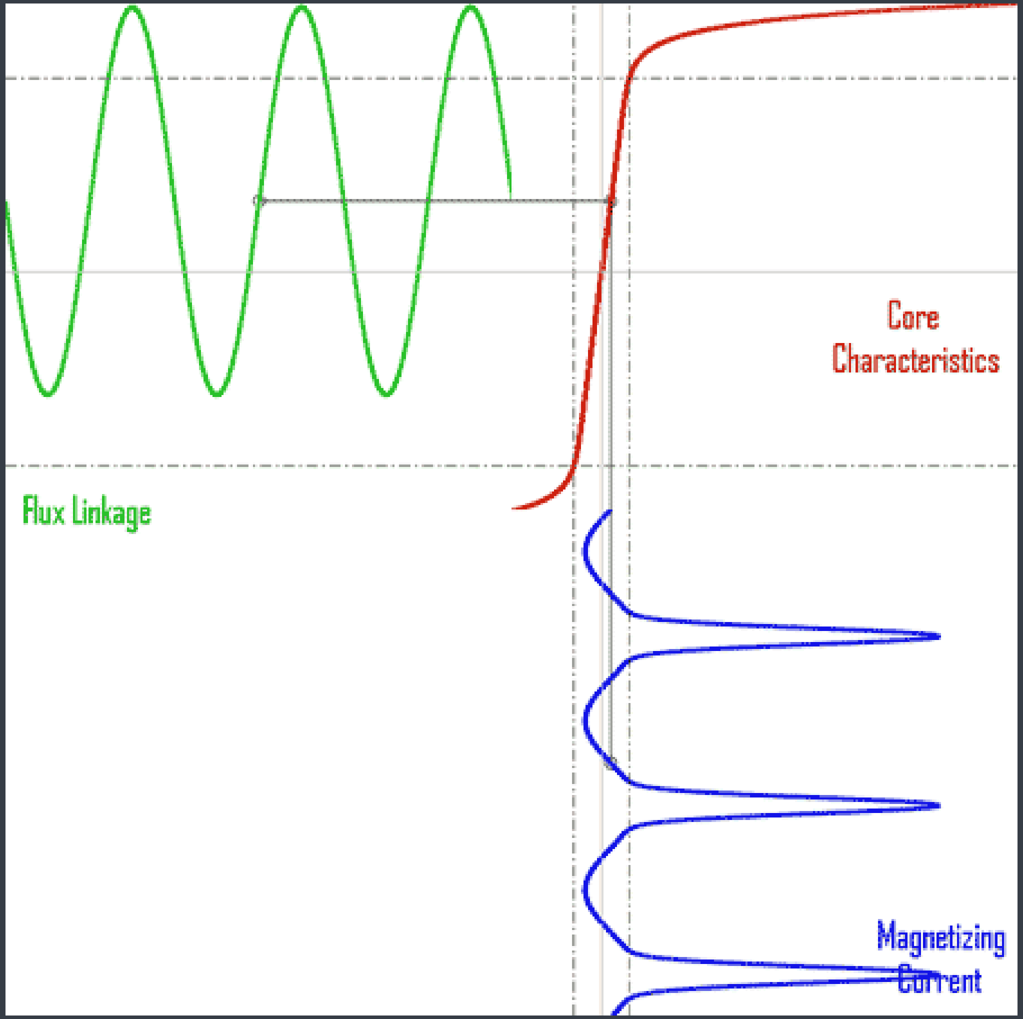


HOW MUCH ERROR CAN YOU EXPECT WITH VARIOUS DEGREES OF CURRENT TRANSFORMER SATURATION

BY
DOUG MILLNER
NERX POWER CONSULTANTS LLC

Why did I want to do a presentation on Current Transformer Saturation?

- Current transformer saturation is often noticed but rarely is it analyzed or reviewed to determine if it is affecting

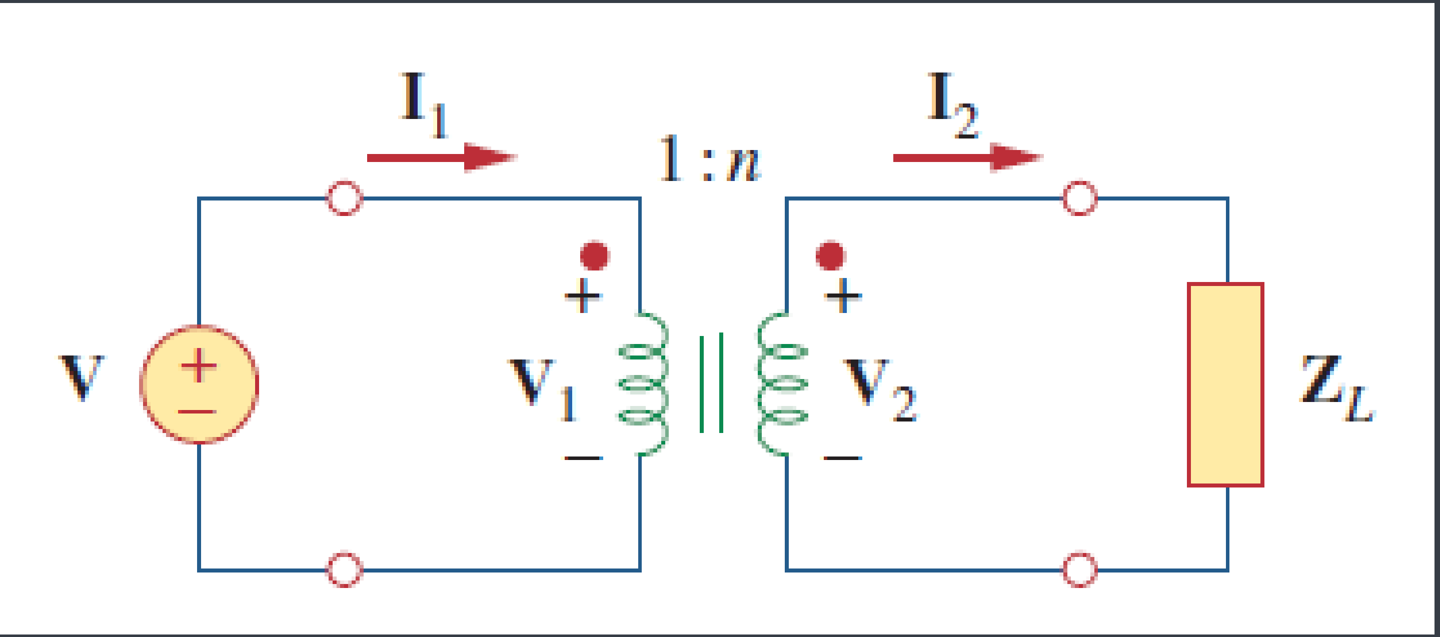
  - It is often impractical to replace or evaluate every partially saturating CT.

Why did I want to do a presentation on current transformer saturation?

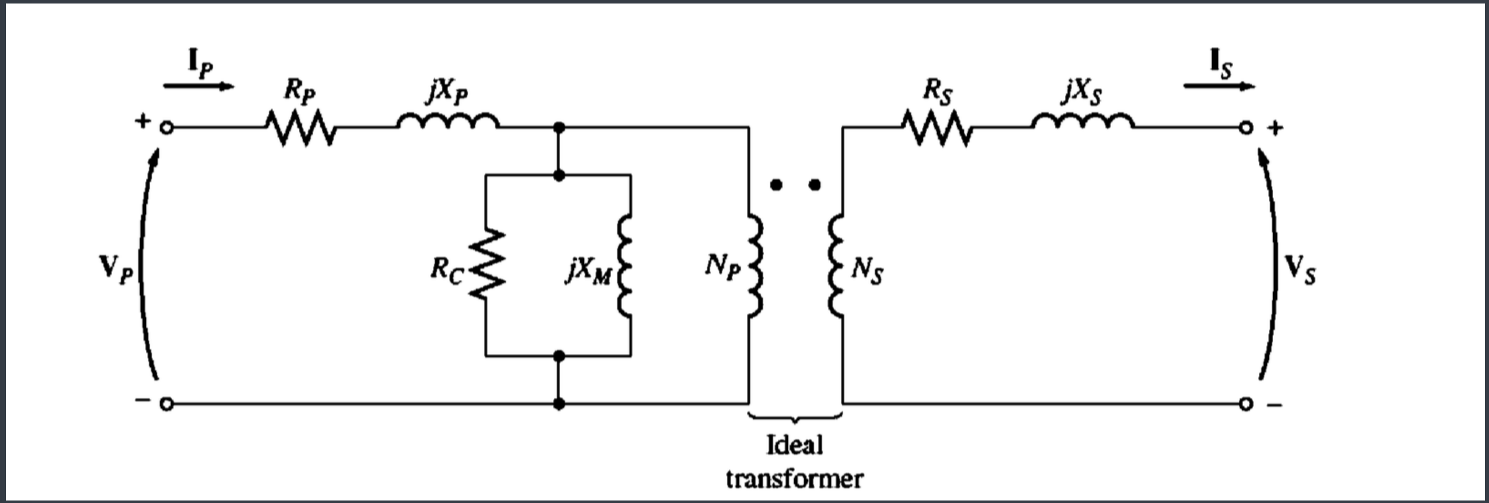
- Mechanical, solid state, and microprocessor relays function on different measurements (For example, peak to peak, RMS, filtered fundamental)
- This isn't inclusive of all measurement methods or include additional methods that manufacturers often include to prevent misoperations due to CT saturation.

BASICS OF CURRENT TRANSFORMER SATURATION

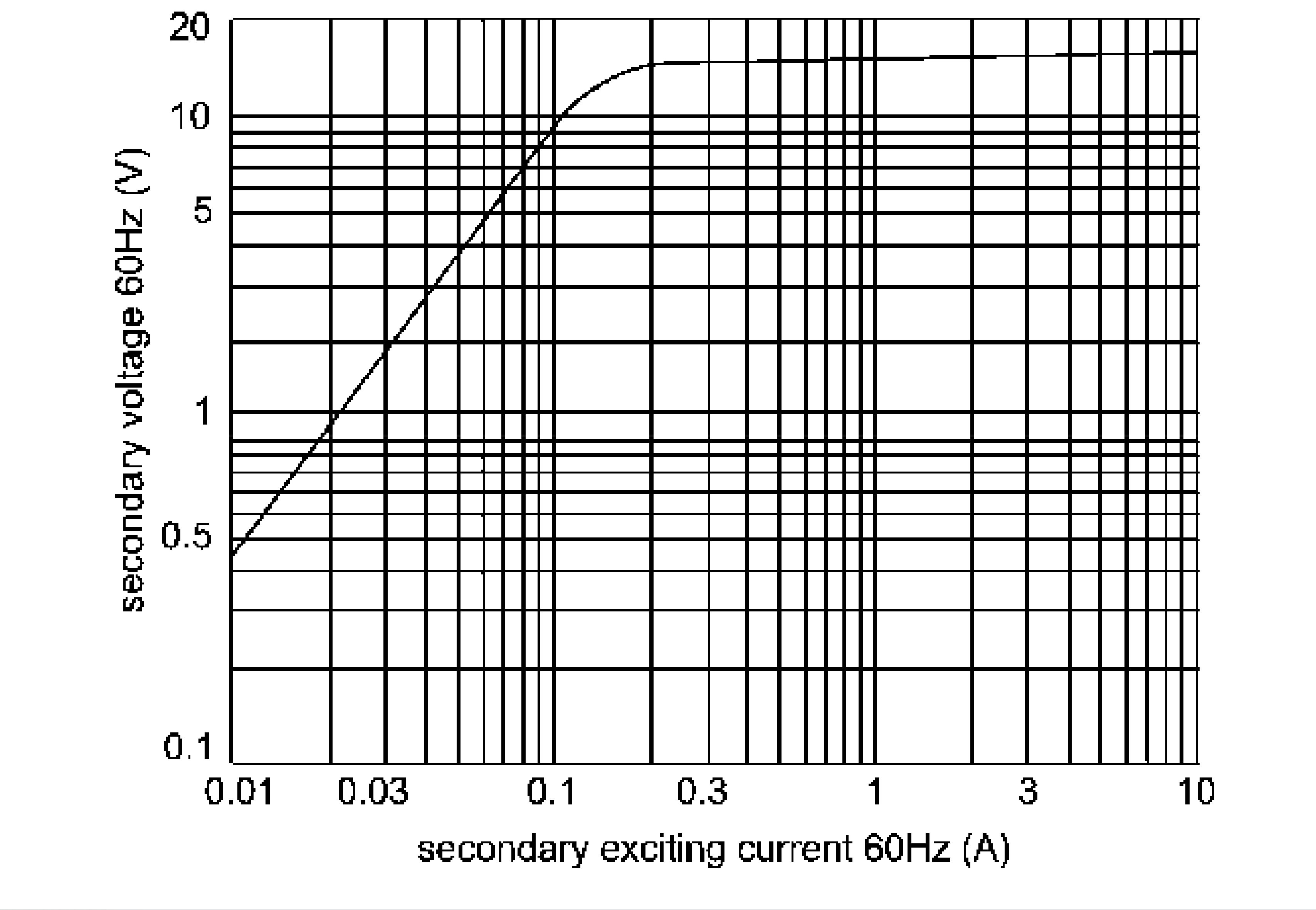
IDEAL CURRENT TRANSFORMER



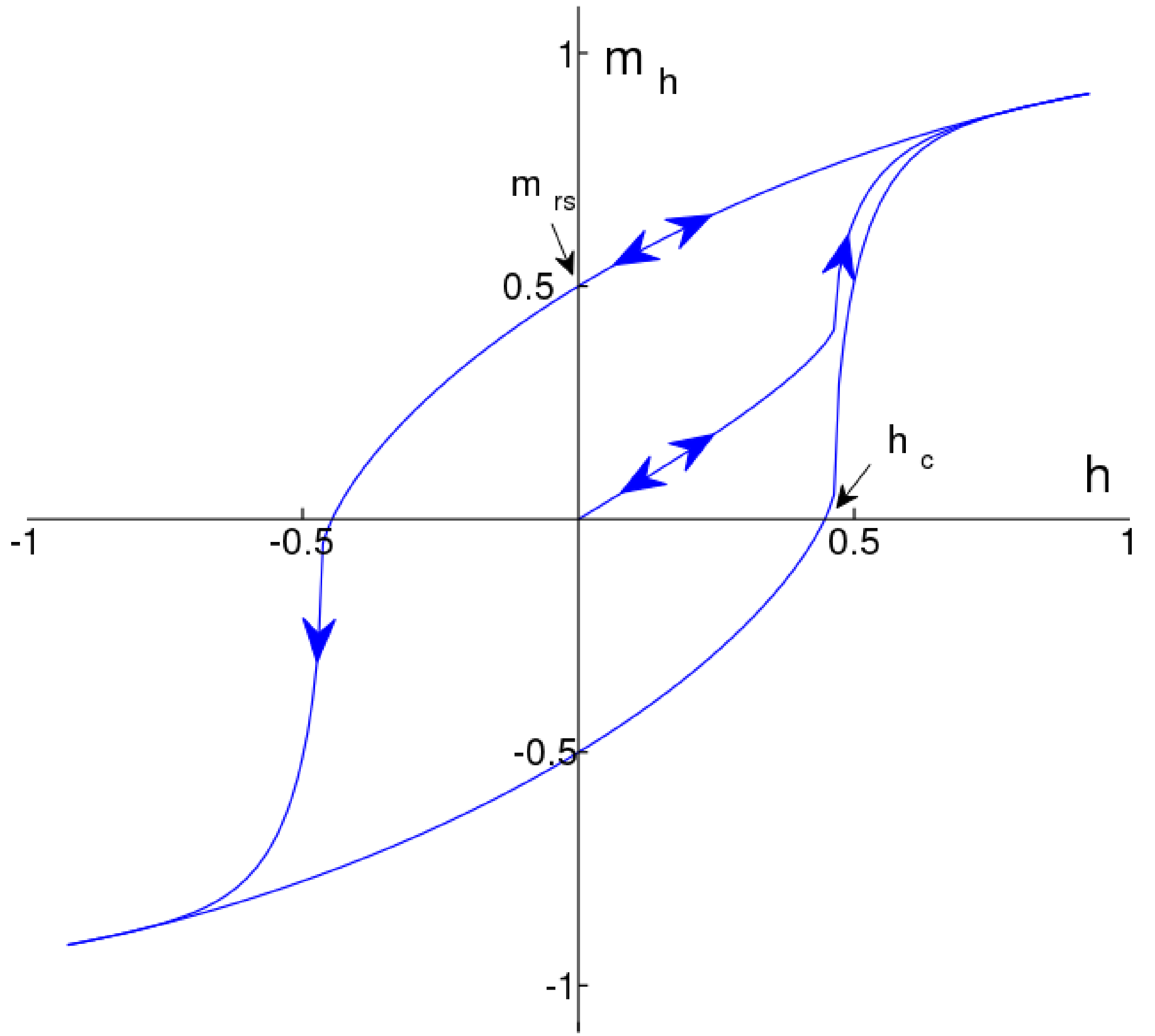
MORE REAL-LIFE TRANSFORMER MODEL



CURRENT TRANSFORMER PERFORMANCE

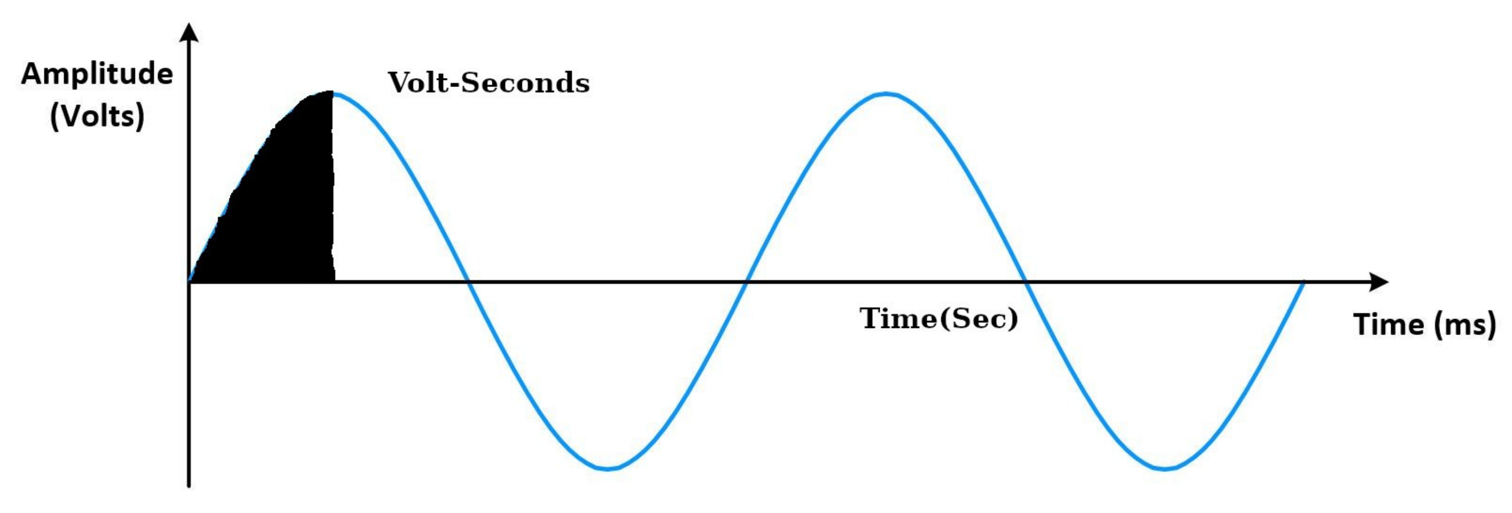


CURRENT TRANSFORMER PERFORMANCE



VOLT-SECOND CONCEPT

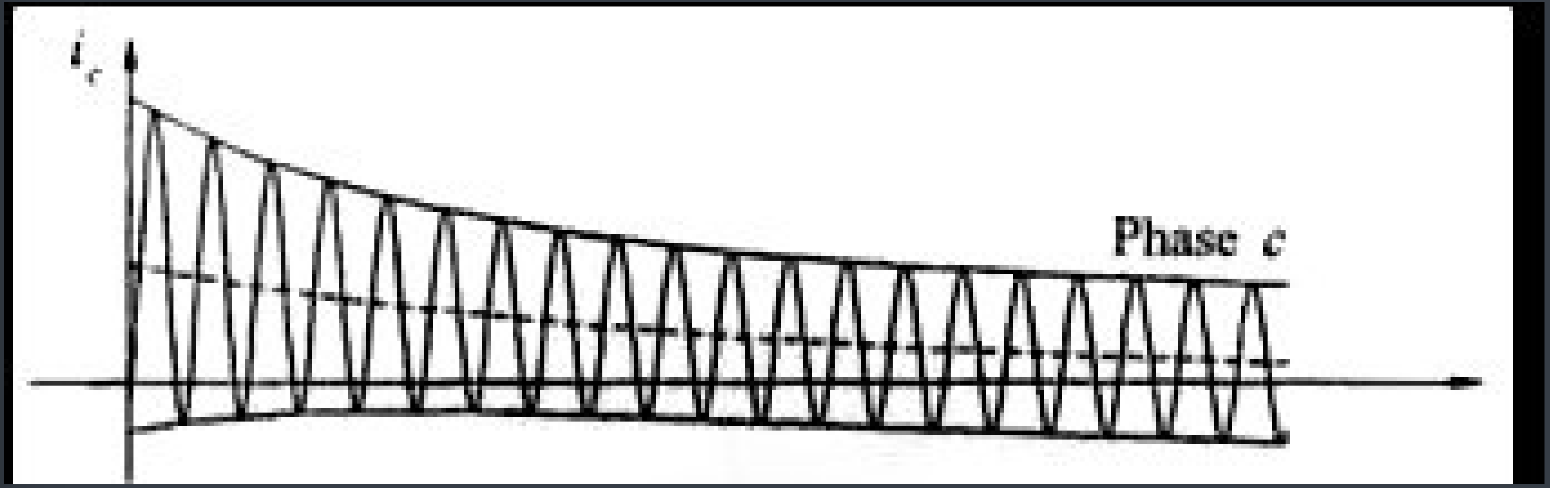
-PROVIDES A BETTER UNDERSTANDING OF SATURATION



VOLT-SECOND CONCEPT

-EXPLAINS WHY DC OFFSET,
BURDEN, AND CURRENT LEVEL CAN CONTRIBUTE TO SATURATION

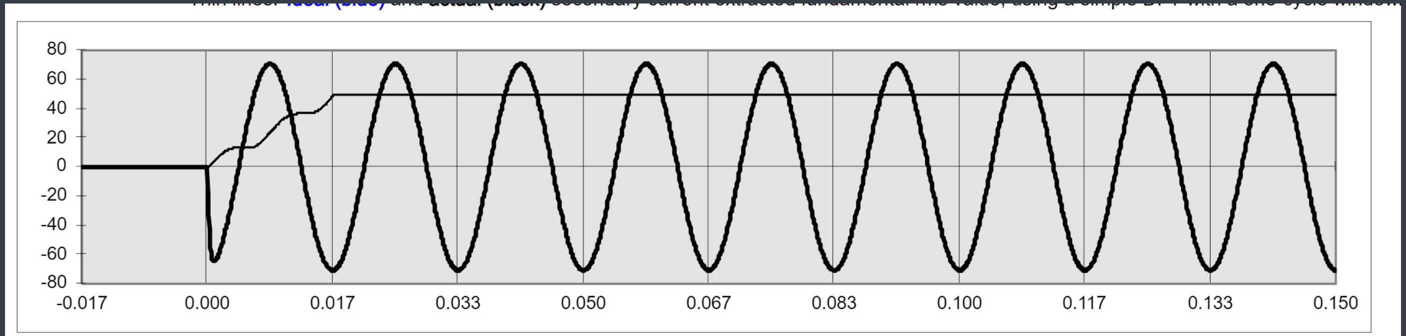
-ALL EXCITATION PROBLEMS ARE CAUSED BY VOLTAGE NOT CURRENT

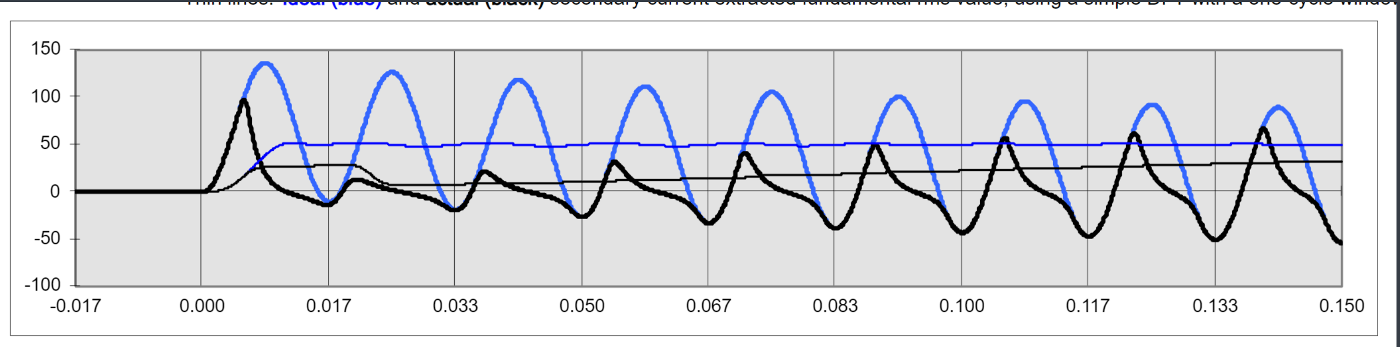


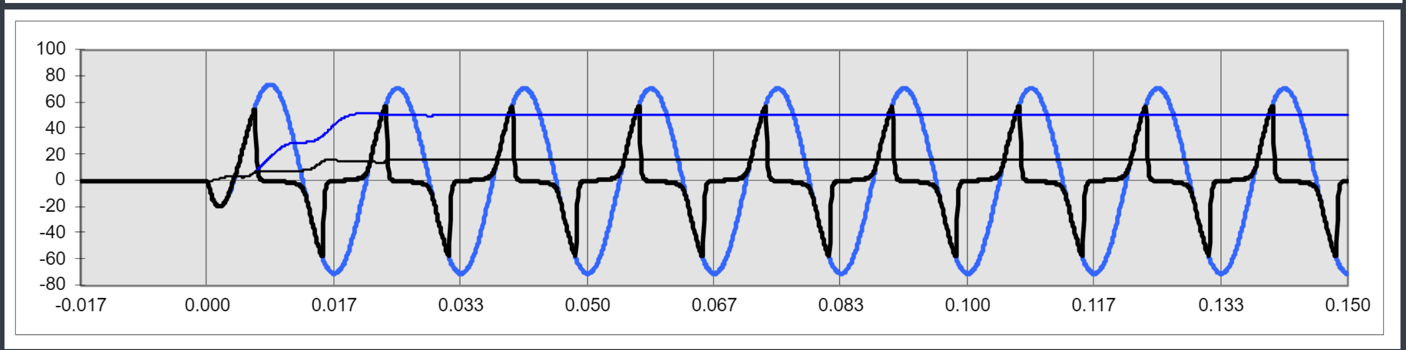
WHAT DOES AC SATURATION LOOK LIKE? (COSINE FILTER)

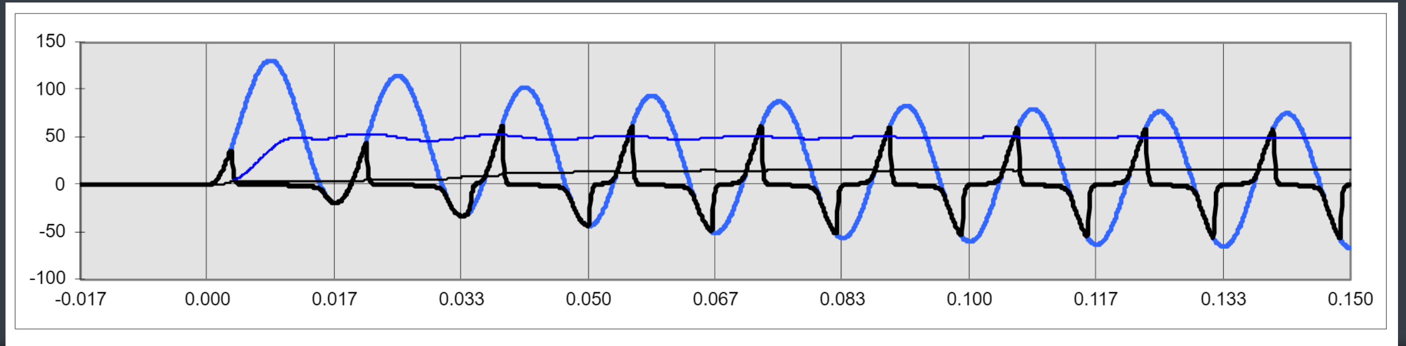
1. NO SATURATION
2. DC SATURATION
3. AC SATURATION
4. AC AND DC SATURATION

*NOTE THAT DC SATURATION DECAYS WITH THE L/R TIME CONSTANT









RELAY RESPONSE

RELAY RESPONSES INVESTIGATED

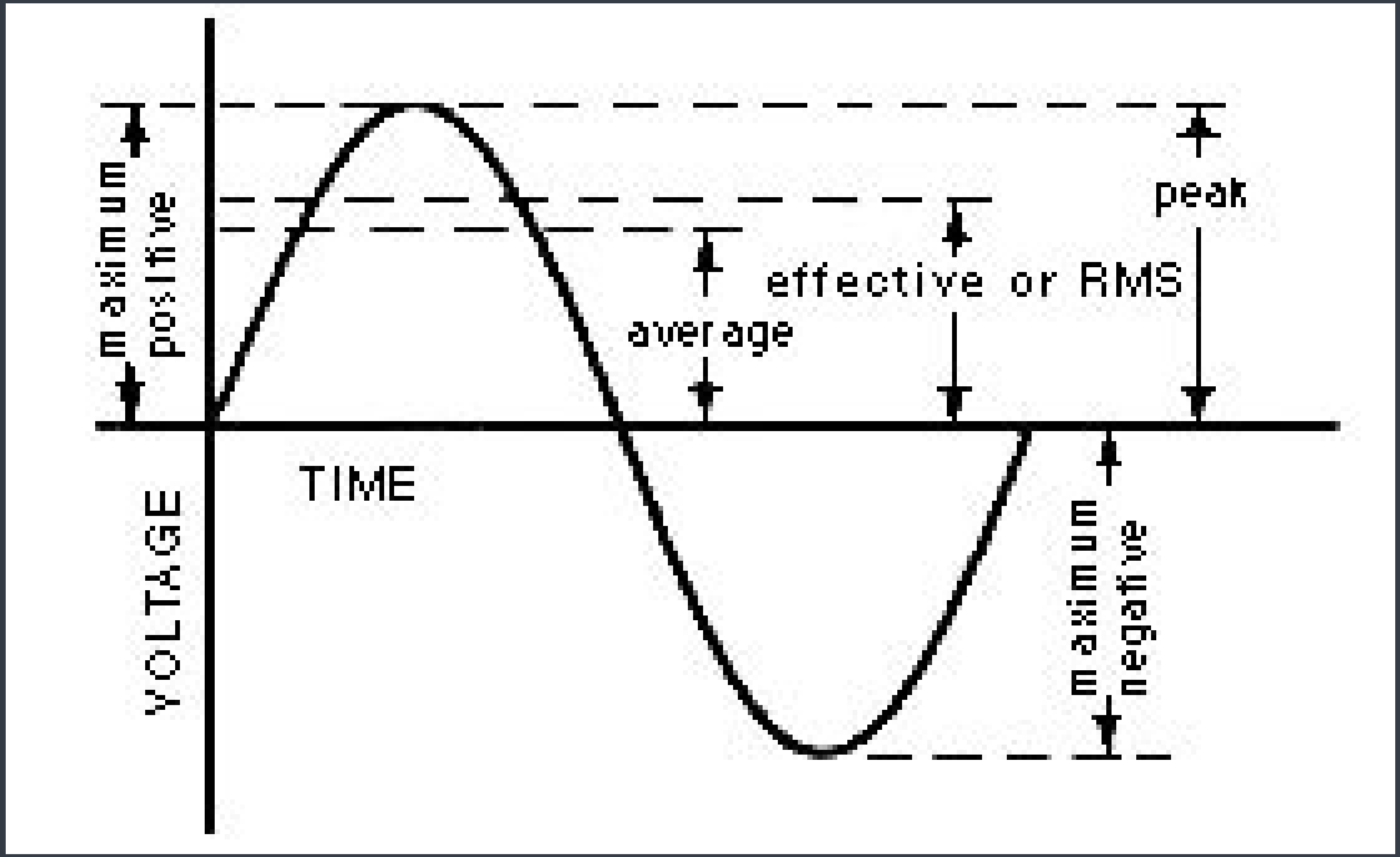
1. MECHANICAL RELAYS GENERALLY ARE RMS RESPONSIVE

2. SOLID STATE RELAYS CAN BE PEAK MEASURING

3. MICROPROCESSOR RELAY CAN USE ONE CYCLE COSINE FILTERS

-EXTRA EMPHASIS ON THE WORD “CAN”

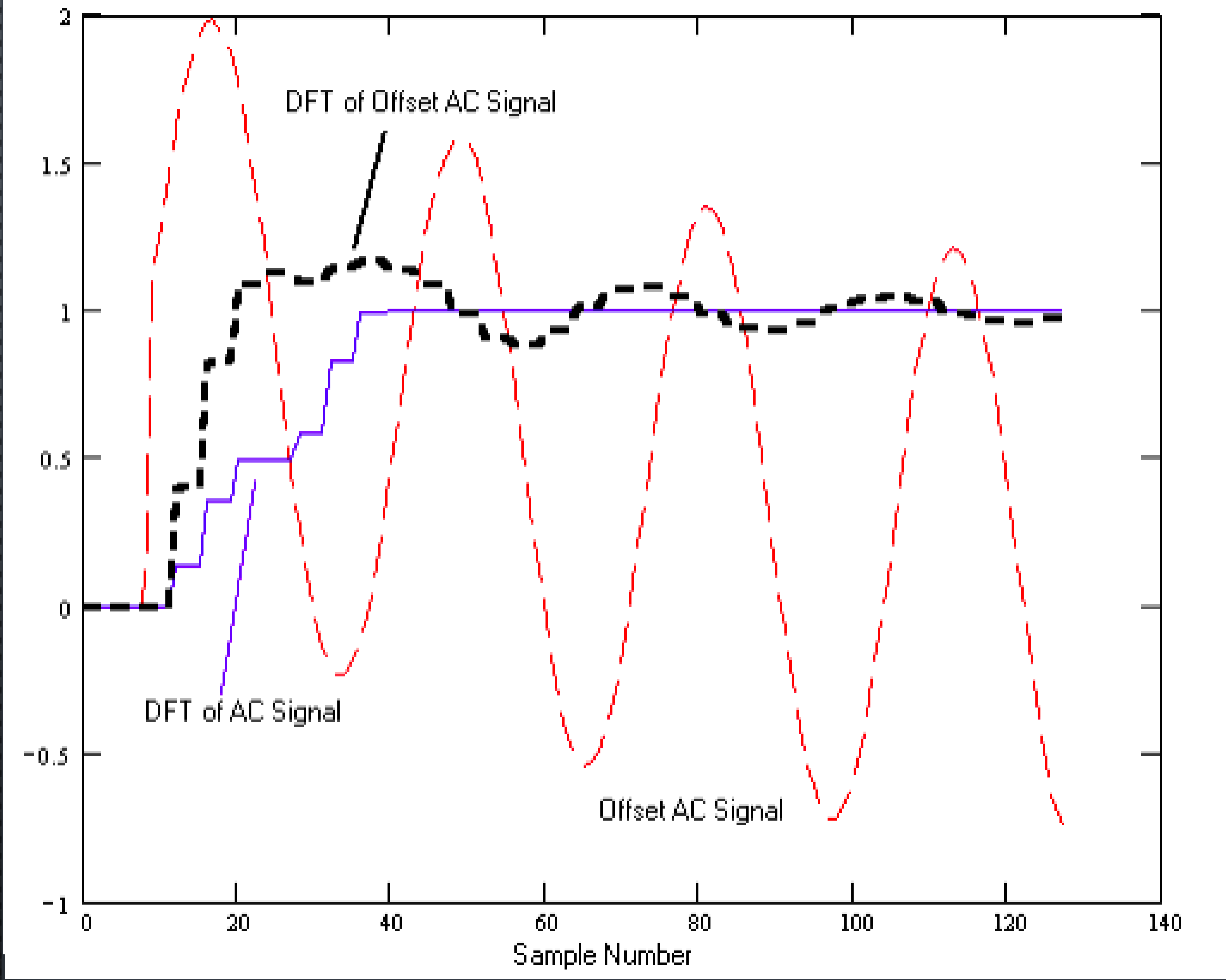
RMS RESPONSE AND PEAK TO PEAK



COSINE FILTER RESPONSE

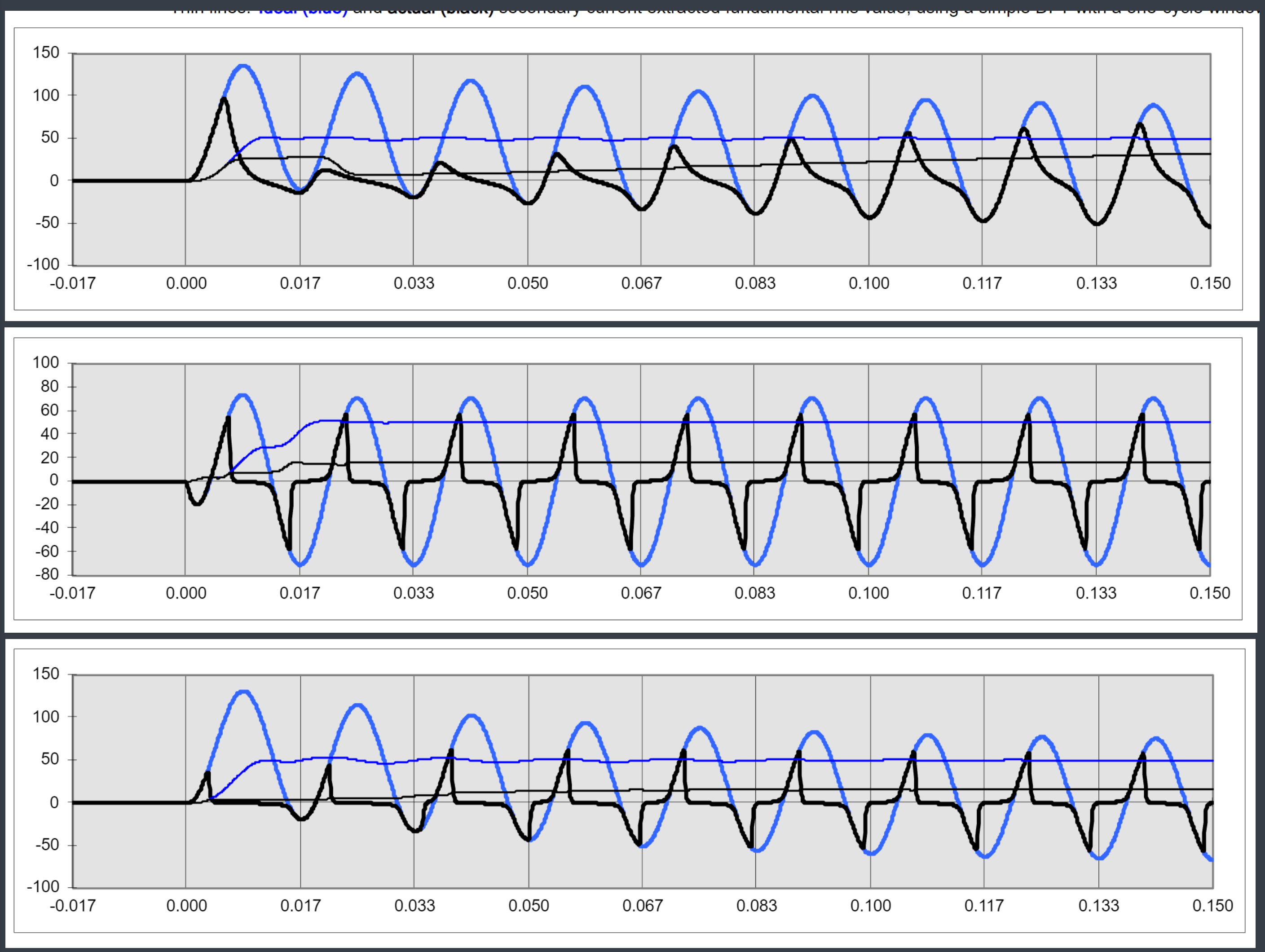
-PSRC CT SATURATION CALCULATOR USES A DFT FILTER

-VERY SIMILAR TO COSINE FILTER USED IN SOME RELAYS BUT SLIGHT WORSE DC PERFORMANCE



-THE PROBLEM WITH CT SATURATION IS THAT THERE ISN'T A STANDARD METHODS FOR ESTIMATING ERROR

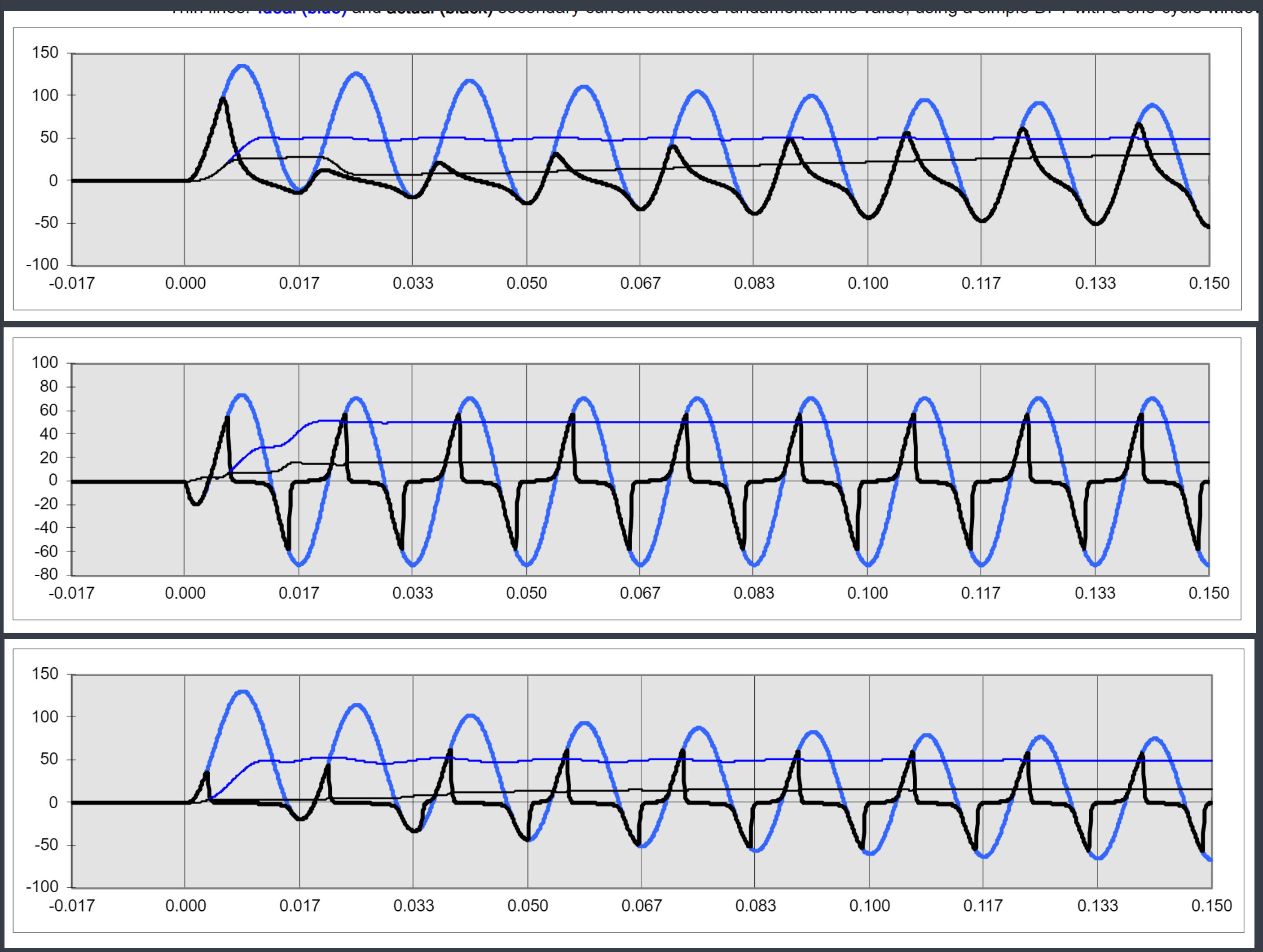
-IT IS DIFFICULT TO DESCRIBE FAMILIES OF SHAPES



IDEA OF PAPER

-ASSUME DC OFFSET, AC SYMMETRICAL CURRENT, AND FREQUENCY DOESN'T CHANGE MUCH OVER ONE CYCLE

-THIS REDUCES THE NUMBER OF SIMILAR OFFSET WAVEFORMS NEEDED TO FORM A USEFUL FAMILY OF WAVEFORMS FOR REFERENCE



A Manageable Family of Waveforms

- Allow for a lookup table to be used to estimate error

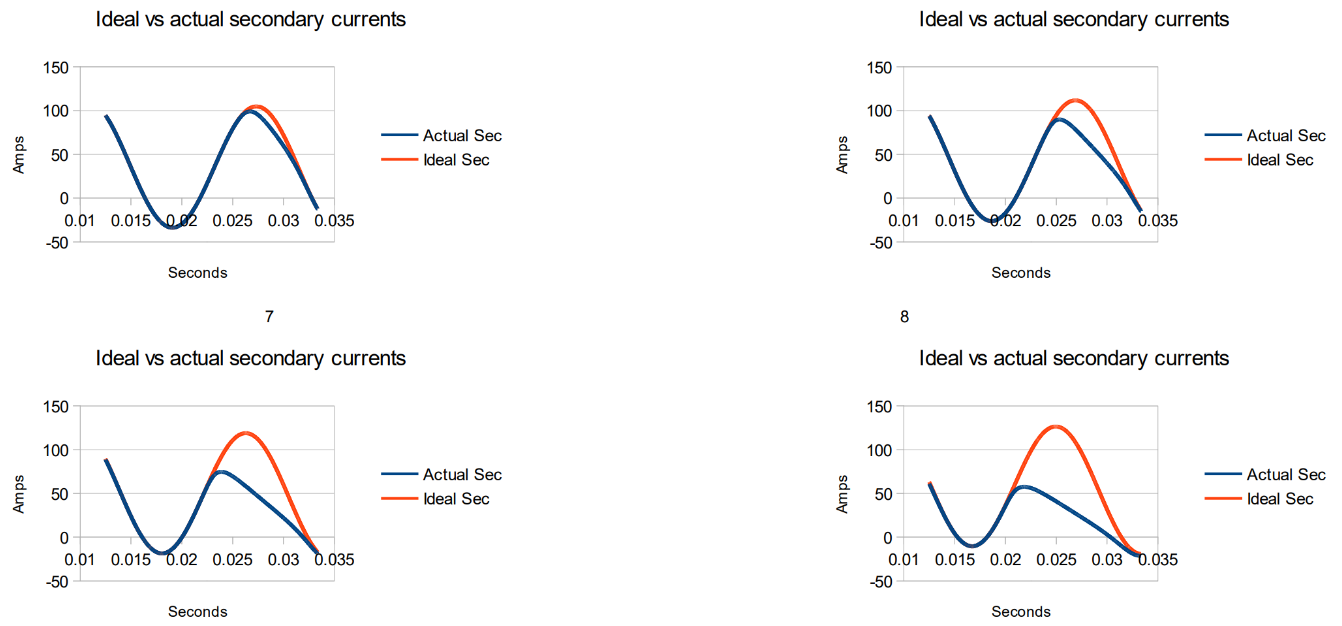
This can avoid some analysis for a rough estimate or be used as a screener for a full investigation

How do you compare waveforms

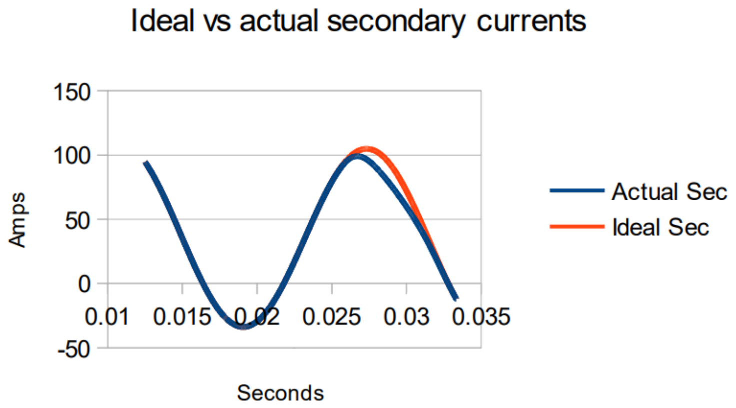
- First compare an inspected cycle to what the ideal waveform probably looks like
  - DC Offset
  - Line up with linear regions
  - Look at how much the peak is cut and compare to peak error
  - Look at where on the waveform there is a strong cut
  - Scale similarly to lookup table
  - Use error for a similar like shape

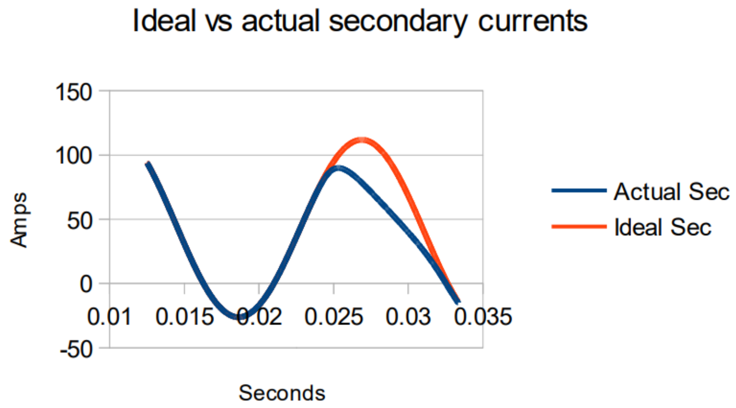
LOW BURDEN – FAIRLY INDUCTIVE

-SATURATION IS LARGELY DUE TO DC OFFSET



Case	5	6	7	8
True RMS Error	7%	23%	41%	57%
Filtered Fundamental Error	4%	16%	35%	58%
Peak Error	5%	20%	37%	54%





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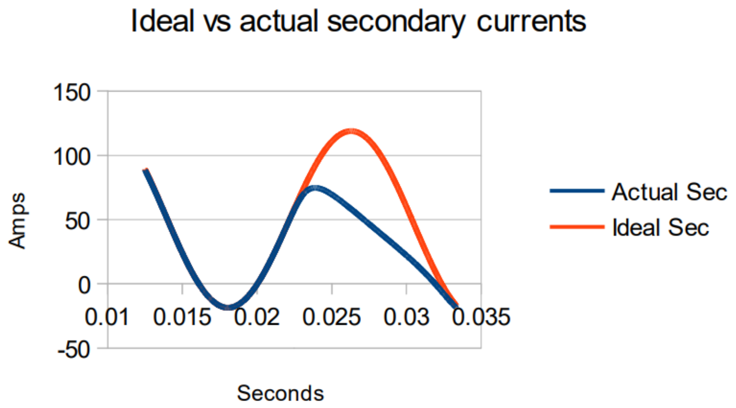

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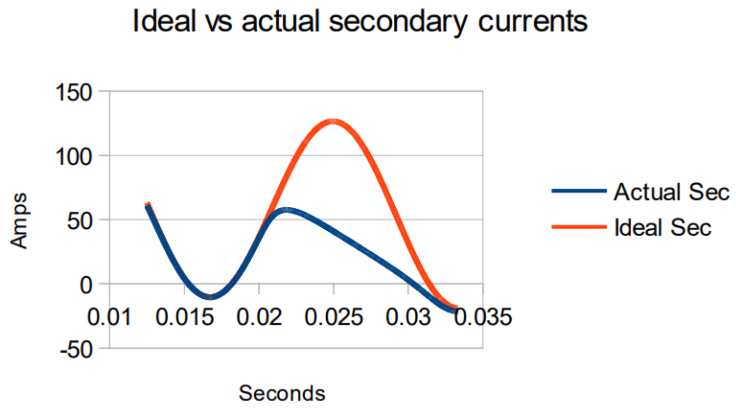

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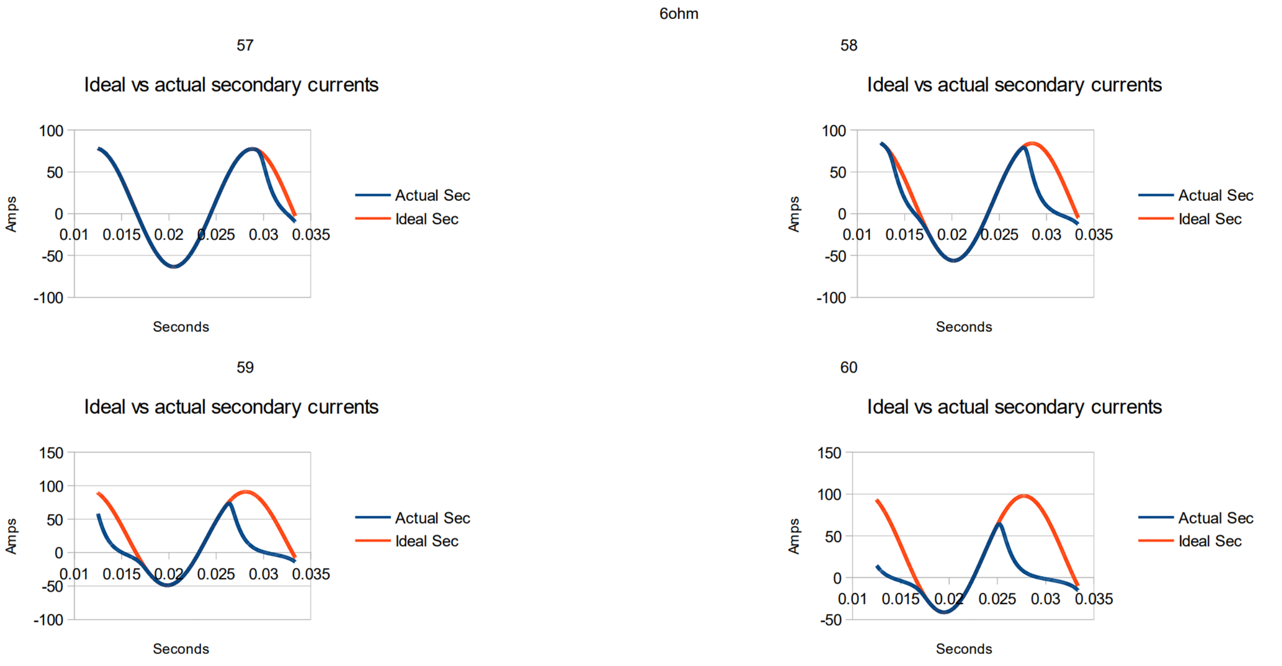
True RMS Error	7%	23%	41%	57%
Filtered Fundamental Error	4%	16%	35%	58%
Peak Error	5%	20%	37%	54%

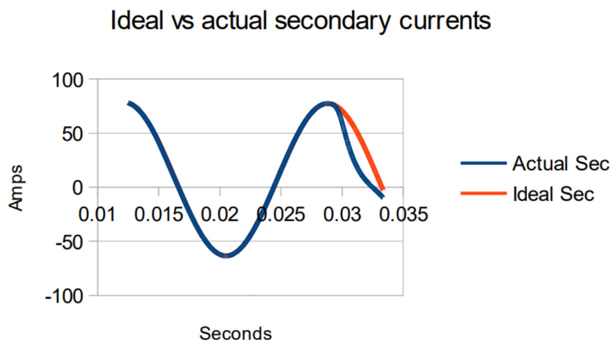
-SATURATION DUE MOSTLY AC SYMMETRICAL CURRENT OR LARGE RESISTIVE BURDEN



Case	57	58	59	60
True RMS Error	6%	22%	36%	50%
Filtered Fundamental Error	1%	6%	33%	51%
Peak Error	0%	6%	19%	34%

6ohm

57



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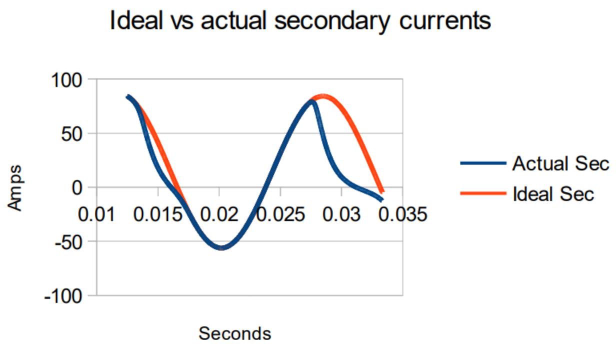

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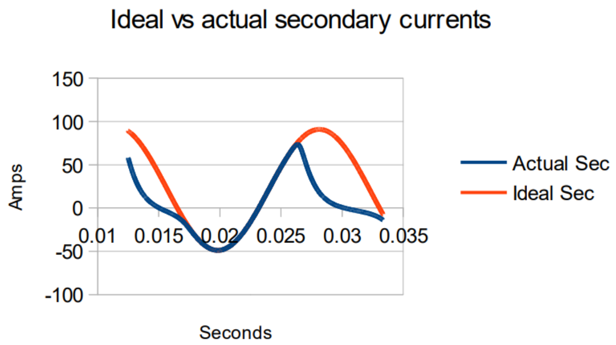

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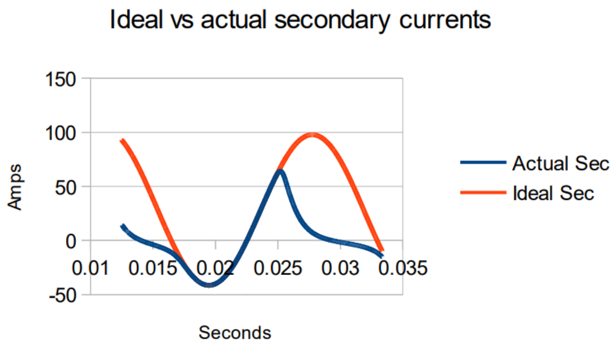
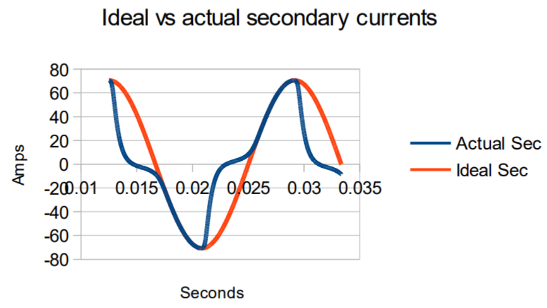
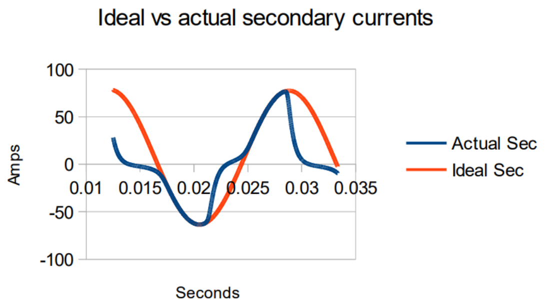


Case	57	58	59	60
True RMS Error	6%	22%	36%	50%
Filtered Fundamental Error	1%	6%	33%	51%
Peak Error	0%	6%	19%	34%

-HEAVY AC BURDEN BECOMING INCREASINGLY WITH INCREASING DC OFFSET

-





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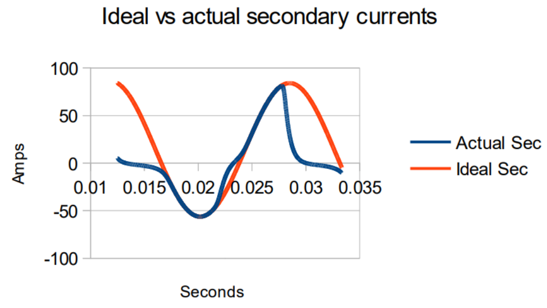
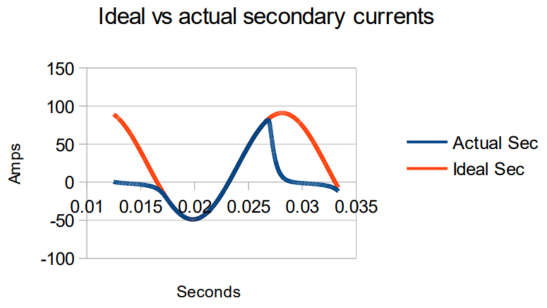
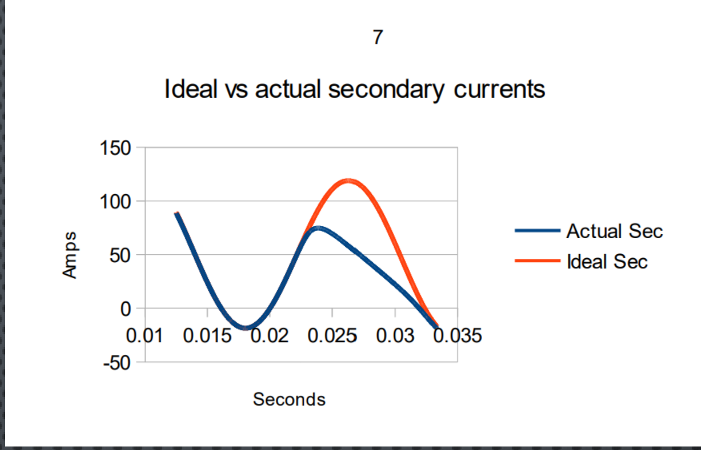


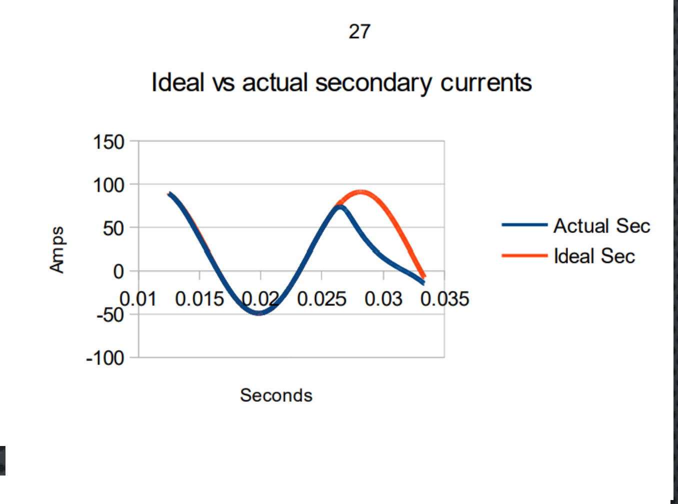


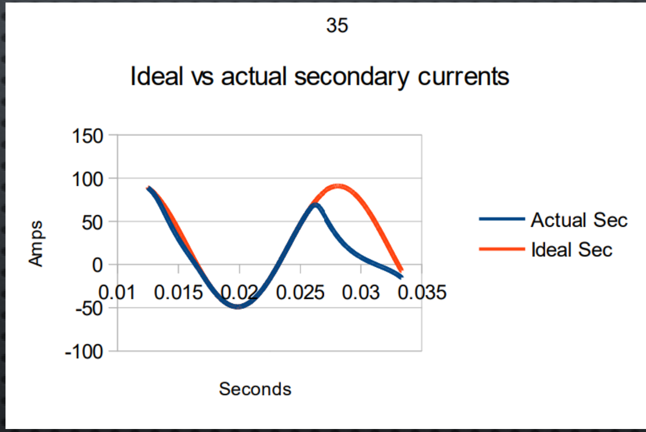
Case	77	78	79	80
True RMS Error	20%	21%	25%	35%
Filtered Fundamental Error	25%	27%	30%	40%
Peak Error	0%	1%	4%	10%

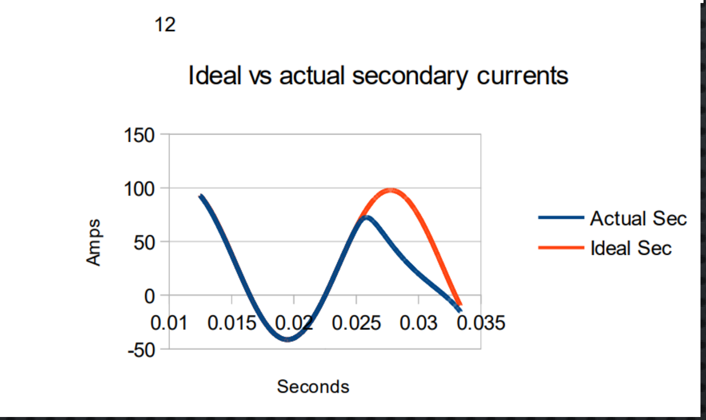
WAVEFORMS WITH SIMILAR ONE CYCLE COSINE FILTER ERROR 10-15%

-ONE CYCLE COSINE FILTER HAS ERROR ROUGHLY PROPORTIONAL TO THE PORTION OF THE AC 60HZ THAT WAS LOST

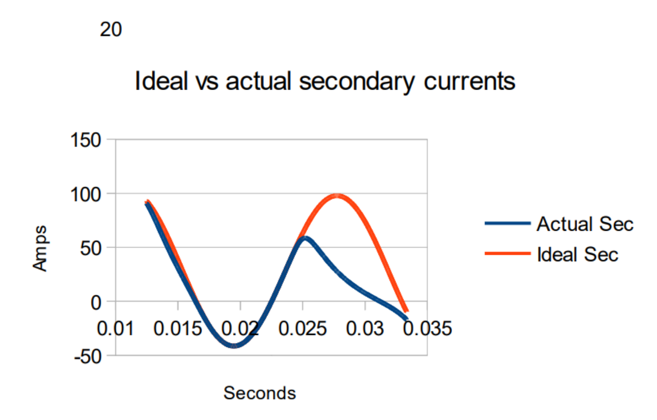


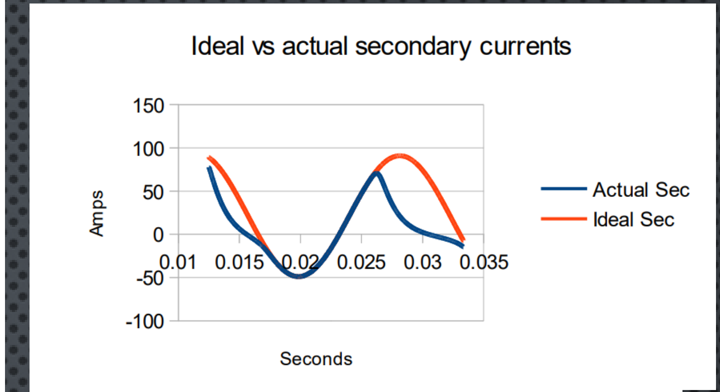


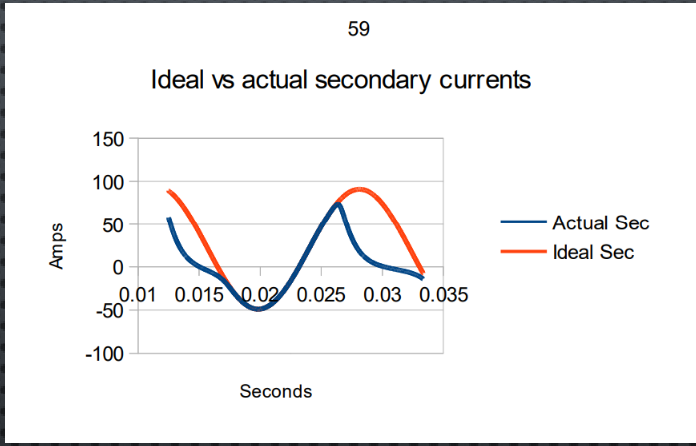


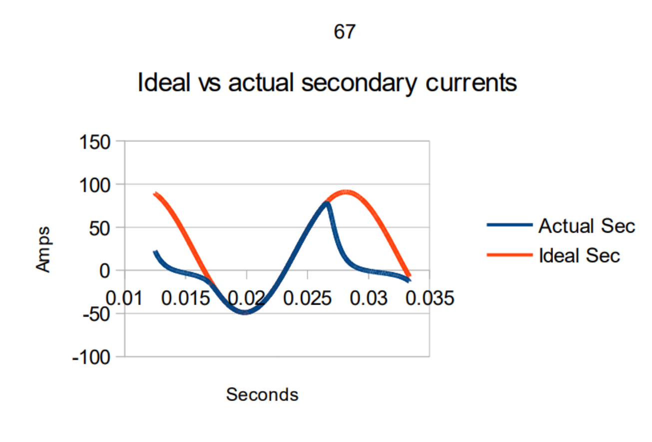


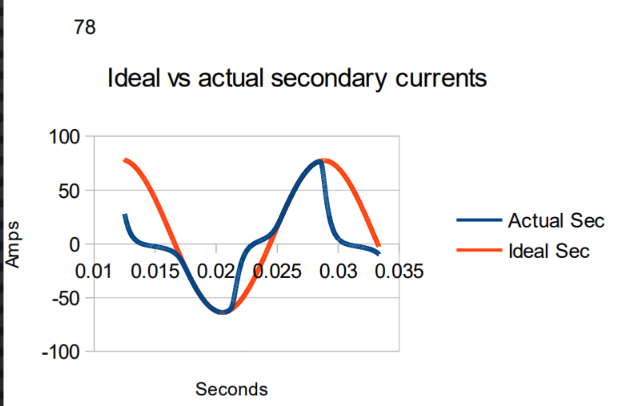
-WAVEFORMS WITH SIMILAR ONE CYCLE COSINE FILTER ERROR 25-35% ERROR

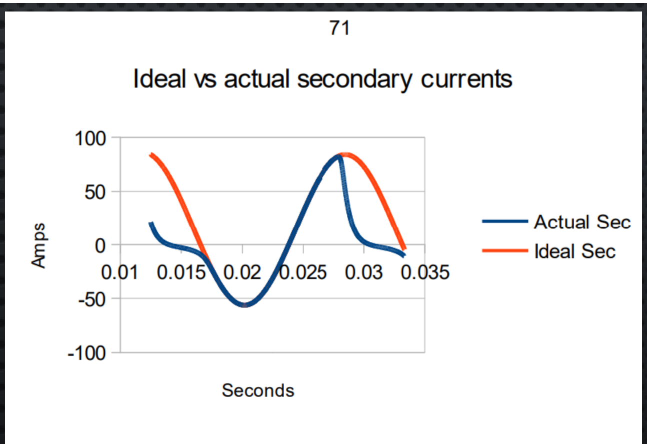


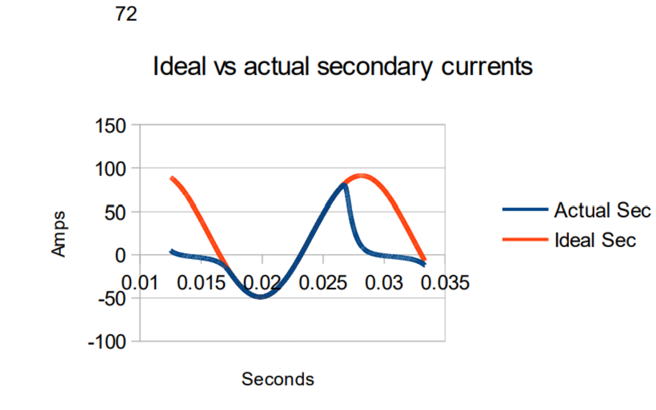


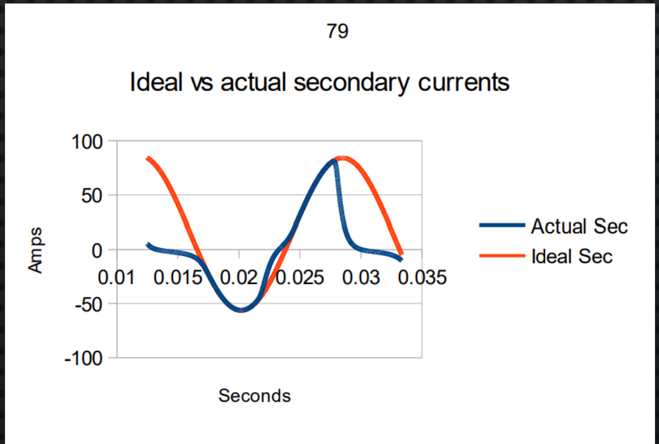












Conclusions

- Lookup tables can be used to estimate error due to CT saturation with a few assumptions
- It is not intuitive how much error is in a wave shape. More so with RMS than cosine filters
- Manufactures might benefit providing something similar for their proprietary algorithms. It would provide confidence of how a relay would perform in a less than ideal situation.
- This topic touches issues of protective relaying and power quality. It might be interesting to know how poor power quality can affects with normally acceptable amount of CT saturation.