Not All Differentials are the Same: How Percent Differential Relay Algorithms Can Impact Relay Settings and Performance

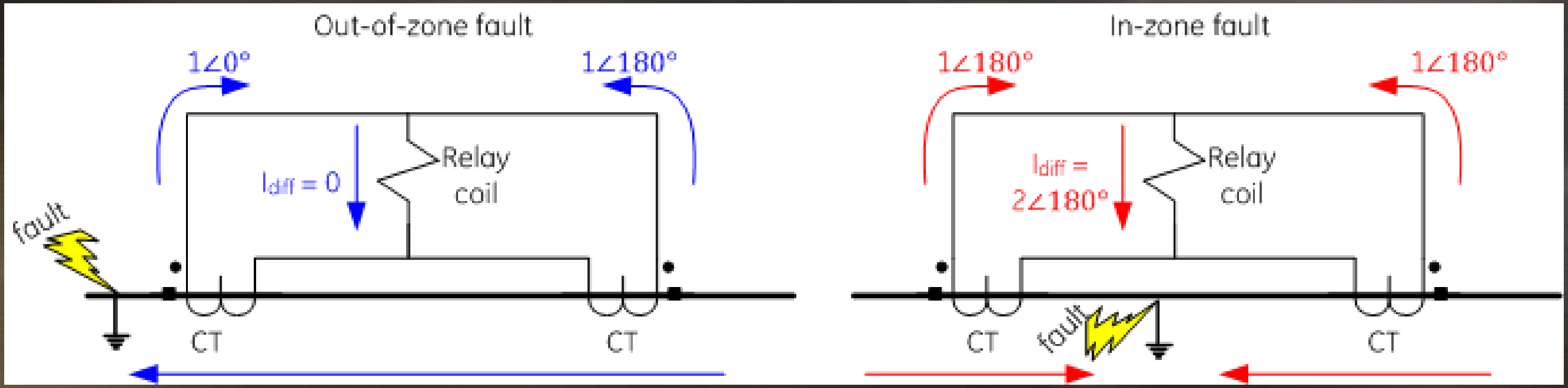
Matt Proctor

GE Grid Solutions

2016 Texas A&M Relay Conference

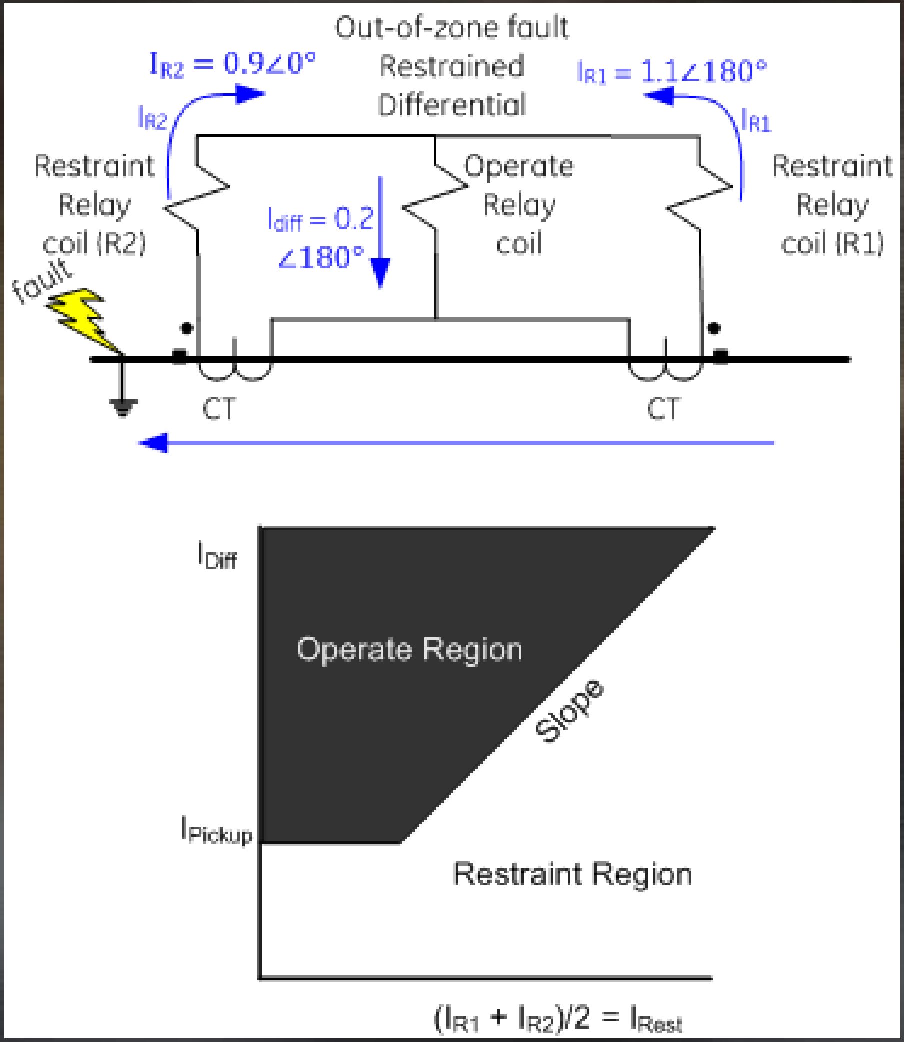
Differential Review

Unrestrained Differential



Differential Review

Restrained Differential



- Bus
- Stator Windings
- Transformer
- Transmission Line

Differential Review

Criteria of Good Protection (“The 5 S’s”)

- Selectivity
- Speed
- Sensitivity
- Security
- Simplicity

Restraint Current Calculations

- Average of Individual Restraints

$$I_{Rest} = \frac{1}{n}\left(I_{Rest1} + I_{Rest2} + \ldots I_{Rest\,n}\right)$$

- Scaled Sum of Individual Restraints

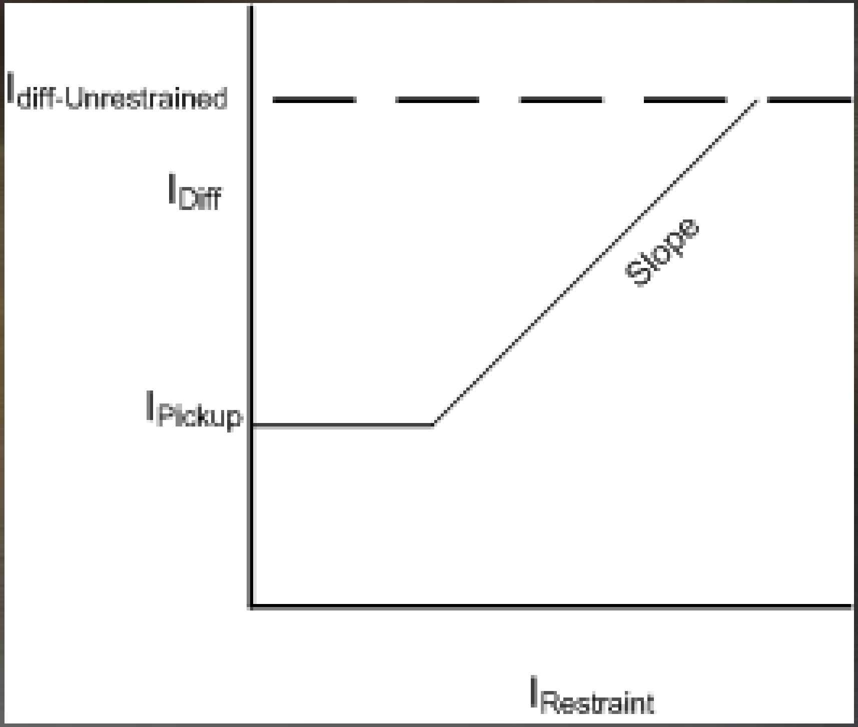
$$I_{Rest} = \frac{1}{k}\left(I_{Rest1} + I_{Rest2} + \ldots I_{Rest\,n}\right)$$

- Maximum of Individual Restraints

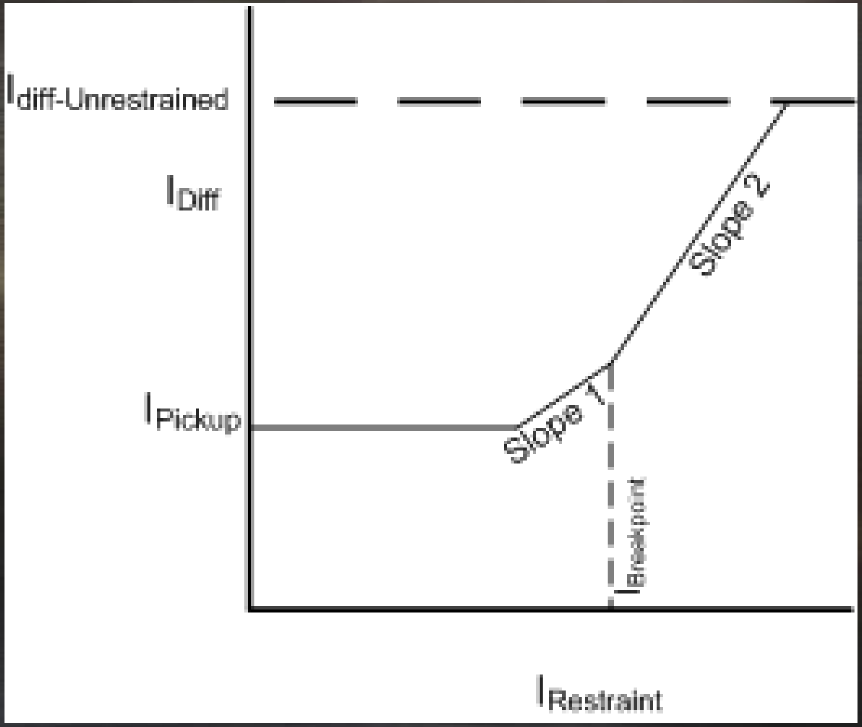
$$I_{Rest} = MAX\left(|I_{Rest1}|, |I_{Rest2}|, \ldots |I_{Rest\,n}|\right)$$

Slope Variations

Single Slope

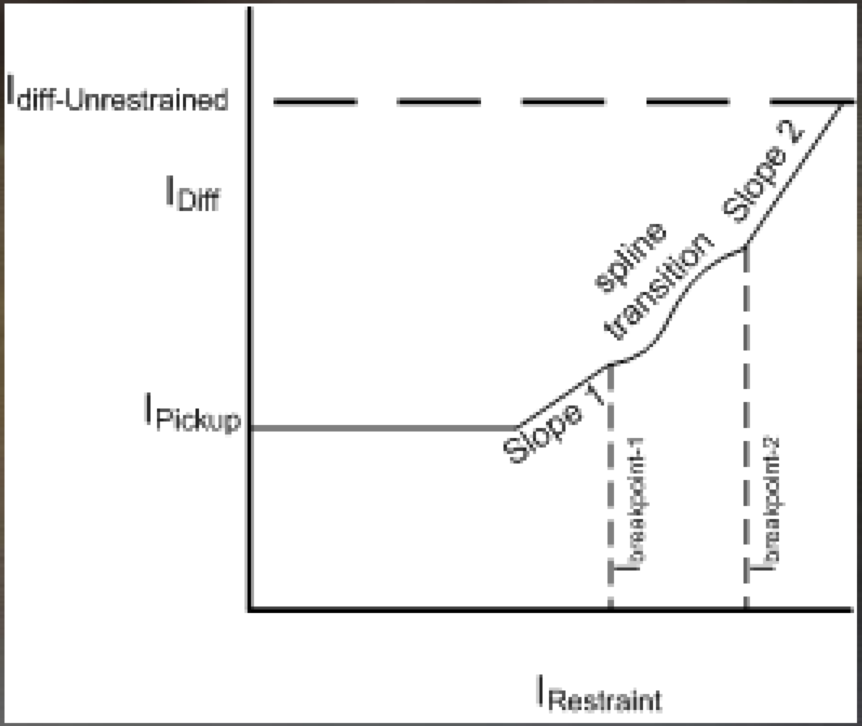


Dual Slope – Single Breakpoint

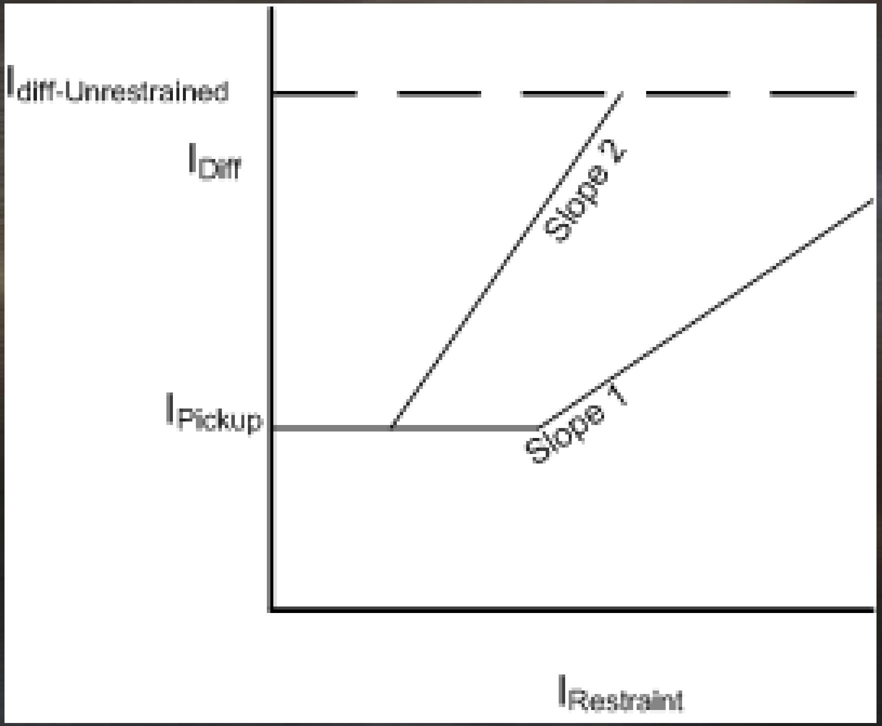


Slope Variations

Dual Slope – Spline Transition

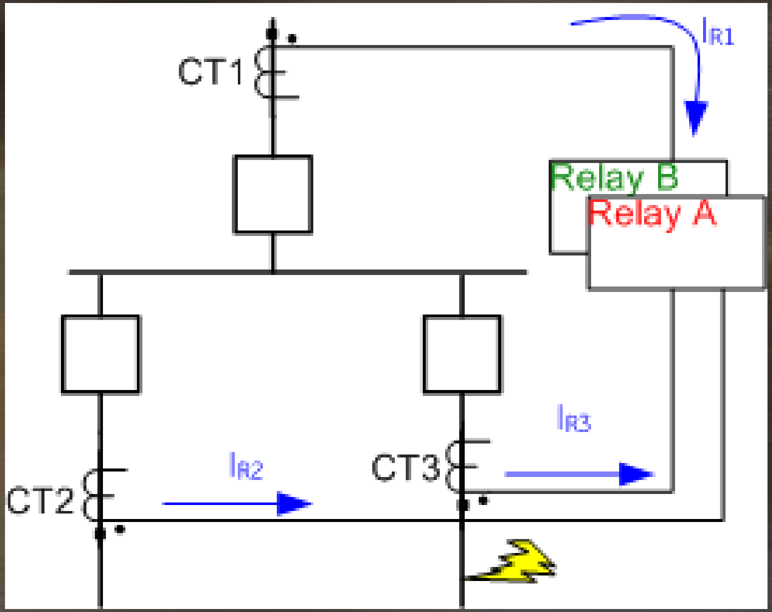


Dual Slope – No Breakpoint



Impact on Performance

Why do the nuances matter? For example:



- I_{R1} = 20 A∠180°
- I_{R2} = 20 A∠180°
- I_{R3} = 23 A∠0° (saturated)

Impact on Performance

Redundant, identically set relays operate differently

	Relay A	Relay B
I_{pickup}	1 Amp	1 Amp
$I_{breakpoint}$	10 Amps	10 Amps
Slope 1	30 %	30 %
Slope 2	70 %	70 %
I_{RTotal} =	23 Amps	31.5 Amps
I_{Diff} =	17 Amps	17 Amps
I_{Diff} / I_{RTotal} =	74 %	54 %
Result =	TRIP	NO OPERATE

- Relay A I_R = MAX(20 A∠180°,20 A∠180°,23 A∠0°)
- Relay B I_R = (20 A∠180°+20 A∠180°+23 A∠0°)/2

Advanced Algorithms

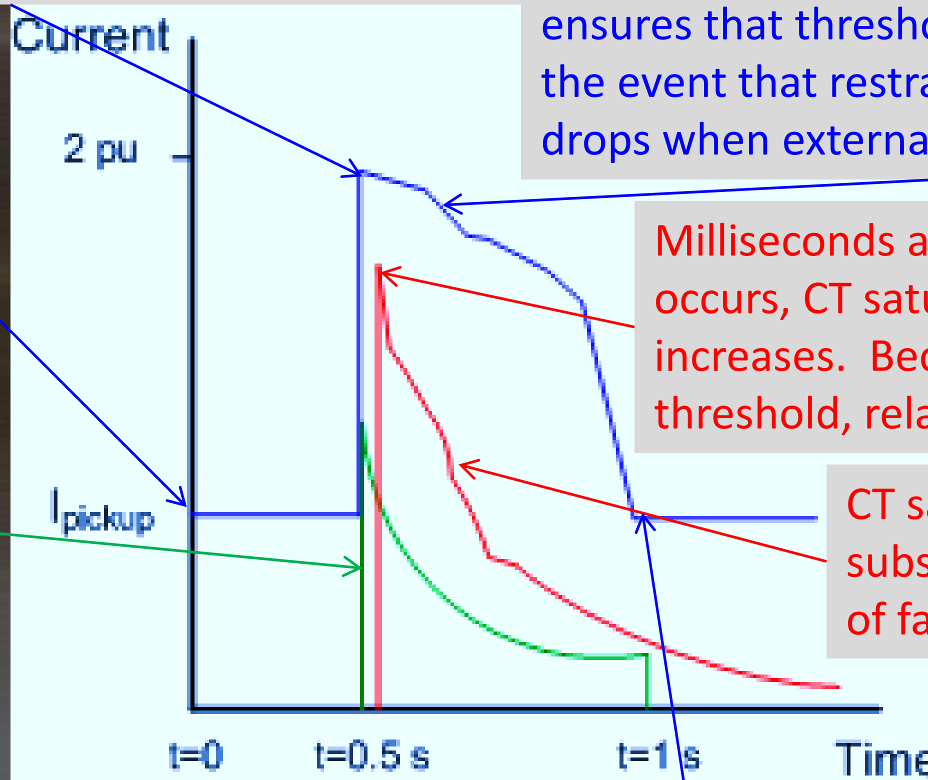
Transient Bias – External Fault

Transient bias causes differential threshold to rise.

Transient Bias decays, and Delayed Bias ensures that threshold remains high in the event that restraint current suddenly drops when external fault is cleared.

Differential threshold set at specific value (I_{pickup}).

Transient bias spikes because CT does not saturate instantly.



Milliseconds after external fault occurs, CT saturates and I_{Diff} increases. Because of increased threshold, relay does not trip.

CT saturation begins to subside as DC component of fault current decays.

Inception of EXTERNAL fault at t = 0.5 s

Transient Bias fully decays, and Delayed Bias returns to steady state. Overall operate threshold returns to normal.

Credit to Moscoso et al: "Improvements to Transformer Differential Protection – Design and Test Experience, " in Universities Power Engineering Conference, 2012. ©IEEE. doi: 10.1109/UPEC.2012.6398637

Advanced Algorithms

Transient Bias – External Fault

Transient bias causes differential threshold to rise.

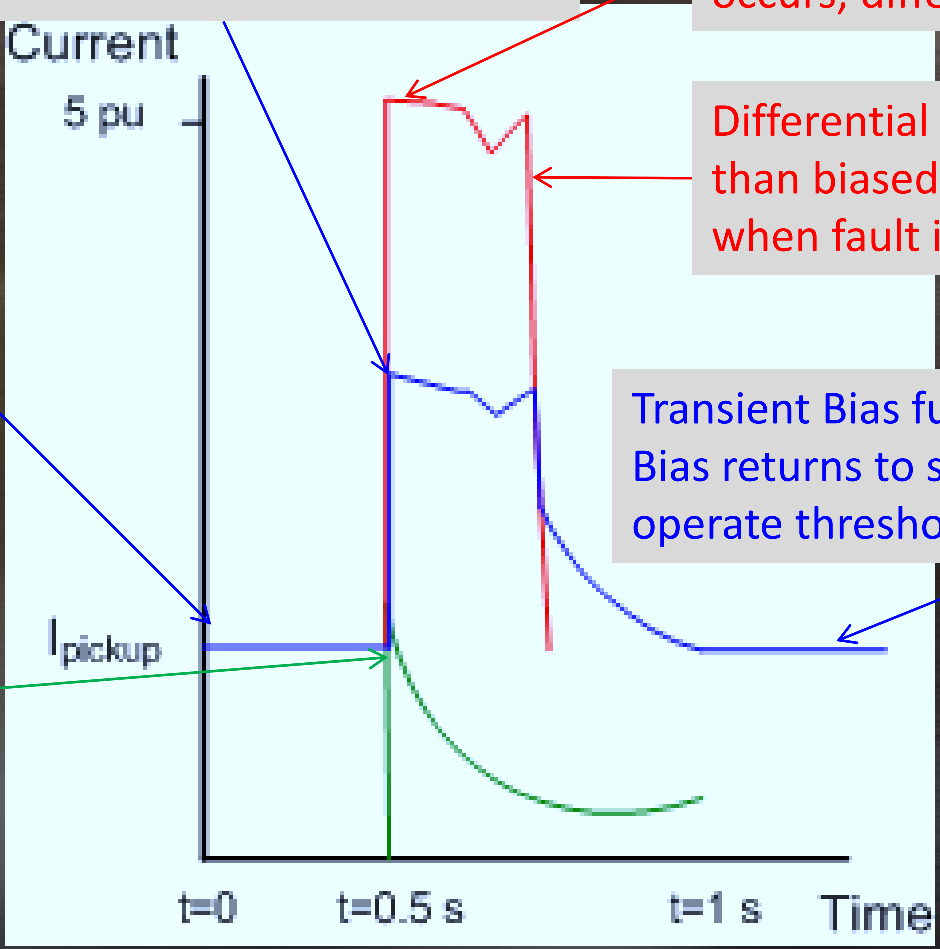
Immediately after internal fault occurs, differential current spikes.

Differential current remains higher than biased restrain and only drops when fault is cleared.

Differential threshold set at specific value (I_{pickup}).

Transient Bias fully decays, and Delayed Bias returns to steady state. Overall operate threshold returns to normal.

Transient bias spikes because restraint current spikes.

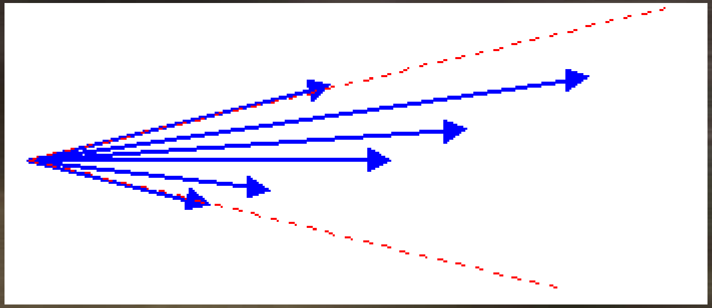


Inception of INTERNAL fault at t = 0.5 s

Credit to Moscoso et al: "Improvements to Transformer Differential Protection – Design and Test Experience, " in Universities Power Engineering Conference, 2012. ©IEEE. doi: 10.1109/UPEC.2012.6398637

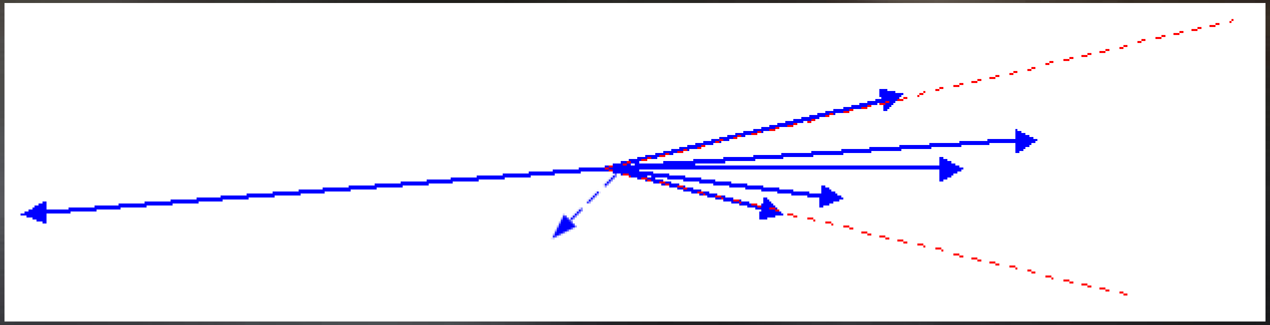
Advanced Algorithms

Directional Principle



Internal Fault – no current source is greater than 90 degrees apart from another.

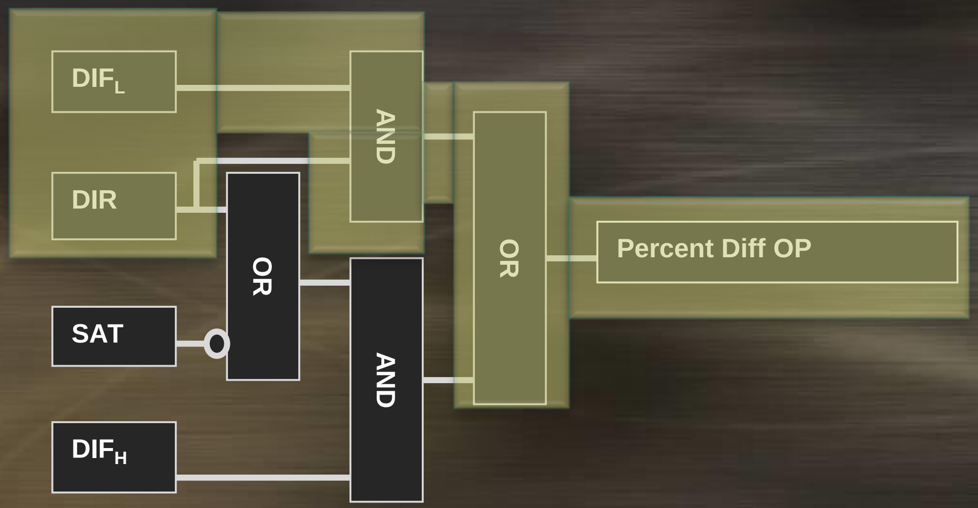
External Fault – one current source is greater than 90 degrees apart from the others



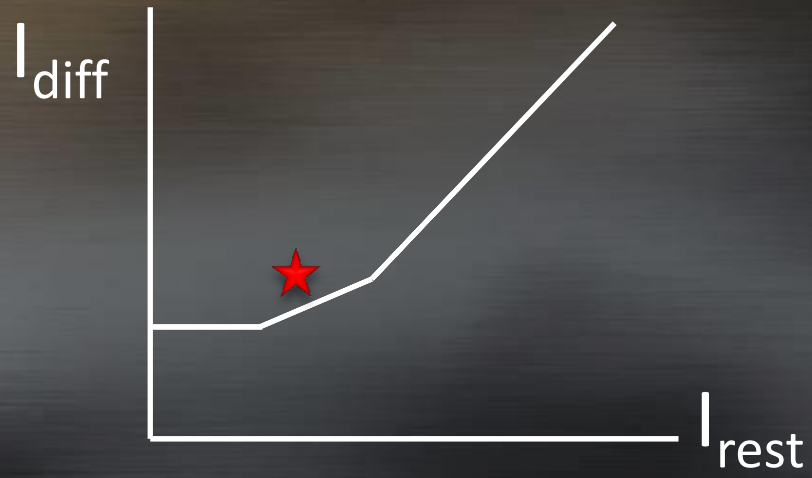
Credit to Kasztenny and Kulidjian: "Differential protective relay for electrical buses with improved immunity to saturation of current transformers," U.S. Patent 6442010, April 3, 2000.

Advanced Algorithms

Directional Principle



When restraint current is low, the relay will trip when Idiff/Irest percentage is met AND directional principle is met.



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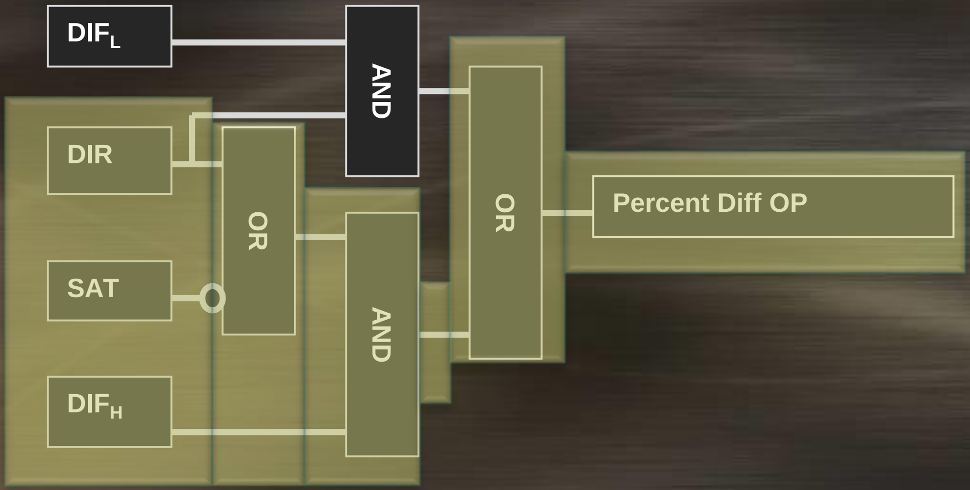
Advanced Algorithms

Directional Principle



When restraint current is high (Slope 2 Region), the relay will trip when Idiff/Irest percentage is met AND either the directional principle is met or CT Saturation is not detected

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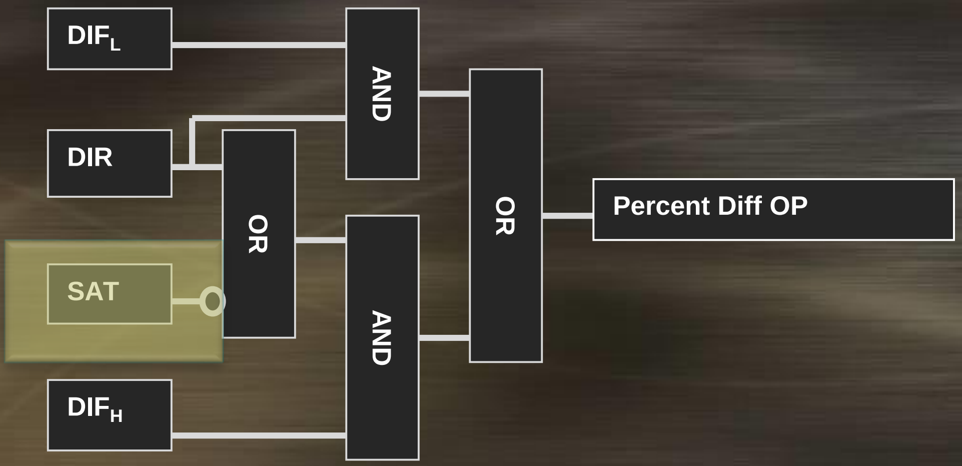
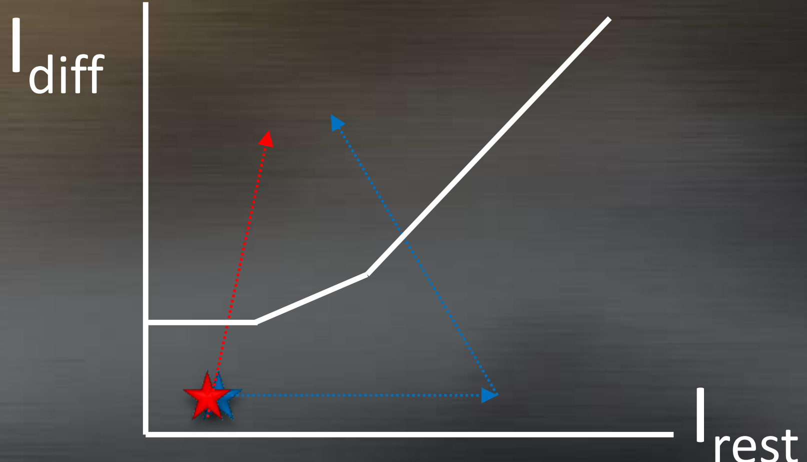
Advanced Algorithms

CT Saturation Detector





External fault with saturation
Internal fault

Flux cannot be created instantly, so CT's cannot saturate instantly

$\nabla \times E = \partial B / \partial t$

CT Saturation can be detected as fast DSP recognizes the swing from restraint to operate region

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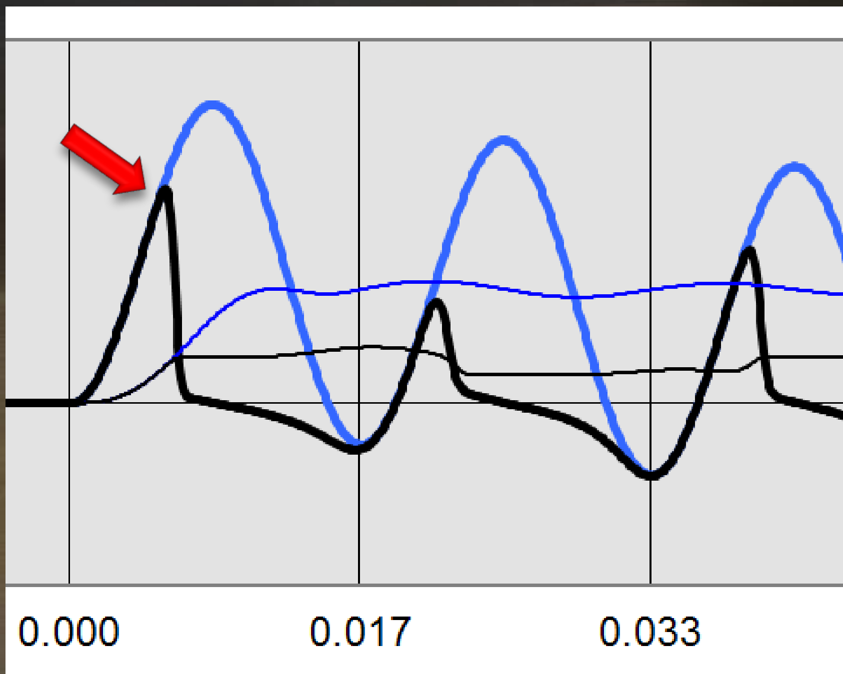
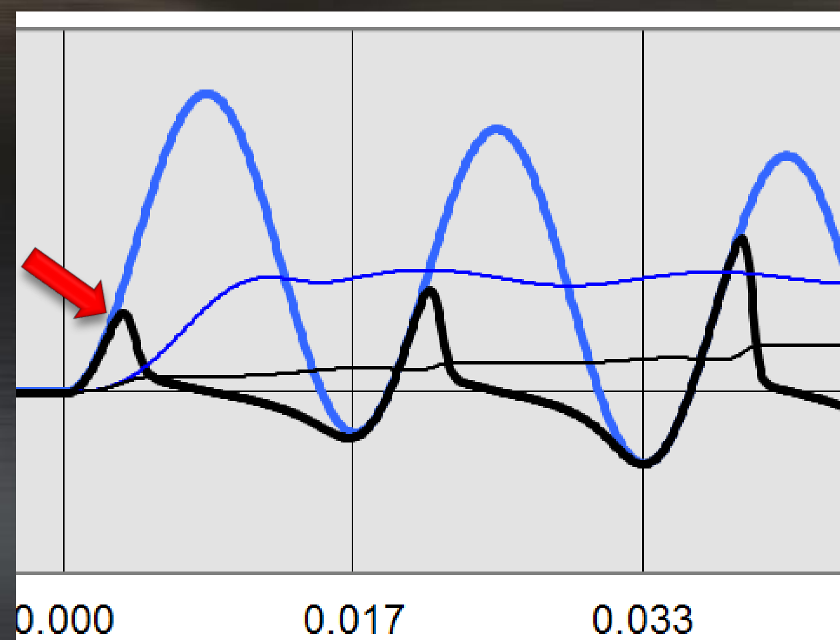
Advanced Algorithms



CT responds linearly for a brief period

More severe saturation results in less time to detect external fault



Conclusions

- Redundant relaying can operate differently based on algorithm nuances
- Understanding these differences is important for:
  - Troubleshooting analysis
  - Test plan development
  - Settings (especially in relay upgrade)
  - CT sizing
- Advanced Algorithms can be very useful but shouldn't be used as a substitute for good engineering practice

Thank You

Questions?