Zone-1 Ground Distance Element Mis-Operation for External Fault

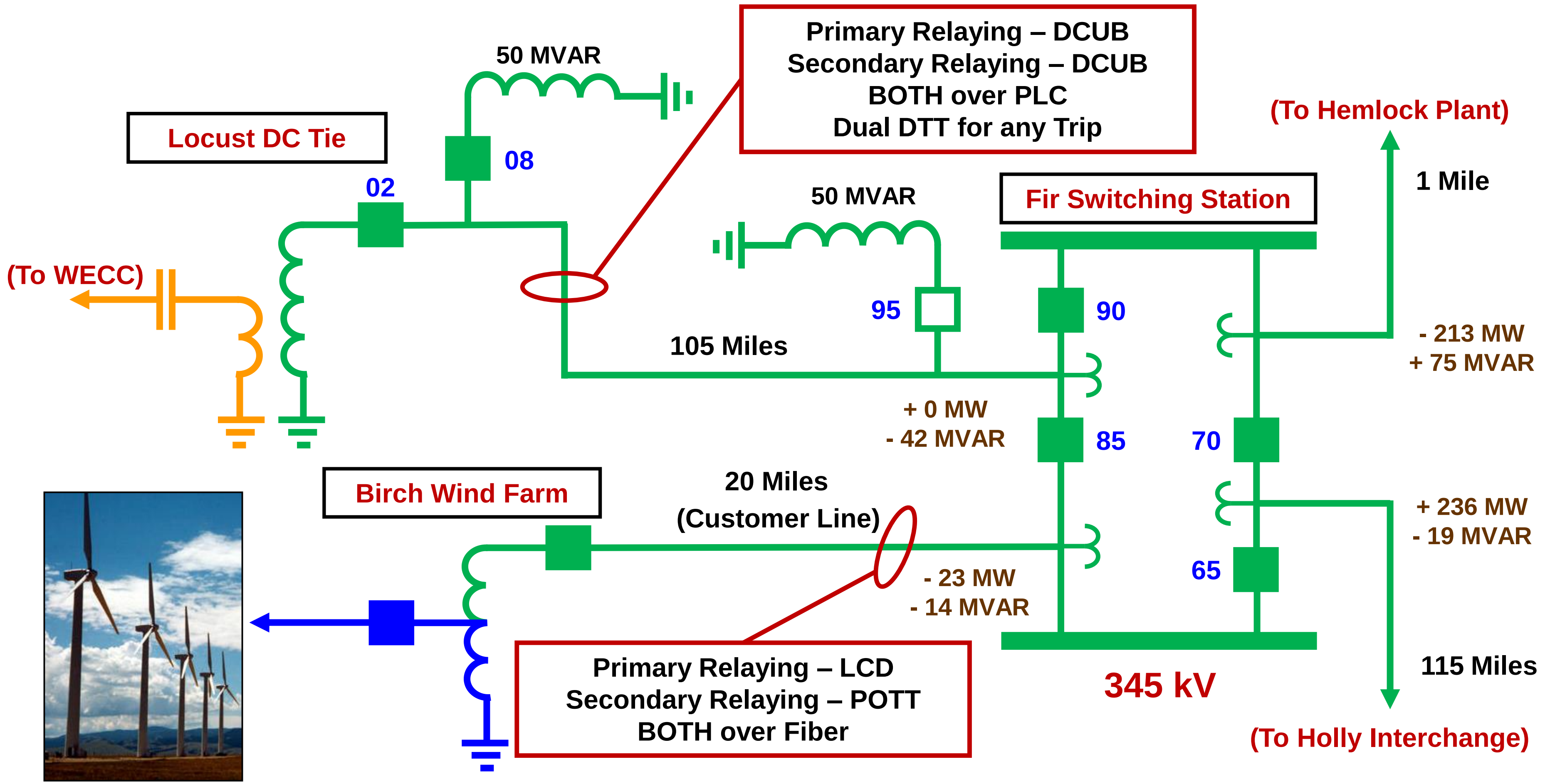
Presented by Kevin W. Jones, P.E.

Consulting Engineer, System Protection Engineering

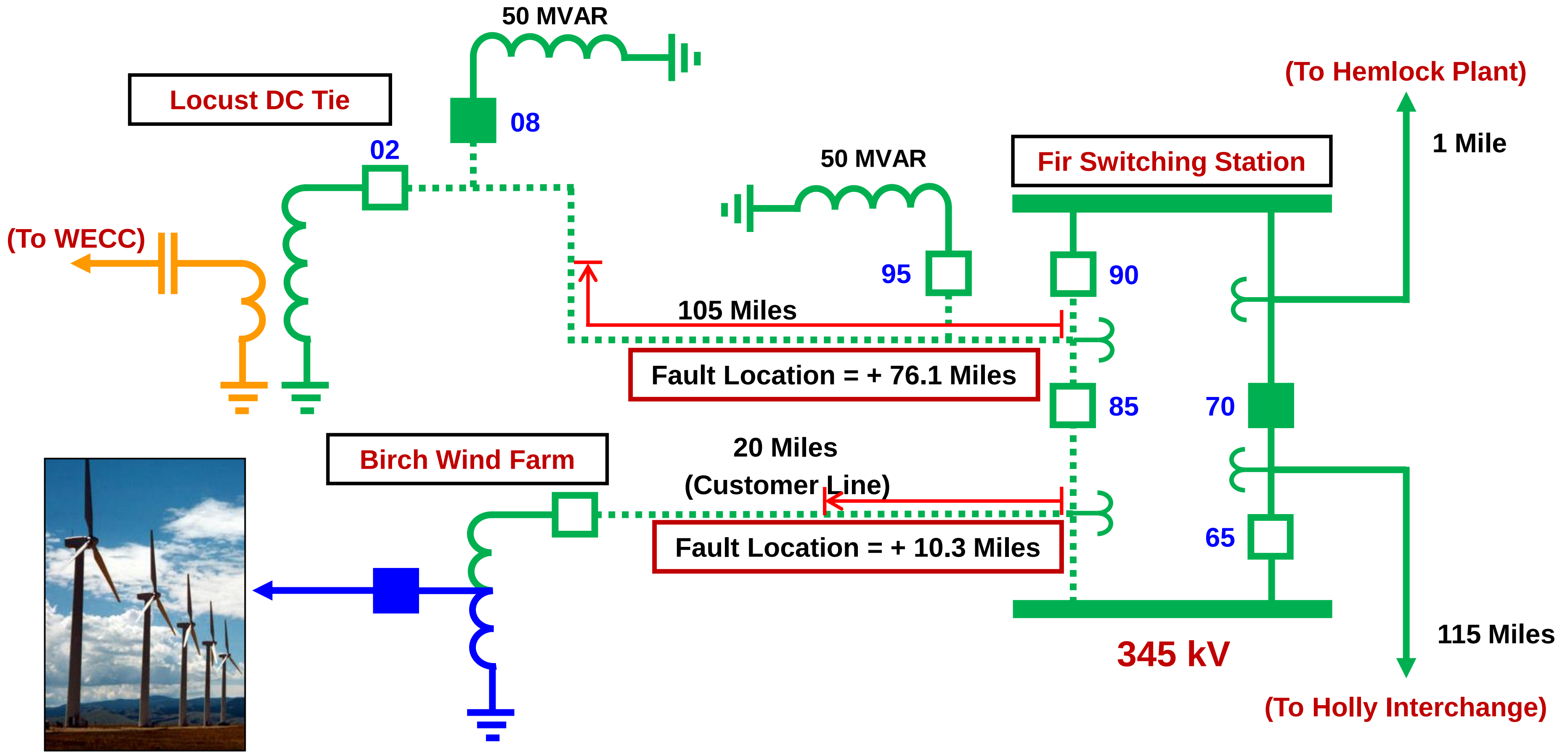
69th Annual Conference for Protective Relay Engineers

April 6, 2016

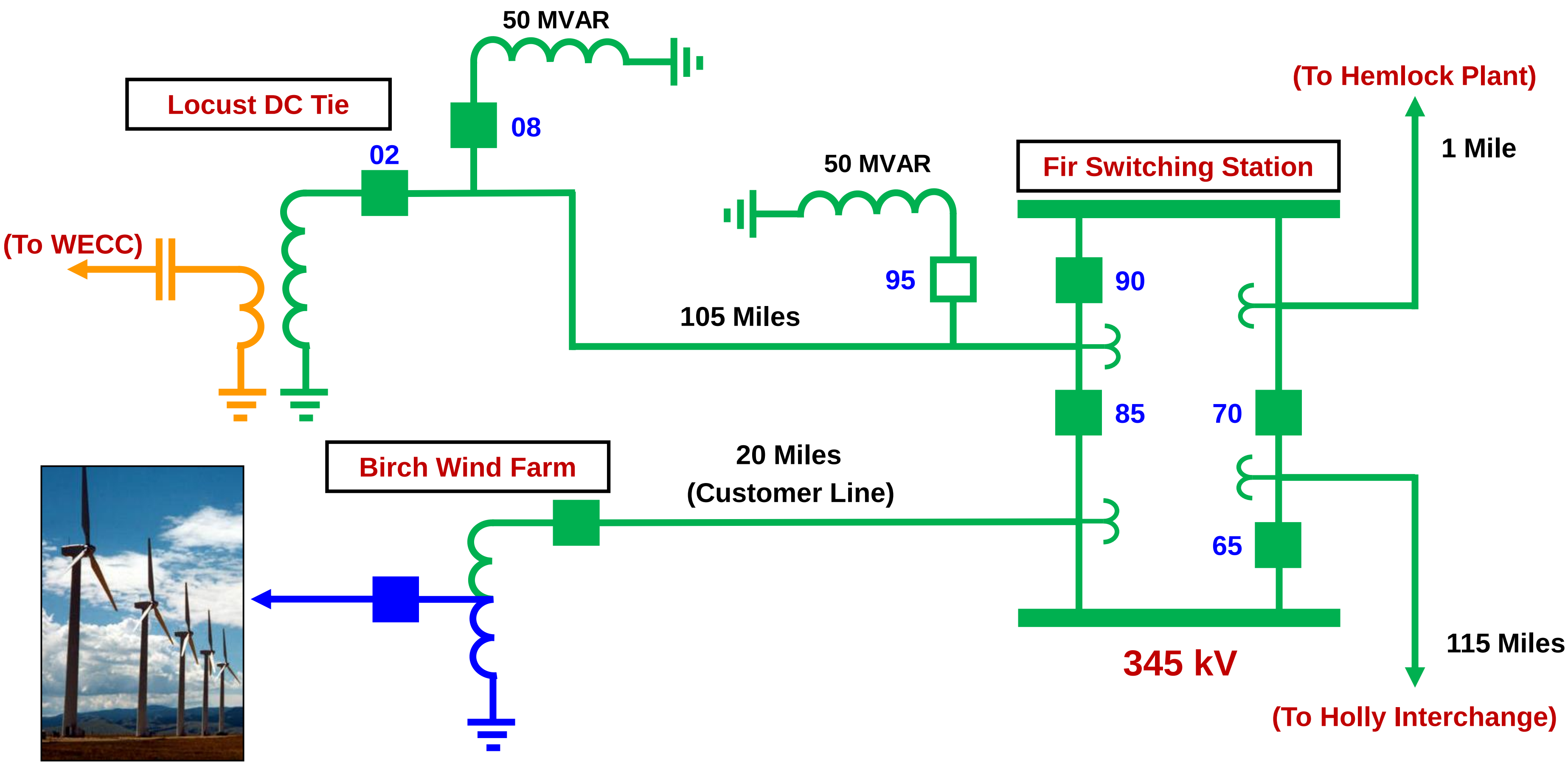
Pre-Disturbance System Configuration



Post-Disturbance System Configuration



Sequence Of Events (SOE) Analysis



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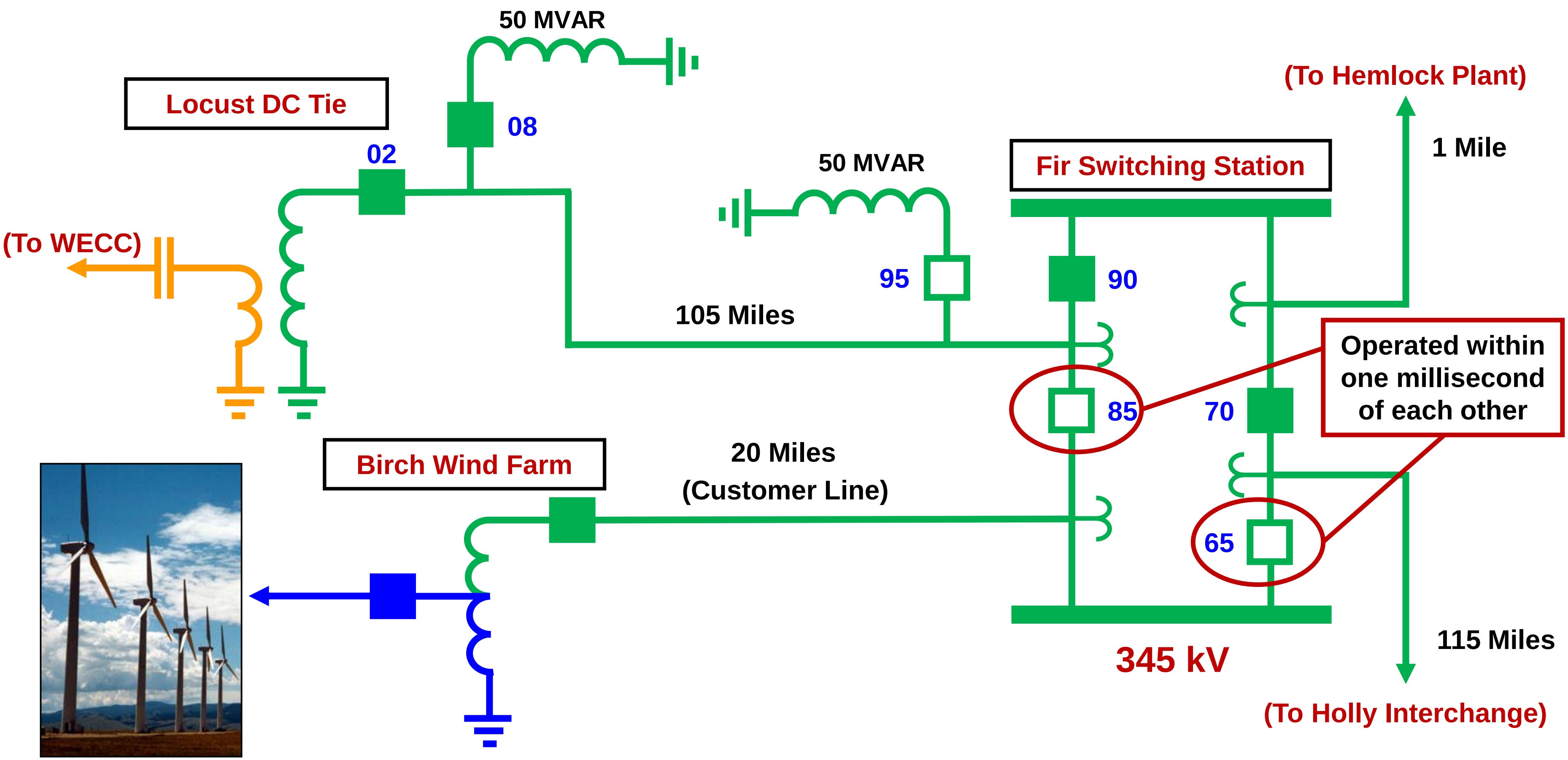

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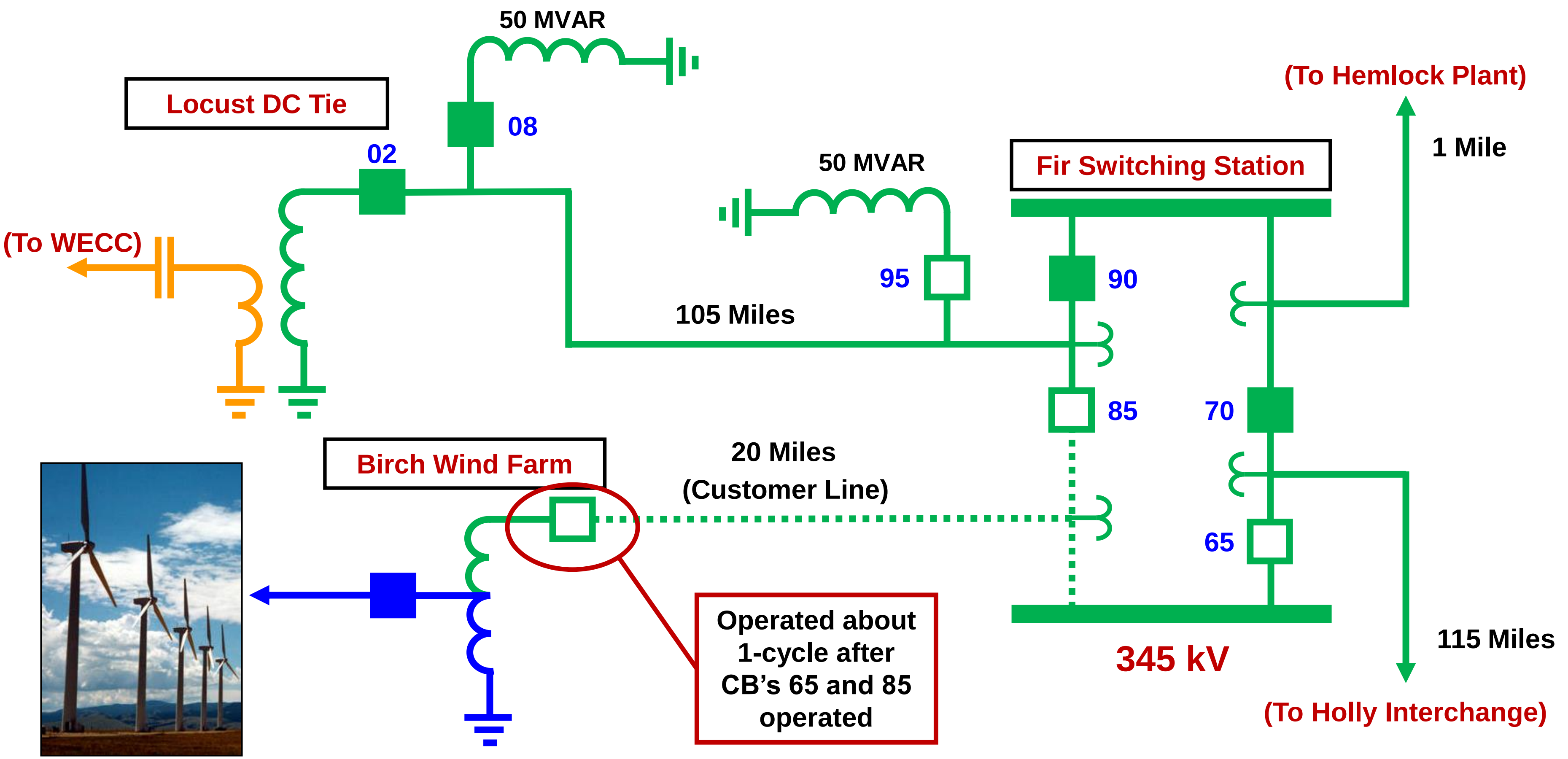

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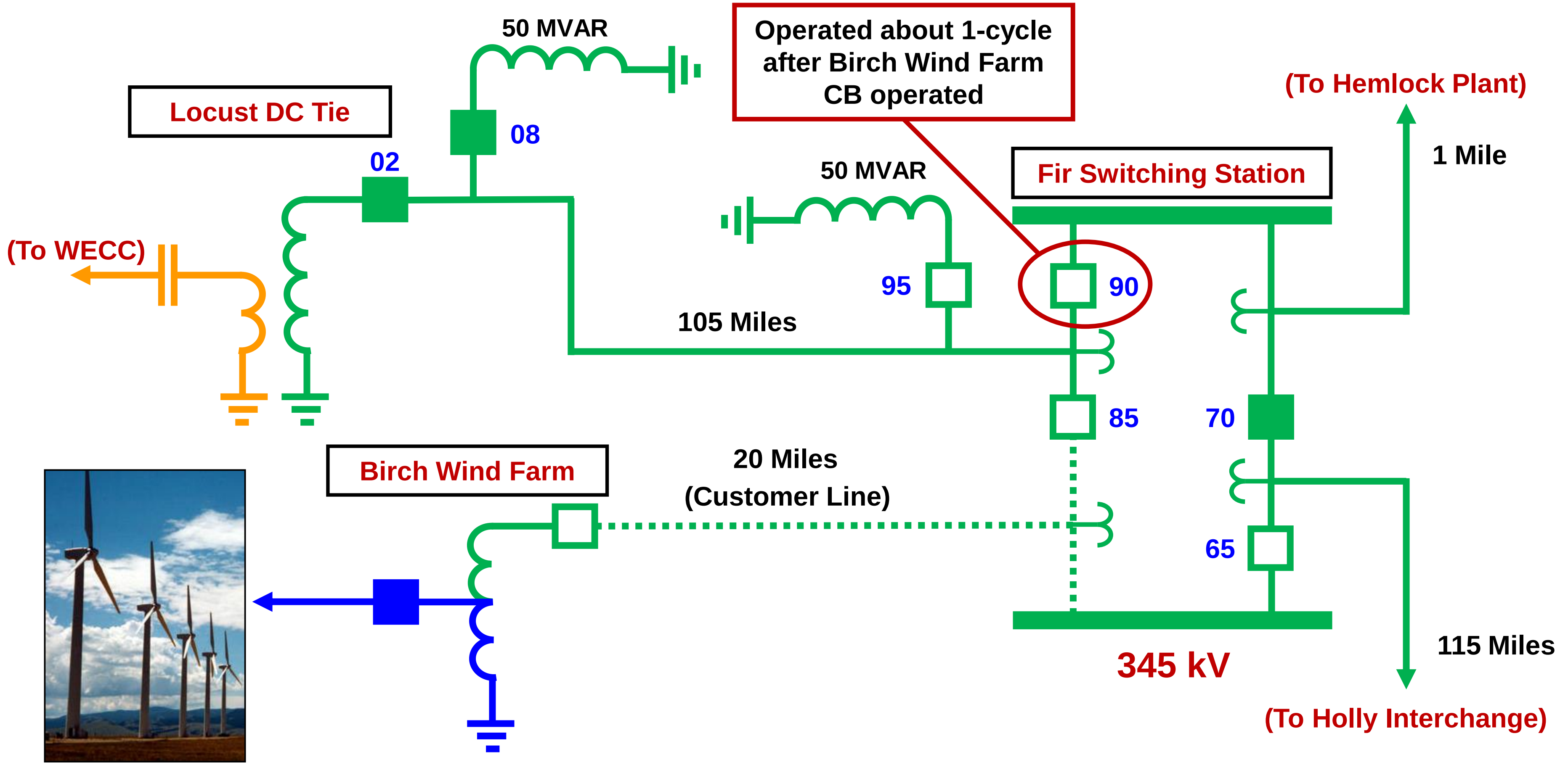

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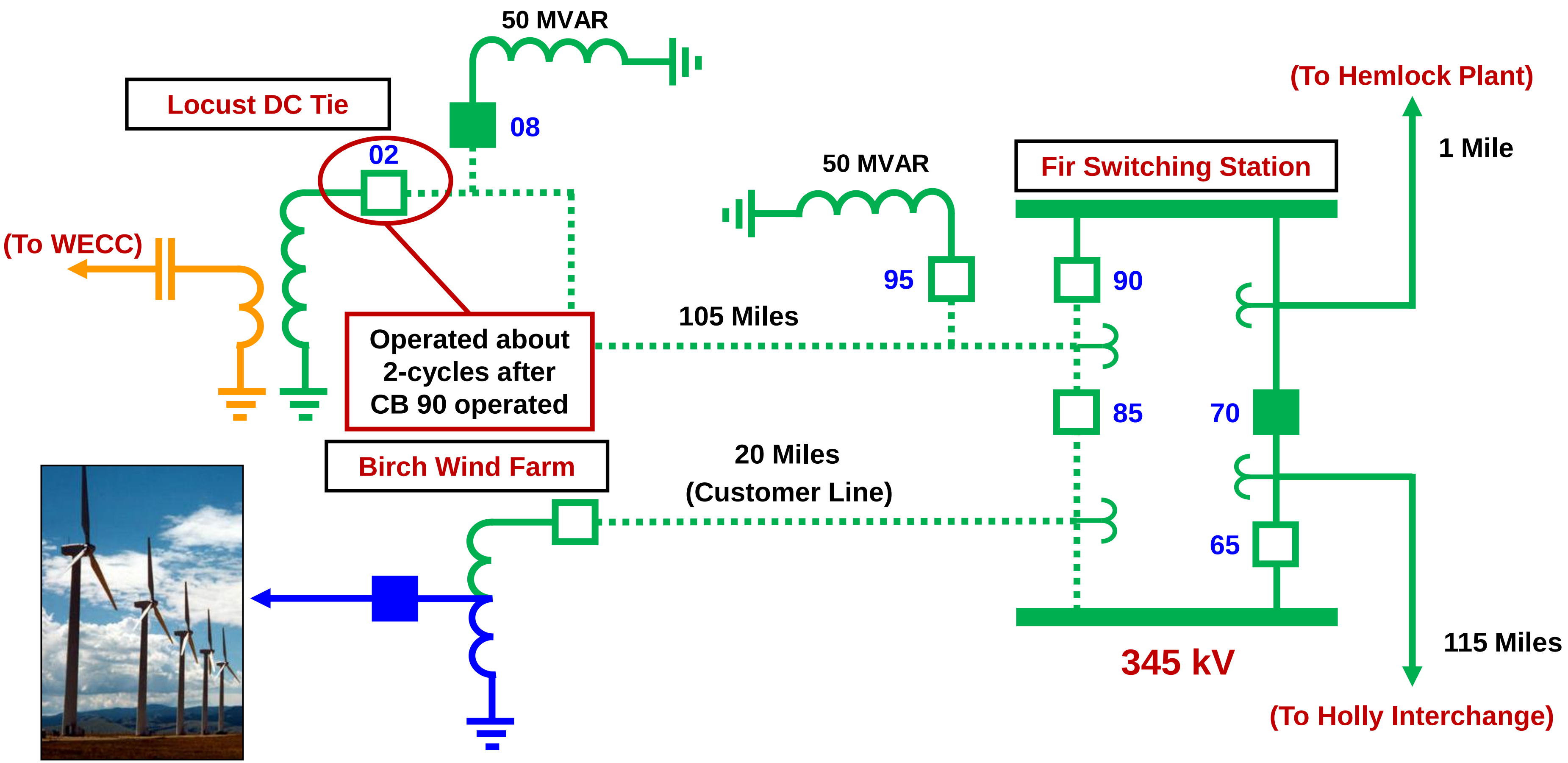
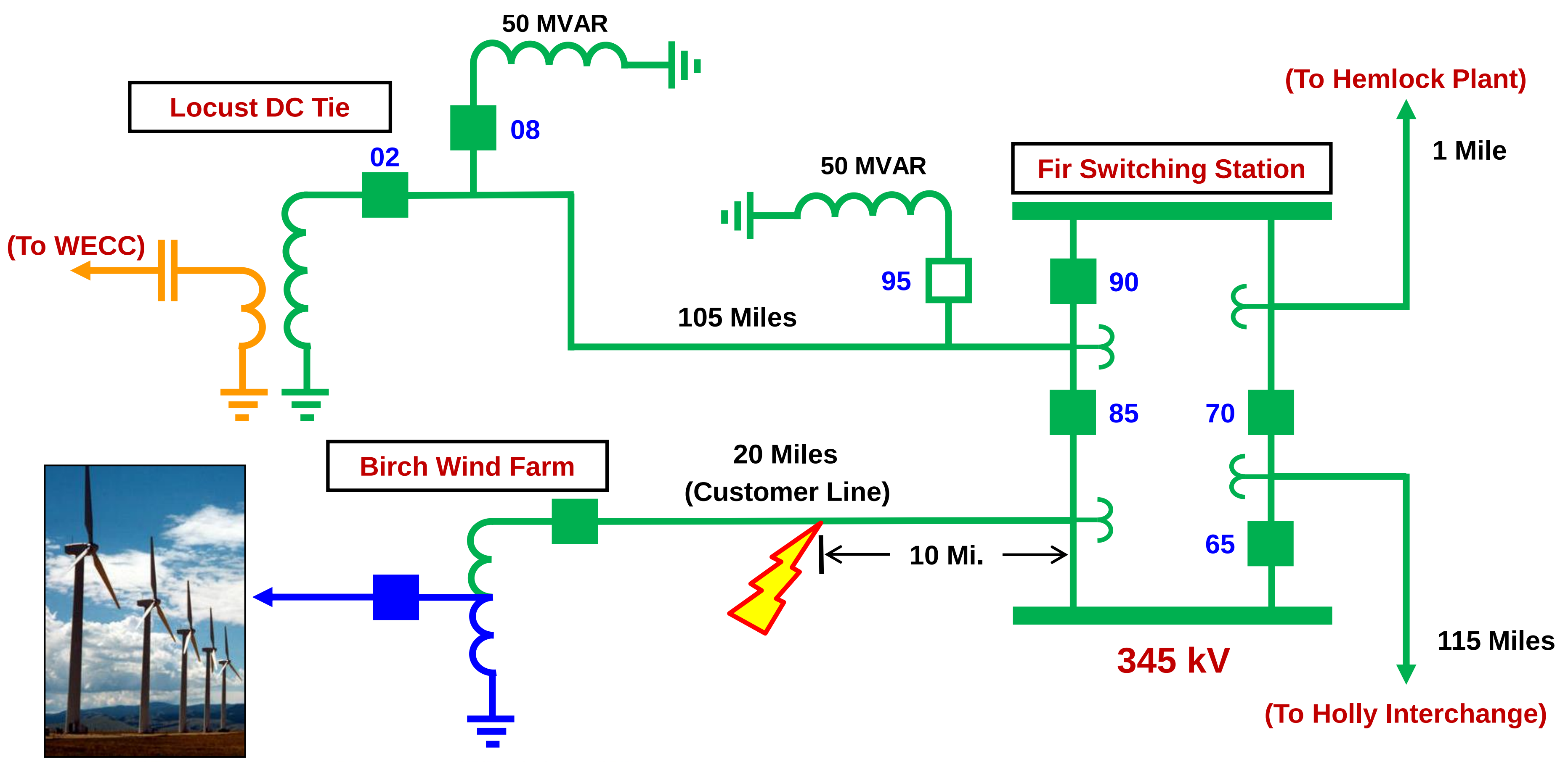
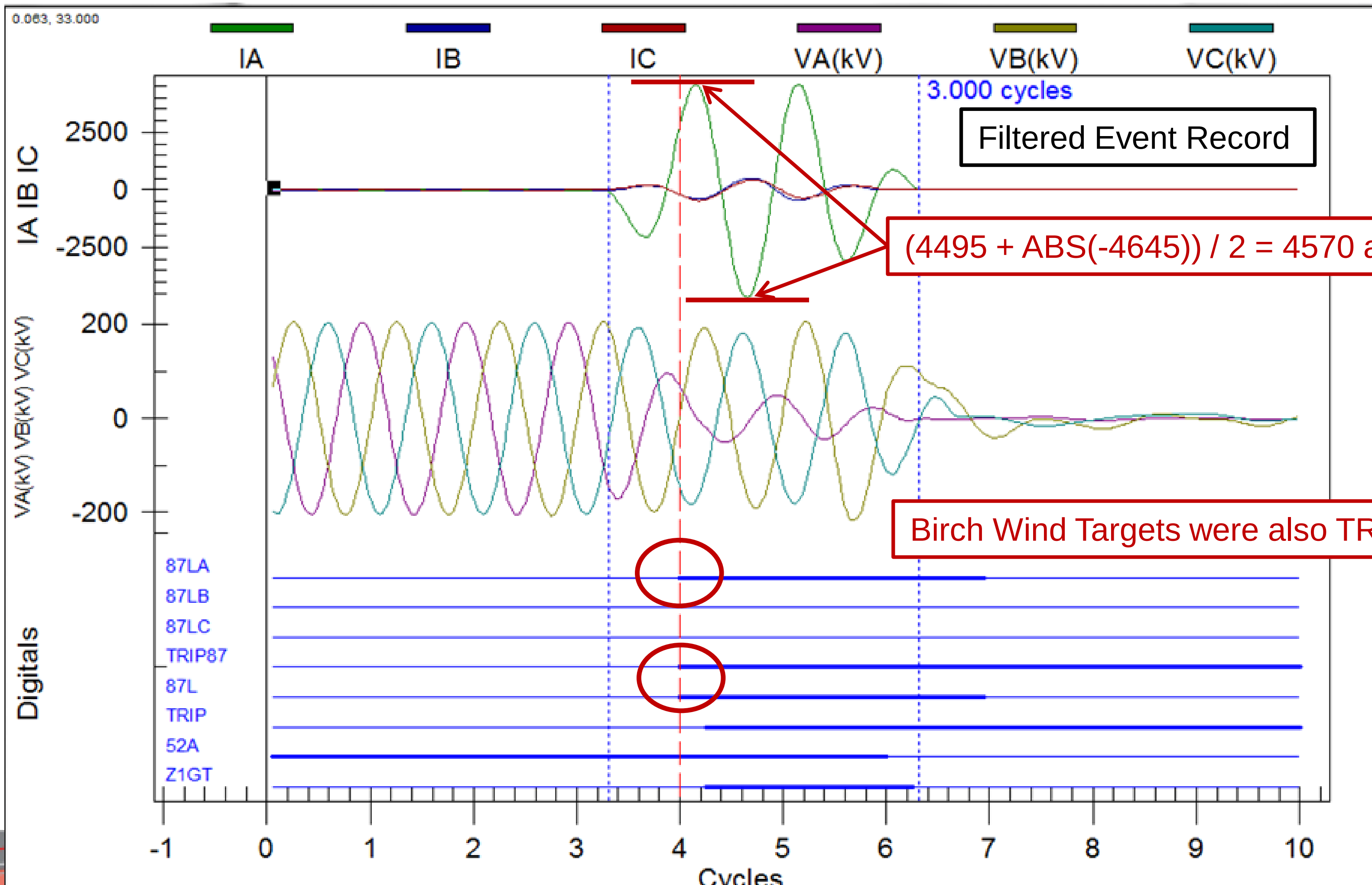


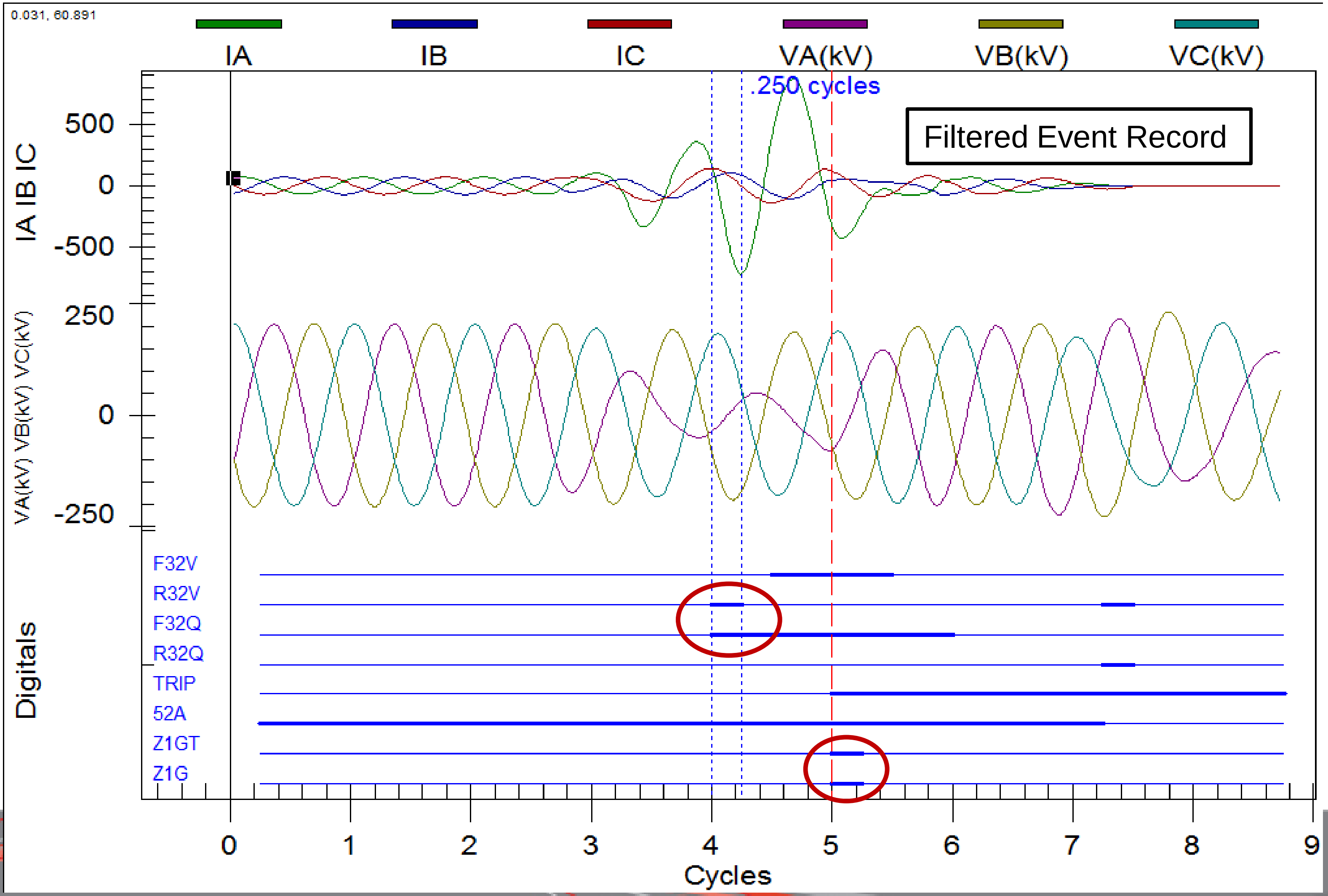
Lightning Analysis



Fir – Birch Event Record Analysis



Fir – Locust Event Record Analysis



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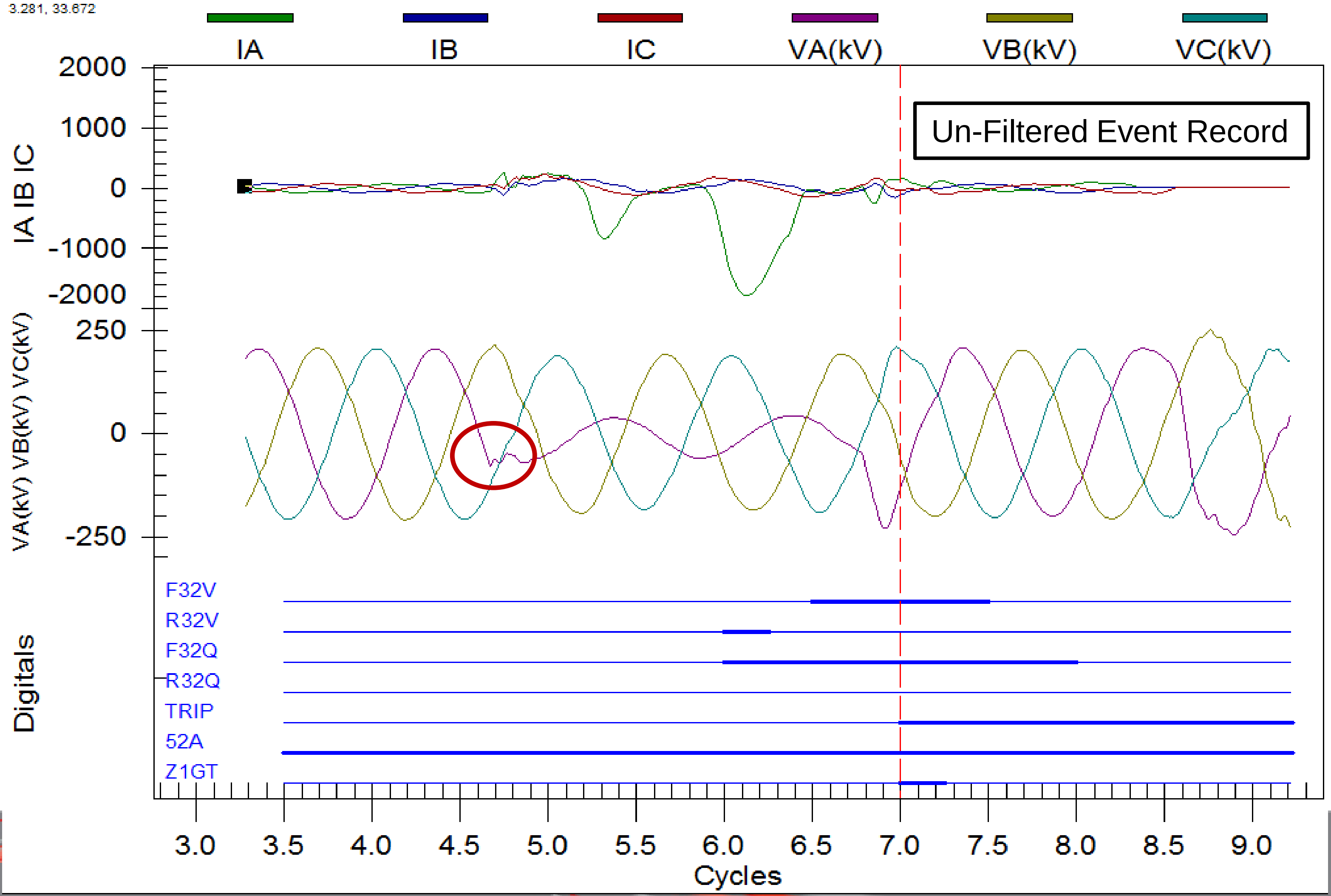

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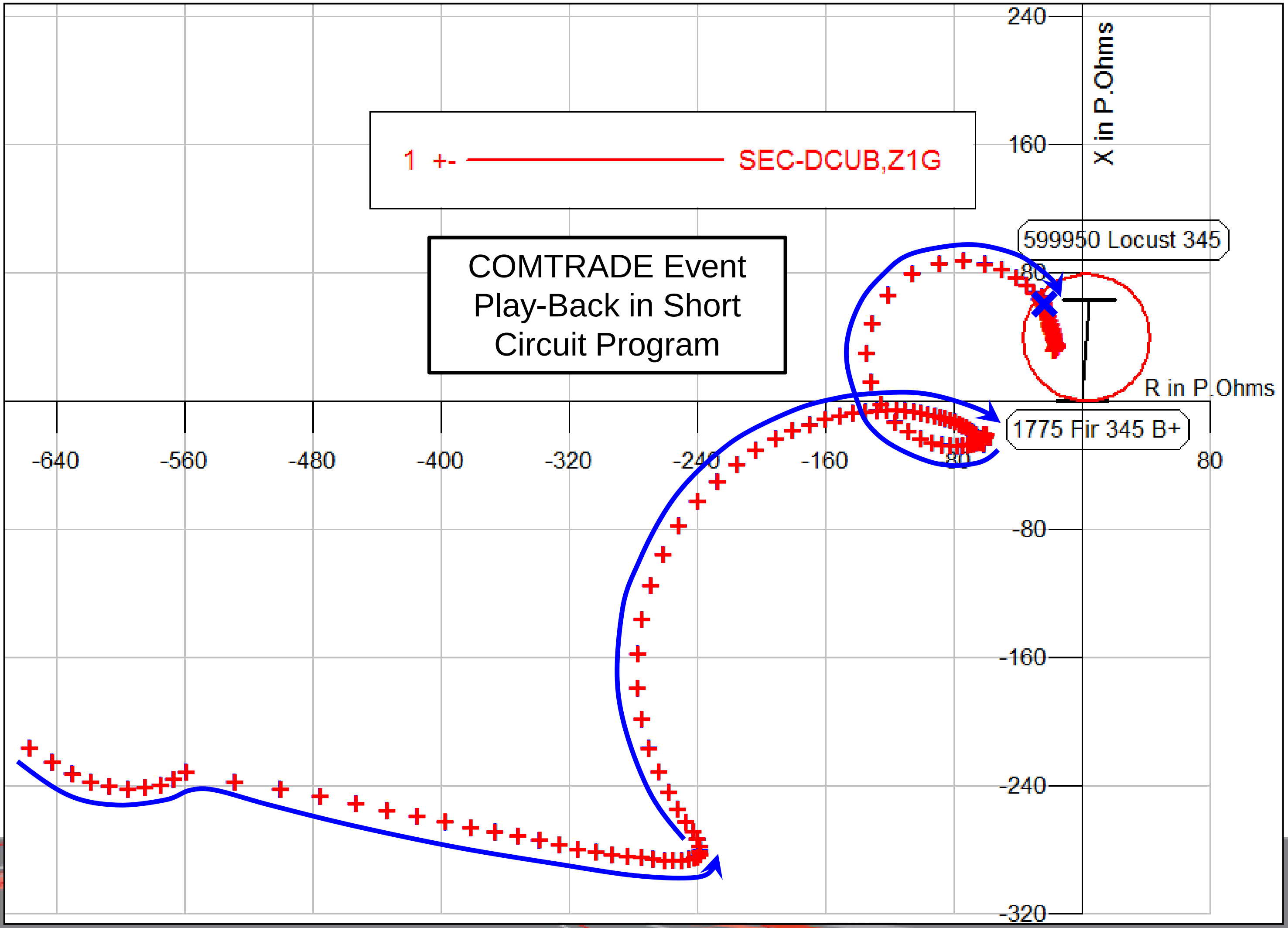


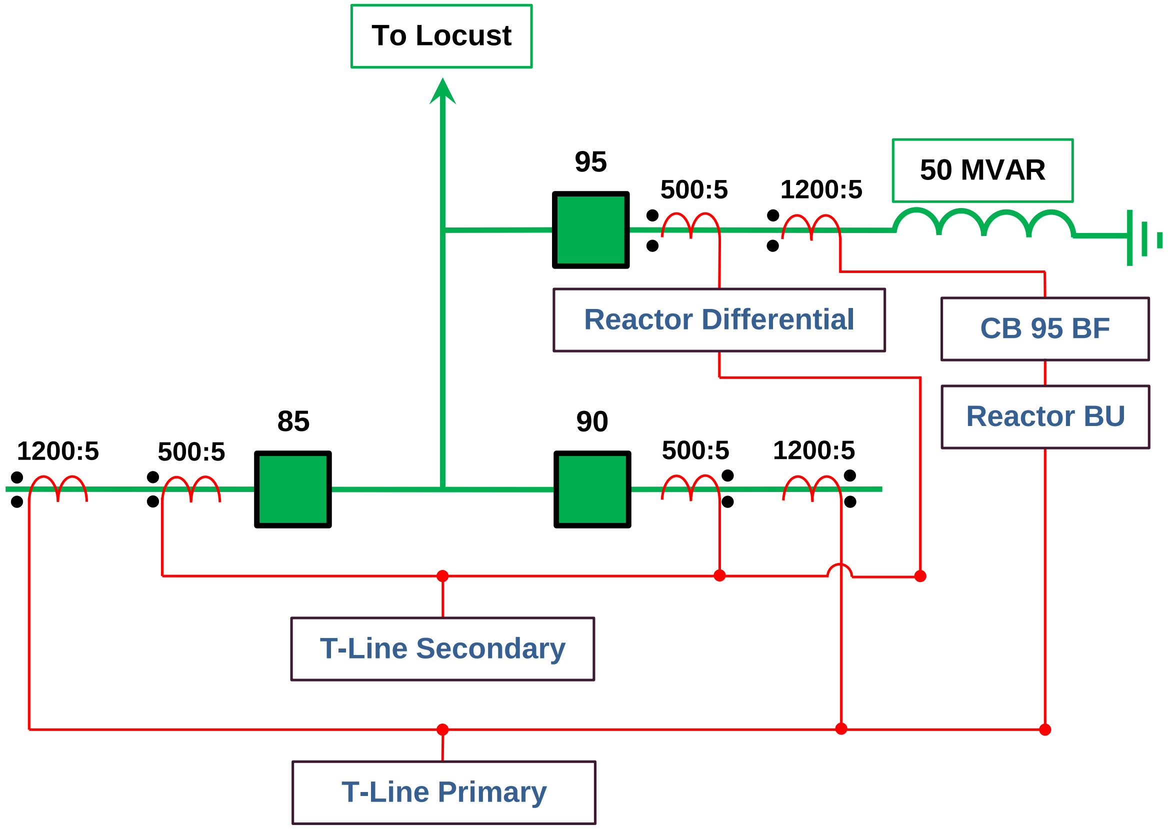
Preliminary Fault Analysis Conclusions

- A lightning induced fault occurred on the Fir to Birch 345 kV line.
- Fir to Birch operated correctly at both ends to clear the fault.
- The Locust end of the Fir to Locust line correctly operated on receive DTT.
- The Fir end of the Fir to Locust line incorrectly tripped due to unknown transient condition.

HELP!!!

- Consulted with a relay manufacturer engineer.
- Engineer's analysis concluded that a CT was severely saturated and caused the mis-operation.

CT Saturation Theory Investigation



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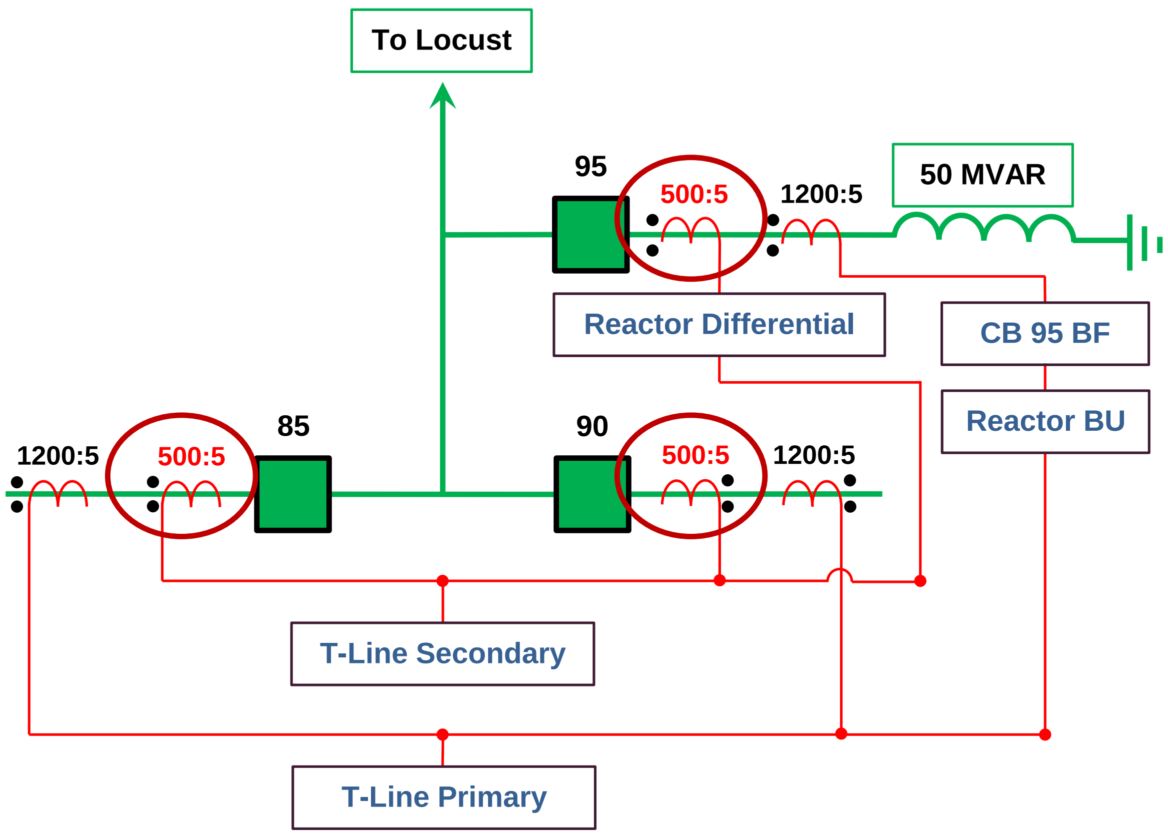

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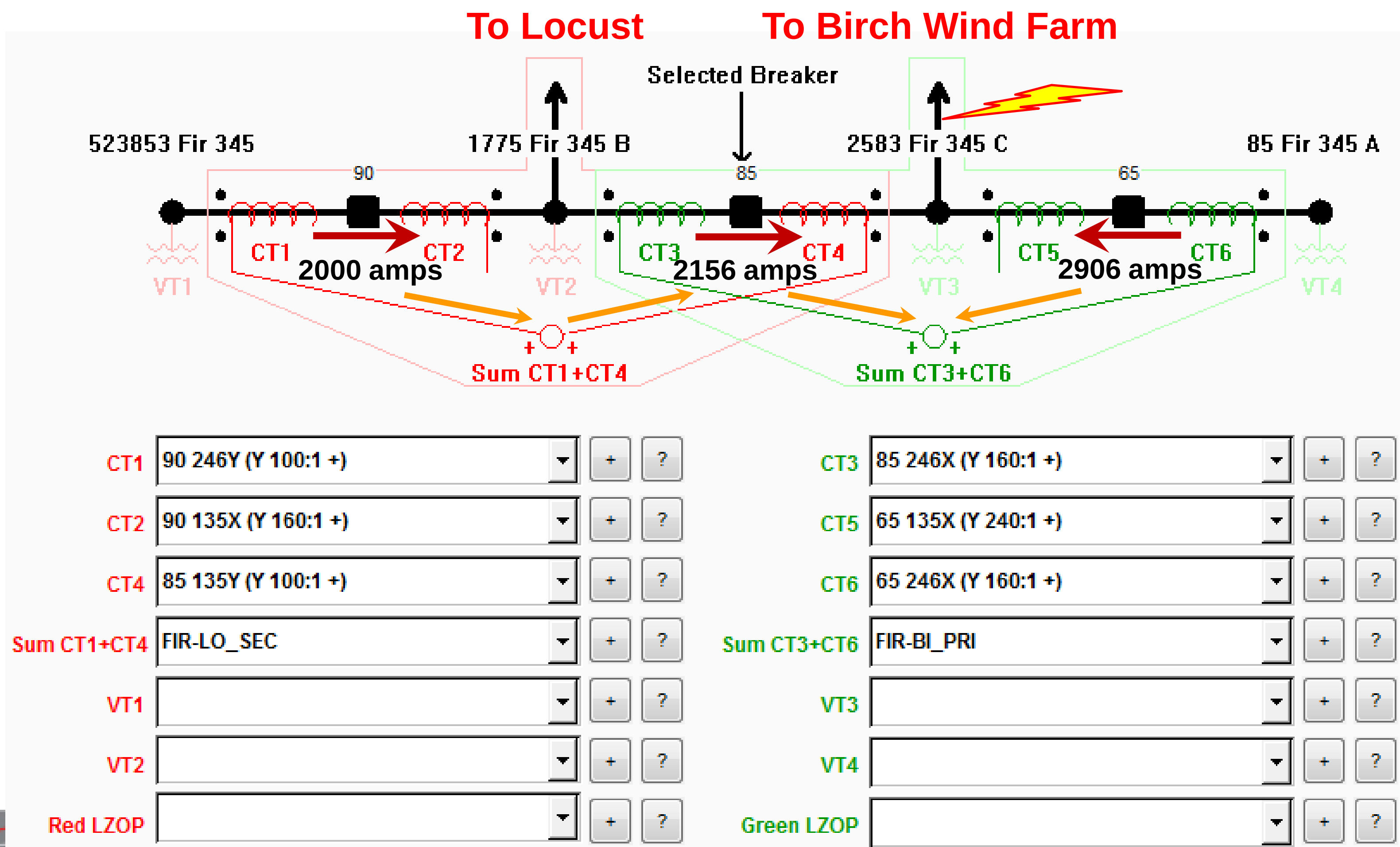

CT Saturation Theory Investigation CB 85

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Sheet 1: CALCULATOR (this sheet)
Sheet 2: INSTRUCTIONS
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CT Saturation Calculator

Excel Spread Sheet
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Contact: gswift@nxtphase.com
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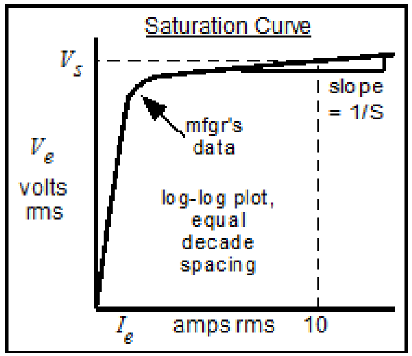
30 Dec 2002

ASSUMPTIONS: CT core losses and sec'y reactance zero (thru-hole primary). Frequency: 60 Hz
CT primary current is zero for t<0. CT is 5 amp nominal Time step = 1/12,000 second.

INPUT PARAMETERS:

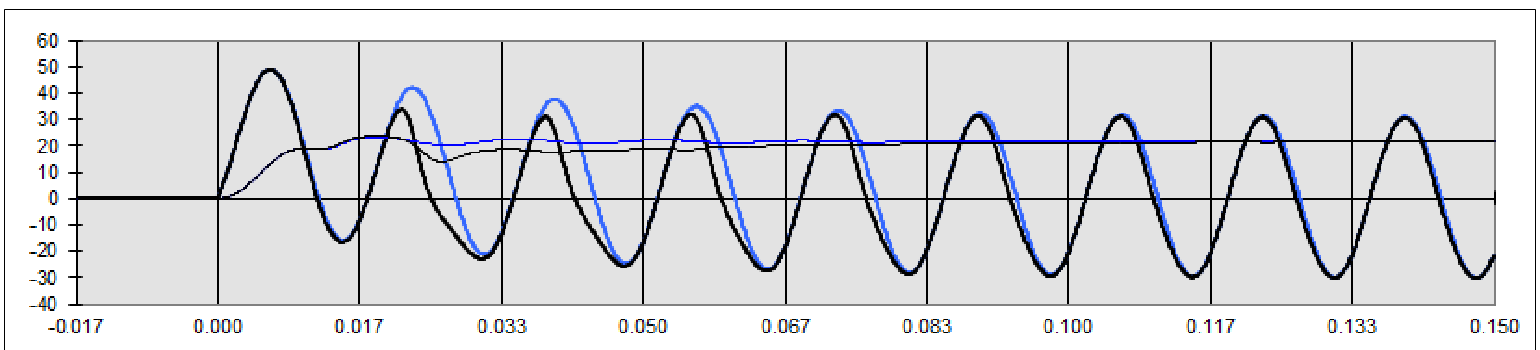
		ENTER:	
Inverse of sat. curve slope =	S =	25.5	---
RMS voltage at 10A exc. current =	Vs =	210	volts rms
Turns ratio = n2/1=	N =	100	---
Winding resistance =	Rw =	0.100	ohms
Burden resistance =	Rb =	0.870	ohms
Burden reactance =	Xb =	0.087	ohms
System X/R ratio =	XoverR =	13.5	---
Per unit offset in primary current =	Off =	-0.72	-1<Off<1
Per unit remanence (based on Vs) =	λrem	0.48	---
Symmetrical primary fault current =	Ip =	-2,156	amps rms



CALCULATED:

Rt =	Total burden resistance = Rw + Rb =	0.970	ohms
pf =	Total burden power factor =	0.996	---
Zb =	Total burden impedance =	0.974	ohms
Tau1 =	System time constant =	0.036	seconds
Lamsat =	Peak flux-linkages corresponding to Vs	0.788	Wb-turns
ω =	Radian freq =	376.99	rad/s
RP =	Rms-to-peak ratio =	0.33344	
A =	Coefficient in instantaneous ie versus lambda curve: ie = A * l^S :	1.31E+04	---
dt =	Time step =	0.000083	seconds
Lb =	Burden inductance =	0.00023	henries

Thick lines: Ideal (blue) and **actual (black)** secondary current in amps vs time in seconds.
Thin lines: Ideal (blue) and **actual (black)** secondary current extracted fundamental rms value, using a simple DFT with a one-cycle window.



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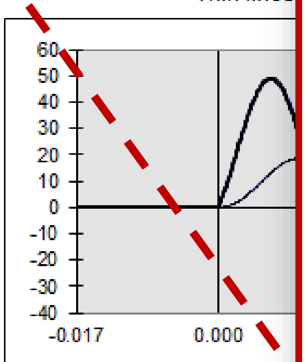

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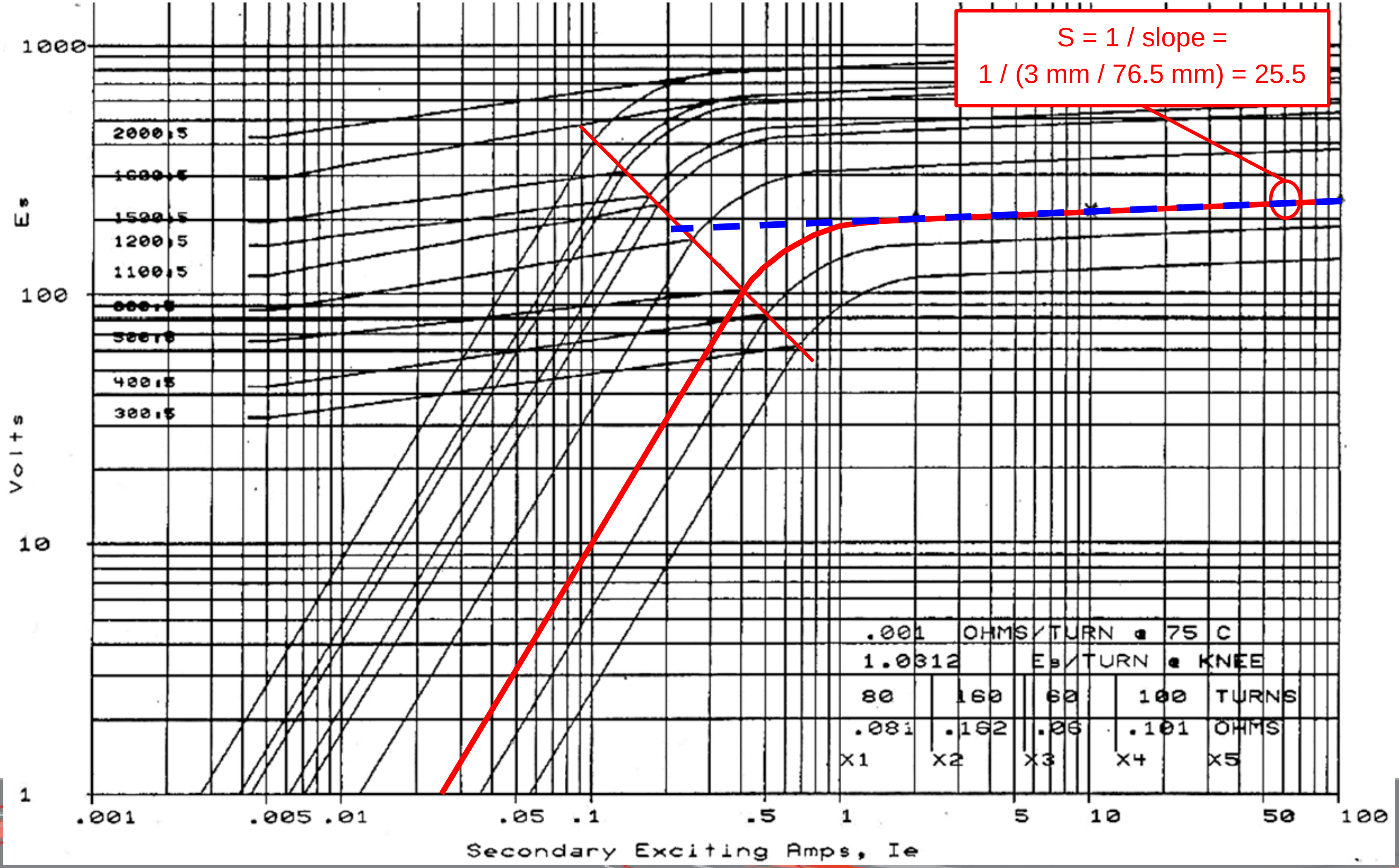

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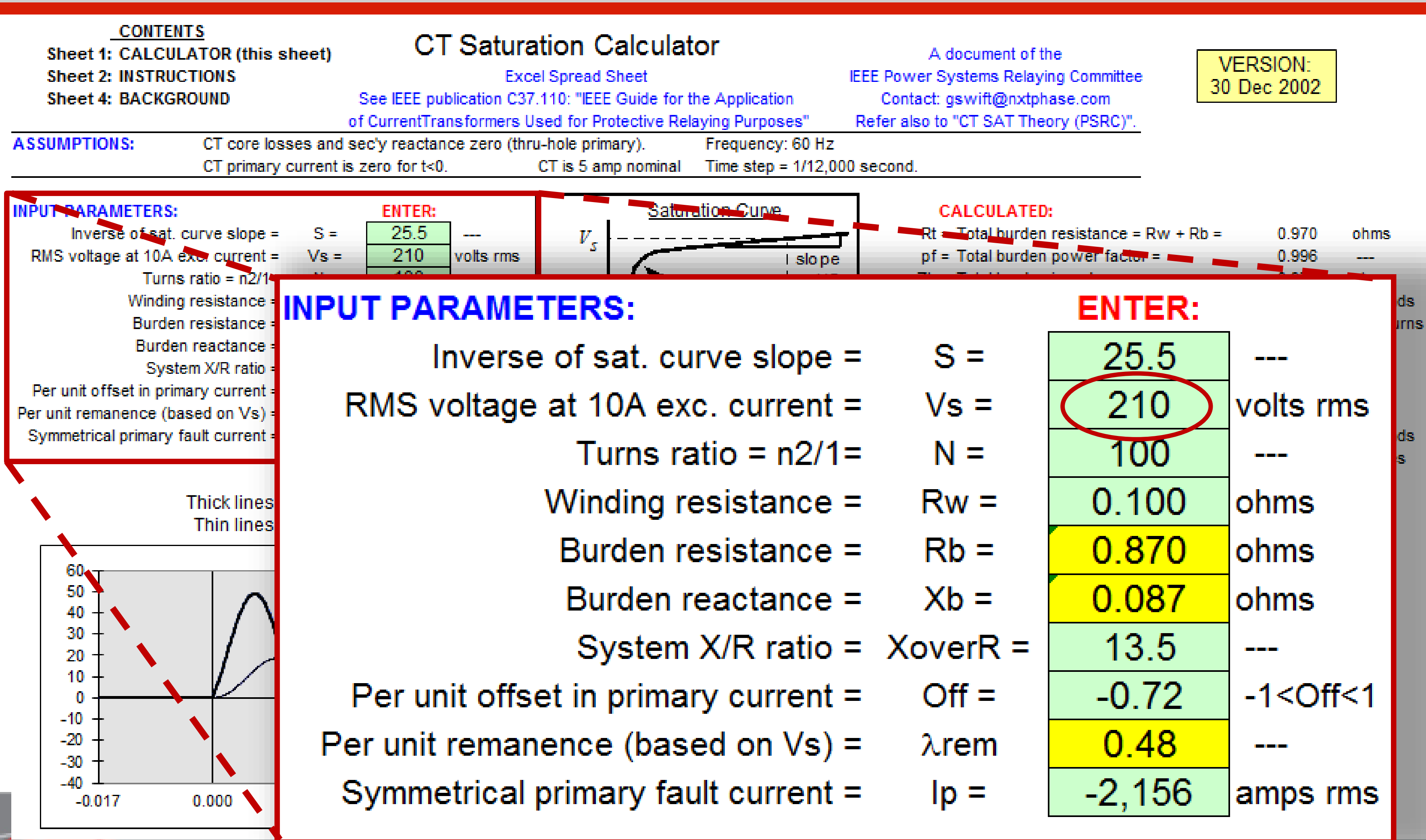

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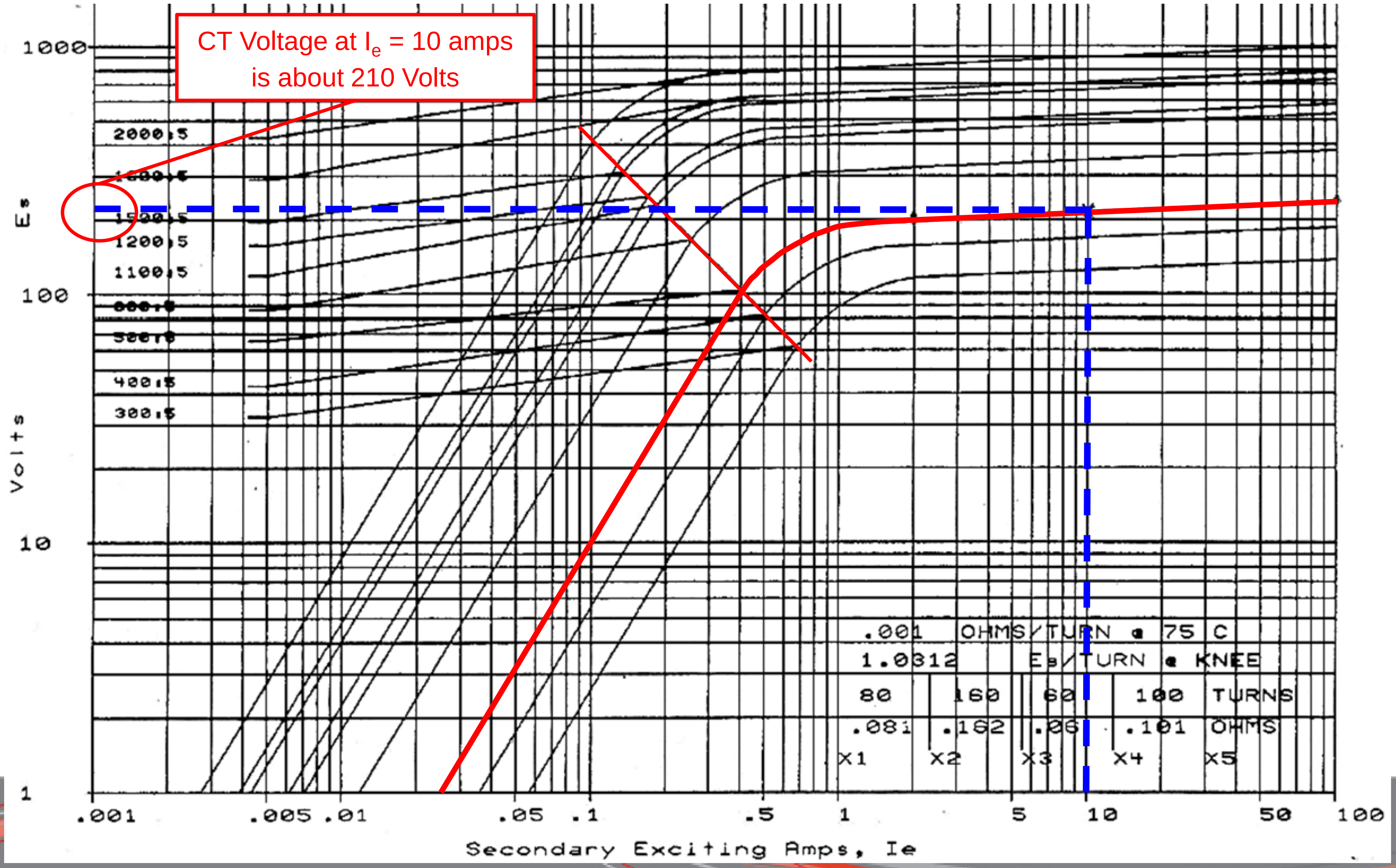

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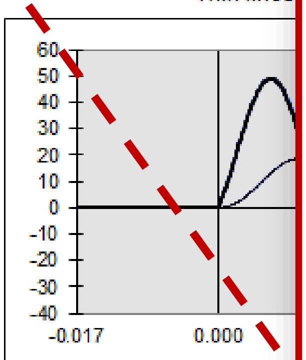

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Saturation Curve

V_s

slope

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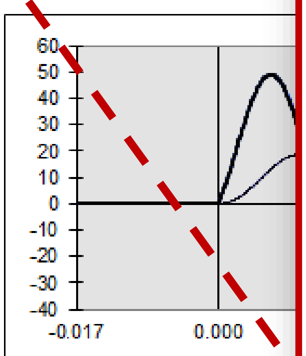

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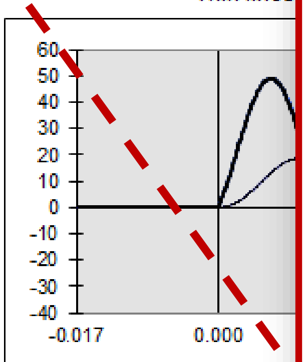

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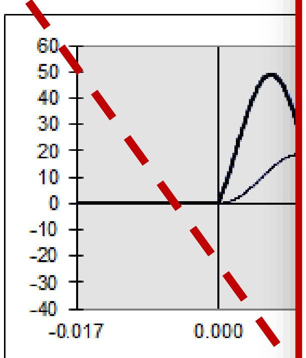

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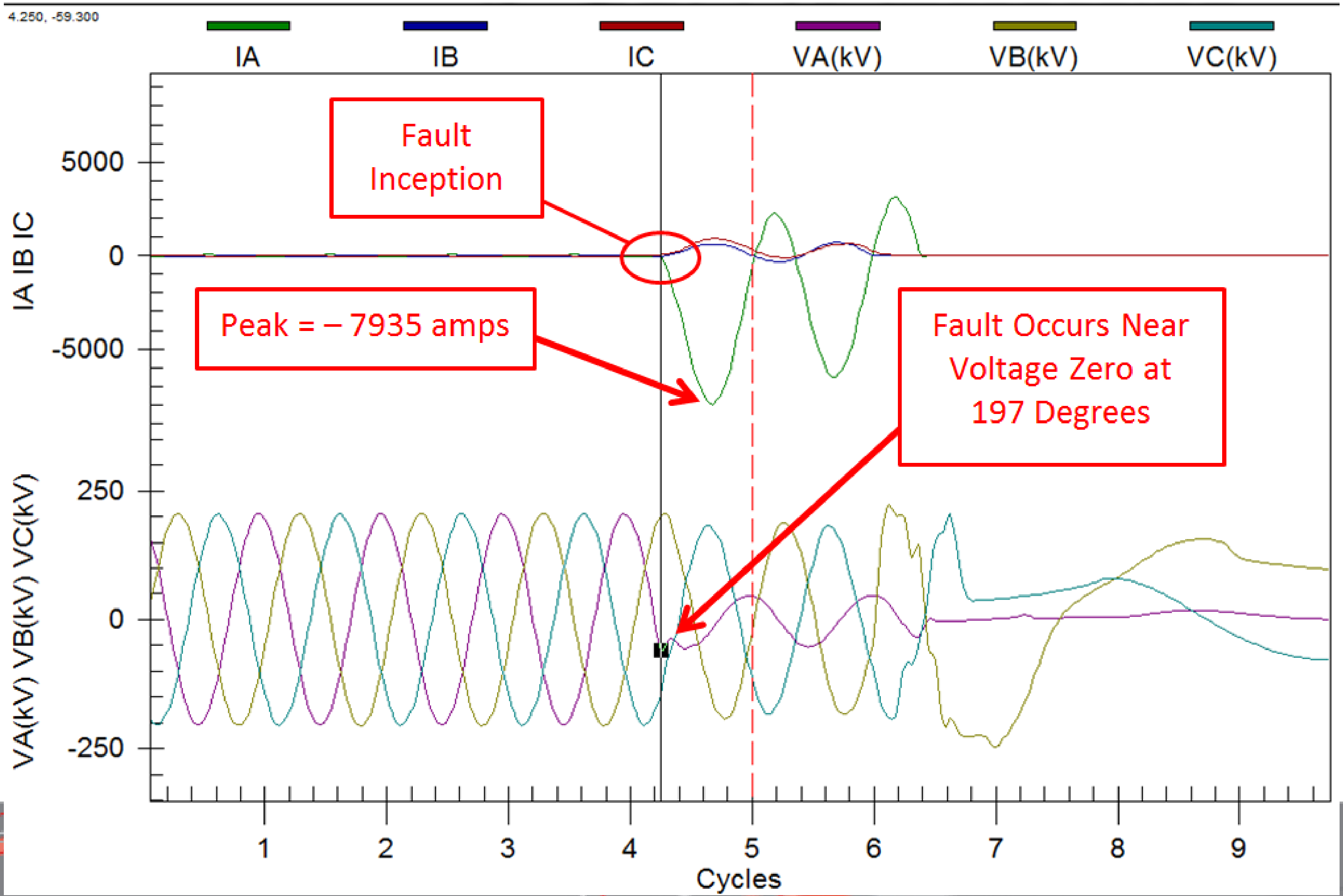

CT Saturation Theory Investigation CB 85

DC Offset Calculator

$f := 60$ hertz $\qquad \omega := 2\cdot\pi\cdot f \qquad I_{max} := 4570$ amps (peak)

$R := 1.322 \qquad X := 14.498 \qquad L := \frac{X}{\omega}$

$\theta := \operatorname{atan}\left(\frac{X}{R}\right) \qquad \theta = 84.7899\cdot deg$

The percent DC offset at 197 degrees is:
(|–7863| – 4570) / 4570 * 100 = 72.06%

$\alpha := 197\cdot deg$ (angle of voltage on faulted phase at fault inception)

$T_c := \frac{L}{R}\cdot 60 \qquad T_c = 1.7454$ cycles (time constant)

$$I(t) := I_{max}\cdot\left(\sin(\omega\cdot t + \alpha - \theta) - e^{-R\cdot\frac{t}{L}}\cdot\sin(\alpha - \theta)\right)$$ amps (peak) theoretical

$$I_{max}\cdot\left(\sin(\omega\cdot 0.00729167 + \alpha - \theta) - e^{-R\cdot\frac{0.00729167}{L}}\cdot\sin(\alpha - \theta)\right) = -7863 \text{ amps}$$

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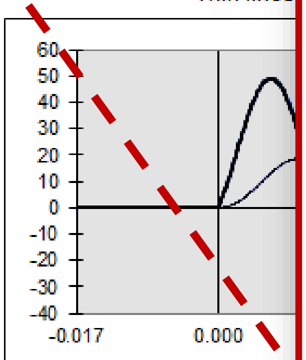

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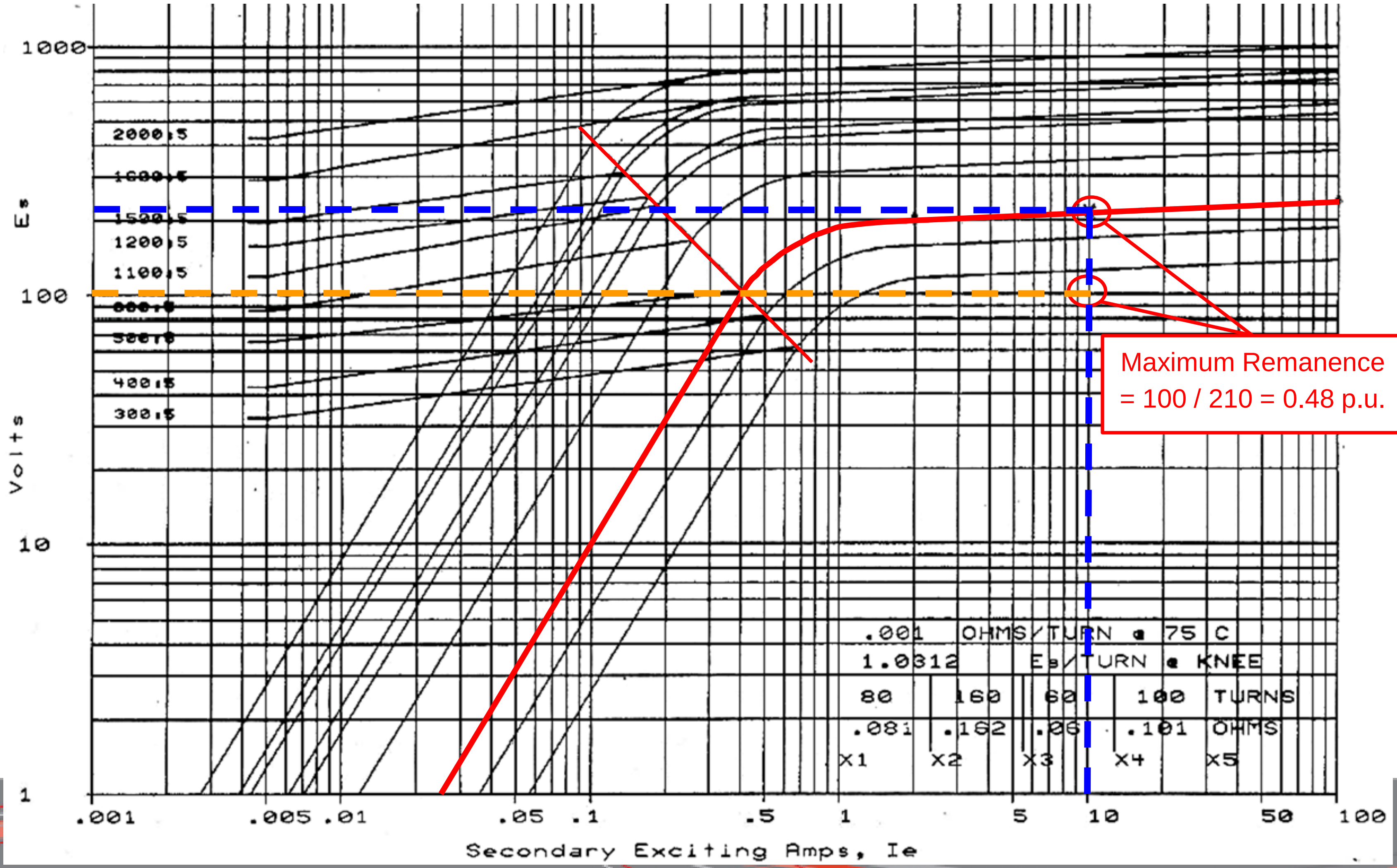

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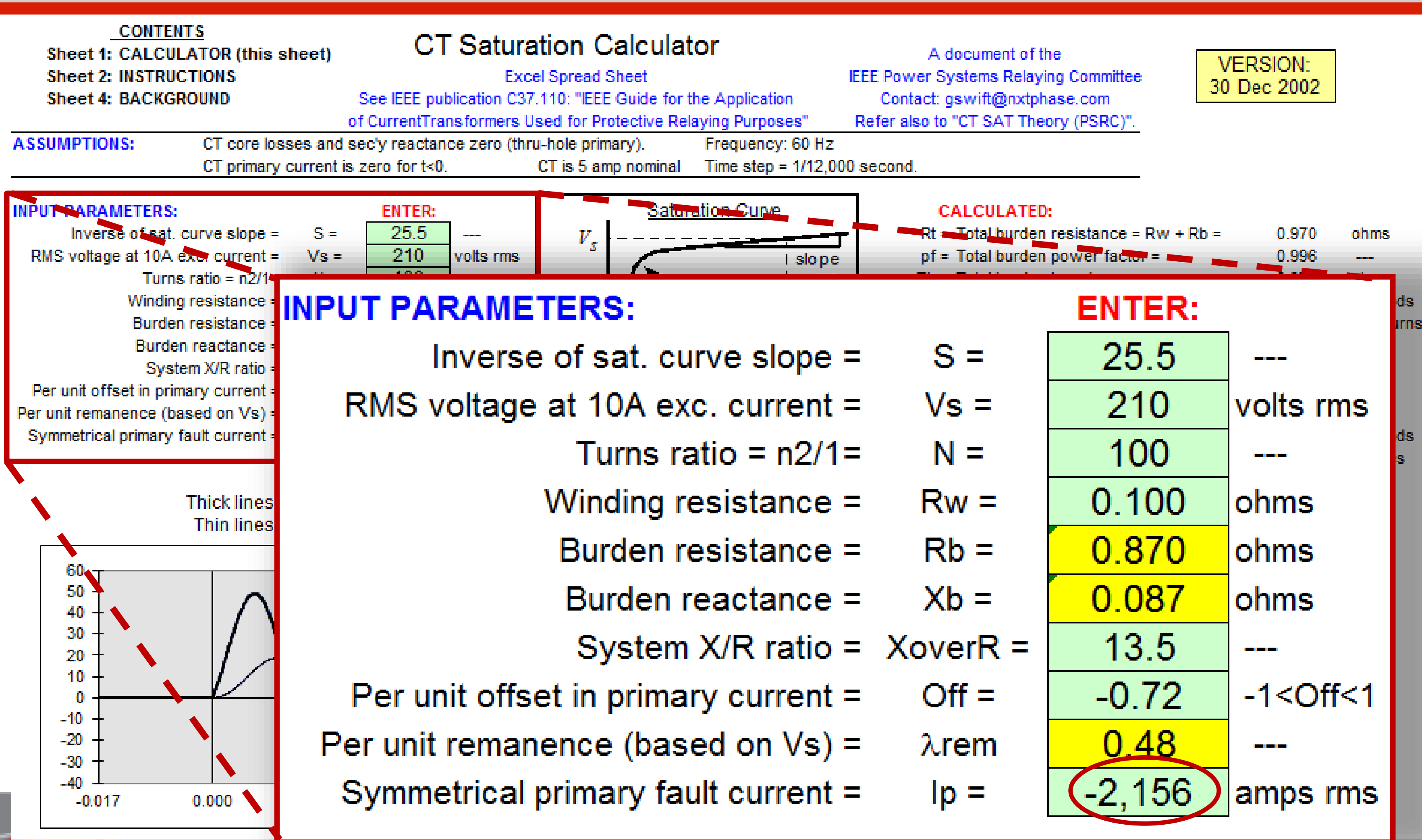

CT Saturation Theory Investigation CB 90

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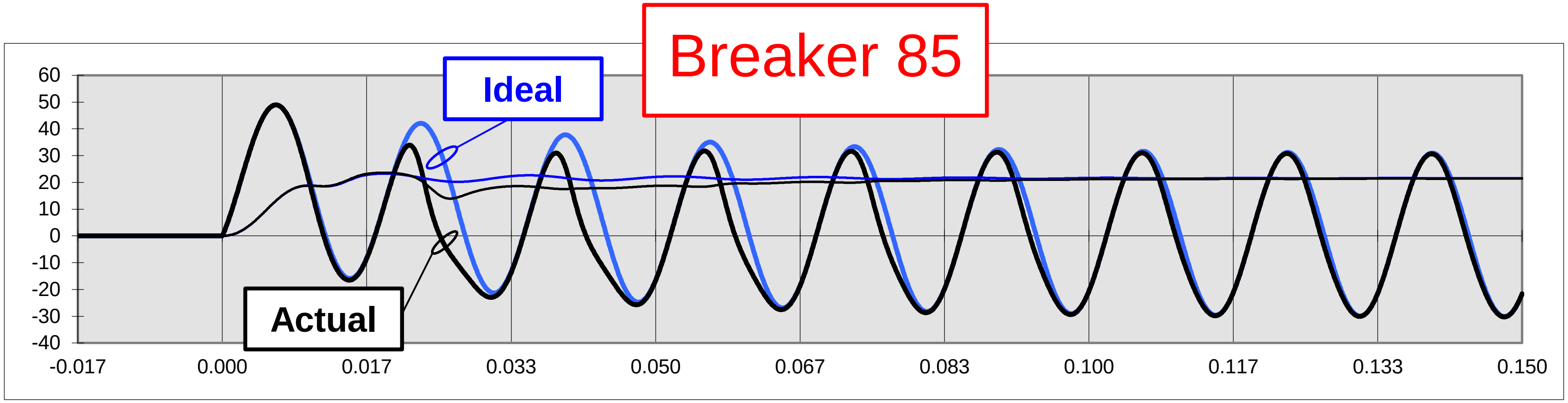
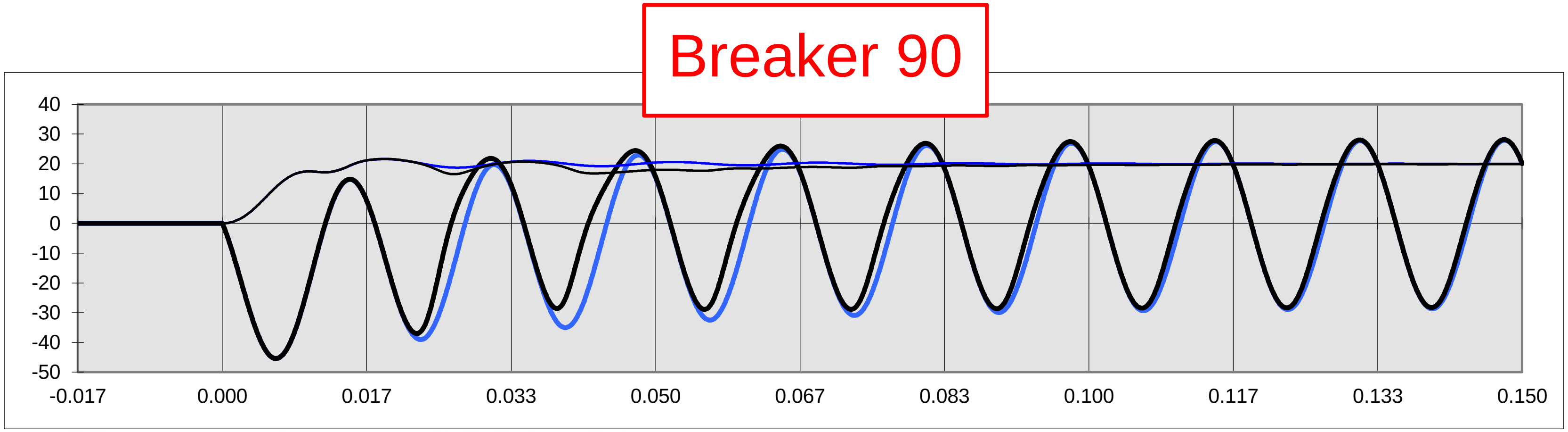
Turns ratio = n2/1=	N =	100	---
Winding resistance =	Rw =	0.100	ohms
Burden resistance =	Rb =	0.750	ohms
Burden reactance =	Xb =	0.075	ohms
System X/R ratio =	XoverR =	13.5	---
Per unit offset in primary current =	Off =	-0.72	-1<Off<1
Per unit remanence (based on Vs) =	λrem	-0.48	---
Symmetrical primary fault current =	Ip =	2,000	amps rms

CT Saturation With 500:5 CT Ratio





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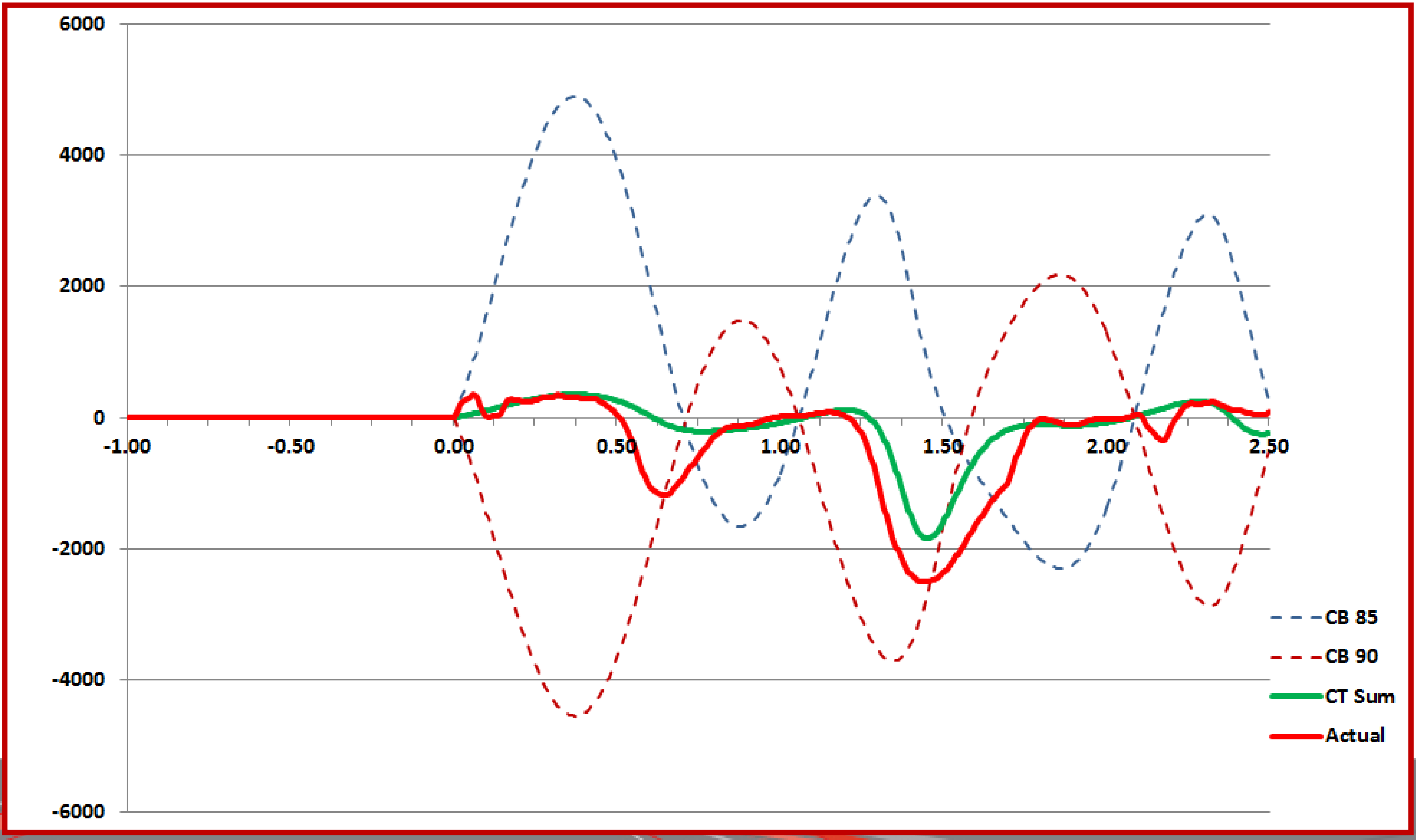

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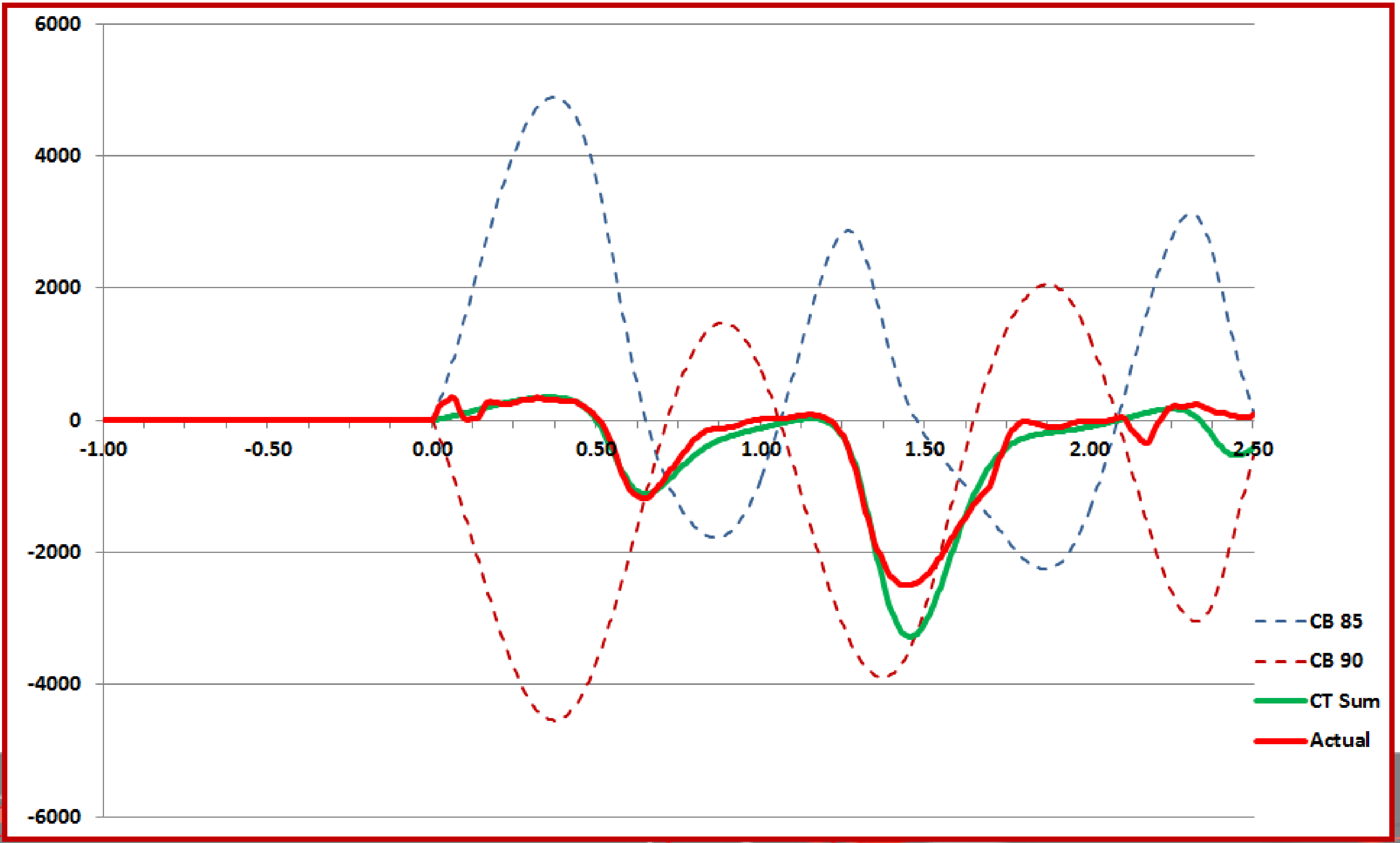
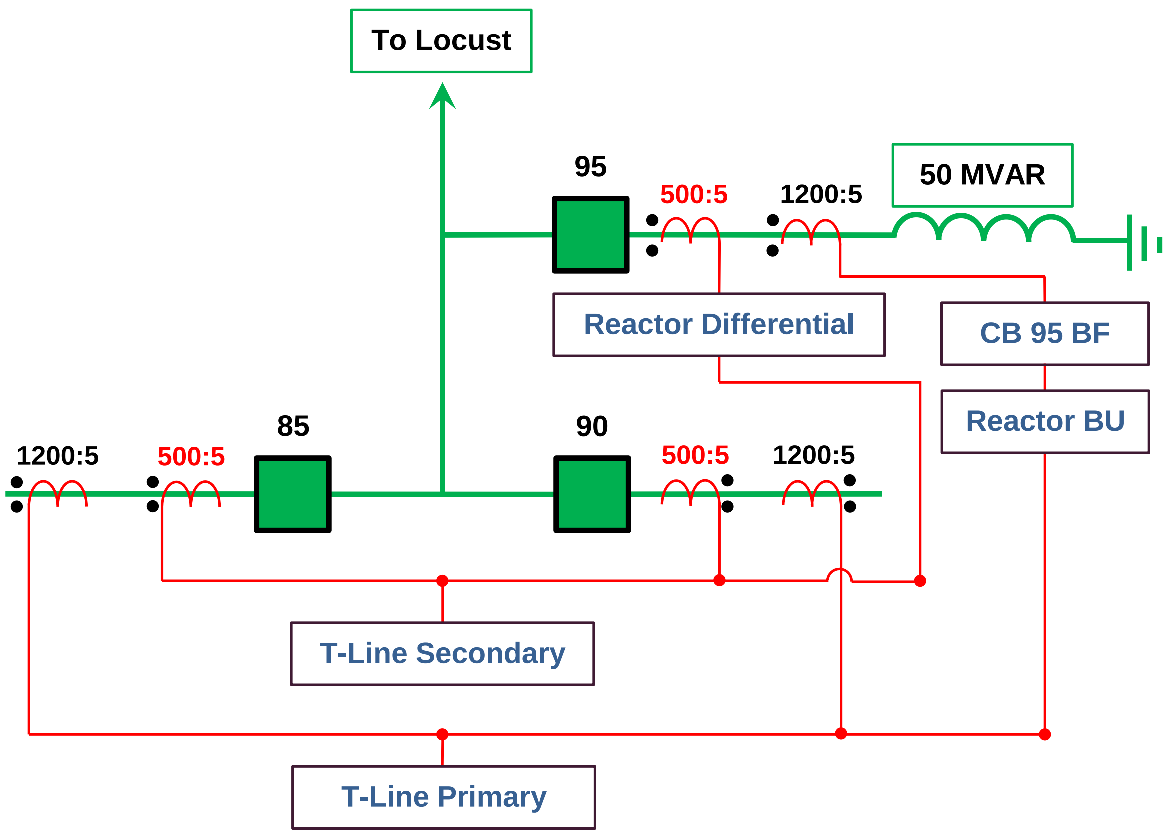


CT Saturation Solutions



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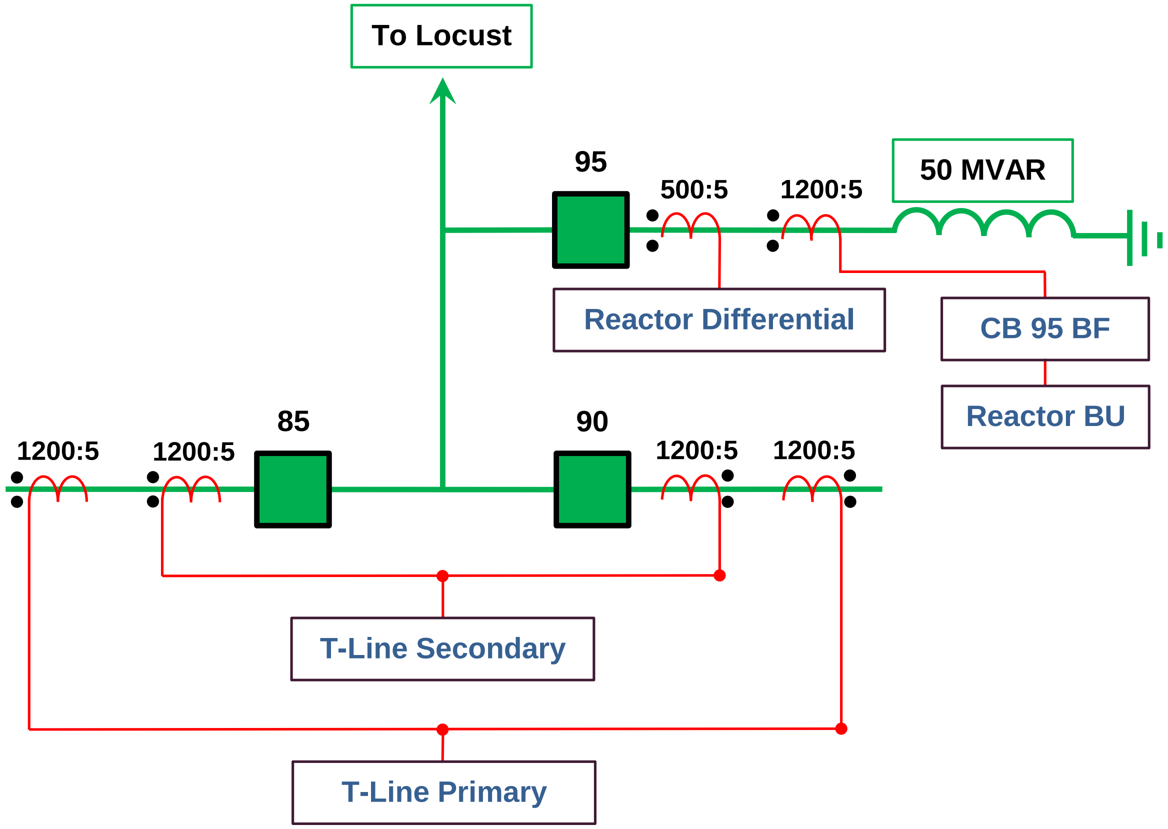
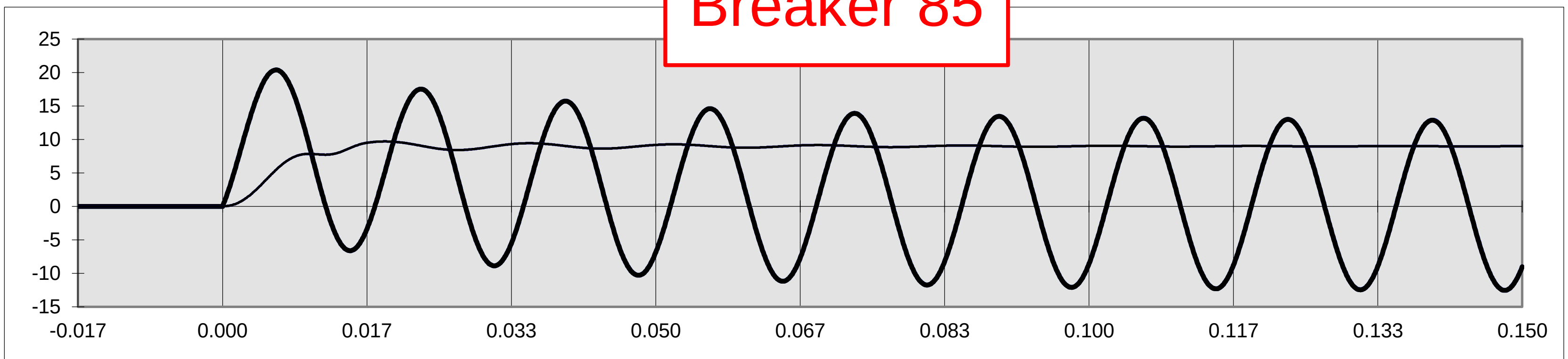
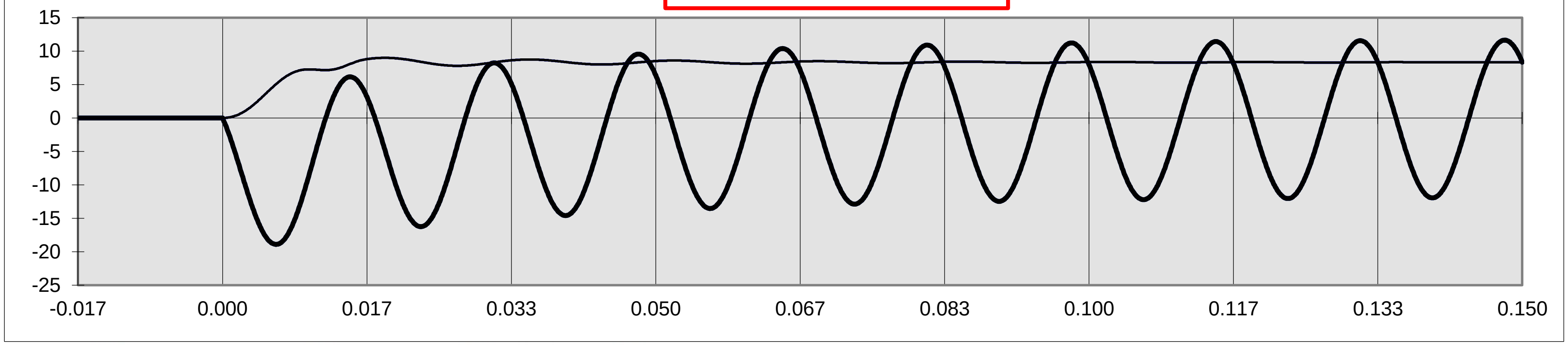


CT Saturation With 1200:5 CT Ratio

Breaker 85



Breaker 90



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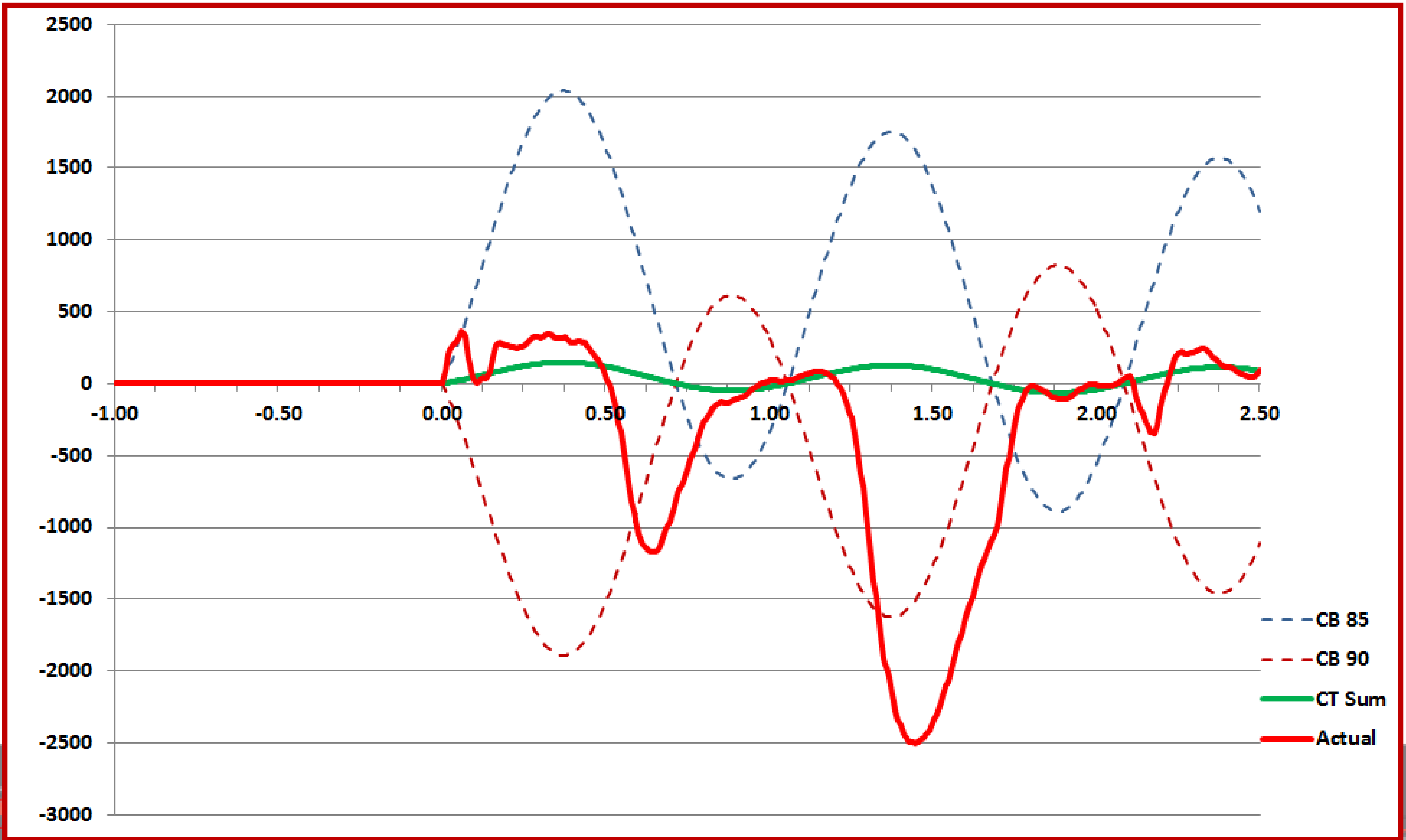

Lessons Learned

- **CT saturation can cause mis-operation of non-differential elements, such as ground distance elements.**
- **ALWAYS be wary of the effects of CT saturation on relay elements, especially when using less than full CT ratio.**
- **ALWAYS analyze un-filtered relay event records to look for waveform distortions that could indicate CT saturation.**

Questions???