A Method for Selecting Secure Slopes in Maximum Restraint Type Differential Relays

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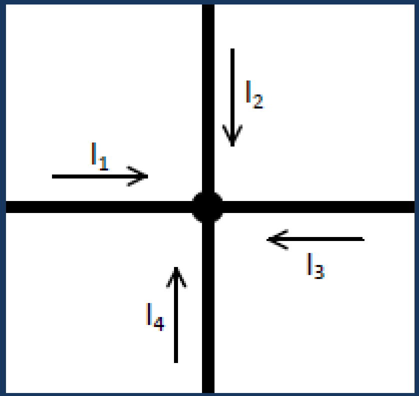
Background

- Kirchoff's Current Law:
  – Sum of all currents entering a node is zero

$$I_1 + I_2 + I_3 + I_4 = 0$$



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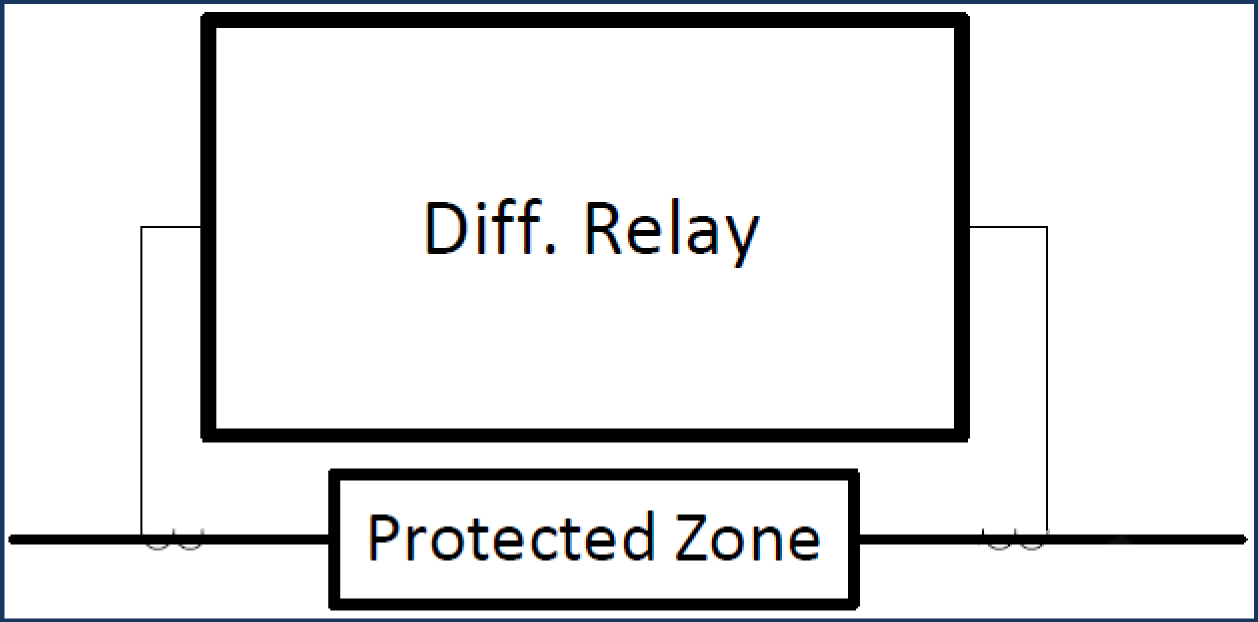
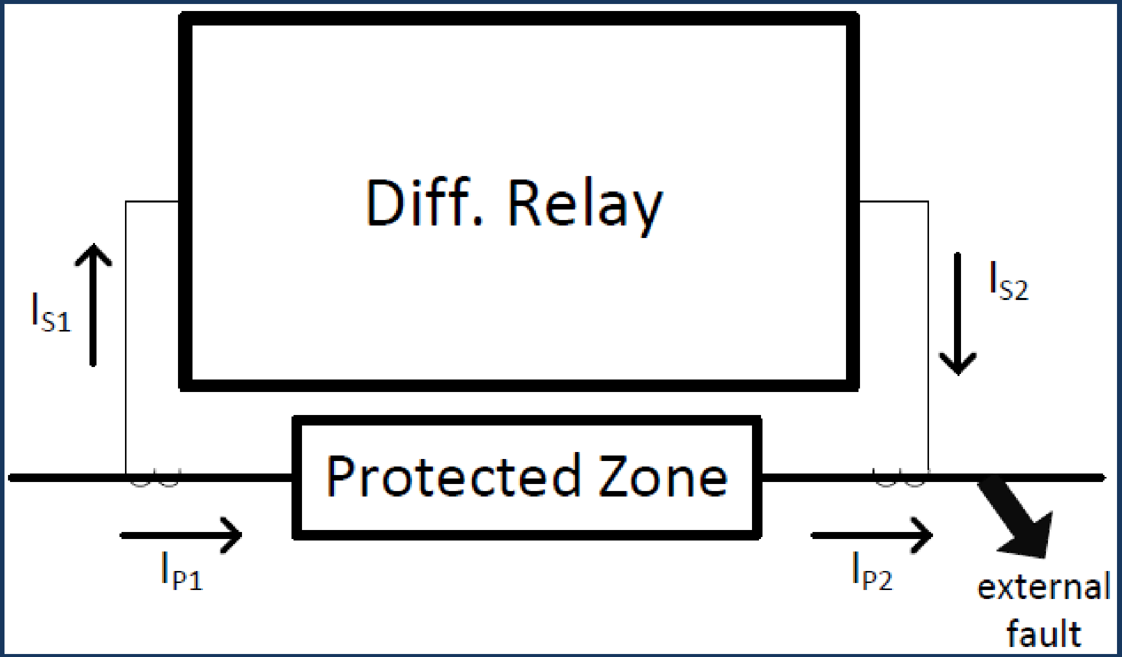


Background

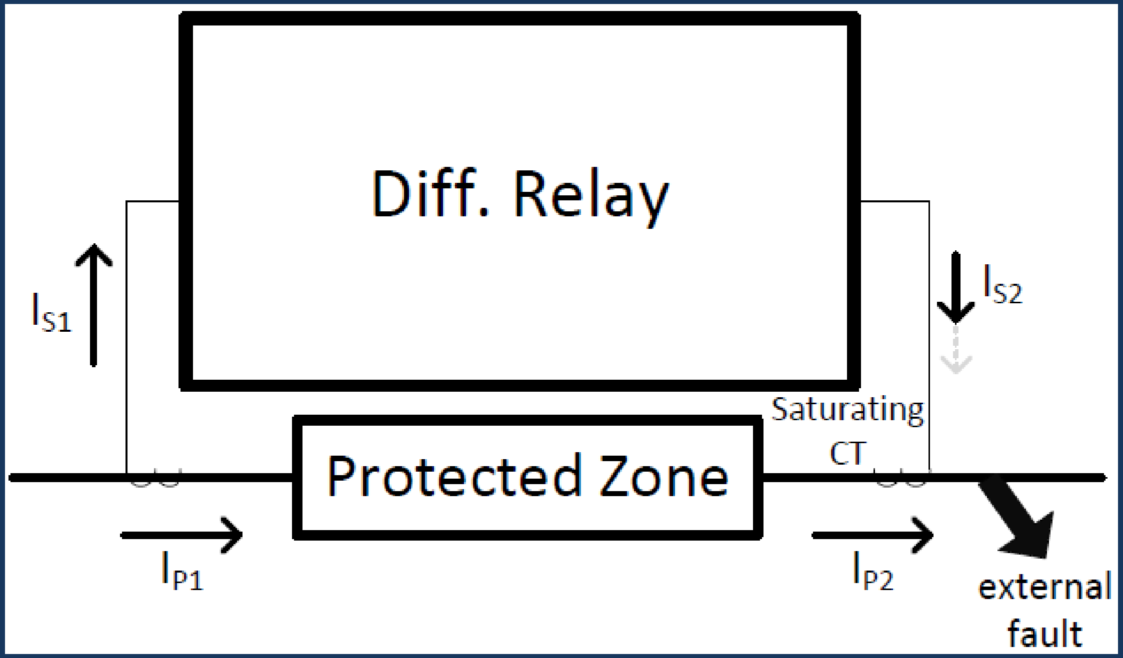
Ideal External Fault Case:



$$I_1 + I_2 = 0$$

Background

External Fault with CT Saturation:



$$I_1 + I_2 \neq 0$$

Background

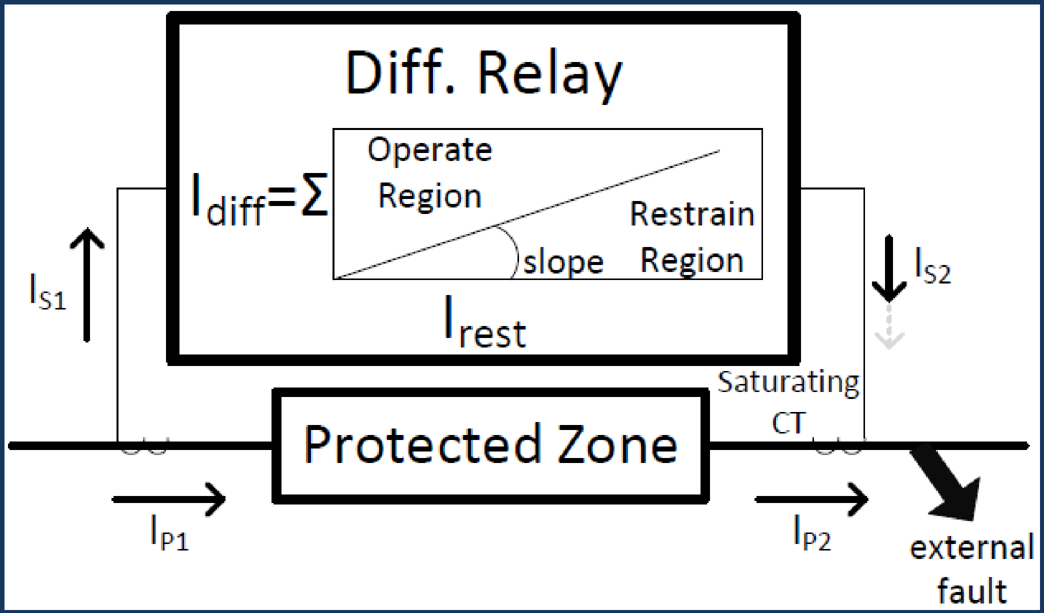
Percentage Restrained Differential:

$$I_{diff} = I_1 + I_2 + \cdots + I_n$$

$$I_{rest\_total} = |I_1| + |I_2| + \cdots + |I_n|$$

$$I_{rest\_max} = \max(|I_1|, |I_2|, \cdots, |I_n|)$$

$$Diff_{op} = \begin{cases} Trip\ if\ \frac{I_{diff}}{I_{rest}} > k \\ No\ Trip\ otherwise \end{cases}$$



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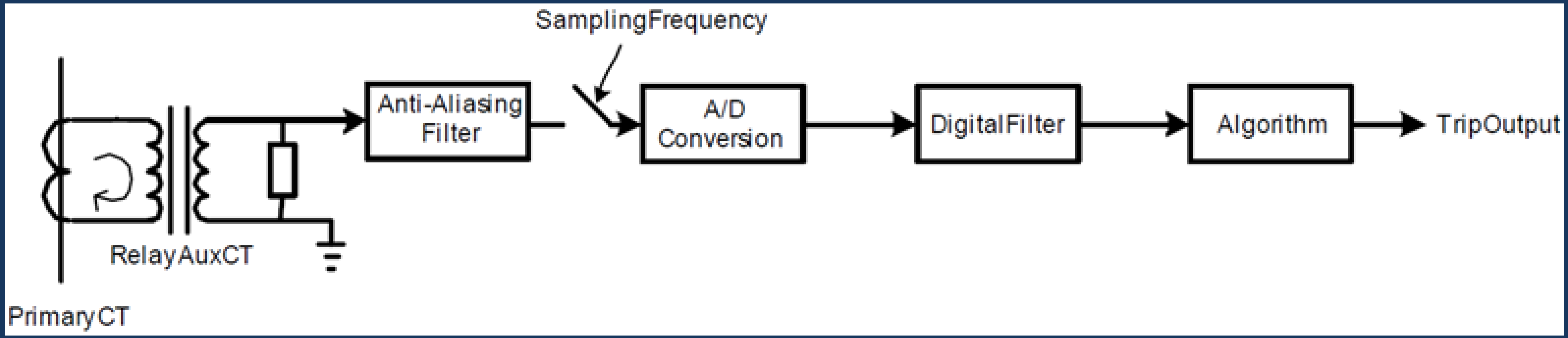


R. E. Cossé, D. G. Dunn, and R. M. Spiewak, "Ct saturation calculations - are they applicable in the modern world? - part i, the question," IEEE Transactions on Industry Applications, vol. 43, pp. 444–452, March-April 2007.

– Complicated / time consuming
– Need detailed data as inputs (CTs, relay etc.)
– May not be practical
  - Is there an easier way?

Previous Work / Model Validation

- Secure slope as a function of V_s:

$$k_{total} = 0.824V_s - 0.00242V_s^{\ 2}$$

$$where: \ V_s = 20 \times \frac{\left(1 + \frac{X}{R}\right) \frac{I_f}{CTR} Z_{burden}}{V_{rated}(1 - \%Rem)}$$

  – Straightforward to apply
  – In use for many years (proven)
  – Valid for total restraint type differential relays
    - What about maximum restraint type?

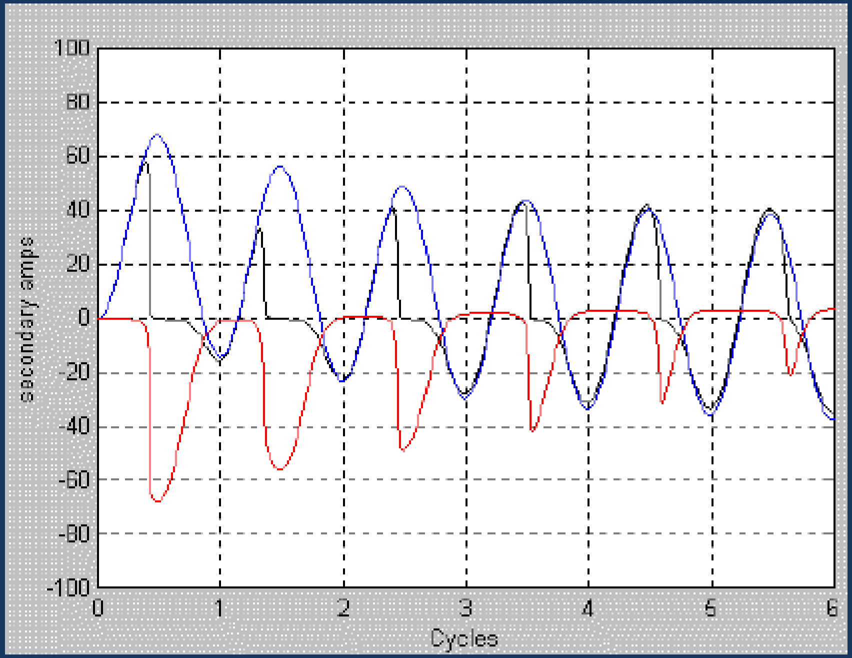
Previous Work / Model Validation

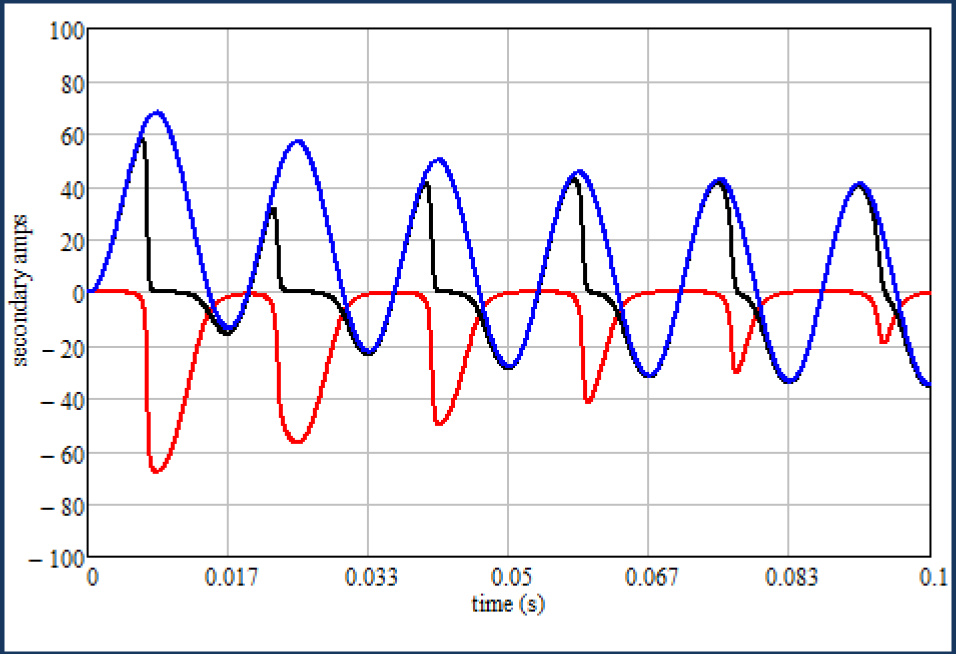
- Computer simulation of a saturated CT's output used to confirm secure slope formula for total restraint type:
  - I=10677A, X/R=14, CTR=2000:5, burden=2Ω,
  - V_{rated}=800, 400, 200 & 100V → V_s=20, 40, 80 & 160

- Relay model:
  - 16 samples/cycle
  - cosine filter
  - total restraint

Previous Work / Model Validation

– Good agreement with reference result
  - V_s=160 case shown

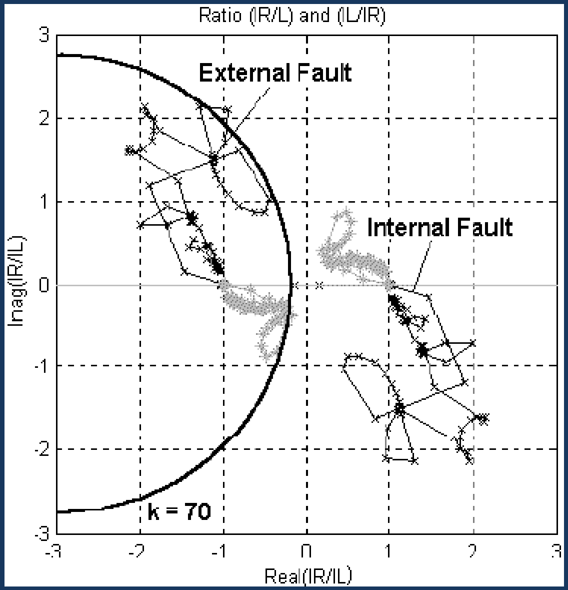




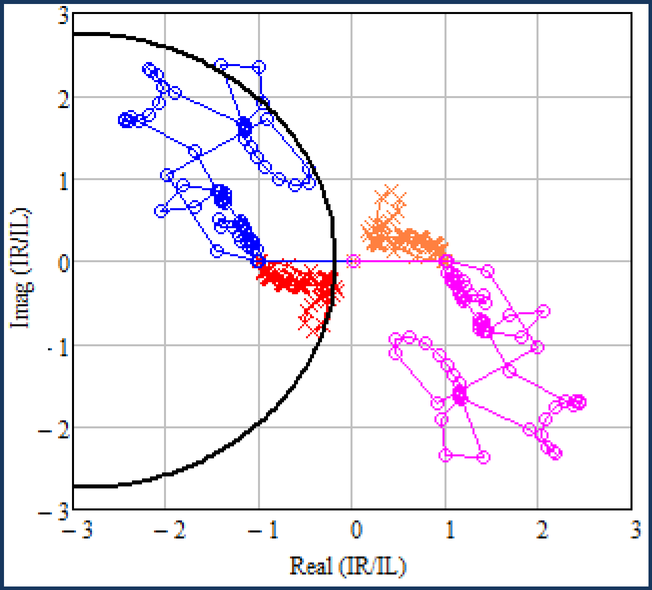
S. E. Zocholl, "Rating cts for low impedance bus and machine differential applications," in 27th Western Protective Relay Conference, Spokane,WA, October 2000.

Previous Work / Model Validation

– Same case transformed on the alpha plane



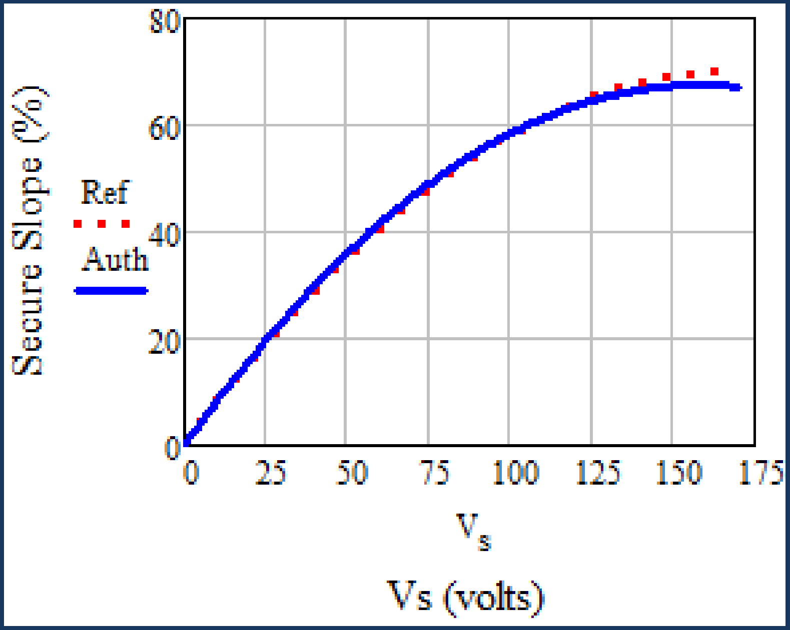
S. E. Zocholl, “Rating cts for low impedance bus and machine differential applications,” in 27th Western Protective Relay Conference, Spokane,WA, October 2000.



Previous Work / Model Validation

$$k_{total} = 0.824V_s - 0.00242V_s^2$$

$$k_{total}' = 0.852V_s - 0.00269V_s^2$$



Maximum Restraint Type

- Similar style of analysis used
- Cases Studied:
  - CTR=2000:5, burden=2Ω, 0% remanance
  - Varied I_f, X/R and V_{rated} in turn to achieve V_s=20 – 160 in steps of 20

Maximum Restraint Type

- Relay Model:

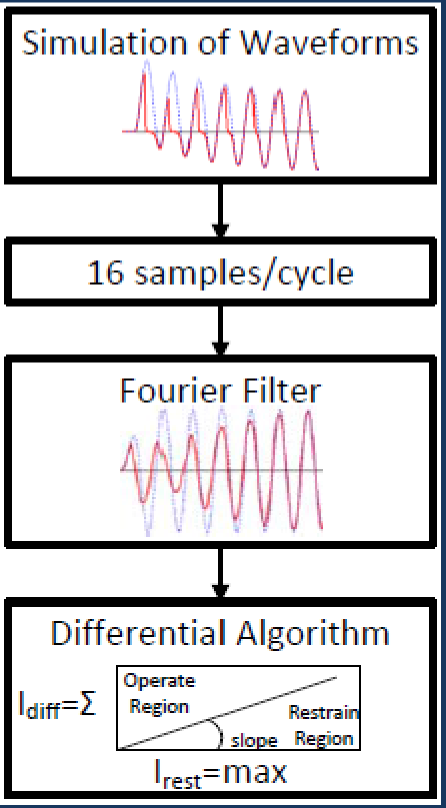
  16 samples/cycle

  FFT used for filtering

  $I_{diff} = I_1 + I_2$

  $I_{rest} = max(|I_1|, |I_2|)$

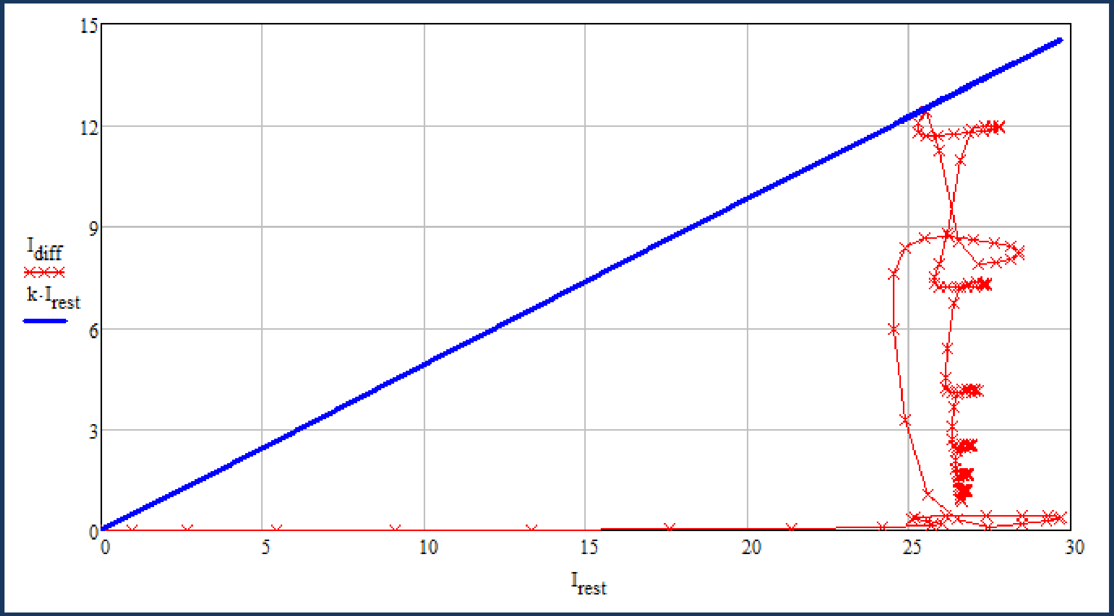
  $k = \frac{Idiff}{Irest}$



Simulations & Results

- I=10667A, X/R=14, V_{rated}=400V

$$k = \frac{I_{diff}}{I_{rest}} = 49\%$$



Simulations & Results

	Vrated	V_s	slope (%)
Ipri=10667A, X/R=14	400	40	49
	266	60	74
	200	80	79
	160	100	81
	133	120	83
	114	140	85
	100	160	91

	X/R	V_s	slope (%)
Ipri=16kA, Vrated=100V	9	40	59
	14	60	77
	19	80	84
	24	100	87
	29	120	89
	34	140	91
	39	160	92

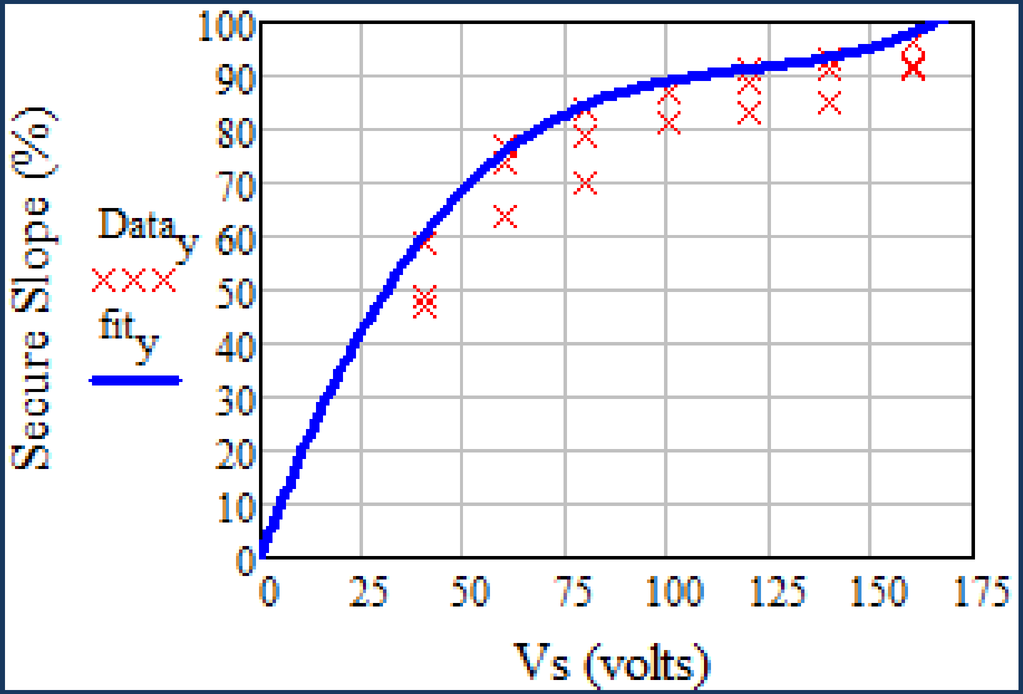
	Ipri	V_s	slope (%)
X/R=14, Vrated=100V	4000	40	47
	6000	60	64
	8000	80	70
	10000	100	81
	12000	120	91
	14000	140	93
	16000	160	96

Simulations & Results

- Max slope for each value of V_s:

V_s	Secure Slope (%)
40	59
60	77
80	84
100	87
120	91
140	93
160	96

Simulations & Results



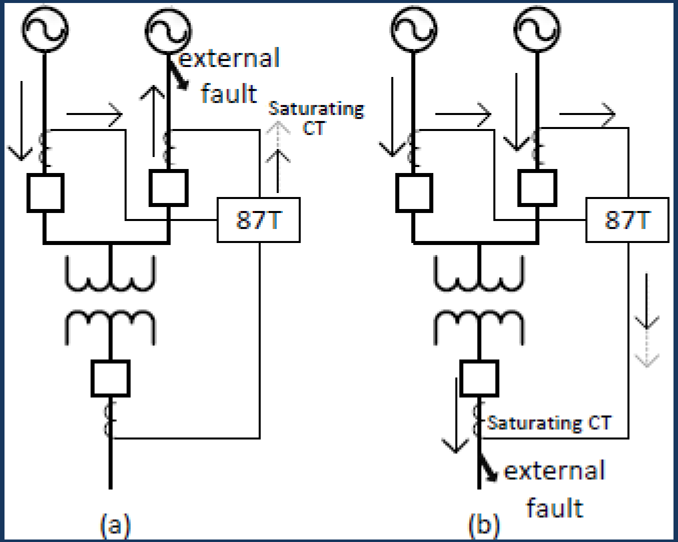
- Fitted curve:

$$k_{max} = 0.000046Vs^3 - 0.0166Vs^2 + 2.09Vs \quad for\ V_s \leq 160$$

Limitations on Application

- Not all max restraint style relays are the same:
  - Filtering method
  - Even restraint calculation itself

Limitations on Application



(a) $I_{rest} = I_f$

(b) $I_{rest} = ?$, could be as little as $I_f/2$

Limitations on Application

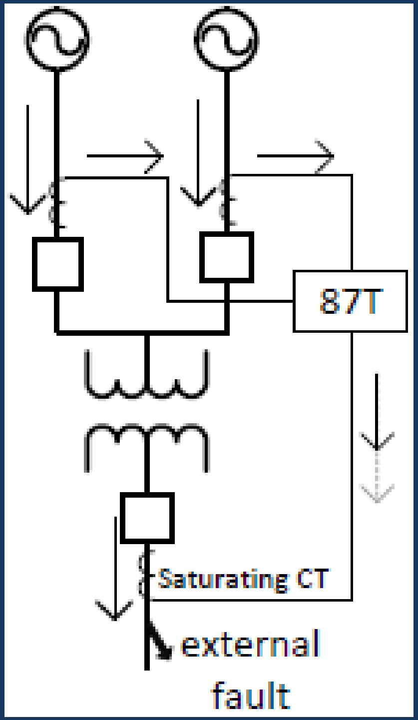
Consider:

$$I_{rest}{}' = \max(|I_{s1}|, |I_{S2}|, \cdots, |I_{Sn}|, |I_{W1}|, |I_{W2}|, \cdots, |I_{Wm}|)$$

$$where\colon\ |I_{Sn}| = magnitude\ of\ current\ in\ source\ n$$

$$|I_{Wm}| = magnitude\ of\ current\ in\ winding\ m$$

Limitations on Application



$I_{rest} = ?$, could be as little as $\frac{I_f}{2}$

$I_{rest}' = I_f$

Conclusions

- Formula for secure slope as a function of V_s for max. restraint type differential relays:

$$k_{max} = 0.000046V_s^3 - 0.0166V_s^2 + 2.09V_s \qquad for\ V_s \leq 160$$

  - Suitable for many common applications
  - Care required
    - Not all applications are the same
    - Not all max. restraint type differentials are the same

Questions?