

ANALYSIS OF A DIFFERENTIAL AND OVERCURRENT OPERATION ON A 345KV HIGH VOLTAGE LINE REACTOR

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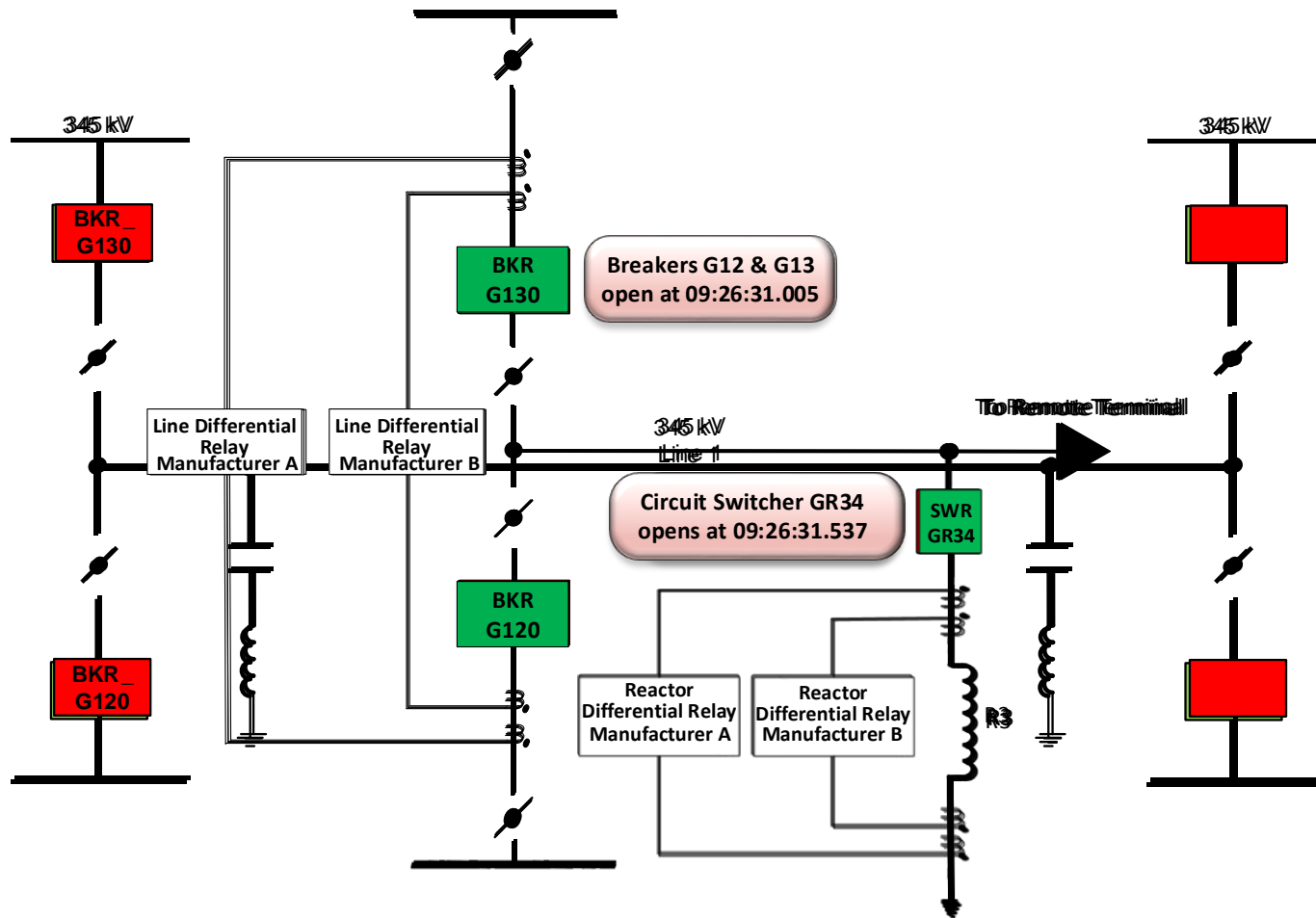
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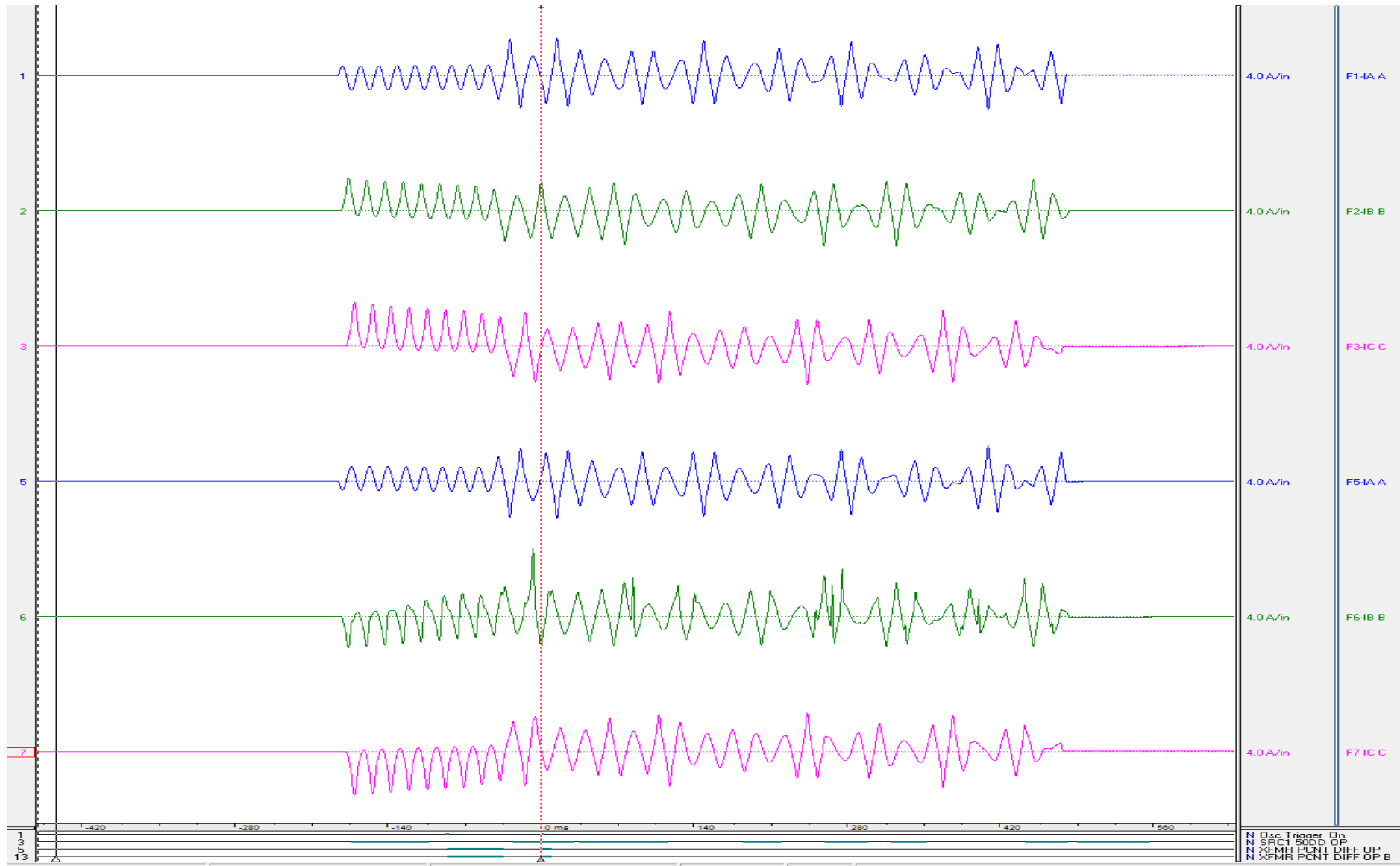
Presentation Outline

- Reactor Operation Sequence of Events
- Waveform Analysis
- Primary and Backup Differential Planes
- Resonance Effect
- Conclusions

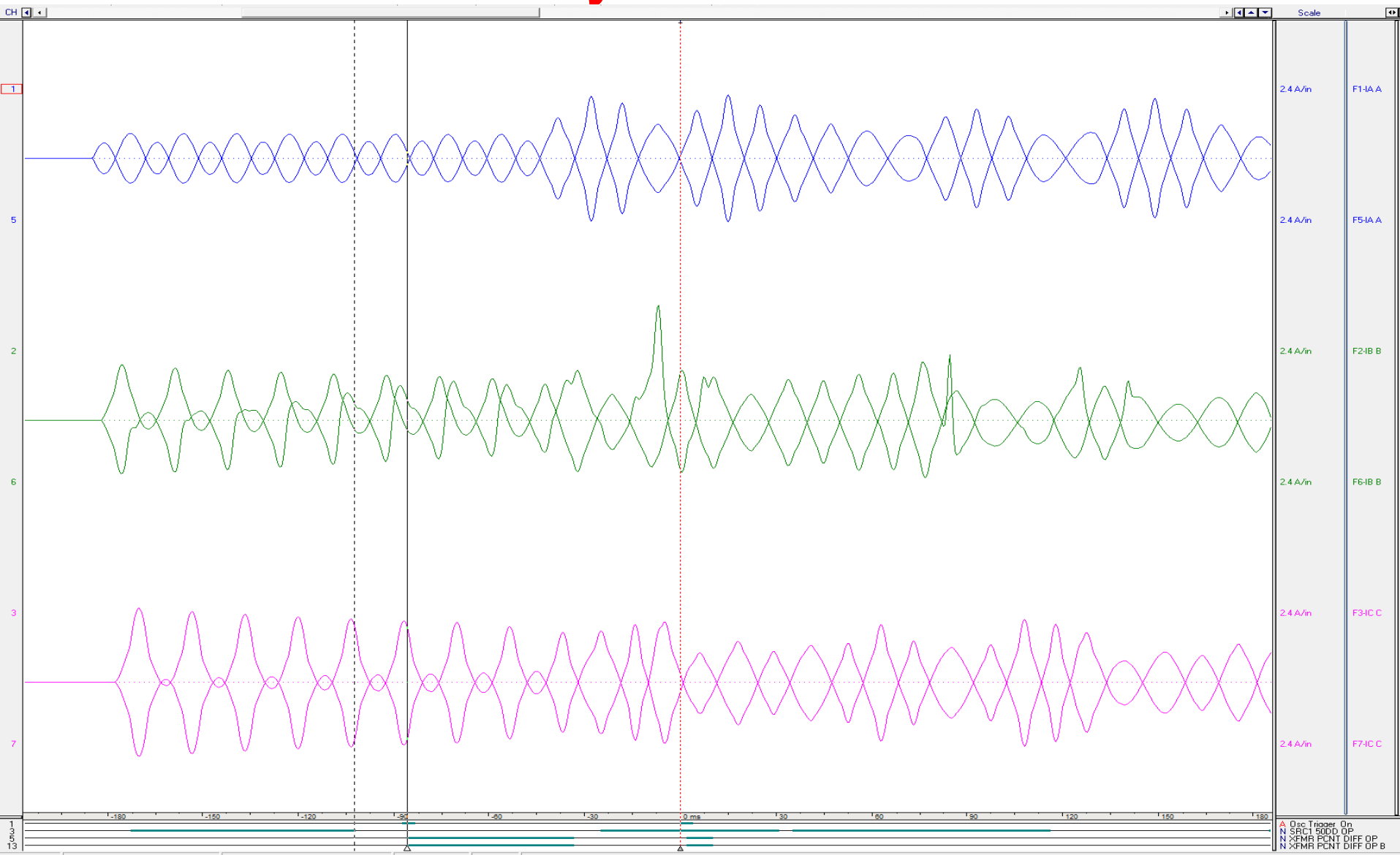
Sequence of Events



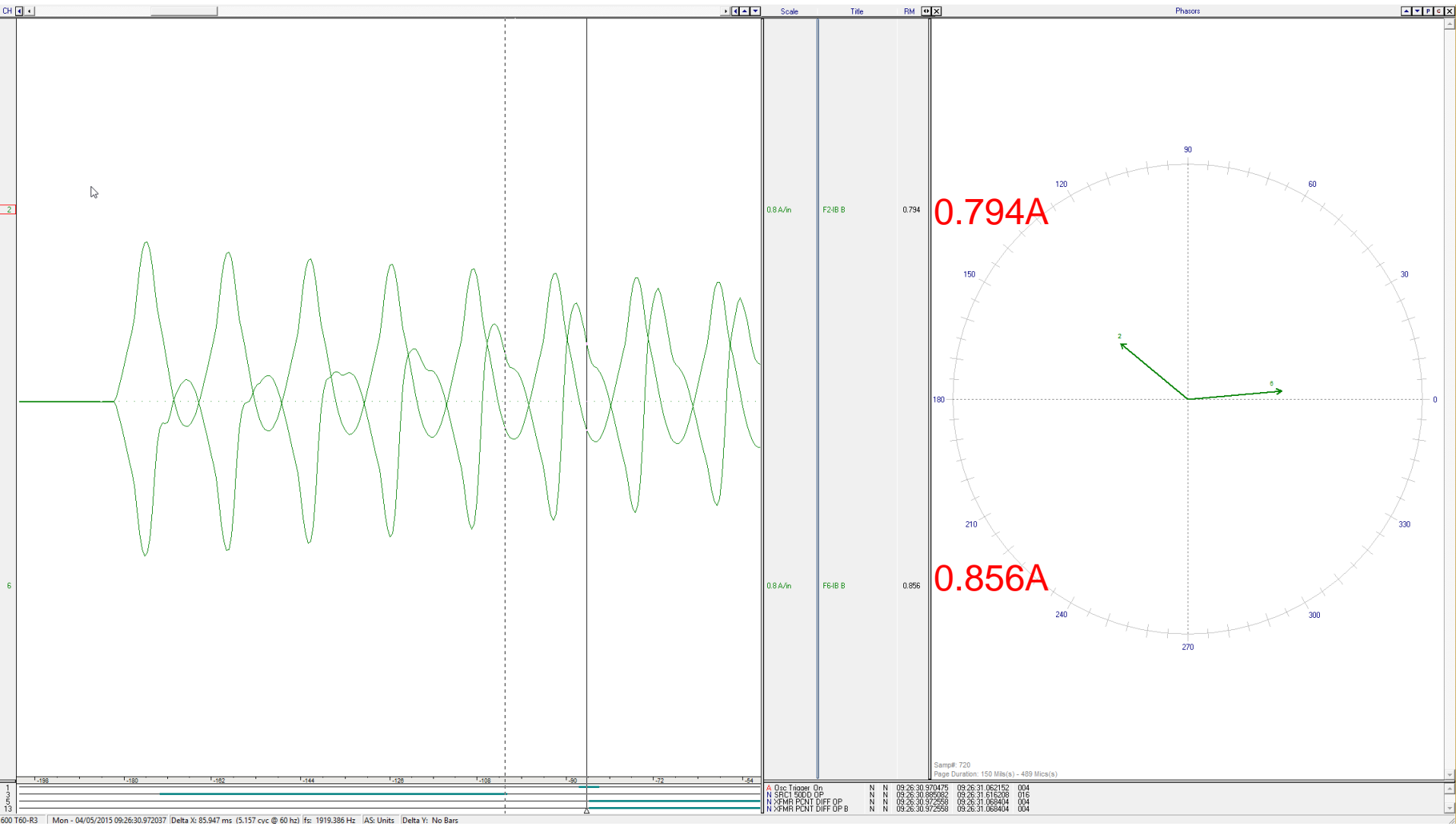
Waveform Analysis-Reactor Inrush



Waveform Analysis-Reactor Inrush



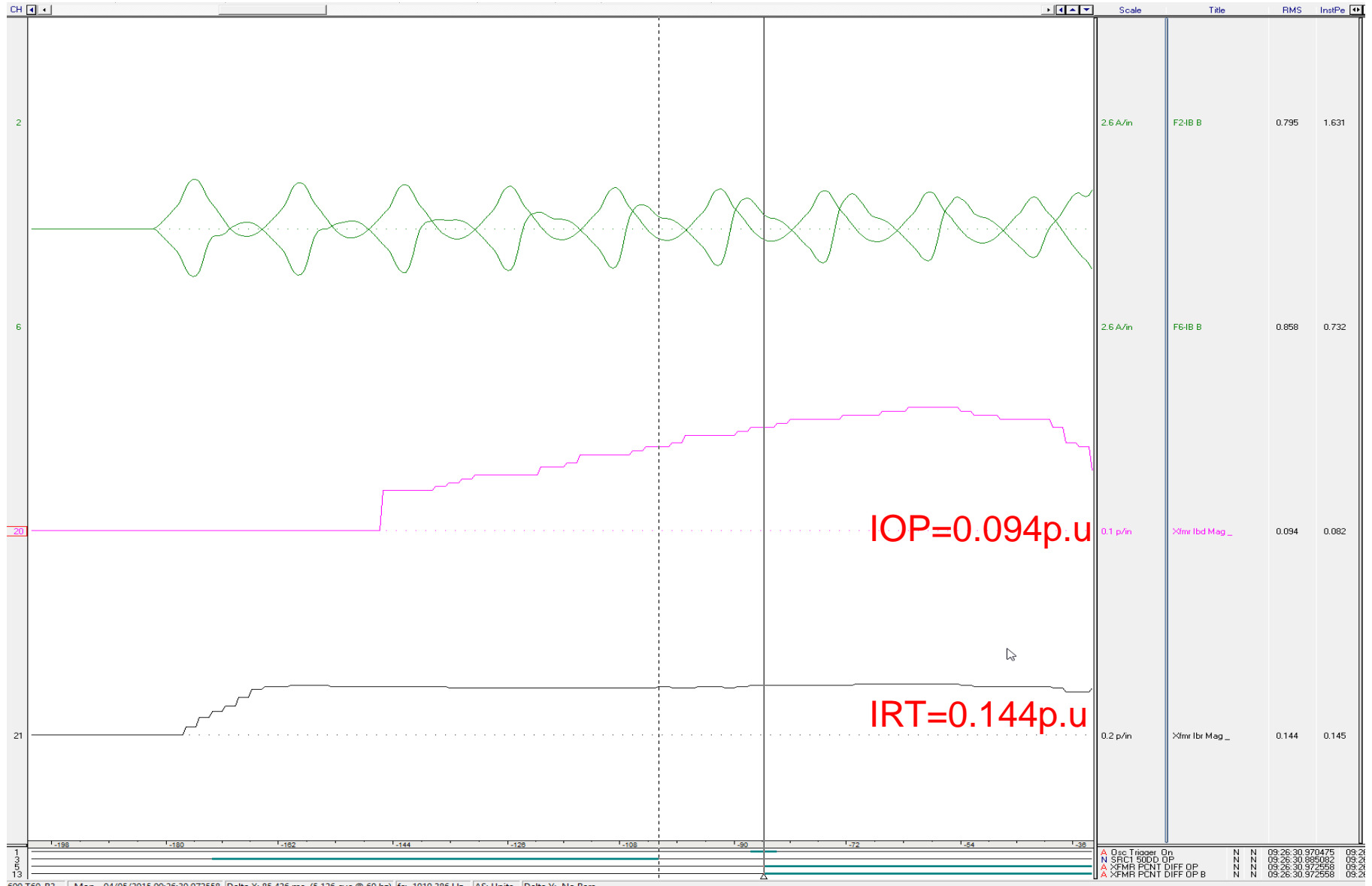
Waveform Analysis-Reactor Inrush



Backup Relay Protection Settings

Description	Setting	Value
PERCENT DIFFERENTIAL	Function	Enabled
PERCENT DIFFERENTIAL	Pickup	0.100 pu (0.5A)
PERCENT DIFFERENTIAL	Slope 1	25 %
PERCENT DIFFERENTIAL	Break 1	1.570 pu
PERCENT DIFFERENTIAL	Break 2	7.840 pu
PERCENT DIFFERENTIAL	Slope 2	98 %
PERCENT DIFFERENTIAL	Inrush Inhibit Function	Adapt. 2nd
PERCENT DIFFERENTIAL	Inrush Inhibit Mode	2-out-of-3
PERCENT DIFFERENTIAL	Inrush Inhibit Level	10.0 % fo
PERCENT DIFFERENTIAL	Function	Enabled
PERCENT DIFFERENTIAL	Block	OFF

B-Phase Differential Calculation

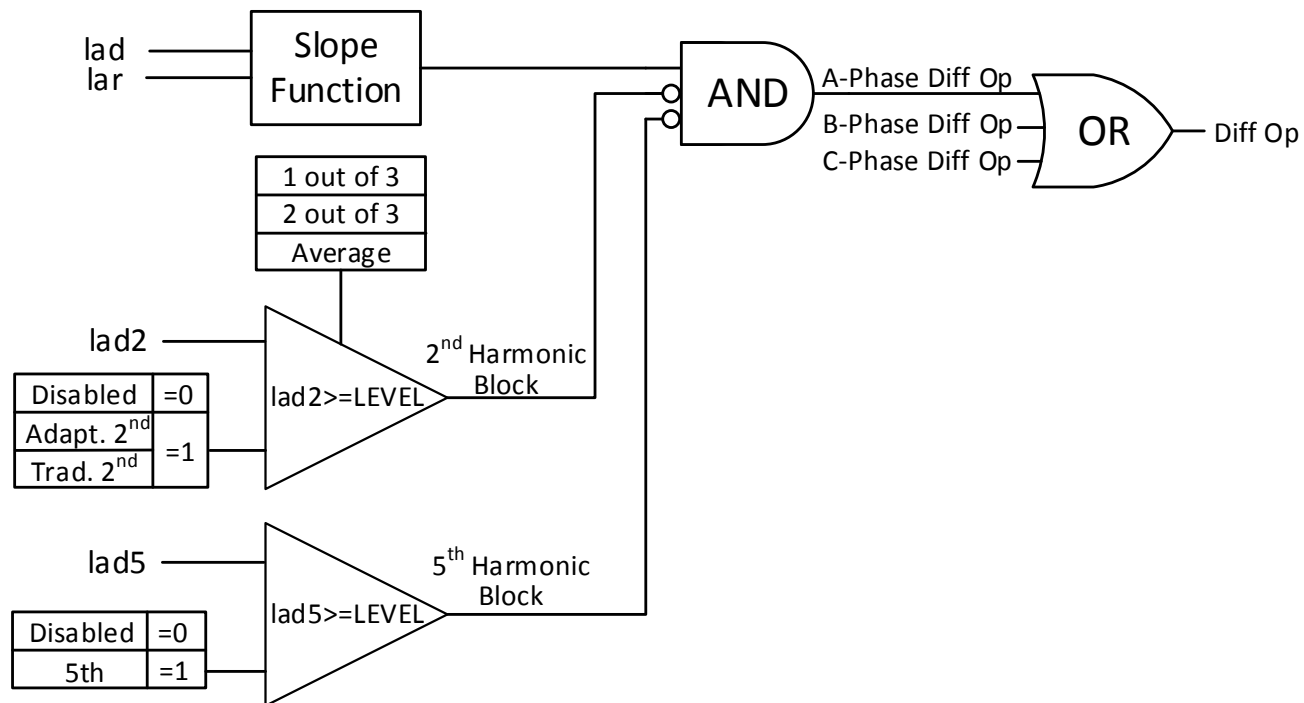


Relay Differential Algorithms

Harmonic Blocking Backup Relay

$$IOP > IRT * SLP$$

$$IOPA > (|IAT + IAW|) * Slope$$



Relay Differential Algorithms

Primary Relay

$$IOPA = |IAT + IAW|$$

$$IRTA = |IAT| + |IAW|$$

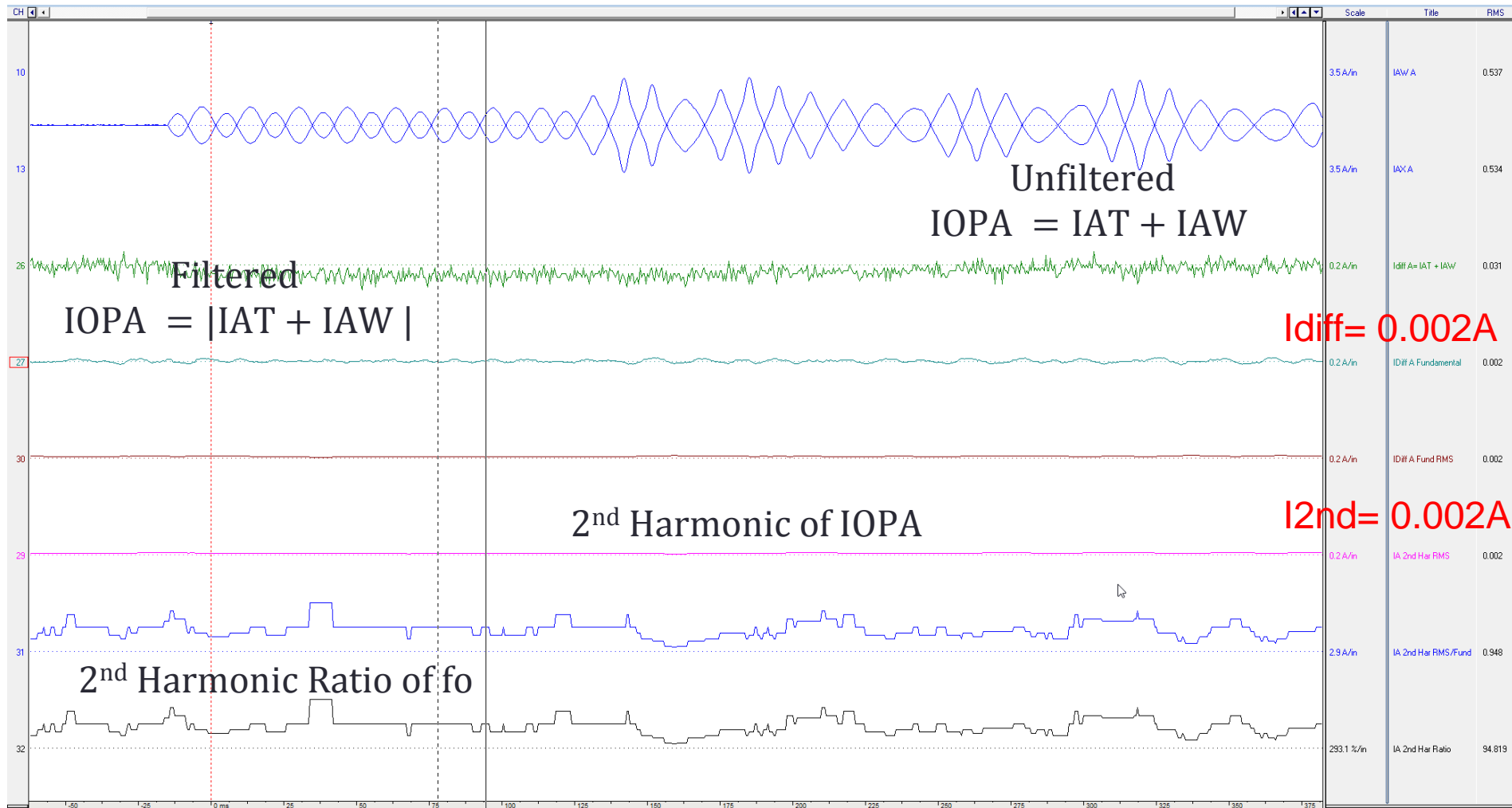
Backup Relay

$$IAdiff = IAT + IAW$$

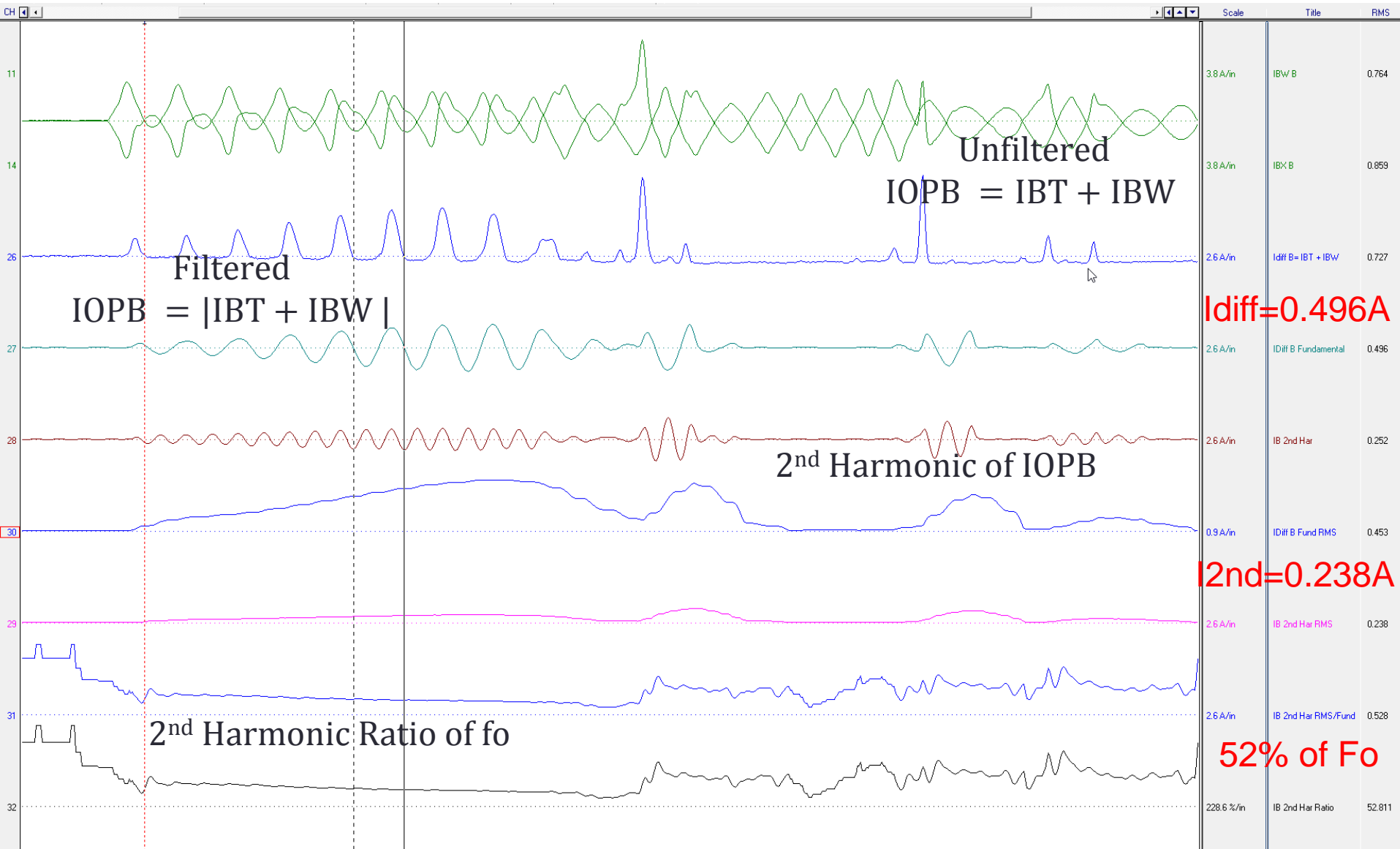
$$IAr = \text{MAX}[(|IAT|), (|IAW|)]$$

$$IOP > IRT * SLP$$

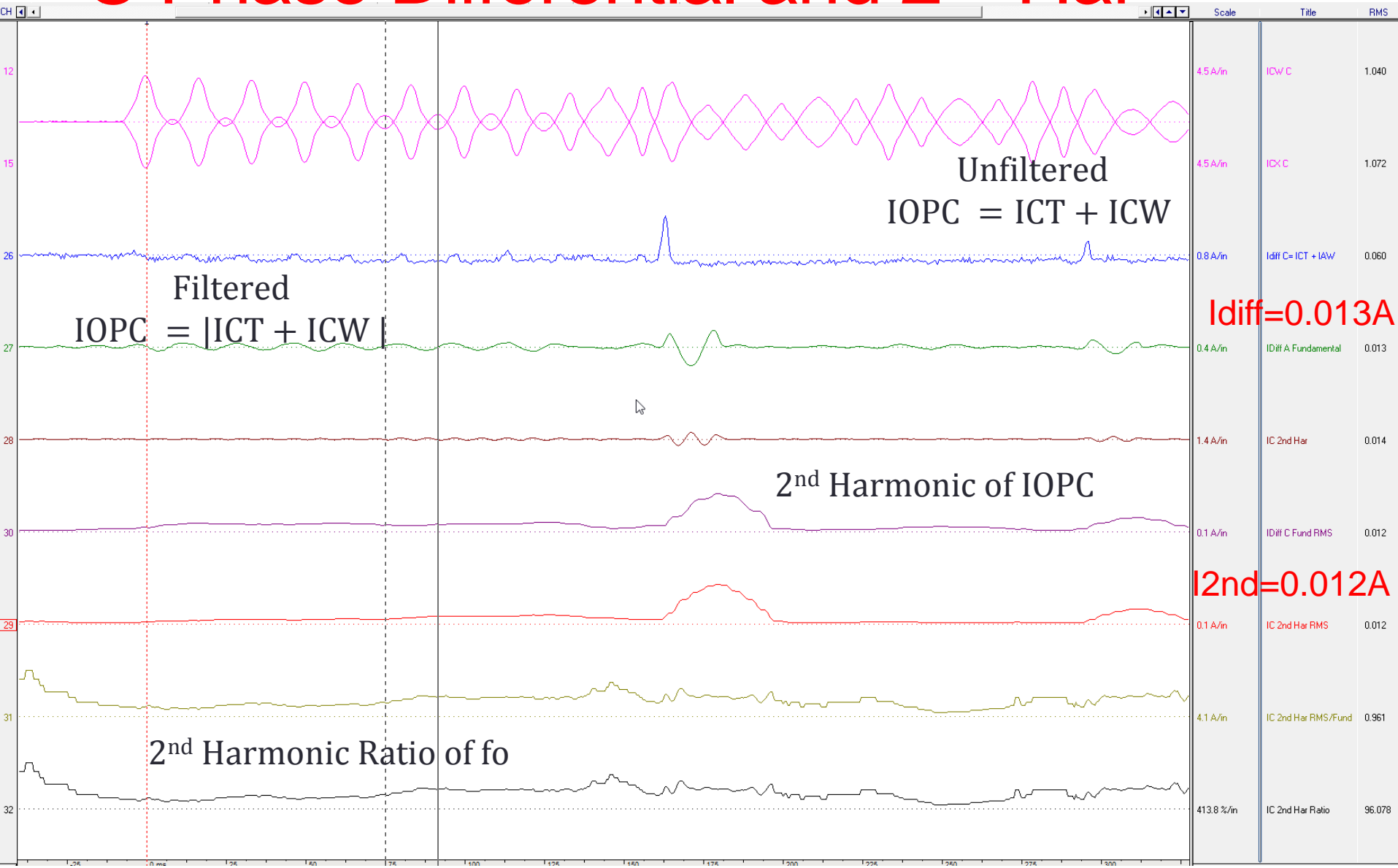
A Phase Differential and 2nd Har



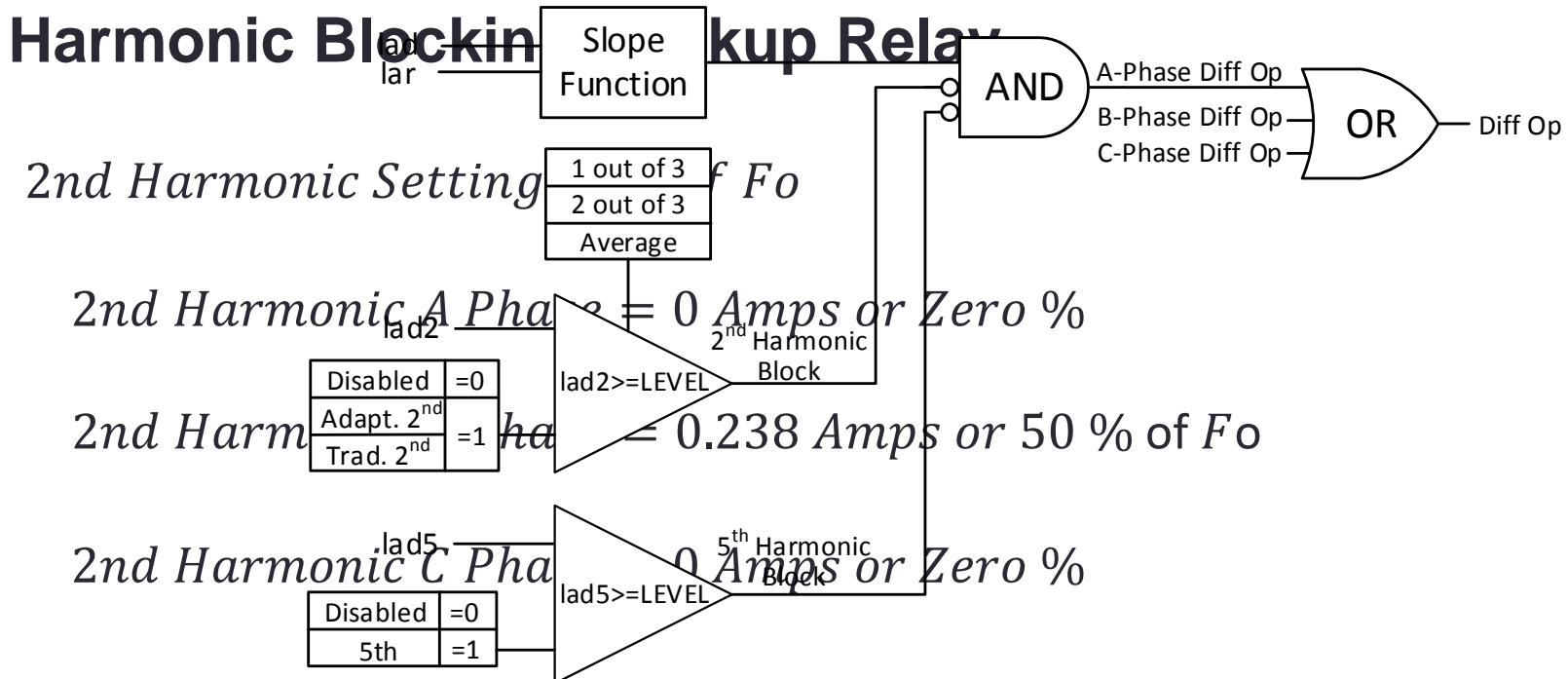
B Phase Differential and 2nd Har



C Phase Differential and 2nd Har



Harmonic Content Summary



Primary Relay Protection Settings

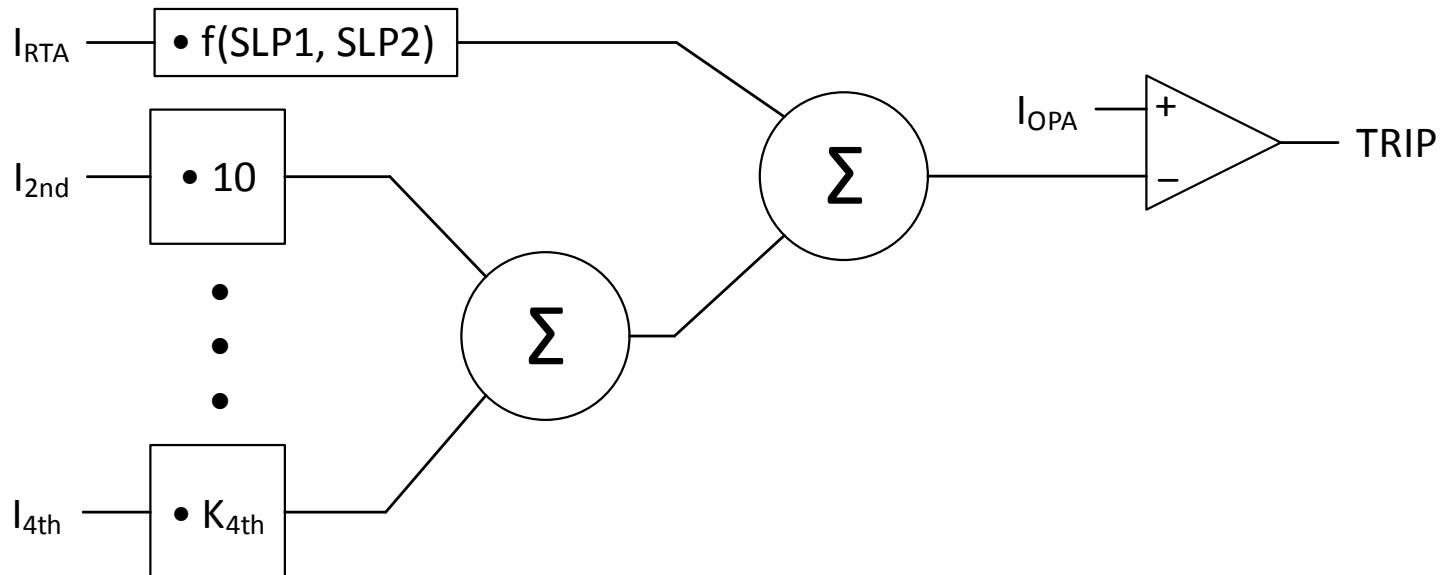
Description	Setting	Value
Diff. Element Operating Current Pickup (p.u.)	O87P	0.5
Slope 1 Setting (%)	SLP1	35
Slope 2 Setting (%)	SLP2	75
Unrestrained Element Current Pickup (p.u.)	U87P	1.00
Incremental Operate Current Pickup (p.u.)	DIOPR	1.2
Incremental Restraint Current Pickup (p.u.)	DIRTR	1.2
Enable Harmonic Blocking Differential Element	E87HB	Y
Enable Harmonic Restraint Differential Element	E87HR	N
Second-Harmonic Percentage (%)	PCT2	10

Relay Differential Algorithms

Harmonic Restraint Primary Relay

$$IOP > IRT * SLP$$

$$IOPA > (|IAT + IAW|) * Slope + K2 * (IOPAph2) + K4 * (IOPAph4)$$

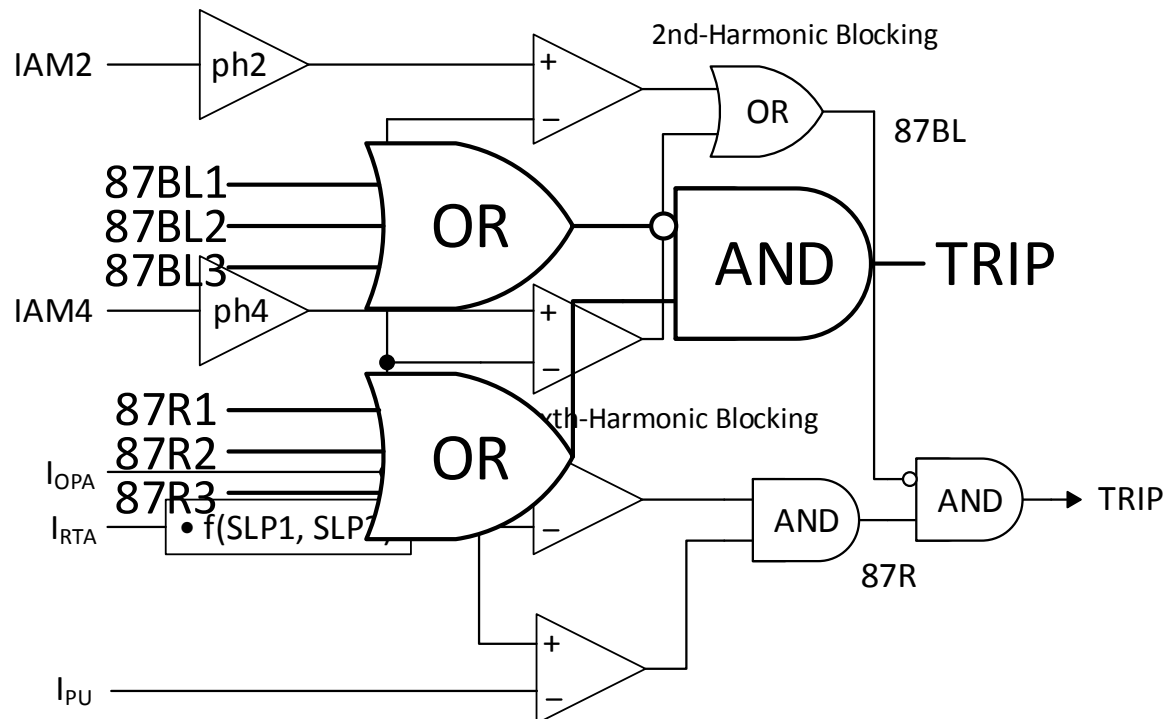


Relay Differential Algorithms

Harmonic Blocking Primary Relay

$$I_{OP} > I_{RT} * SLP$$

$$I_{OPA} > (|I_{AT} + I_{AW}|) * Slope$$



Differences in Differential Algorithms

Primary Relay

$$IOPA = |IAT + IAW|$$

$$IRTA = |IAT| + |IAW|$$

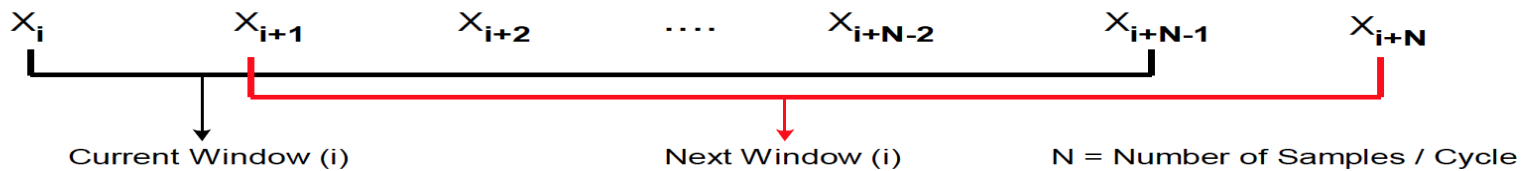
Backup Relay

$$IAdiff = IAT + IAW$$

$$IAr = \text{MAX}[(|IAT|), (|IAW|)]$$

$$IOP > IRT * SLP$$

Recursive Fourier Transform



$$\left. \begin{aligned} \text{RMS}_i &= \sqrt{\frac{1}{N} \sum_{n=0}^{N-1} X_{i+n}^2} \\ \text{RMS}_{i+1} &= \sqrt{\frac{1}{N} \sum_{n=0}^{N-1} X_{i+1+n}^2} \end{aligned} \right\} \text{RMS}_{i+1} = \sqrt{\text{RMS}_i^2 + \frac{1}{N} [X_{i+N}^2 - X_i^2]} \quad (1)$$

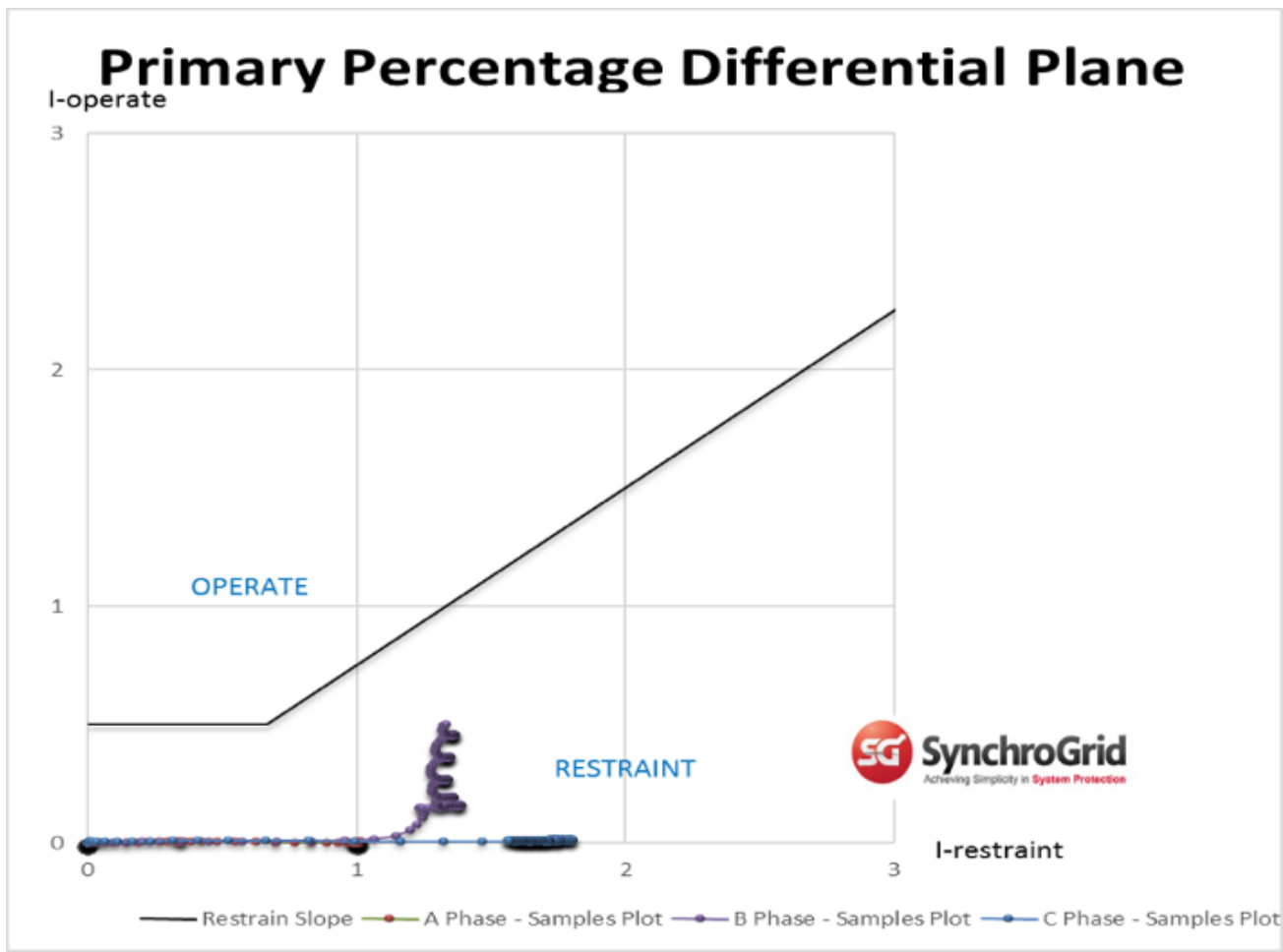
$$\left. \begin{aligned} \text{DFT}_{ki} &= \frac{2}{N} \sum_{n=0}^{N-1} X_{i+n} e^{-\frac{j 2\pi kn}{N}} \\ \text{DFT}_{k(i+1)} &= \frac{2}{N} \sum_{n=0}^{N-1} X_{i+1+n} e^{-\frac{j 2\pi kn}{N}} \end{aligned} \right\} \text{DFT}_{k(i+1)} = \left(\text{DFT}_{ki} + \frac{2}{N} [X_{i+N} - X_i] \right) e^{\frac{j 2\pi k}{N}} \quad (2)$$

Recursive Fourier Transform

33.3	2	1	Sample No.	1	2	3	4	5	6	7	8	9
600	1	1.414213562	PHASOR ANGLE	180	#DIV/0!	0	41.39328223	89.10483	28.951	257.1957	#DIV/0!	317.0454
	1	1	I-dft	-0.02828427	4.56952104039979E-17	1.387778780781	2.558559483431	1.04083408	2.71773344	-2.47817639	4.68375338	2.23586581
1	-0.014142136	-0.028284271247462		-0.014142135	-0.01414213562373	-0.014142135623	-0.014142135623	-0.01414213	-0.01414213	-0.01414213	-0.01414213	-0.01414213
2	-0.014142136	4.56952104039979E-17		0	0.014142135623731	0.007071067811	4.937664789745	-0.00437016	-0.00707106	-0.00881747	-0.01+0.01i	-0.0108335i
3	-0.014142136	1.38777878078145E-17		0	0	0.007071067811	0.014142135623	0.01144122	0.00707106	0.00314692	4.93766478	-0.0024557i
4	-0.014142136	2.55855948343145E-17+2.25514051876985E-17i		0	0	0	2.598932341278	0.01144122	0.01414213	0.01274162	0.00999999	0.00707106
5	-0.014142136	1.04083408558608E-18+6.66133814775092E-17i		0	0	0	0	-0.00437016	0.00707106	0.01274162	0.01414213	0.01328926
6	-0.014142136	2.717733445697E-17+1.50342701251323E-17i		0	0	0	0	0	-0.00707106	0.00314692	0.01-0.0099	0.01328926
7	-0.014142136	-2.47817639425258E-18-1.09039761347114E-17i		0	0	0	0	0	0	-0.00881747	2.59893234	0.00707106
8	-0.014142136	4.68375338513737E-17i		0	0	0	0	0	0	0	-0.01-0.0099	-0.0024557i
9	-0.014142136	2.23586581348122E-17-2.08166817117217E-17i		0	0	0	0	0	0	0	0	-0.0108335i
10	-0.014142136	1.59594559789866E-17+2.9837243786801E-17i		0	0	0	0	0	0	0	0	0
11	-0.014142136	-1.16699579292985E-17+1.5770213417971E-18i		0	0	0	0	0	0	0	0	0
12	-0.014142136	2.262284608369E-17+2.6599093298311E-17i		0	0	0	0	0	0	0	0	0
13	-0.014142136	-6.40513283437591E-18+1.86816374335963E-18i		0	0	0	0	0	0	0	0	0
14	-0.014142136	6.69107626448197E-18+1.36299701683892E-18i		0	0	0	0	0	0	0	0	0
15	-0.014142136	1.41090842712178E-17+3.98986399474665E-17i		0	0	0	0	0	0	0	0	0
16	-0.014142136	-6.93889390390723E-18+1.48535697630514E-17i		0	0	0	0	0	0	0	0	0
17	-0.014142136	-6.93889390390722E-18+8.87770249470483E-18i		0	0	0	0	0	0	0	0	0
18	-0.014142136	1.69617406539954E-17+1.73472347597681E-18i		0	0	0	0	0	0	0	0	0
19	-0.014142136	-3.10424200964271E-18+2.42861286636753E-17i		0	0	0	0	0	0	0	0	0
20	-0.014142136	9.0205620750794E-18+2.52402265754625E-17i		0	0	0	0	0	0	0	0	0
21	-0.014142136	-4.95635278850516E-19-8.34319386065036E-18i		0	0	0	0	0	0	0	0	0
22	-0.014142136	2.20782987851594E-18+9.93523445332173E-18i		0	0	0	0	0	0	0	0	0
23	-0.014142136	-7.08973942355738E-18-6.1469549257439E-18i		0	0	0	0	0	0	0	0	0
24	-0.014142136	1.54679509941265E-17+3.34657070573859E-17i		0	0	0	0	0	0	0	0	0
25	-0.014142136	-8.32667268468864E-19+2.32452945780892E-18i		0	0	0	0	0	0	0	0	0
26	-0.014142136	1.25433851339862E-17+1.10421821259293E-17i		0	0	0	0	0	0	0	0	0
27	-0.014142136	2.44146266989328E-18+2.69845874040836E-18i		0	0	0	0	0	0	0	0	0
28	-0.014142136	1.16474290529871E-17+1.23289275614066E-17i		0	0	0	0	0	0	0	0	0
29	-0.014142136	7.29780220928172E-18+6.57998559853272E-18i		0	0	0	0	0	0	0	0	0
30	-0.014142136	1.39934360395463E-17+2.95481232074716E-17i		0	0	0	0	0	0	0	0	0
31	-0.014142136	-1.18632702228092E-17+8.72957620168974E-18i		0	0	0	0	0	0	0	0	0
32	-0.014142136	-1.10588621593521E-17-4.03865309250851E-18i		0	0	0	0	0	0	0	0	0
33	-0.014142136	-1.14596884170589E-17+1.41931920761739E-18i		0	0	0	0	0	0	0	0	0
34	-0.014142136	0.000254601374321329+0.0000168382291854917i		0	0	0	0	0	0	0	0	0
35	-0.014142136	0.000254601374321329+0.0000168382291854917i		0	0	0	0	0	0	0	0	0
36	-0.014142136	0.000254601374321329+0.0000168382291854917i		0	0	0	0	0	0	0	0	0
37	-0.014142136	0.000254601374321329+0.0000168382291854917i		0	0	0	0	0	0	0	0	0
38	-0.014142136	0.000254601374321329+0.0000168382291854917i		0	0	0	0	0	0	0	0	0

Primary Relay Protection Settings

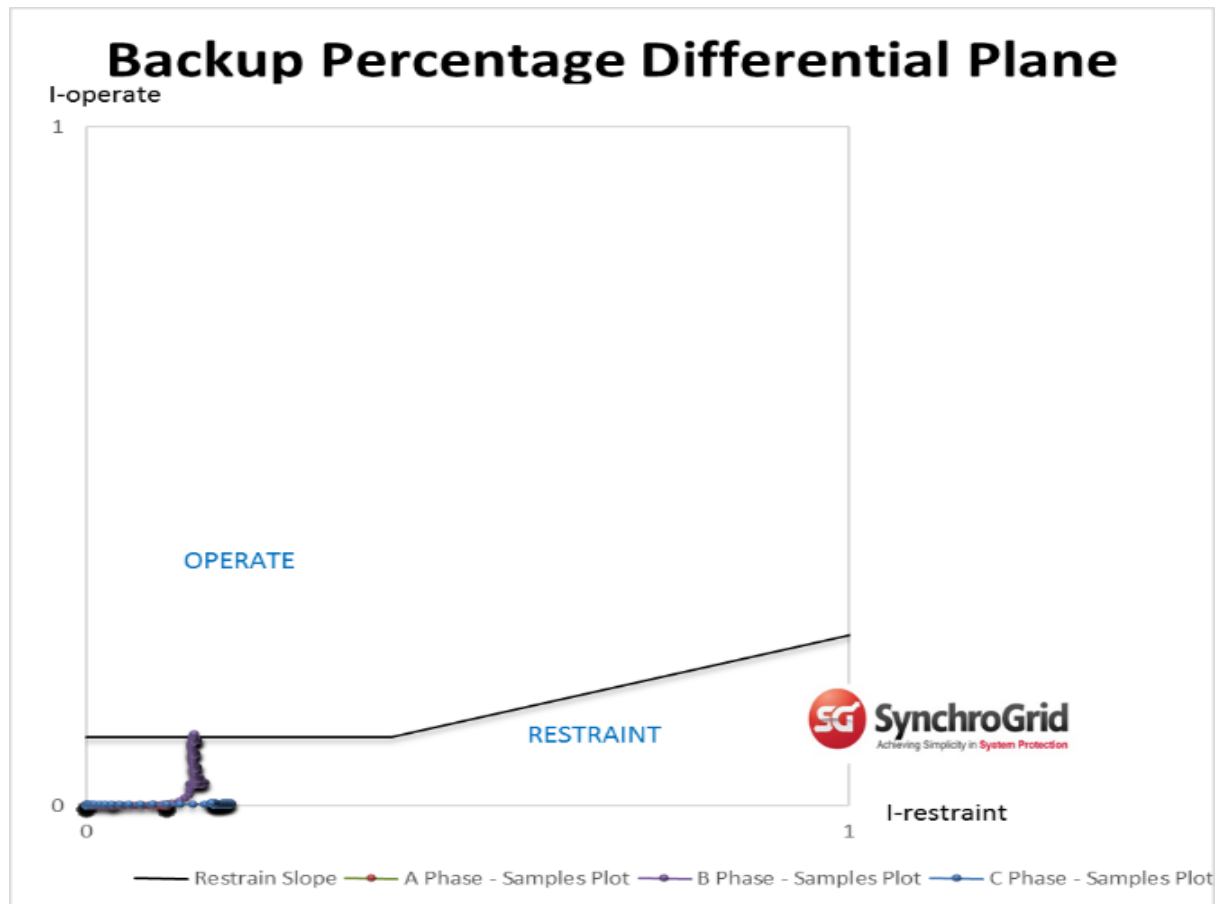
$$IOPA > (|IAT + IAW|) * Slope + K2 * (IOPA_{ph2}) + K4 * (IOPA_{ph4})$$



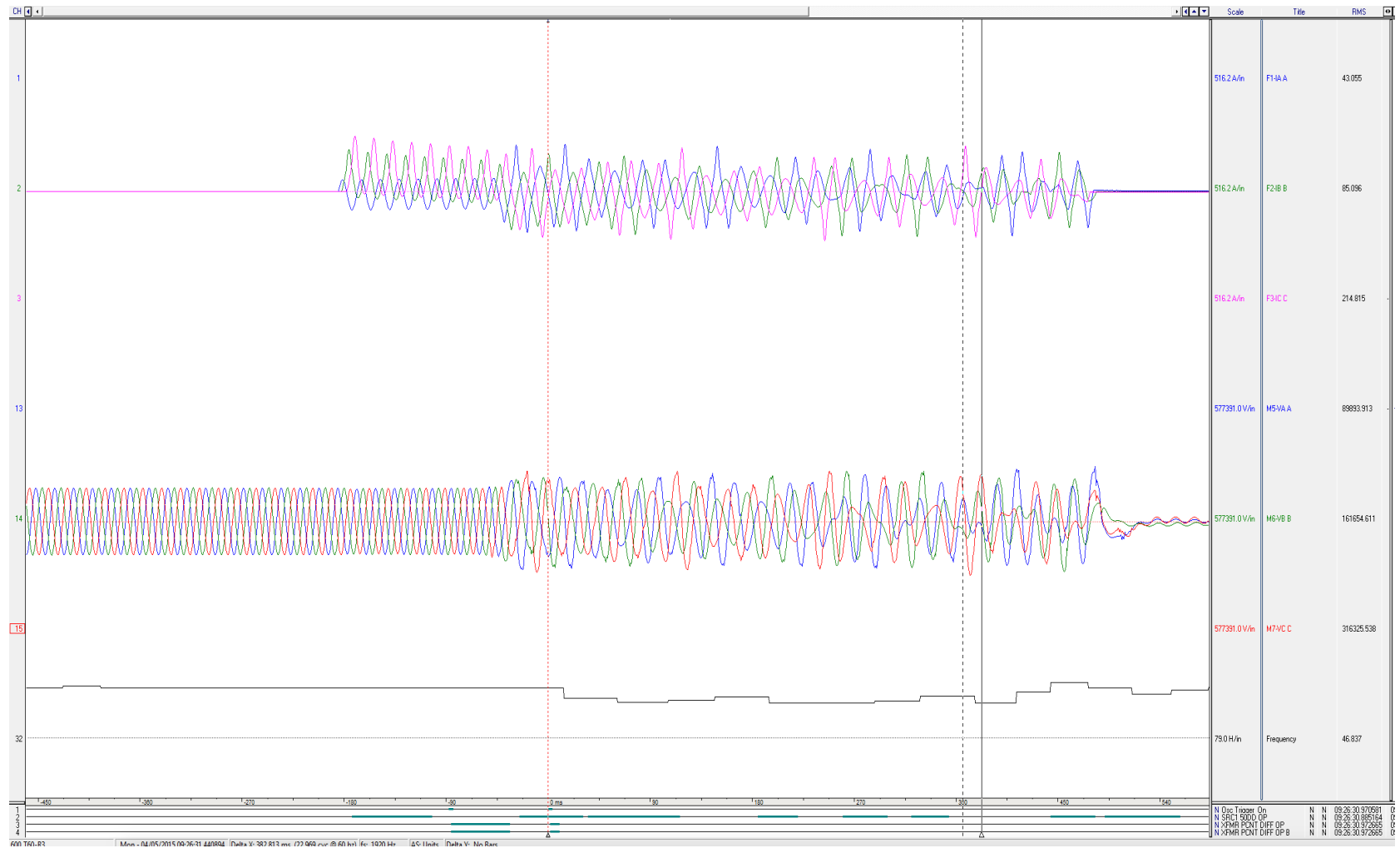
Primary Relay Protection Settings

$$IADiff = IAT + IAW$$

$$IRA = \text{MAX}[(|IAT|), (|IAW|)]$$



Bonus – Resonance Effect



Conclusions

- Understand behavior of high voltage reactors during in-rush conditions
- When applying two different relays from different or same manufacturer, make sure the protection algorithms are well understood.
- Use harmonic cross blocking for reactor applications to avoid operating during energizations

QUESTIONS

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