Distance Relay Accelerator- Achieving Subcycle Operation Time

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Agenda

- Introduction
- Short window phasor estimation algorithm with decaying DC accounted
- CVT transients and mitigation methods
- Voltage and current phasors used in the subcycle distance algorithm, tripping count strategy
- Arming and overall protection logic
- Performance evaluations
- Conclusions

Introduction

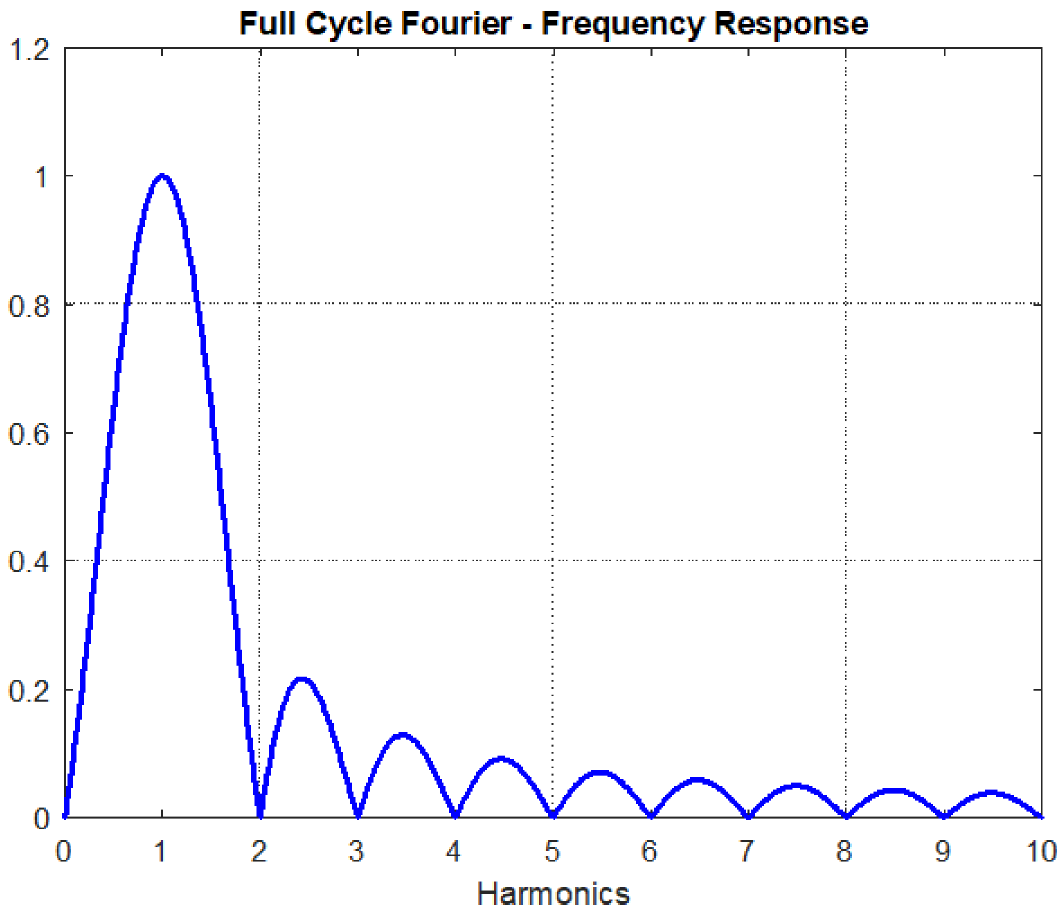
- Distance relays are to date widely used in transmission line protection, due to use of the local terminal voltage and current signals only.
- Distance elements provide good selectivity, easy to set and used in both step-distance and pilot schemes.
- To prevent overreach, pre-filtering to remove decaying DC in current signals and CVT transients in voltage signals is required.

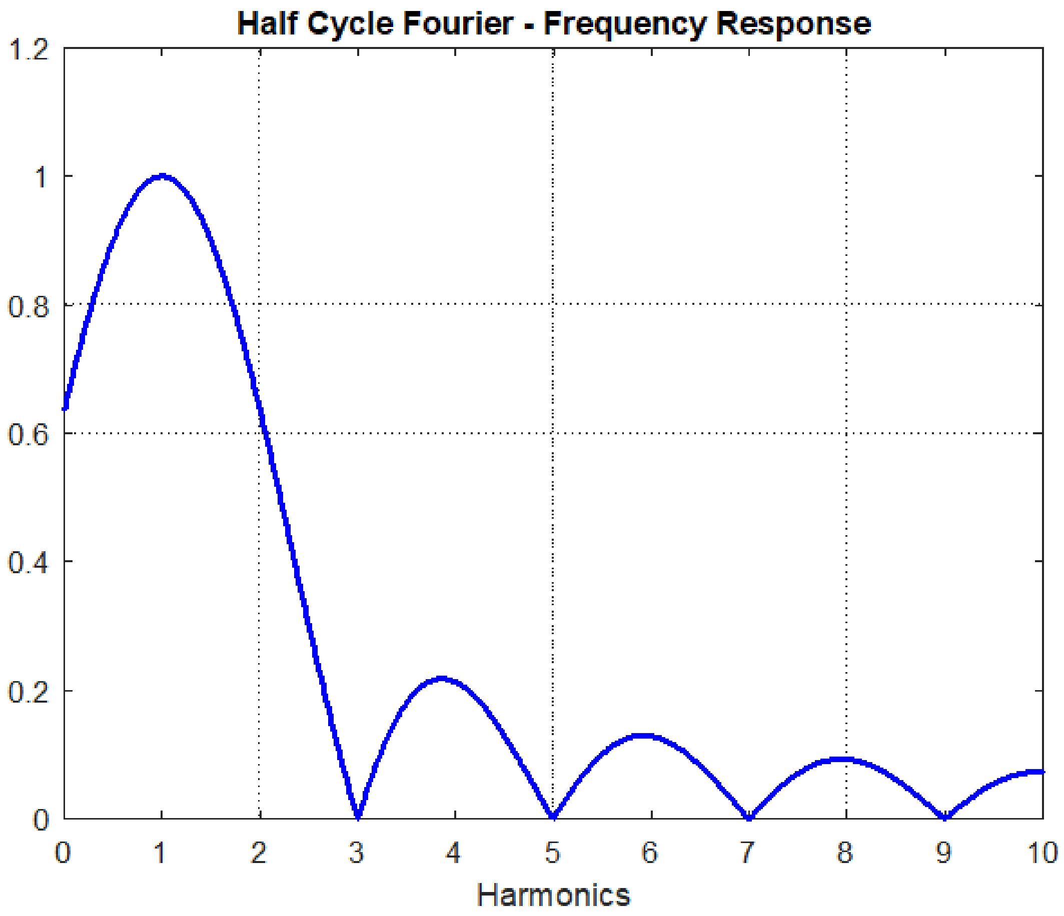
Introduction

- Distance relays speed is essential especially for EHV or UHV applications. Sub-cycle operation time for the distance underreach zones is desirable.
- Faster fault clearing improves system stability, reduces the stress on power transformers, reduces equipment damages.
- Traditional full cycle DFT operation time is 1 ½ cycles or longer. One of solutions to improve speed is phaselet-based algorithms.

Introduction

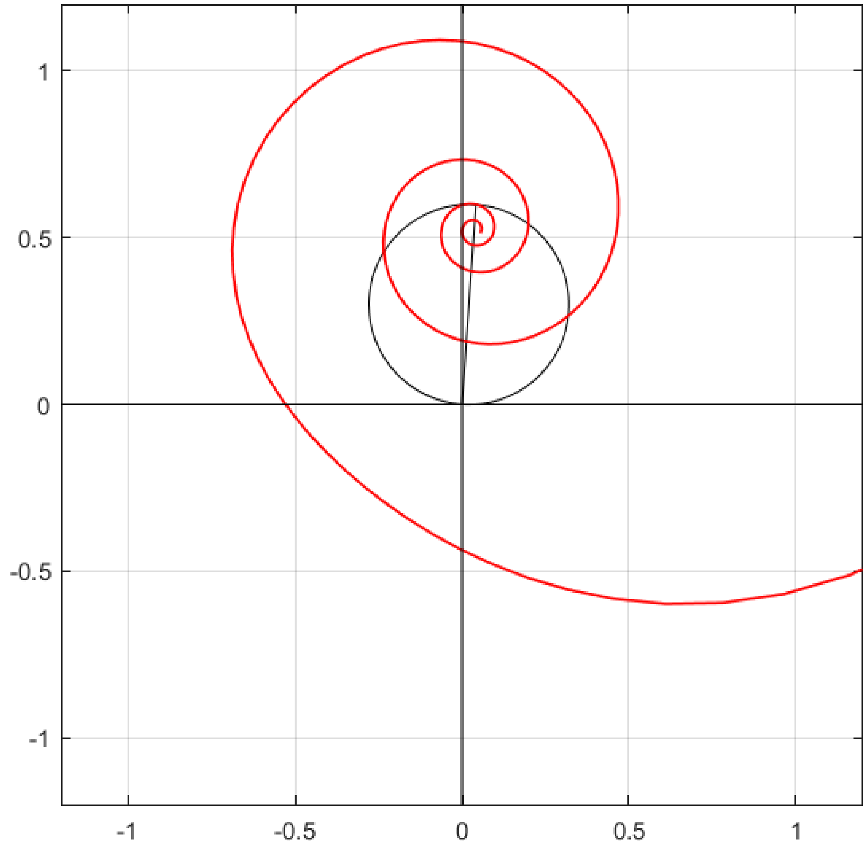
Phaselet-based algorithms are faster, but less accurate than the full cycle DFT based algorithms



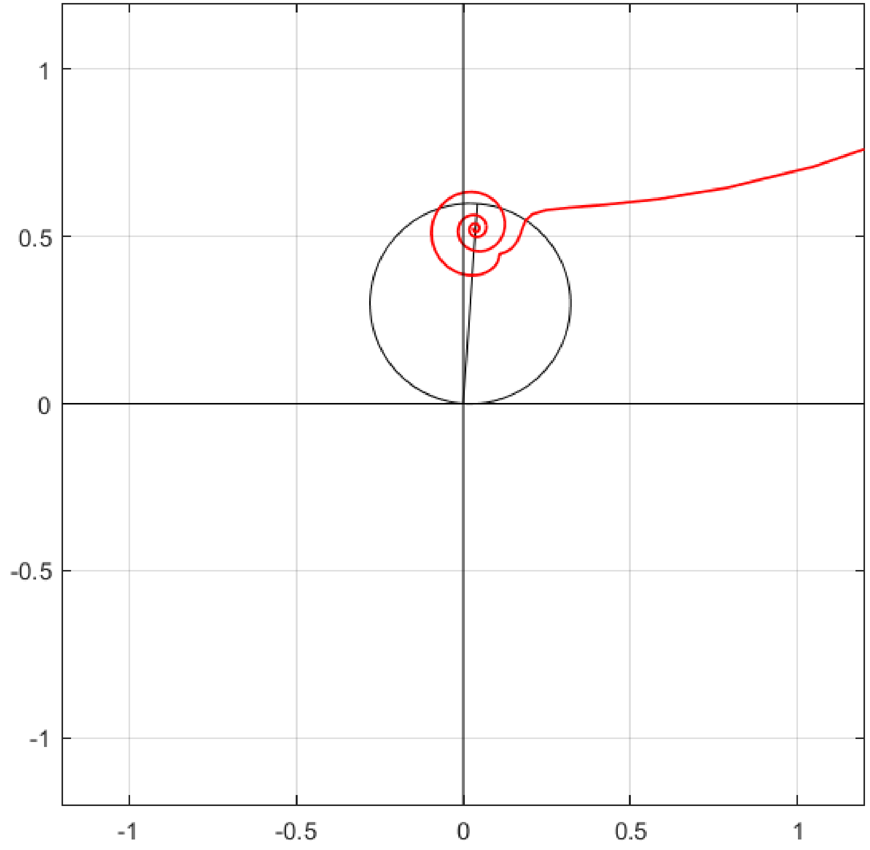


Introduction

This results in higher transients' errors



Impedance trajectory based on phasors via half cycle DFT



Impedance trajectory based on phasors via full cycle DFT

Introduction

- In this paper, a new algorithm is presented, in which voltage and current phasors are estimated through two short window orthogonal filters with decaying DC accounted for.
- With additional filtering, averaging, switching, and tripping count strategy, both sub-cycle operation time and accuracy (transient overreach less than 5%) for the underreach zones of distance elements can be achieved.

Short Window Phasor Estimation

Most significant challenge for fast speed and still accurate impedance estimation is to remove DC component. AC signal can be described as:

$$i(n) = ID \cdot e^{-\frac{T_s}{T_N} \cdot n} + I_P \cdot \cos\left(\frac{2\pi}{N} \cdot n\right)$$

Based on the Eular's equation, can be re-written as:

$$i(n) = I_D \cdot z_0^n + \frac{\dot{I}_P}{2} \cdot z_1^n + \frac{\bar{I}_P}{2} \cdot \bar{z}_2^n$$

Goal is to extract I_P component from the unknown variables

Short Window Phasor Estimation

With 3 or more known AC signal samples, the unknown variables ($I_D, \dot{I}_P$ and $\bar{I}_P$) can be worked out

$$\underbrace{\begin{bmatrix} i(W-1) \\ i(W-2) \\ \cdots\cdots \\ i(1) \\ i(0) \end{bmatrix}}_{\text{I}} = \underbrace{\begin{bmatrix} z_0^{W-1} & \frac{z_1^{W-1}}{2} & \frac{z_2^{W-1}}{2} \\ z_0^{W-2} & \frac{z_1^{W-2}}{2} & \frac{z_2^{W-2}}{2} \\ \cdots & \cdots & \cdots \\ z_0^{1} & \frac{z_1^{1}}{2} & \frac{z_2^{1}}{2} \\ 1 & 1 & 1 \end{bmatrix}}_{\text{M}} \underbrace{\begin{bmatrix} I_D \\ \dot{I}_P \\ \bar{I}_P \end{bmatrix}}_{\text{X}}$$

$$z_0 = e^{-Ts/Ta}, \qquad z_1 = e^{j\frac{2\pi}{N}}, \qquad z_2 = e^{-j\frac{2\pi}{N}}$$

Short Window Phasor Estimation

Using inverse matrix to solve unknown variables, following is defined.

$$X = \underbrace{(M^T M)^{-1} M^T}_{\text{H}} \cdot I$$

Further h coefficients are obtained from the 2nd raw of H matrix

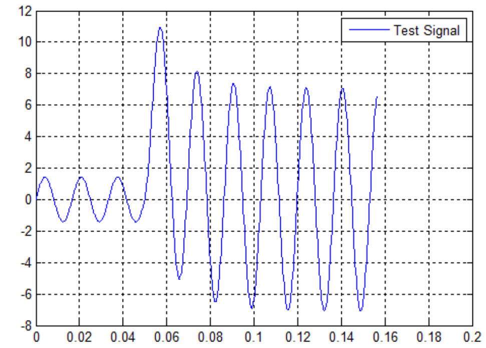
$$h(1{:}W) = H(2, 1{:}W)$$

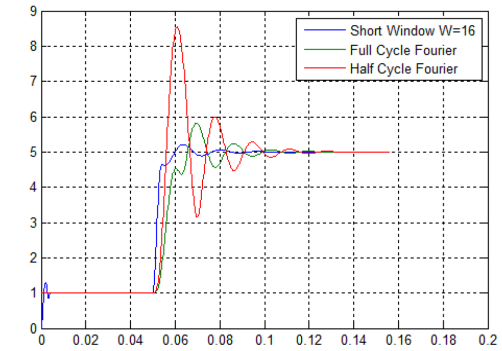
Short window fundamental phasor $\dot{I}_P(n)$ without DC component can be obtained by

$$\dot{I}_P(n) = \sum_{k=1}^{W} h(k) i(n-k+1)$$

Short Window Phasor Estimation

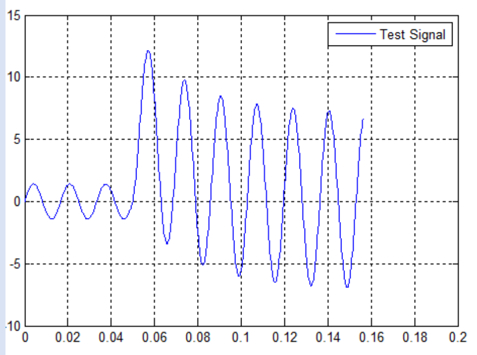
Simulation signal with X/R=5

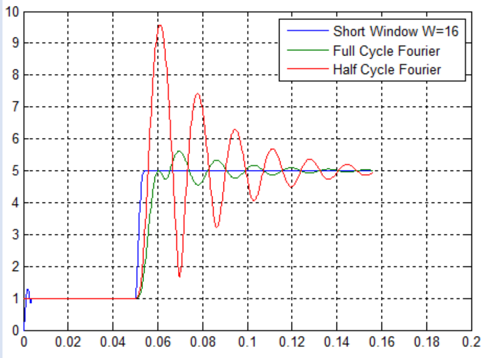




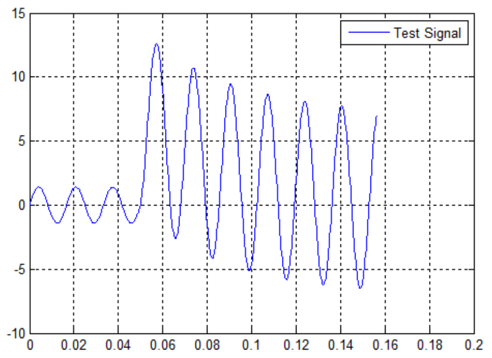
Simulation signal with X/R=10

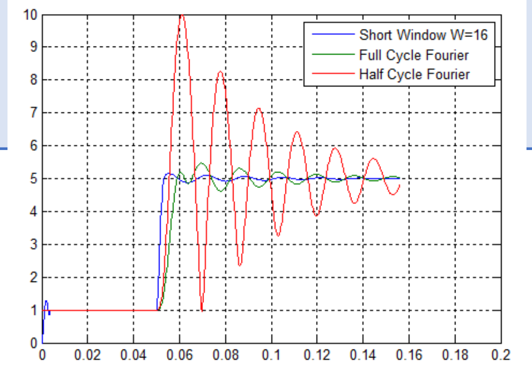
Exactly matches the time constant, Ta, we preselected in the short window phasor estimation method



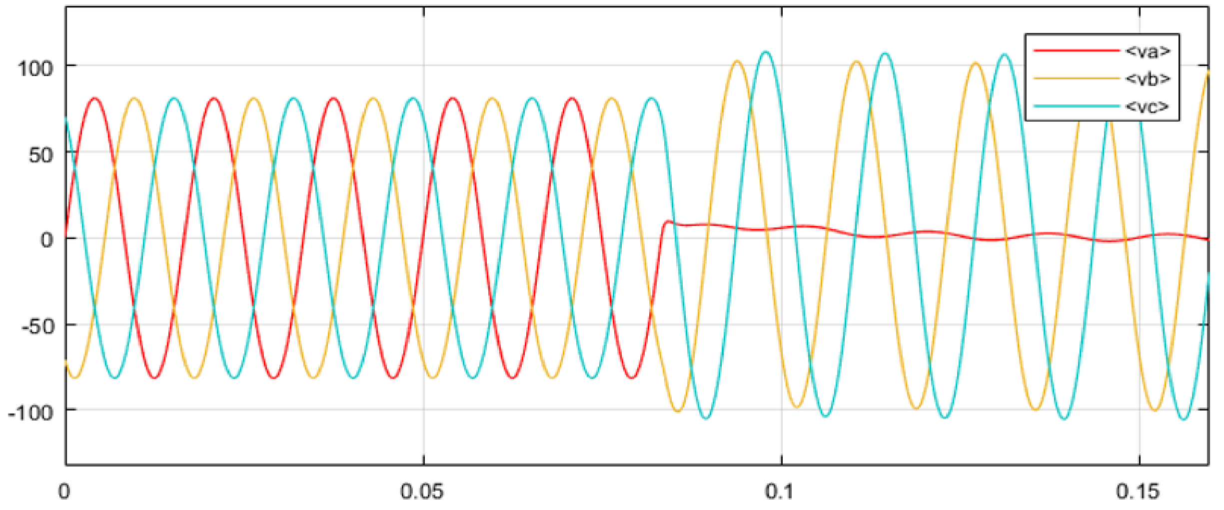
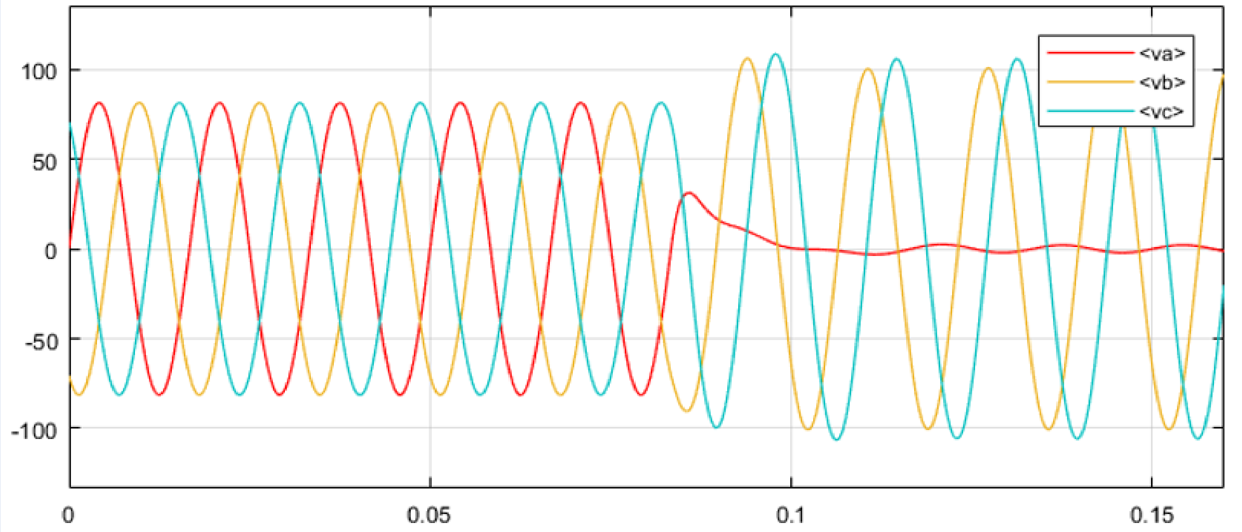


Simulation signal with X/R=15

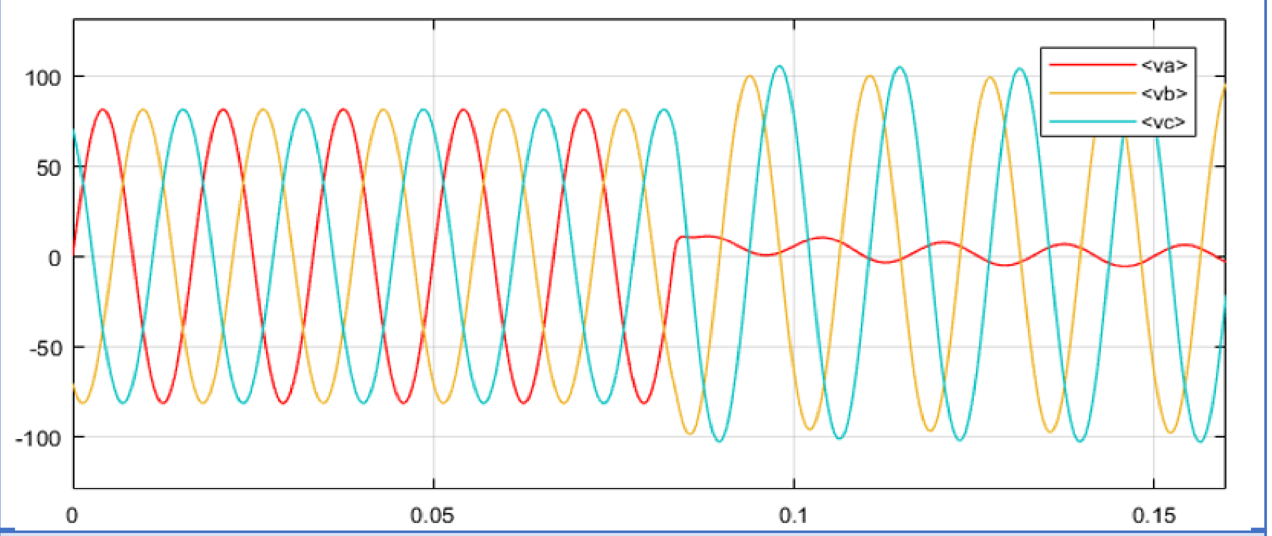
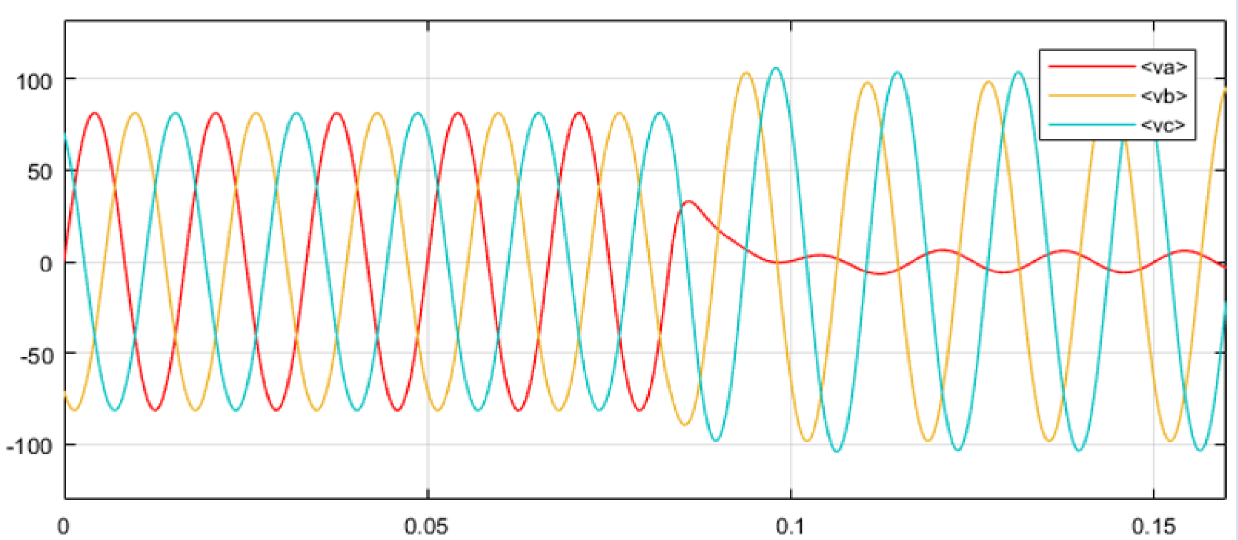




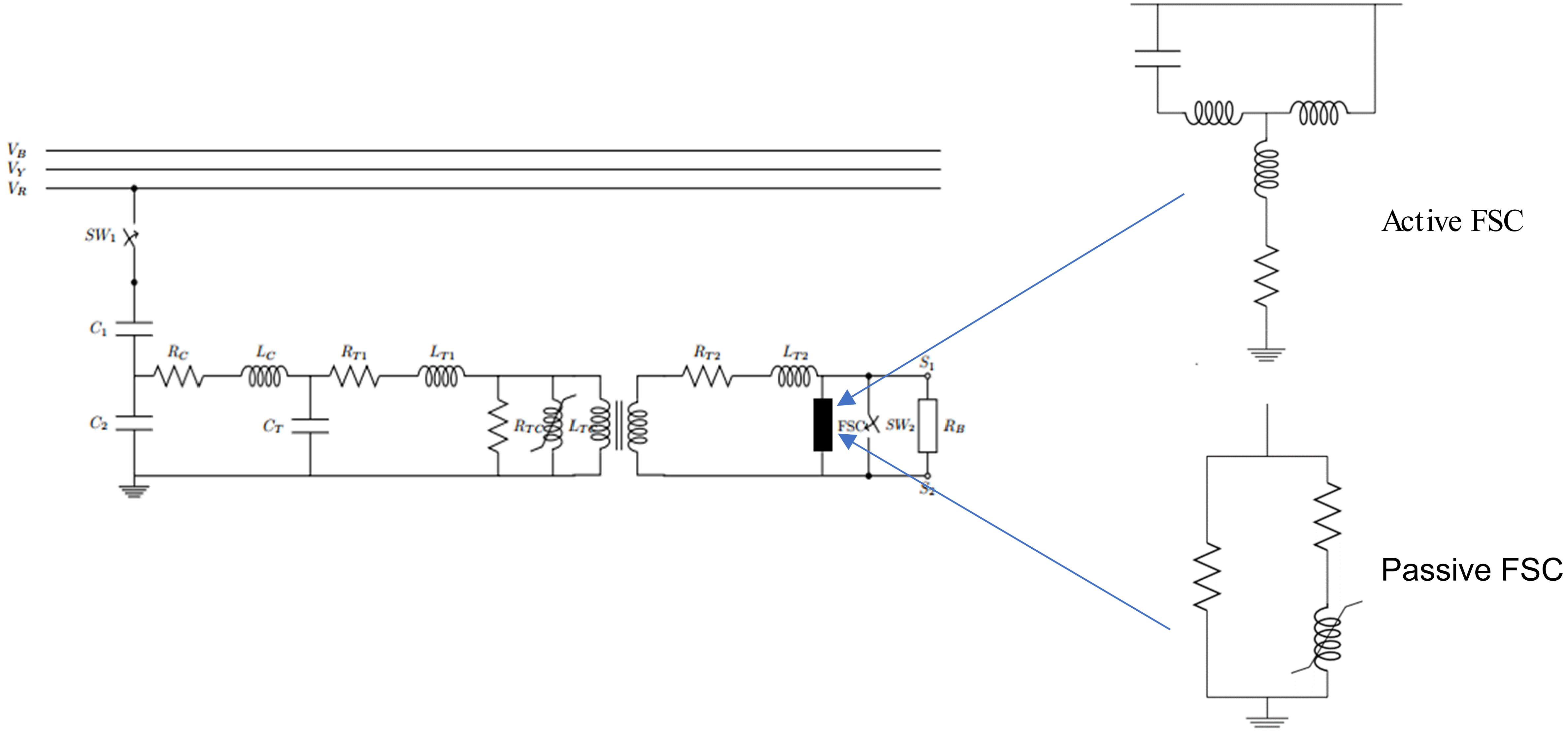
CVT Transients and Mitigation Methods

Secondary voltage obtained from a passive CVT with SIR=30, AG fault at 80% of line	
Secondary voltage obtained from an active CVT with SIR=30, AG fault at 80% of line	

CVT Transients and Mitigation Methods

Secondary voltage obtained from a passive CVT with SIR=10, AG fault at 80% of line	
Secondary voltage obtained from an active CVT with SIR=10, AG fault at 80% of line	

CVT Transients and Mitigation Methods



CVT Transients and Mitigation Methods

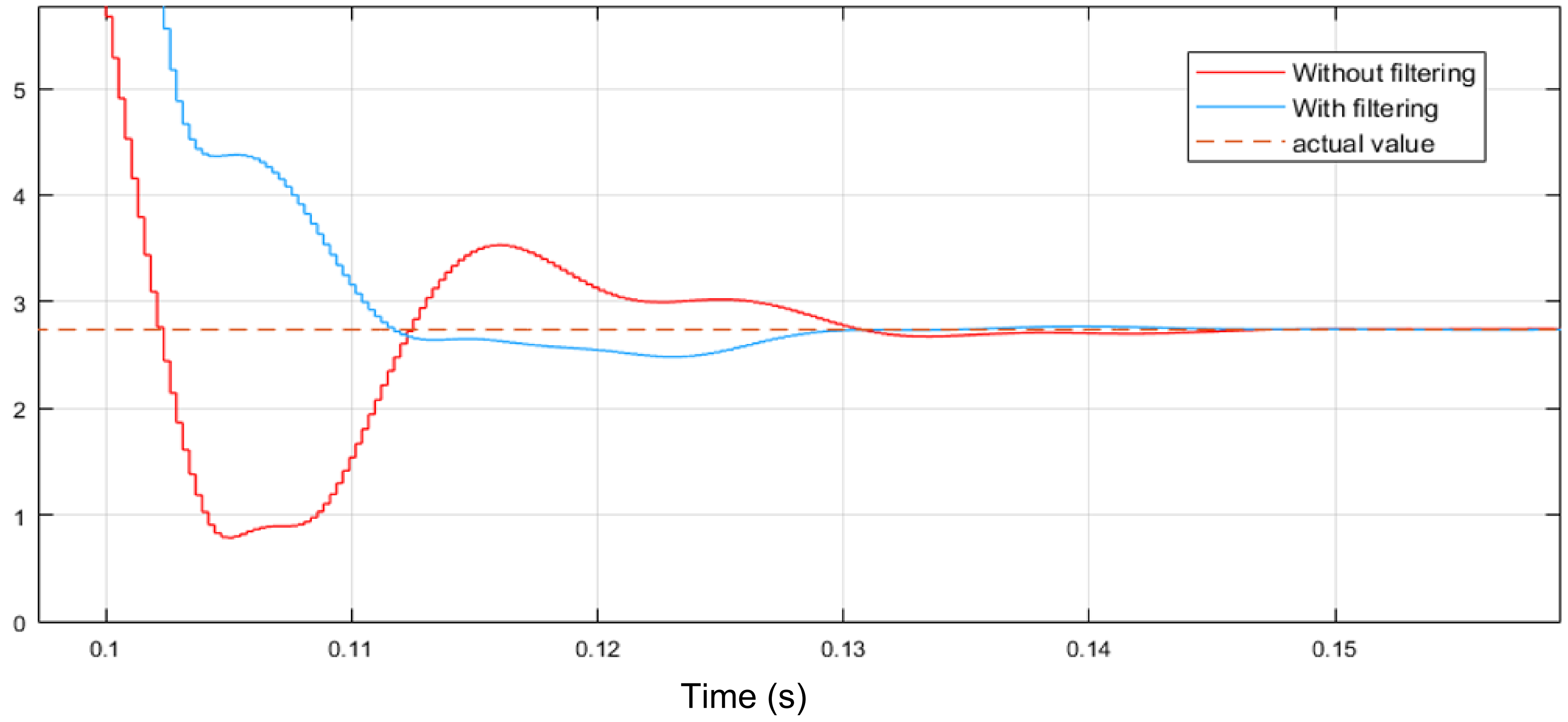
- Active CVT transients are more severe than from a passive CVT and are more difficult to filter out.
- CVT transients at high SIR are much severe than that at low SIR.
- The most severe CVT transients when fault occurs near zero crossing of the primary voltage.

CVT Transients and Mitigation Methods

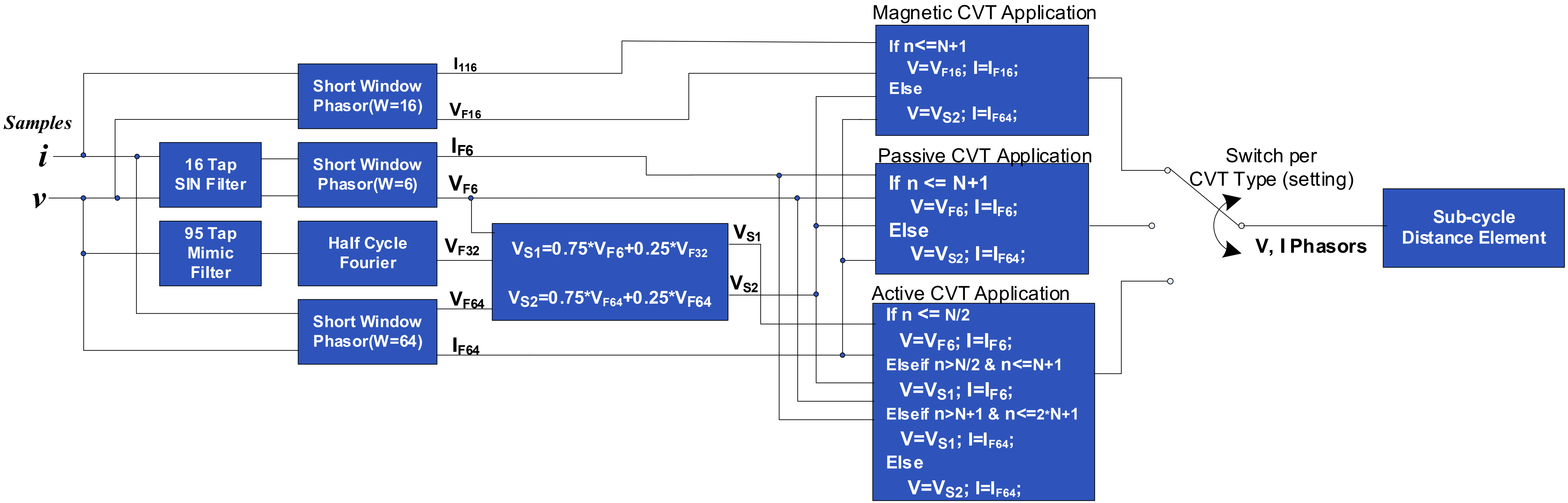
- CVT transients is the major cause of the distance element overreach.
- Several methods are used to address the transient overreach in distance elements, including:
  - Reach reduction
  - Additional delay
  - Application of filtering to remove CVT transients
  - Combination of above methods based on certain logic, such as SIR detection, CVT transient detection, etc.

CVT Transients and Mitigation Methods

Filtering technique is commonly used by microprocessor relays.

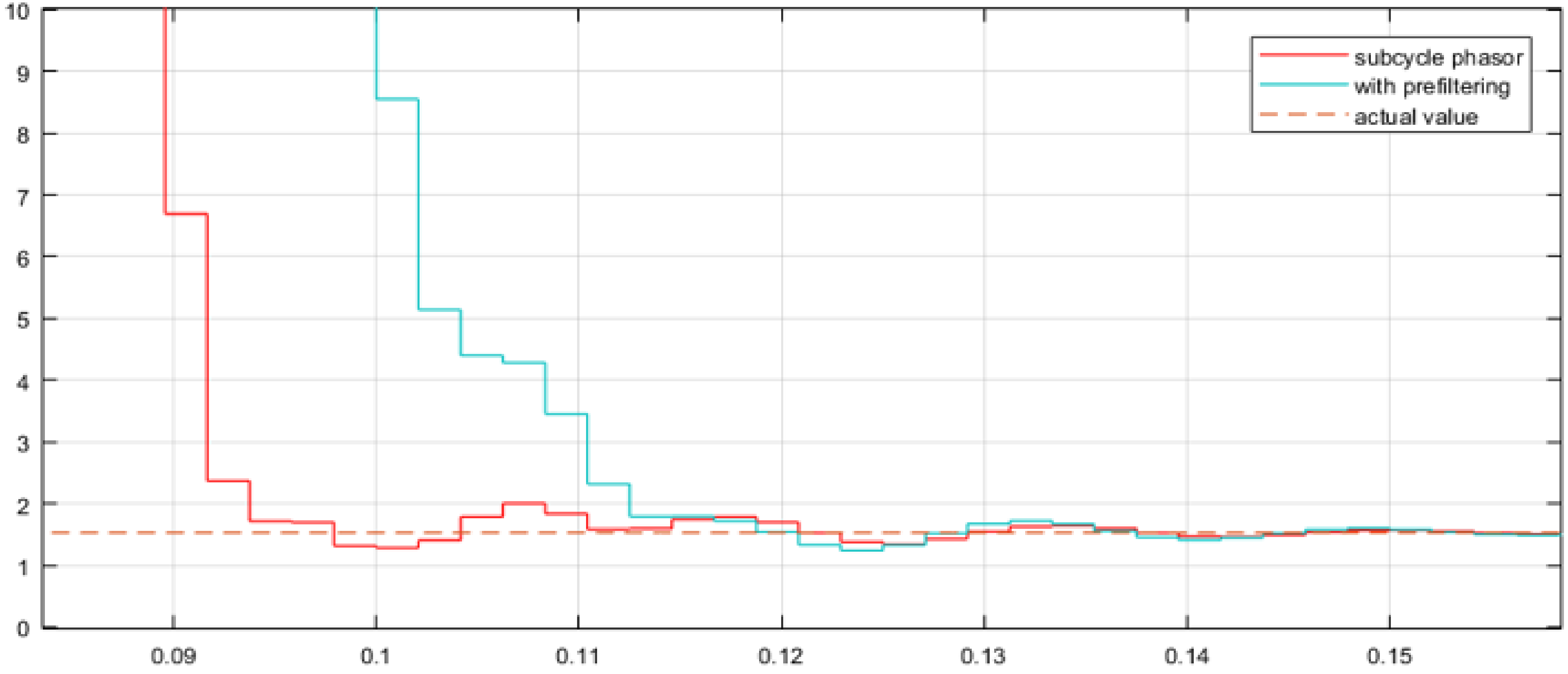


Sub-cycle Distance Algorithm

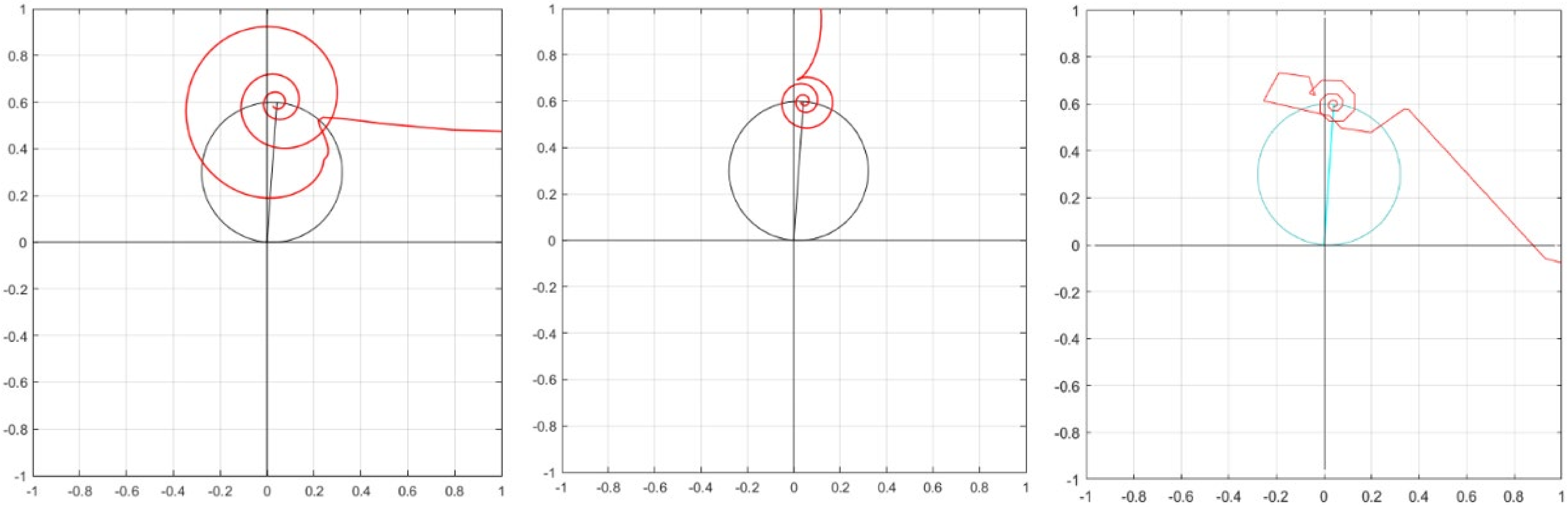


Sub-cycle Distance Algorithm

- The sub-cycle phasor magnitude and long window size phasor magnitude with prefiltering from passive CVT at SIR=30 are plotted below.

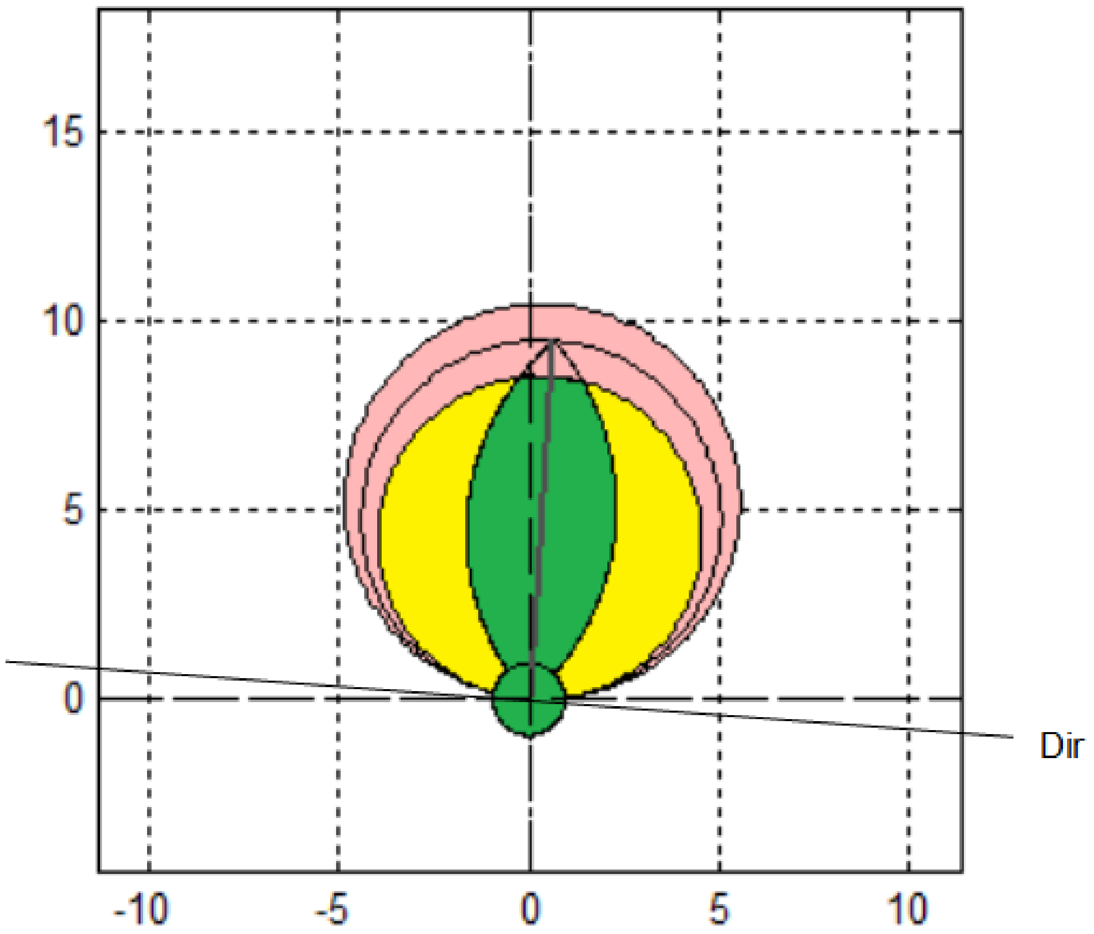


Sub-cycle Distance Algorithm



Tripping Count Strategy

Additional measures have been taken to further reduce transient overreach, in which Tripping Count Strategy is applied

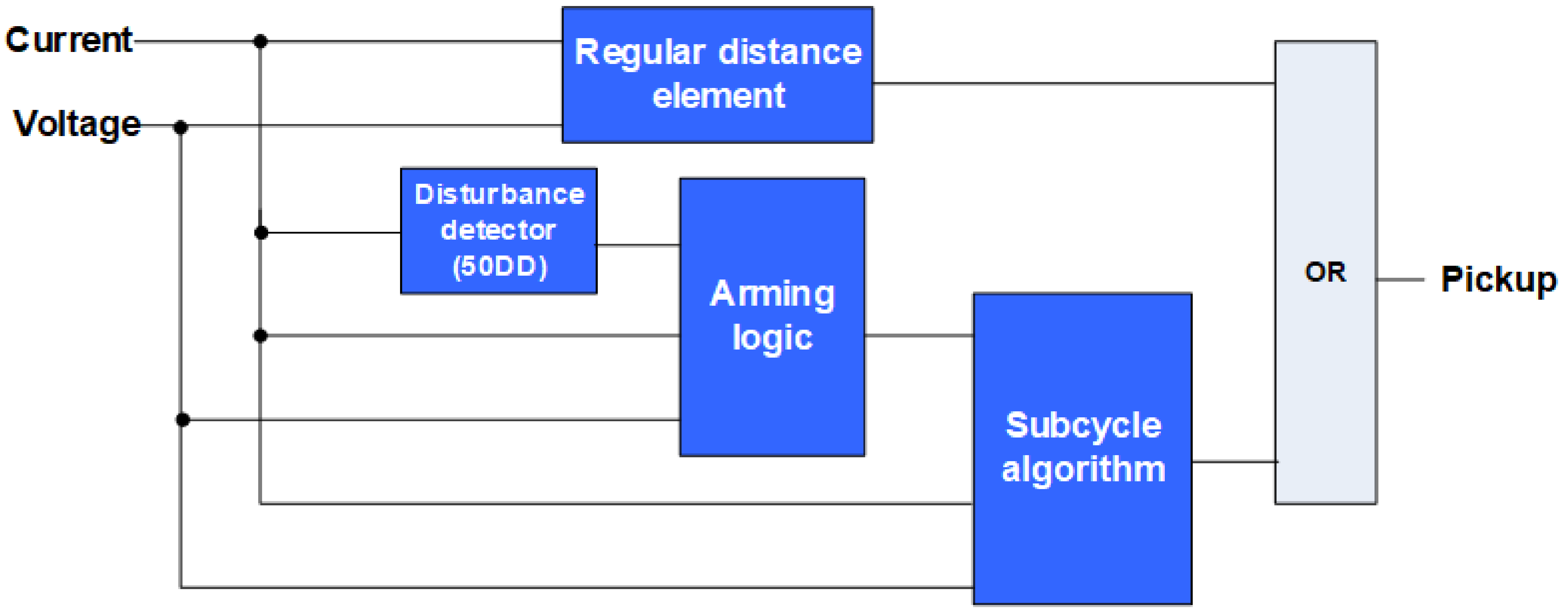


Phase Selection Supervision

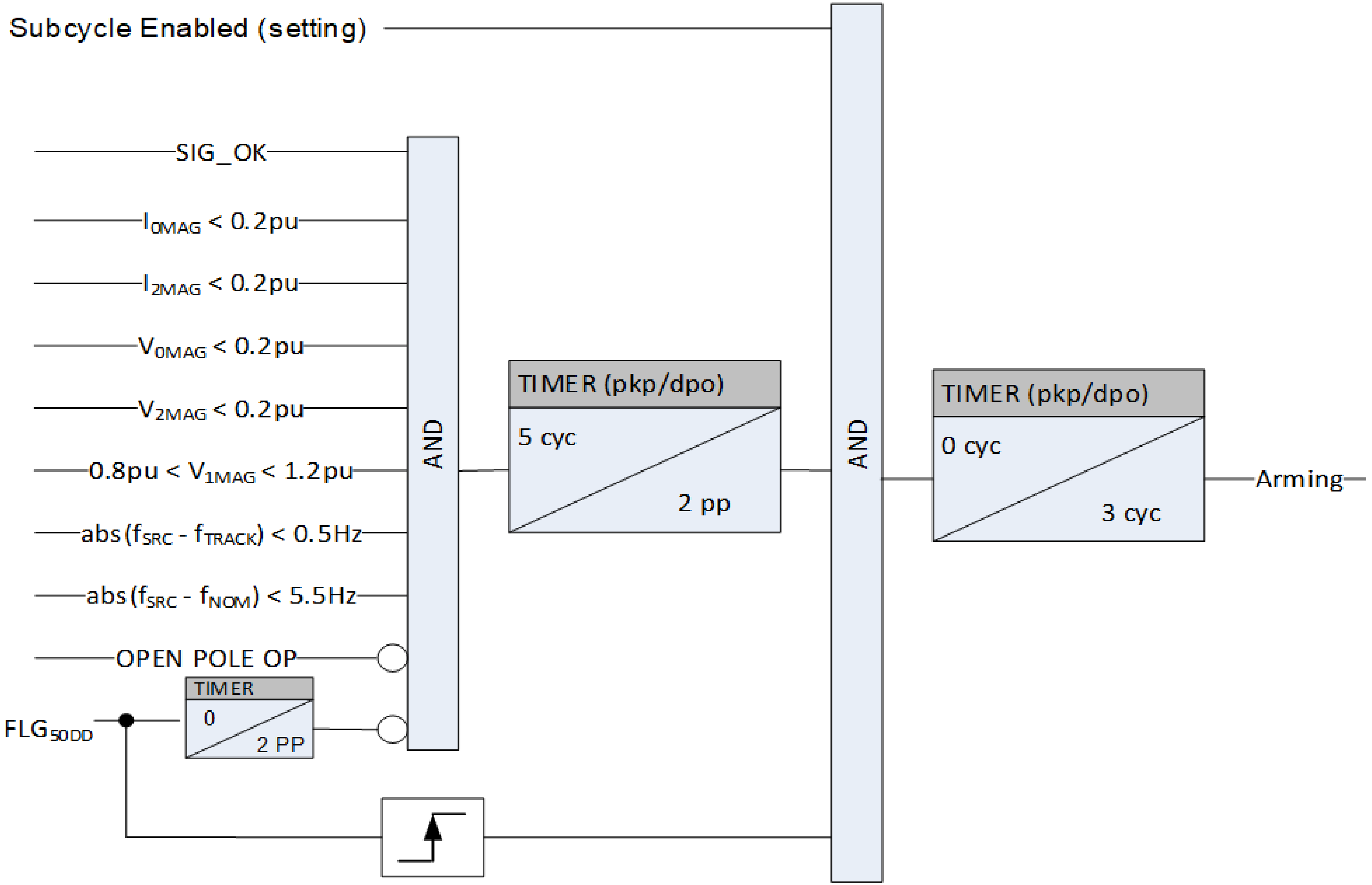
To obtain sub-cycle speed, very fast fault type supervision is needed

Ph-Ph Delta I / Loop selected	A	B	C	AB	BC	CA
ΔI AB Valid	yes	yes	no	yes	no	no
ΔI BC Valid	no	yes	yes	no	yes	no
ΔI CA Valid	yes	no	yes	no	no	yes

Arming and Overall Protection Logic

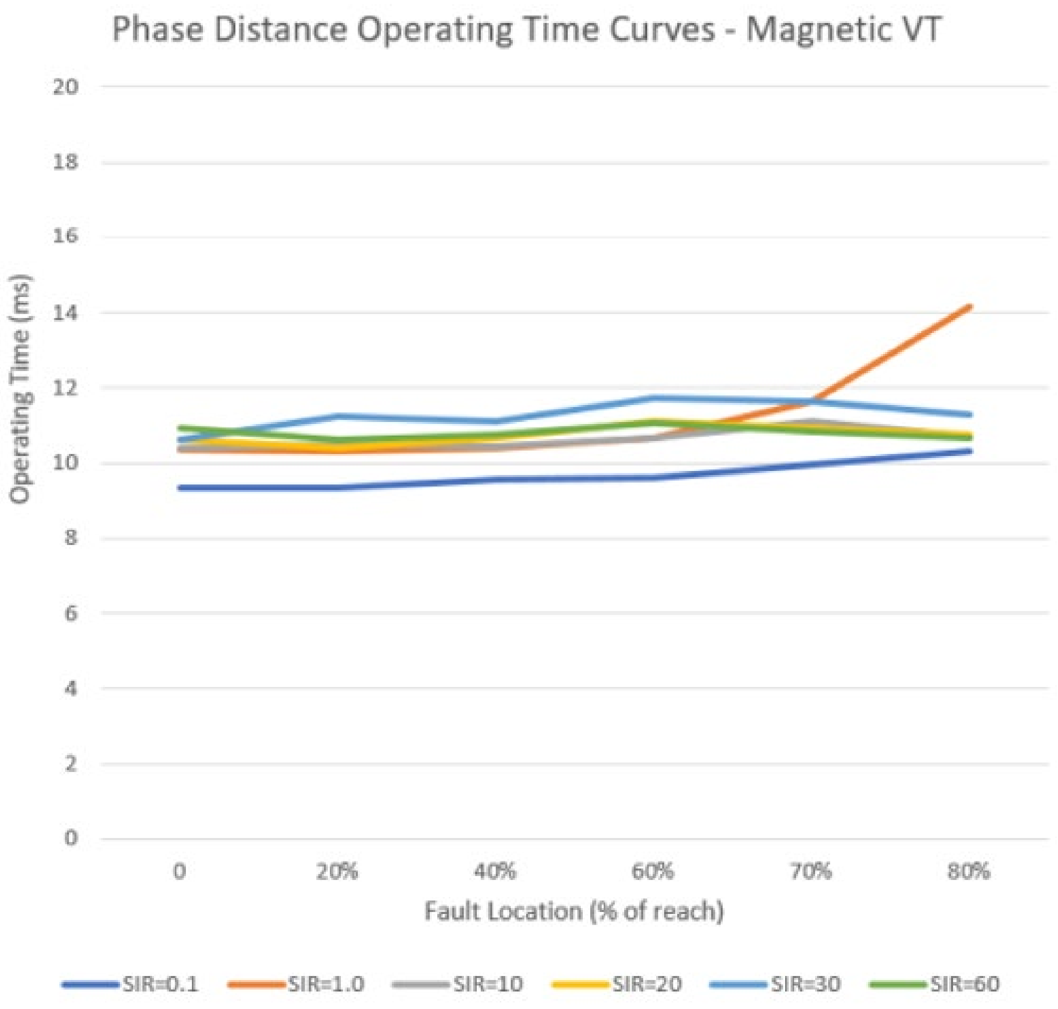


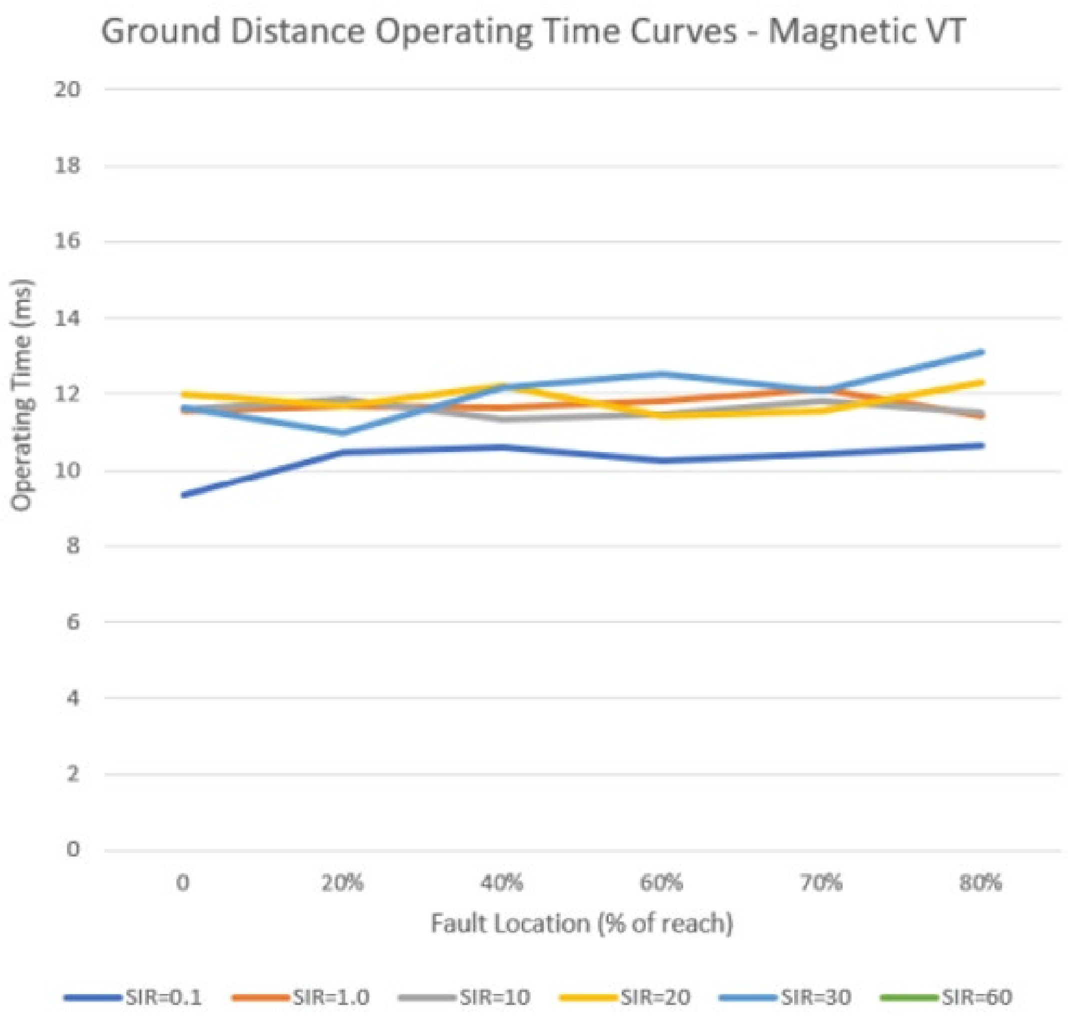
Arming and Overall Protection Logic



Performance Evaluations

60Hz





Performance Evaluations

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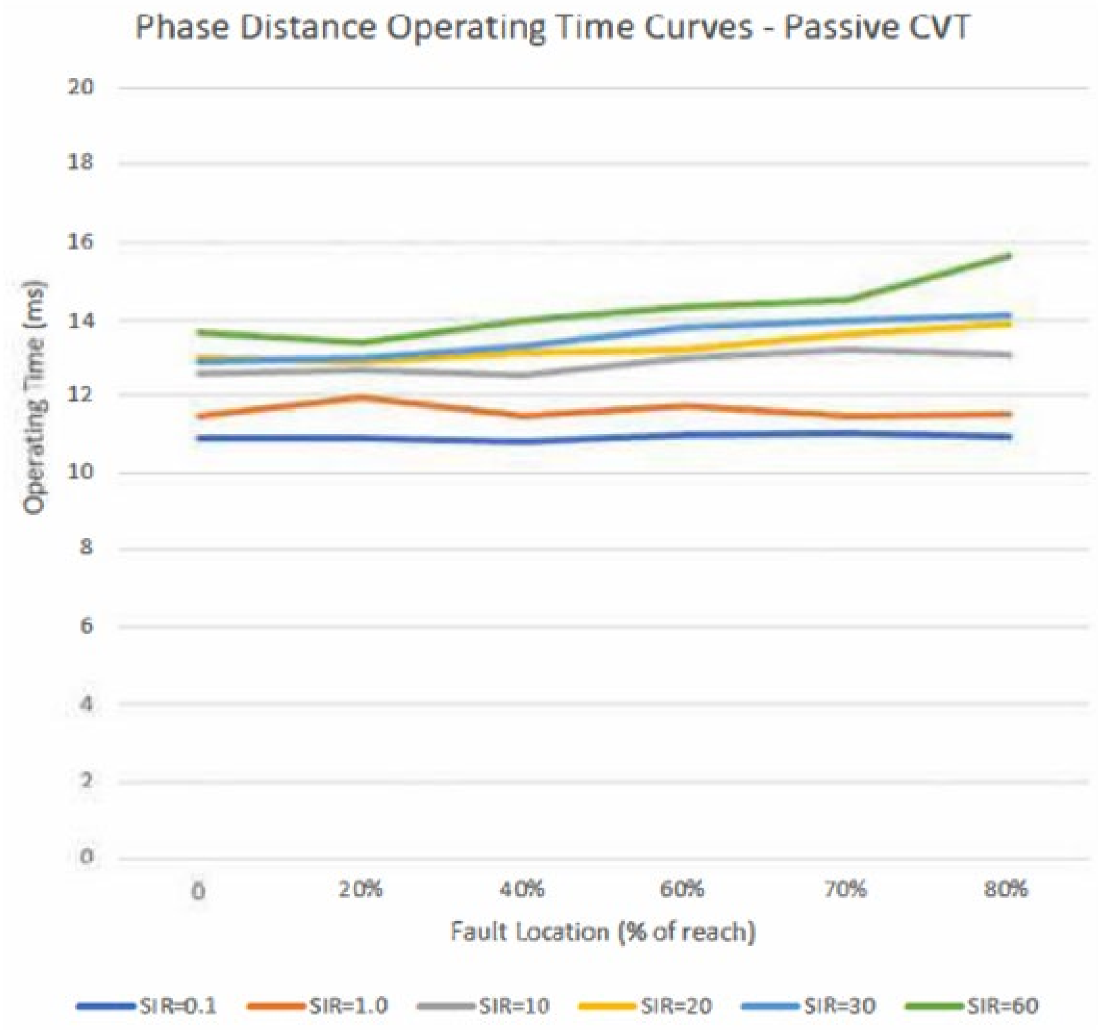
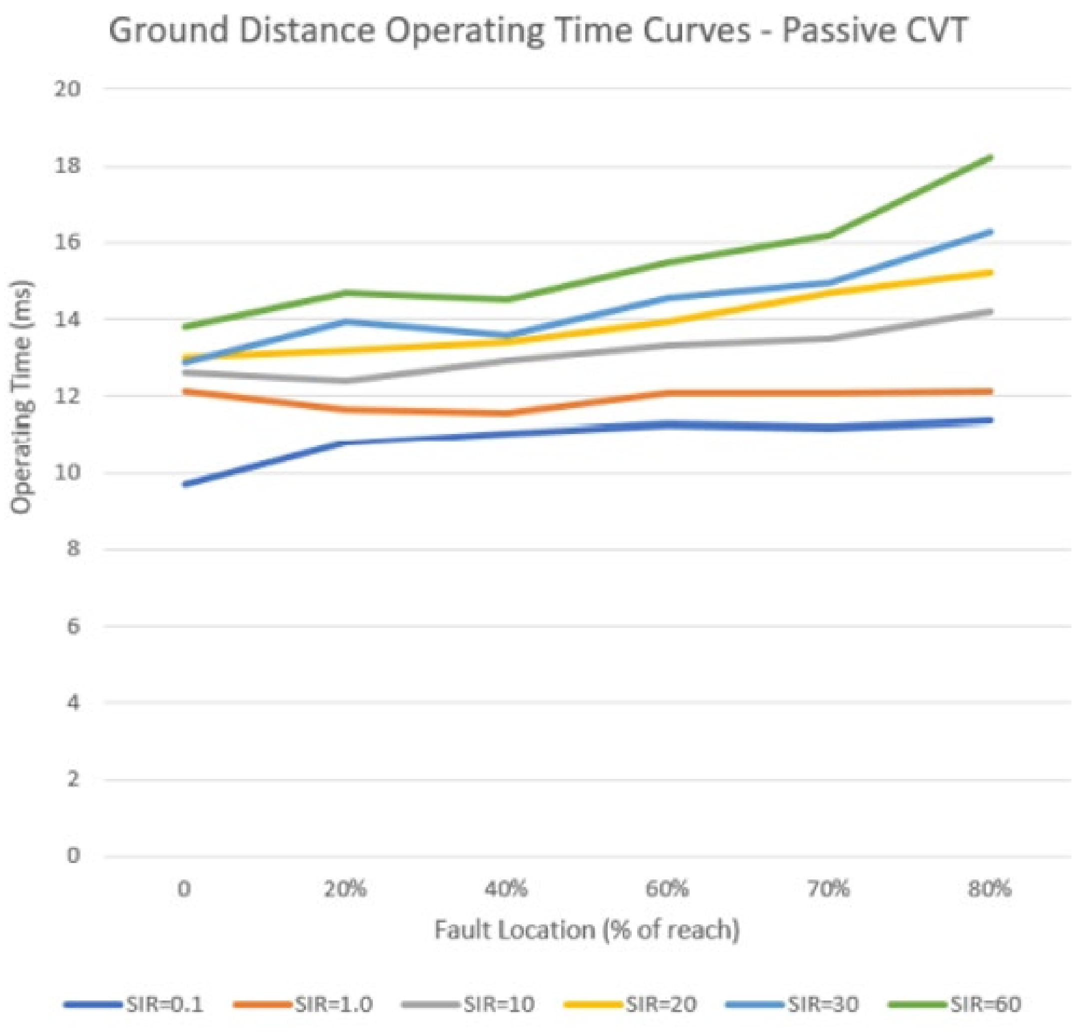
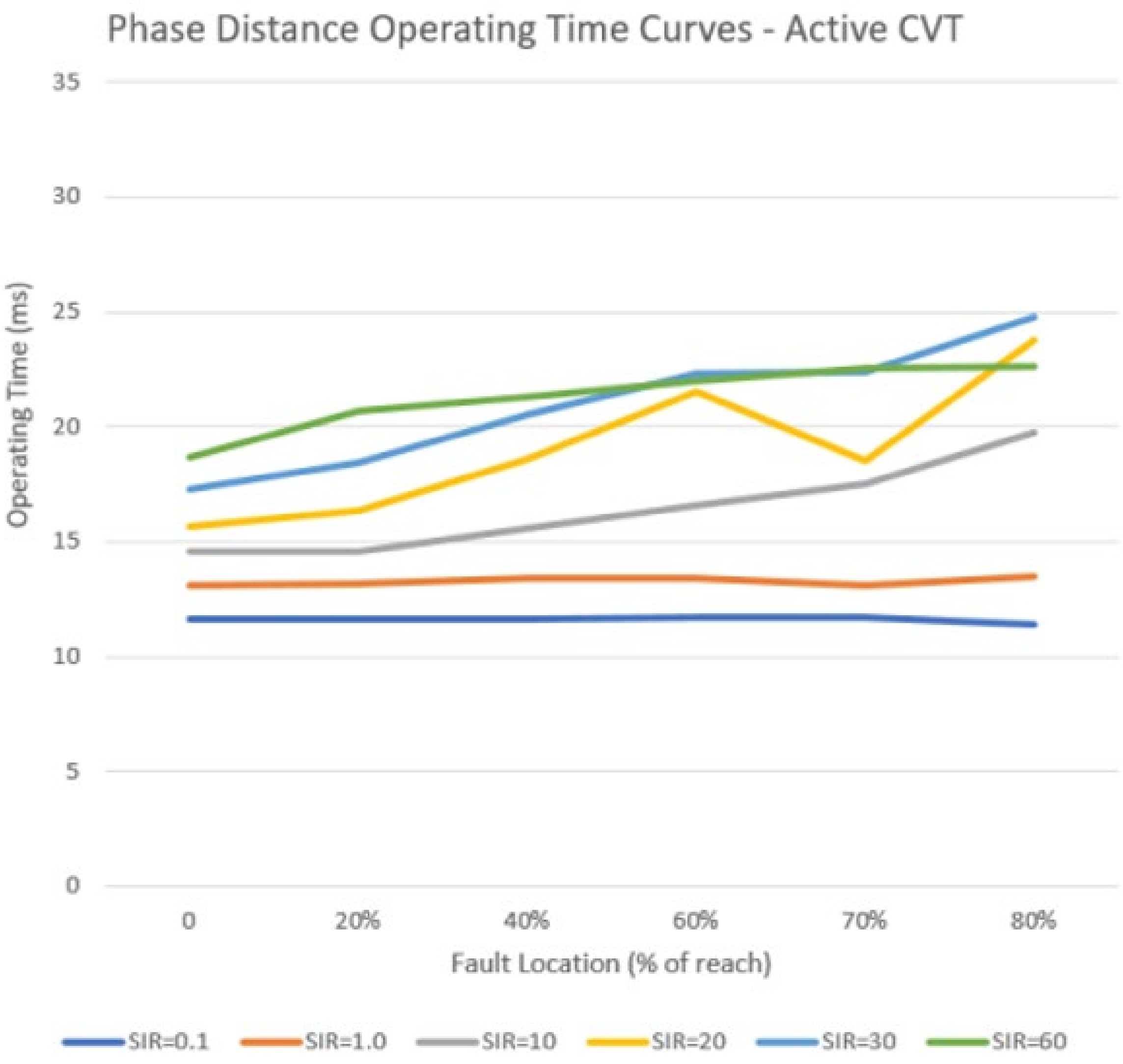
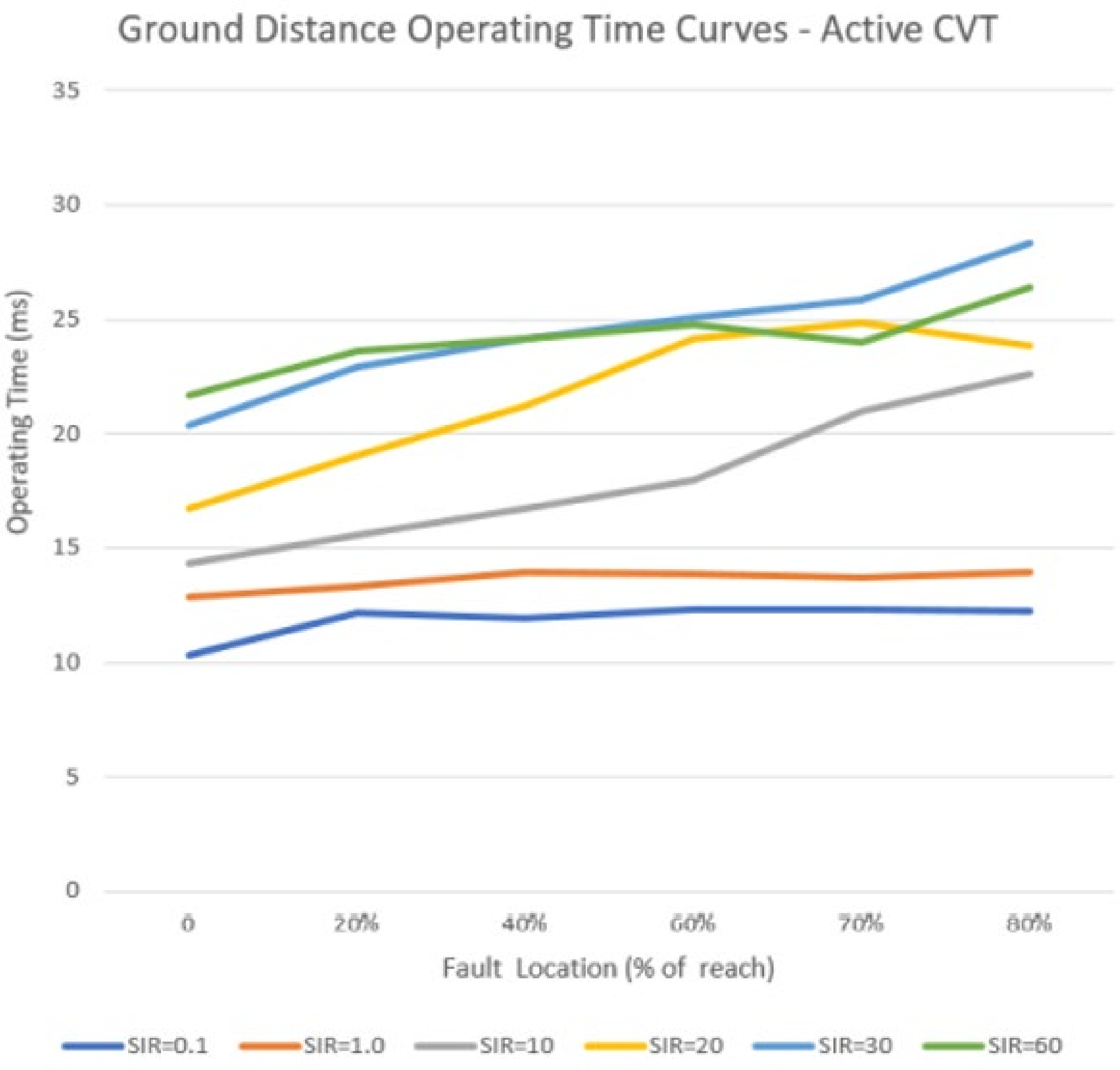




Performance Evaluations

60Hz





Conclusions

- Short window-based phasor estimation algorithm with decaying DC accounted for can achieve distance sub-cycle operation time.
- The sub-cycle distance algorithm only acts as an accelerator and is a complement to the regular full cycle Fourier phasor-based distance element.
- Regular full cycle Fourier phasor-based distance element remains always functional therefore the dependability of the overall distance protection is not affected at all.

Conclusions

- The novel short window phasor estimation method removes decaying DC and CVT transients effectively.
- Additional filtering, averaging, switching, and tripping count strategy ensures security. Transient overreach is less than 5% for SIR up to 60 with both magnetic VTs and CVTs applications.
- Different filtering techniques are applied to different VT types.

Thank You

Questions?