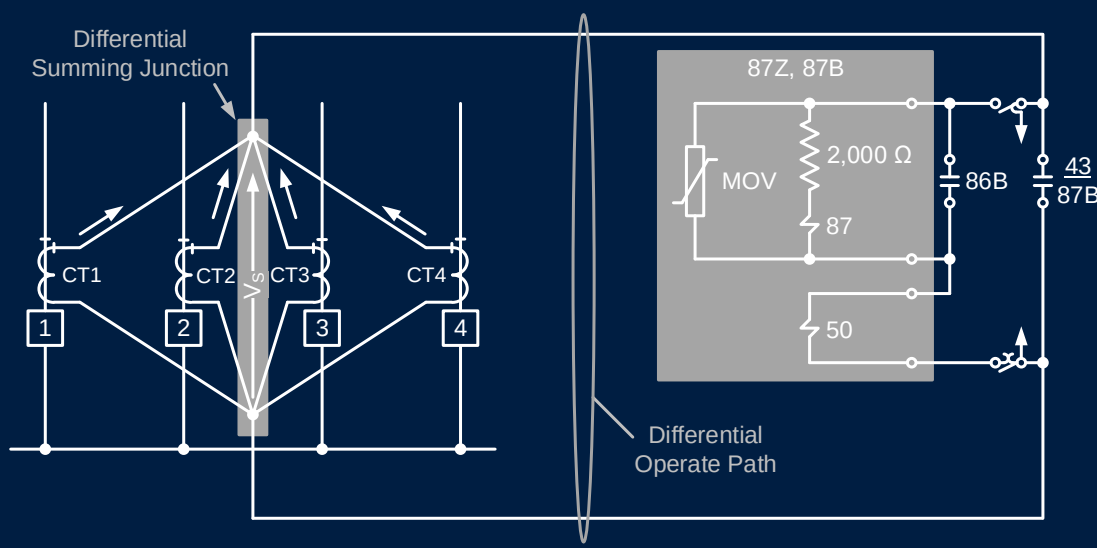
- All breakers have an unused CT Y circuit, though three different full-tap CT ratios exist
- None of these CTs are wired into the control house



## Other Redundancy Schemes

- High-impedance primary, percentage restrained differential secondary relaying
- High-impedance primary, high-impedance secondary relaying
- Percentage restrained differential (line CT circuit)
- Zone interlock directional blocking

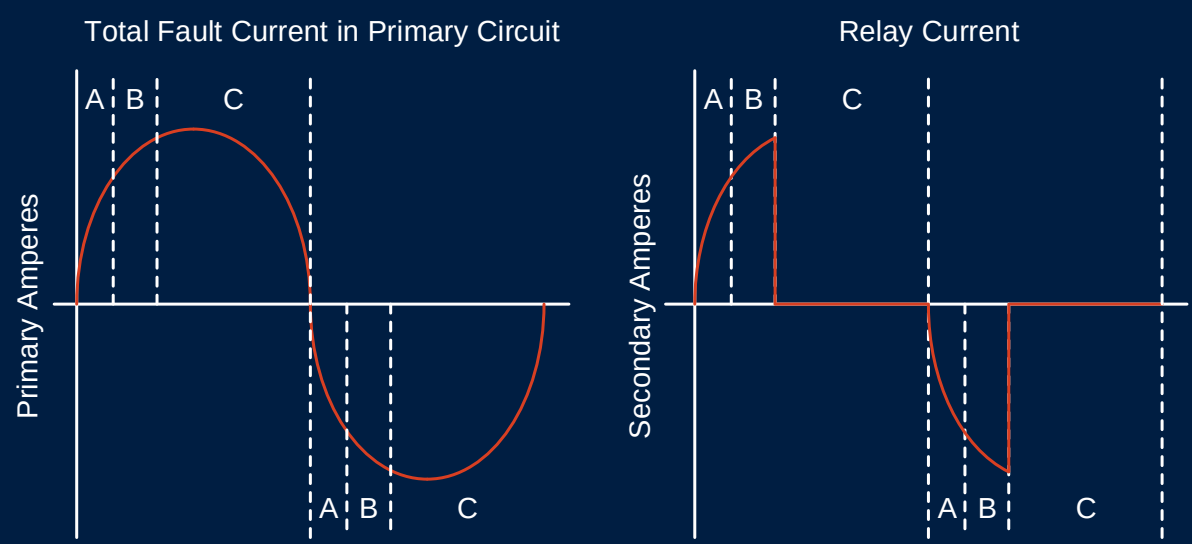
## High-Impedance Bus Differential Application



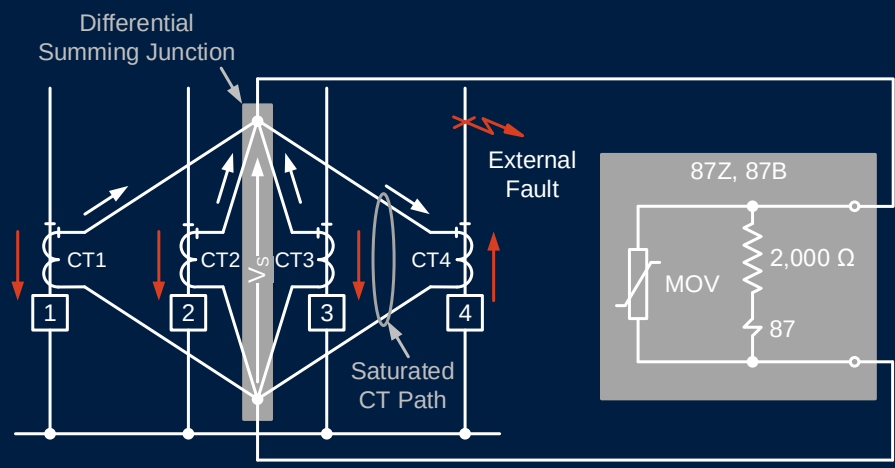
## Modes of Operation for Internal Fault

1. Upon fault inception, high voltage raises nearly instantaneously
2. Metal-oxide varistor clamps voltage to safe level
3. CT saturates and shunts differential current through saturated CT
4. At next zero crossing of waveform, process repeats itself

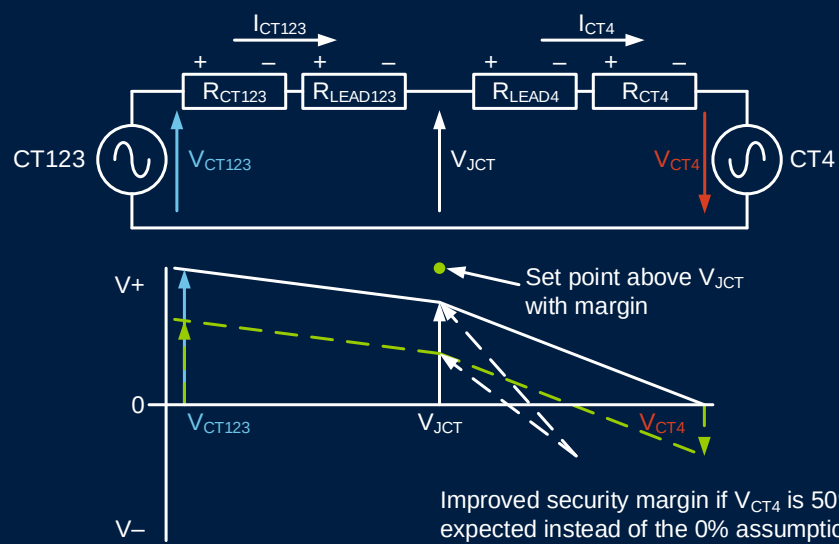
## Current Waveform During Internal Faults



# CT Saturation for External Fault




# Relay Voltage During Saturation

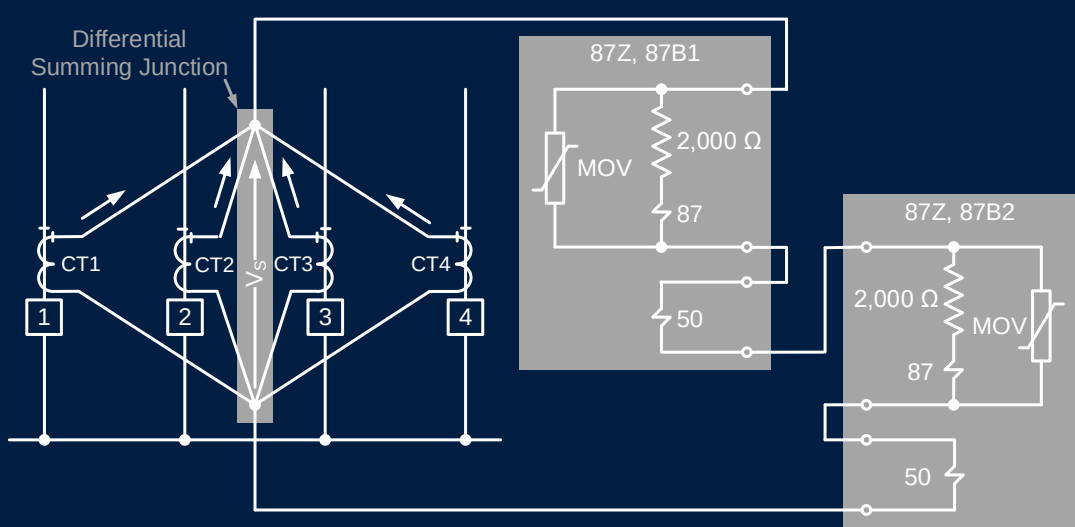



Improved security margin if $V_{CT4}$ is 50% expected instead of the 0% assumption

# High-Impedance Differential Relaying Redundancy Configurations

- Series
- Parallel
- Differentially connected overcurrent backup

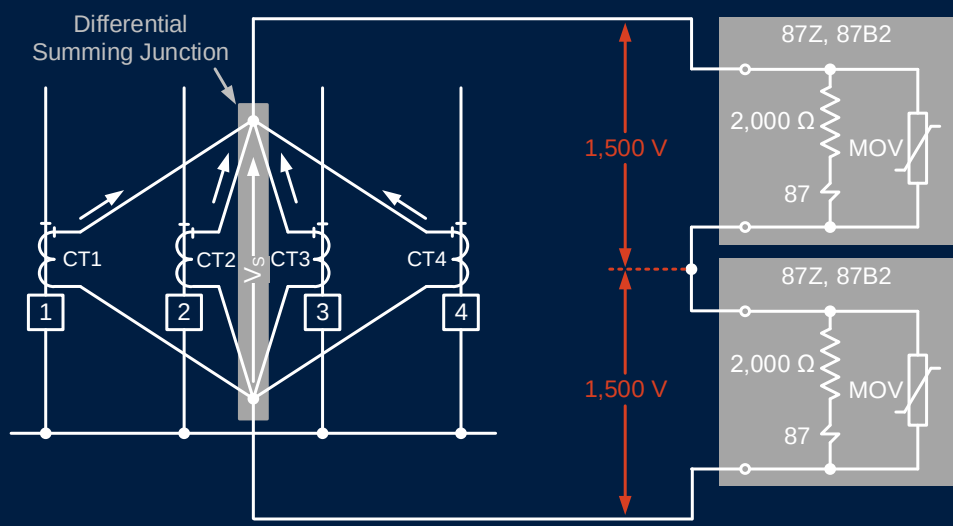
# Series Configuration



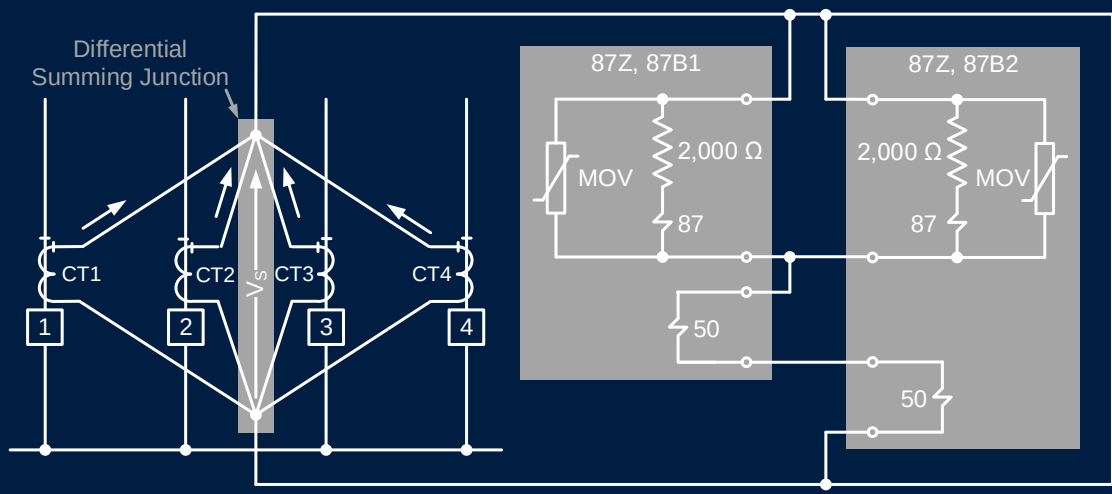
## Series Configuration Details

- Relay sensitivity considerations
  - Voltage pulse width is a function of CT accuracy rating
  - Clamping voltage doubles causing earlier CT saturation
  - Voltage pulse width reduces by about half
- CT insulation impact – higher voltage impresses greater stress on circuit insulation

## Series Circuit Clamping Voltage



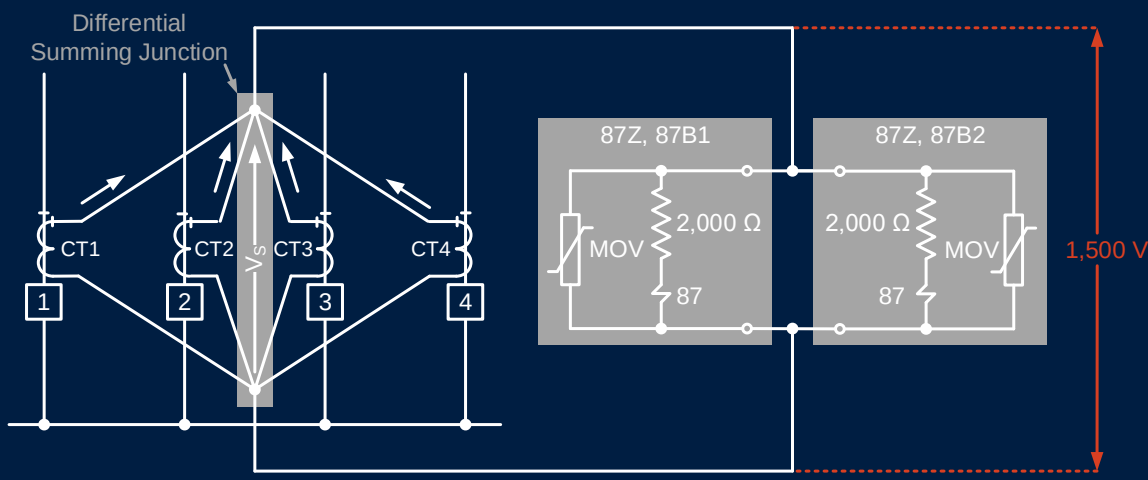
# Parallel Configuration



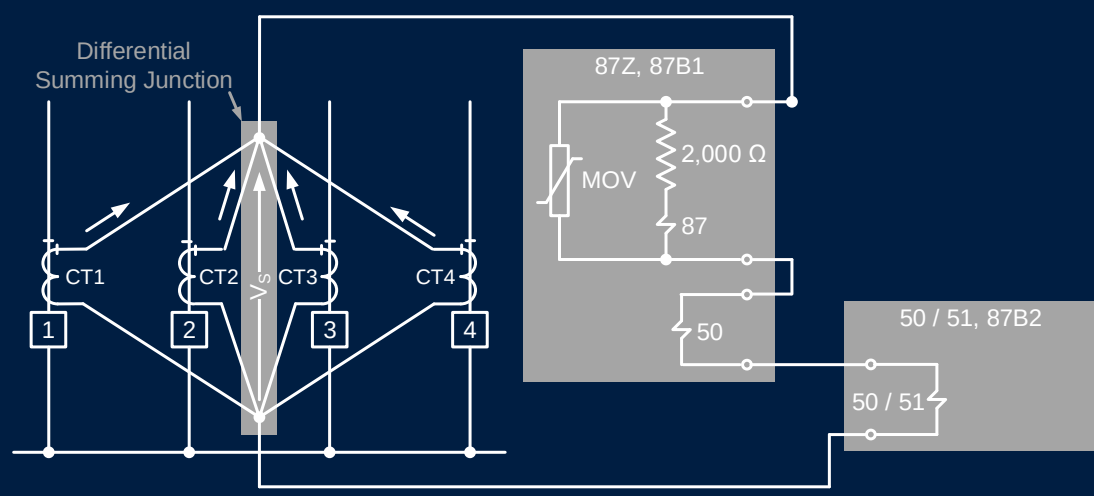

# Parallel Configuration Details

- Relay sensitivity considerations
  - MOV clamping voltage
  - Sensitivity
  - Relay heating
- CT insulation impact – same as single relay application
- 43 / 87B switch requires make-before-break contacts

# Parallel Circuit Clamping Voltage




# Differentially Connected Overcurrent



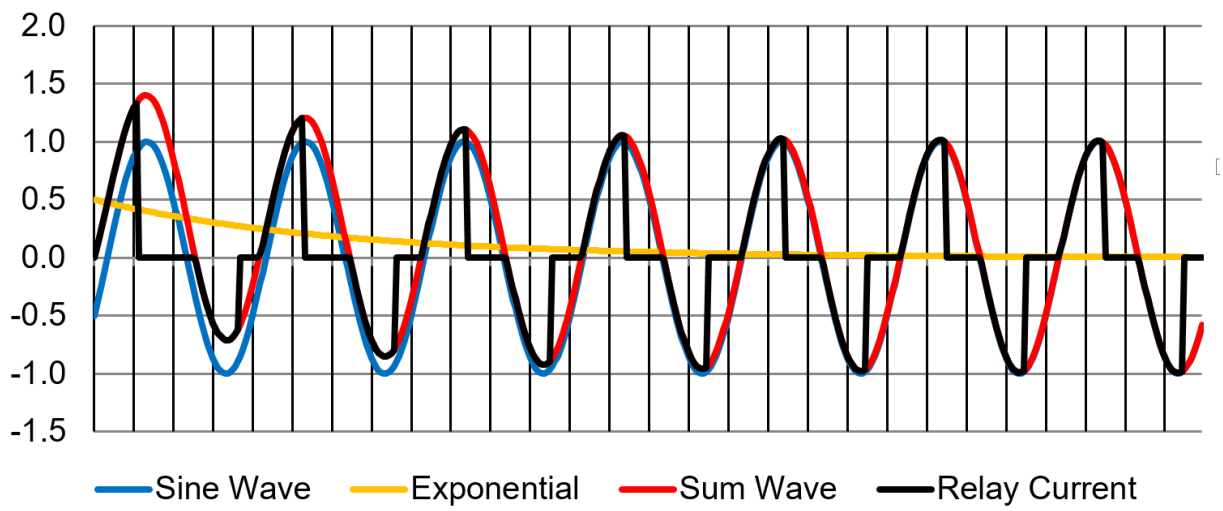
## Differentially Overcurrent Configuration Details

- CT performance when 87Z element is shorted
  - System acts as unrestrained differential overcurrent scheme
  - CT performance needs to be evaluated
- 43 / 87B switch status is used to disable sensitive functions

## Attenuation With In-Service MOV

- The three stages of high-impedance relay performance attenuate the current signal
- Degree of attenuation is dependent on
  - Maximum and minimum internal fault current levels
  - Fault X/R ratio
  - Fault point-on-wave or dc offset

## Attenuation Example




## Conclusion

- 87Z modes of operation
- Voltage / current attenuation
- Insulation impacts
- Clamping voltage
- Settings considerations