Protection for Sub SSTI Conditions Using an Industrial Sub-harmonic Relay

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Outline

- Sub Synchronous Torsional Interactions
- Sub Harmonic Relay and Principle of Sub-harmonic Detection
- Operations/Duration Detector
- Development of Protection Settings
- Case Studies
- Conclusions

Sub Synchronous Interactions

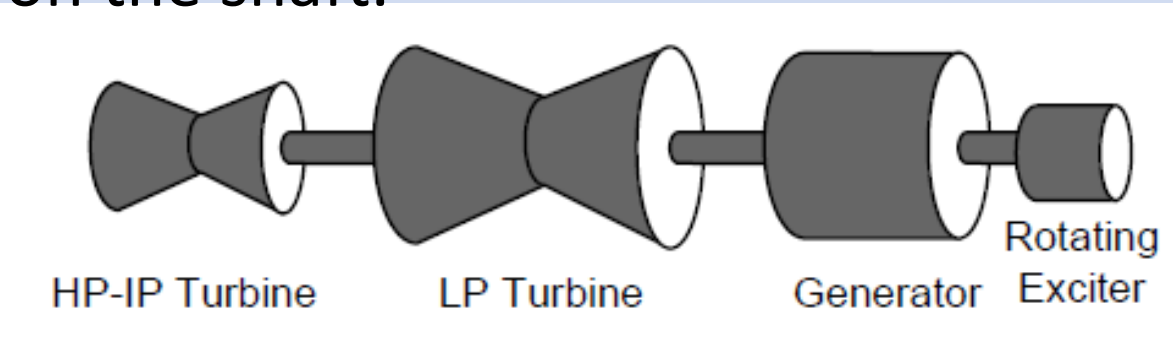
- Subsynchronous torque interaction (SSTI) is a well known phenomenon in high voltage AC networks.
- It can be sustained and amplified in power systems with series compensated lines or active devices for power flow or voltage control.
- These devices introduce negative damping for the turbine-generator system critical frequencies.
- It is known that also a high voltage direct current (HVDC) link may have a similar effect particularly when connected near a turbine generator as the only load.

Sub Synchronous Interactions

- In order to identify the risk of interaction in an HVDC project, an SSTI screening study is always performed.
- If the screening study indicates a potential risk for SSTI oscillations, a more detailed SSTI study is performed, and, if necessary, an SSTI damping controller has to be adapted and integrated in the HVDC control system.
- The technology for HVDC transmission system that includes voltage source converters may not have any established method to assess and perform SSTI studies.

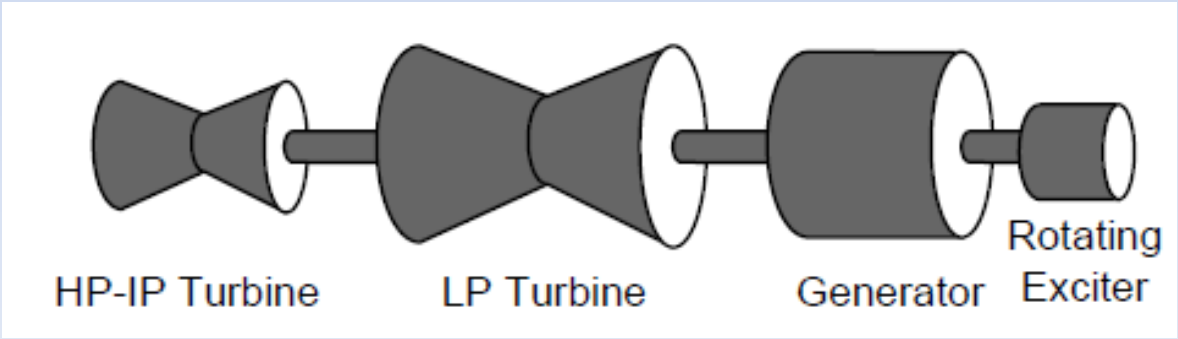
Sub Synchronous Interactions

- The SSTI phenomenon can be understood by considering both the torsional modes of turbine-generators and the control methods used for the power-electronic equipment.
- A generic turbine-generator system is illustrated in the figure. In this case there are six masses – the high-pressure and intermediate pressure turbines, the two segments of the low-pressure turbine, the generator and the exciter. Any given system may have more or less masses on the shaft.



Sub Synchronous Interactions

- If the system has N masses there will be N-1 oscillatory mechanical torsional modes. The frequency of each oscillatory mode and how well it is damped (decays away) will be dependent upon the relative sizes of the masses, the stiffness of the shaft and the magnitude of various losses in the mechanical system. Of these modes, those that occur at frequencies below the system frequency – in other words, at subsynchronous frequencies – are of particular concern.



Sub Synchronous Torsional Interactions

- Torsional interaction occurs when the induced subsynchronous torque in the generator is close to one of the torsional natural modes of the turbine-generator shaft.
- When this happens, generator rotor oscillations will build up and this motion will induce armature voltage components at subsynchronous frequencies.
- Moreover, the phase of this induced subsynchronous frequency voltage is such that it sustains the subsynchronous torque.

Sub Synchronous Torsional Interactions

- If this torque equals or exceeds the inherent mechanical damping of the rotating system, the system will become self-excited.
- This phenomenon is called torsional interaction and occurs in the frequency range of ~10-45 Hz.
- Hydro generator systems are not SSTI sensitive when connected to an HVDC transmission link. This is due to the fact that the mechanical damping for possible subsynchronous torsional frequencies is considerably high, and also because the natural torsion frequencies are at higher frequencies compared with thermal generators.

Sub Synchronous Torsional Interactions

- The most common example of the natural mode subsynchronous oscillation is found in networks that include series capacitor compensated transmission lines or at the rectifier side of an HVDC transmission.
- When connecting the rectifier side of an HVDC transmission link to an AC network with a turbo generator, the rectifier contributes with negative damping in the subsynchronous frequency range.
- Depending on the AC network configuration, this may increase the risk of SSTI in the generator system.

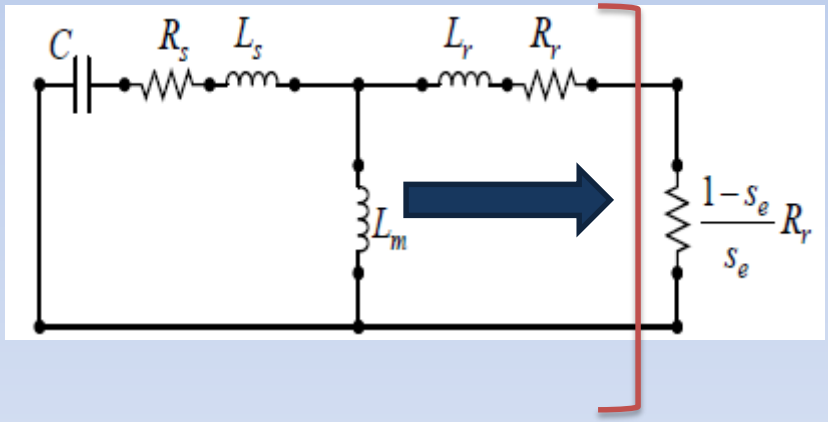
Sub Synchronous Interactions

System electrical dynamics

current →

← voltage

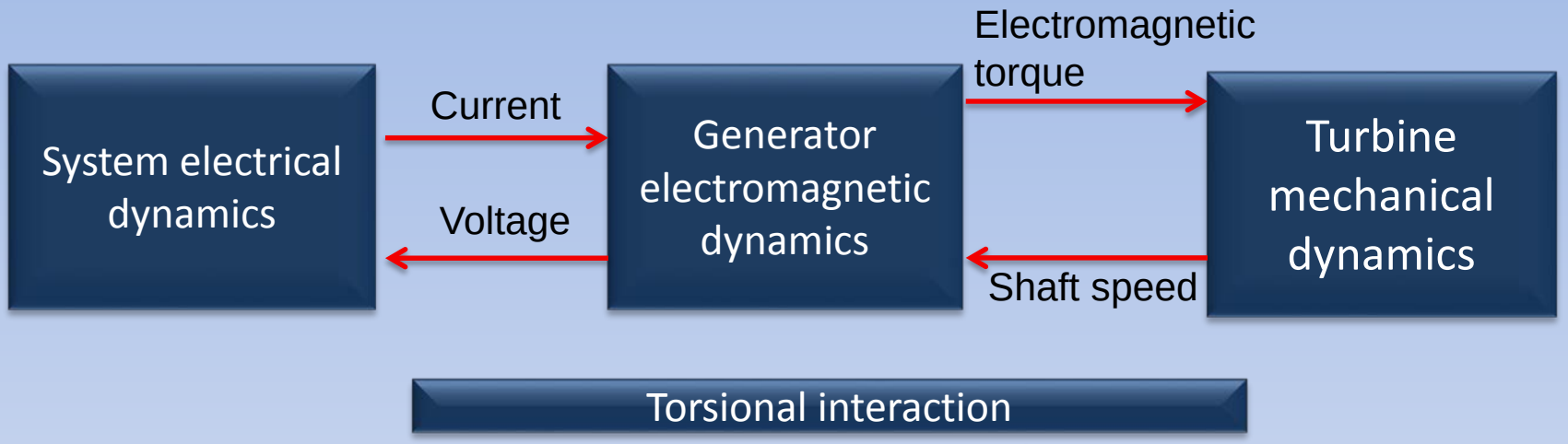
Generator electromagnetic dynamics

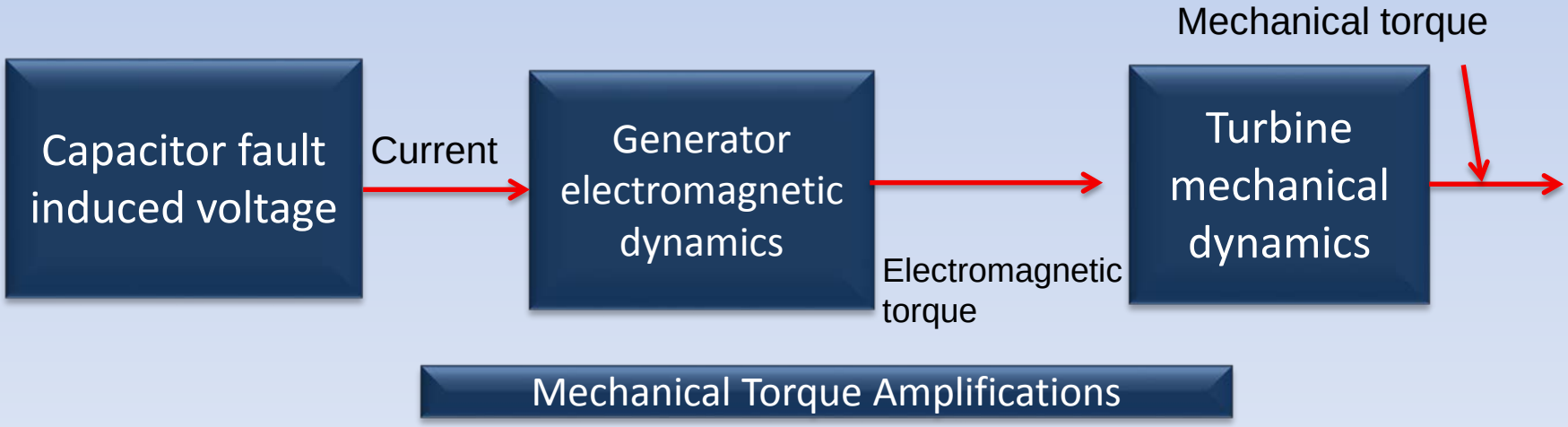


$$se = \frac{fn - fsys}{fn}$$

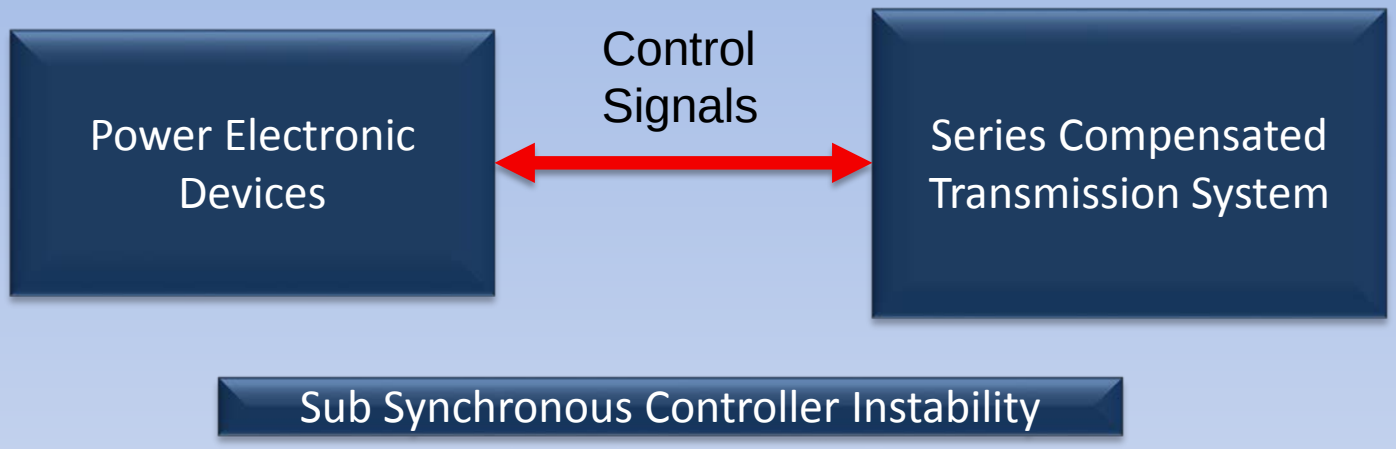
Electrical self excitation or Induction generator effect (IGE)

Types of Sub Synchronous Interactions



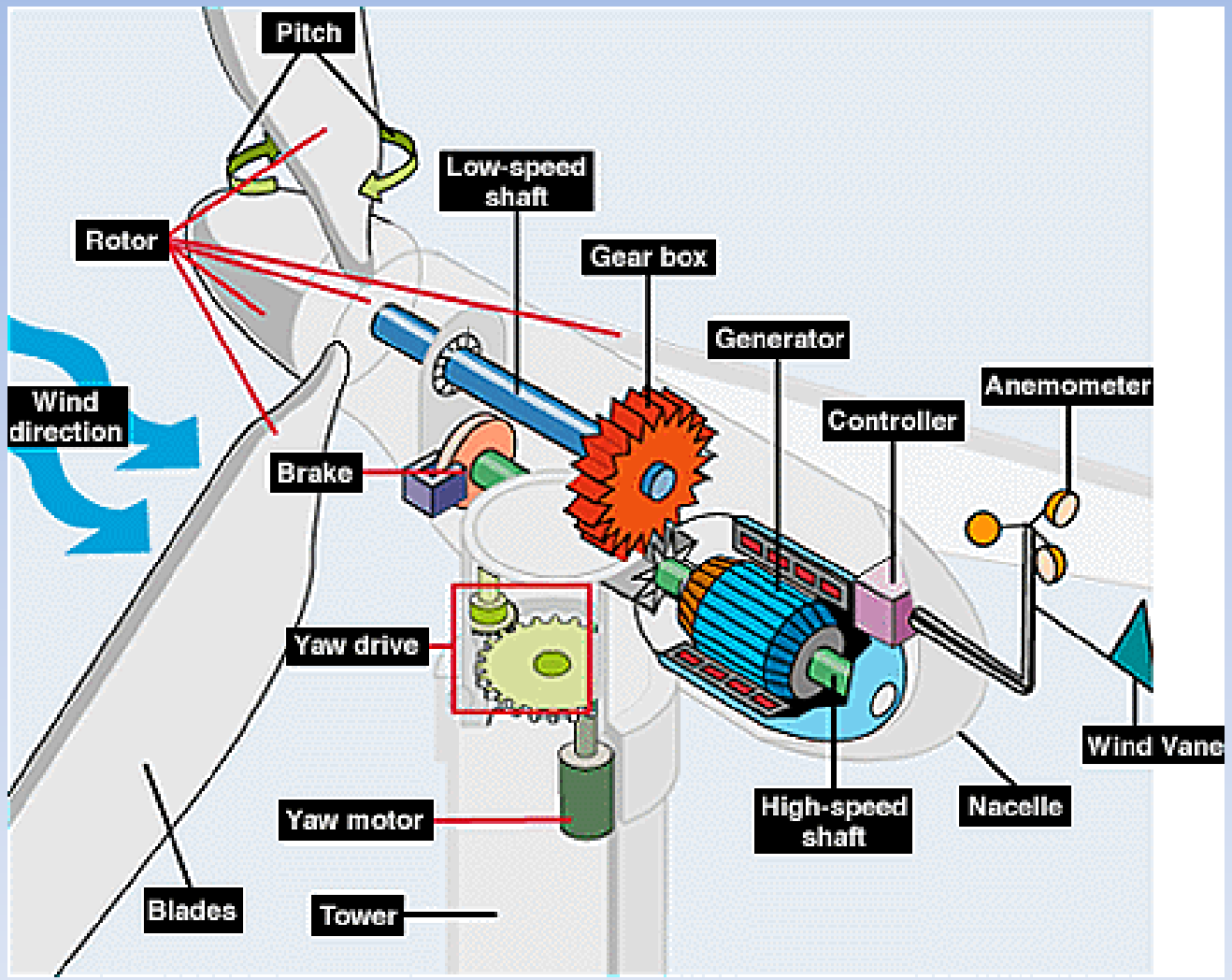


Types of Sub Synchronous Interactions



– Interaction Between Power Electronics Devices (Wind Turbine, HVDC, SVC etc.) and Series Compensated Transmission System.

Sub Synchronous Interactions

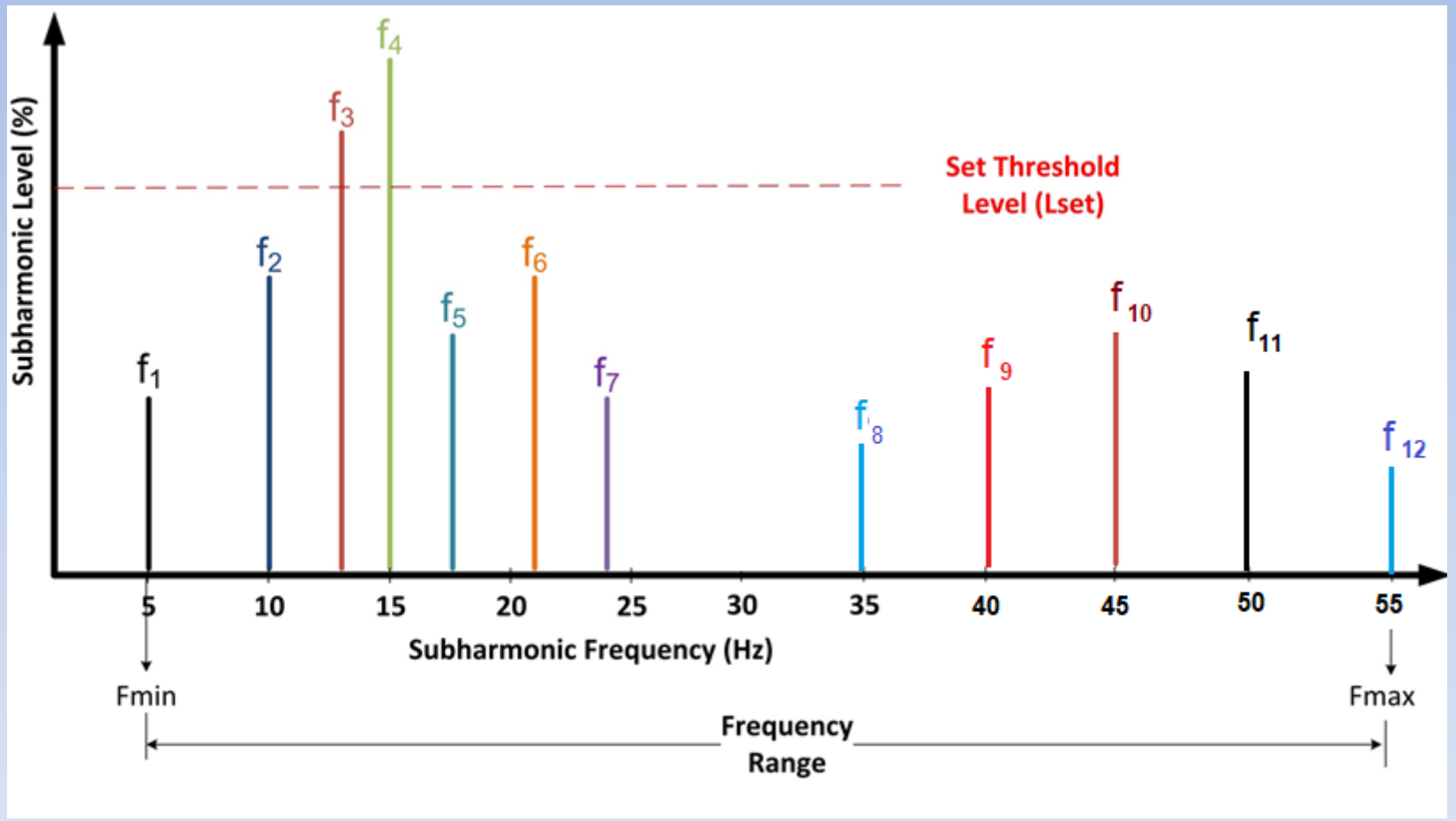


Effect of Series Capacitors

On Combustion Turbine

- The study concluded that the CT generator units are stable under base (normal) condition but with some potential for SSR under N-1 contingency.
- Since conclusion depended heavily on the actual mode shape of the turbine-generators and damping due to load, it was decided to determine the load damping and mode shape through actual measurement on one of the units.

Sub Harmonic Detection



Trip or Alarm: = max (f2, f3, f4, ….. f12) > Lset

Nominal Ratio Vs Fundamental Ratio

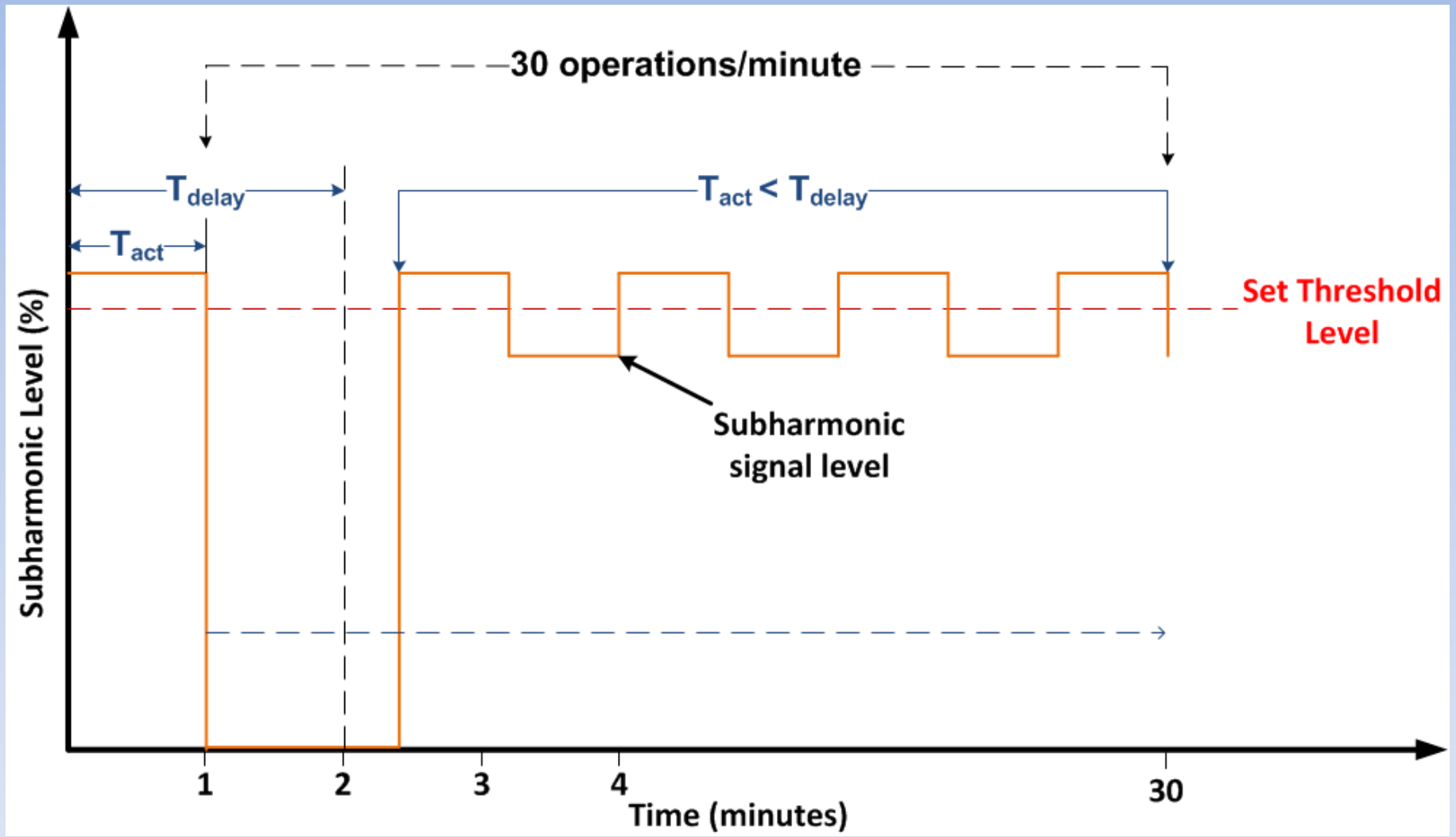
- Nominal Ratio
  - Sub harmonics are calculated as a percentage of nominal secondary CT and PT levels
  - Relay picks up for the maximum nominal sub-harmonic component above the threshold.

- Fundamental Ratio
  - Sub harmonics are calculated as a percentage of calculated fundamental quantities.
  - Relay picks up for the maximum fundamental sub-harmonic component above the threshold.

Total Sub Harmonic Distortion (TSHD)

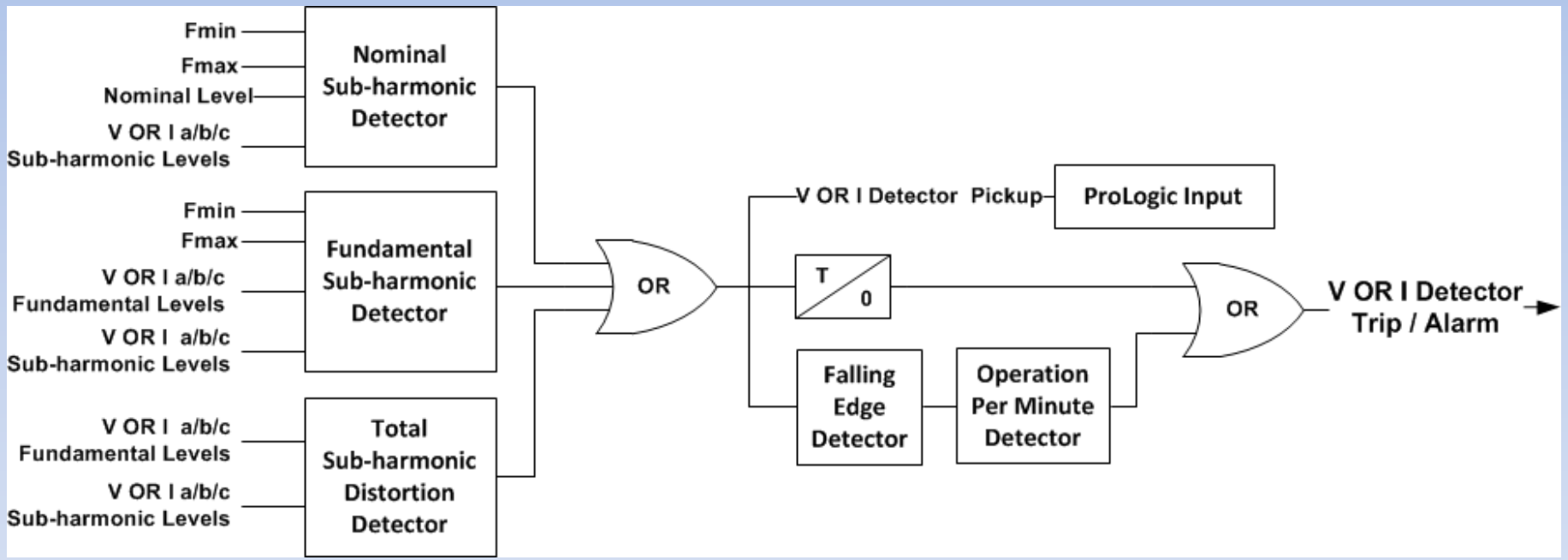
- TSHD represents the cumulative effect of the sub-harmonics.
  - $TSHD = \frac{\sqrt{f1^2 + f2^2 + \cdots + fn^2}}{fund}$
  - f1….. f2 are the sub-harmonic frequencies

Operations/Minute Detection



Return

Sub Harmonic Detection Logic Diagram



Frequency Modes

Multiple Modes

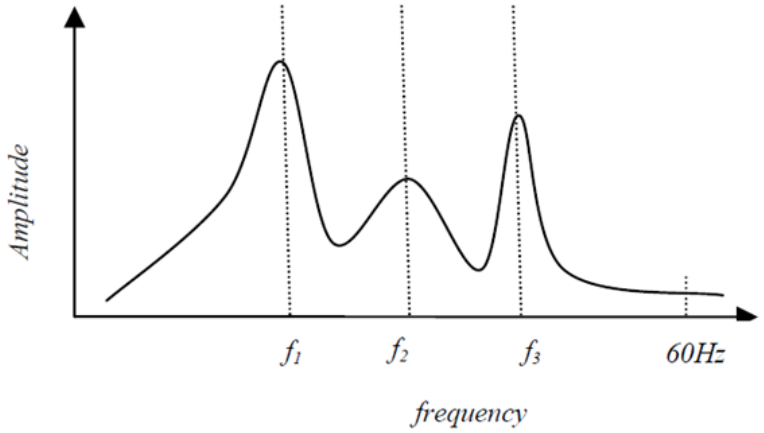


Fig. 2. Mechanical response of a turbine with multiple frequency mode

Single Mode

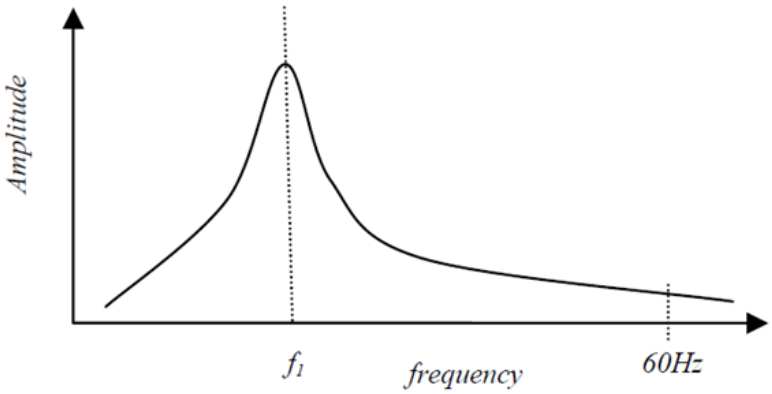


Fig. 1. Mechanical response of a turbine with a single frequency mode

Complementary frequencies are visible on the network side.

- 60-f_1
- 60-f_2
- 60-f_3

Logic for SSTI Detection

- Inverse Time Setting: Formation

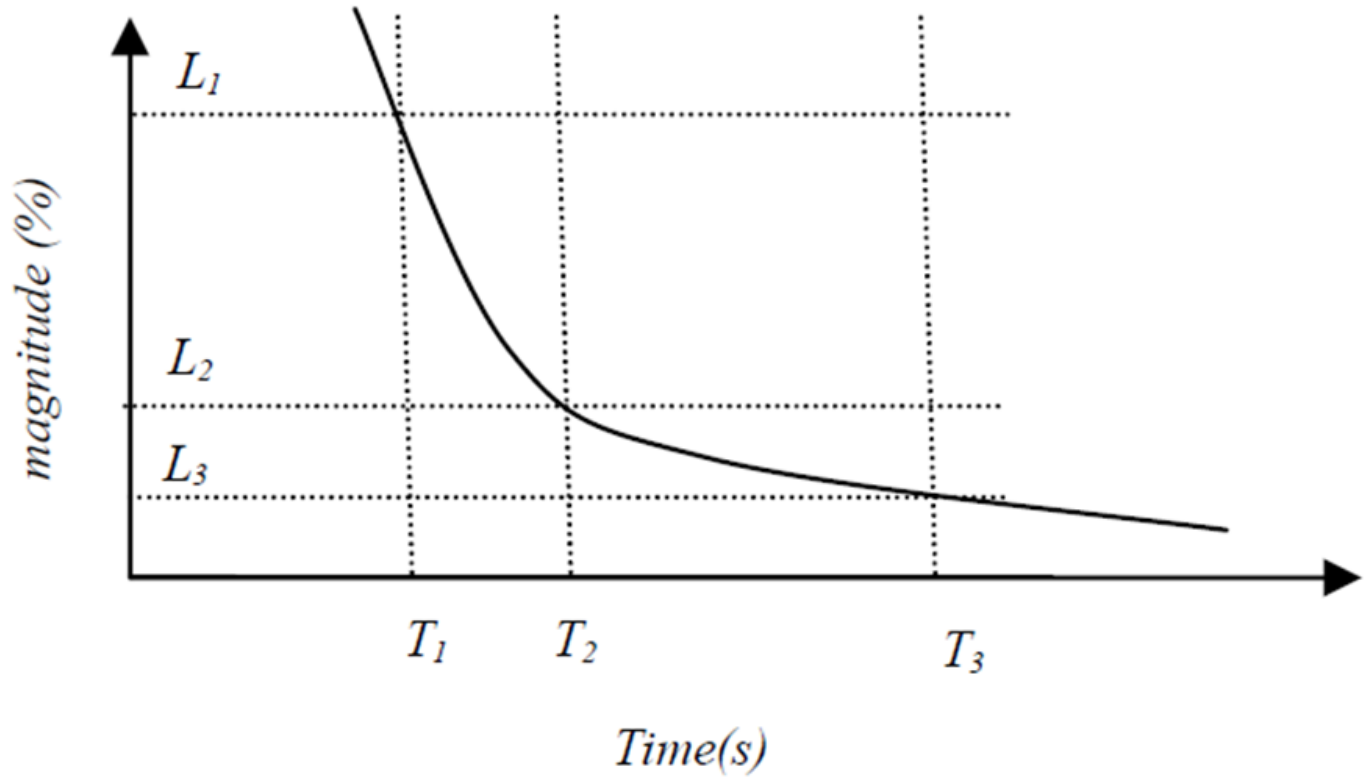


Fig. 4. Formation of inverse characteristics

Logic for SSTI Detection

- Inverse Time Setting: Basic Logic

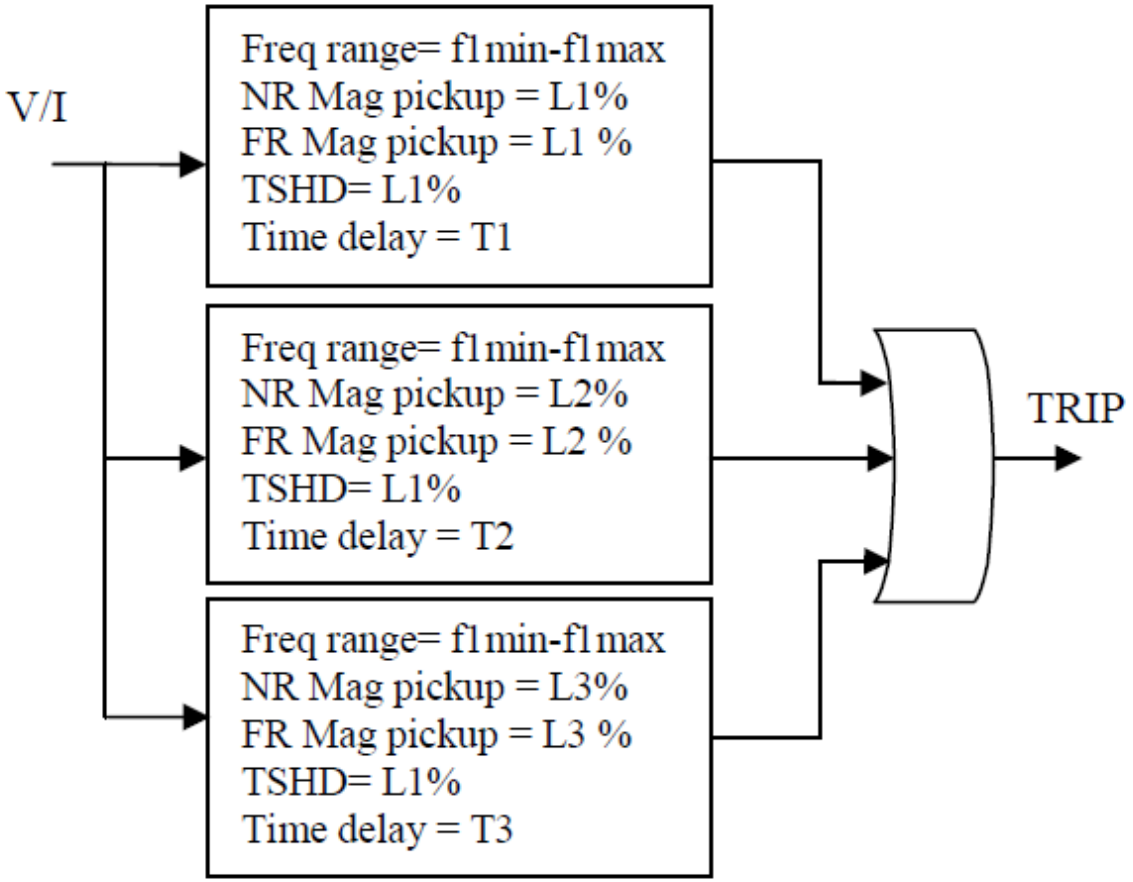


Fig. 6. Extended SSTI logic with TSHD

Logic for SSTI Detection

- Inverse Time Setting: Application Example

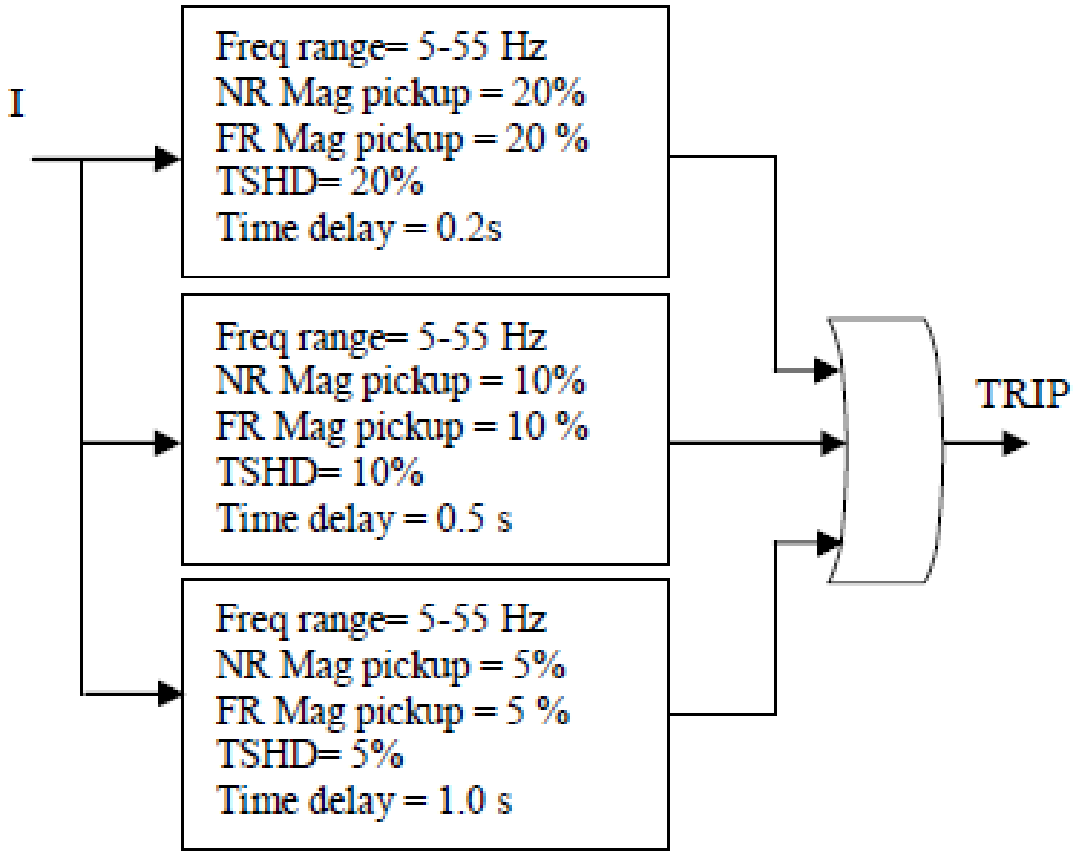


Fig. 7. Standard settings for current detection

Logic for SSTI Detection

- Inverse Time Setting: Application Example

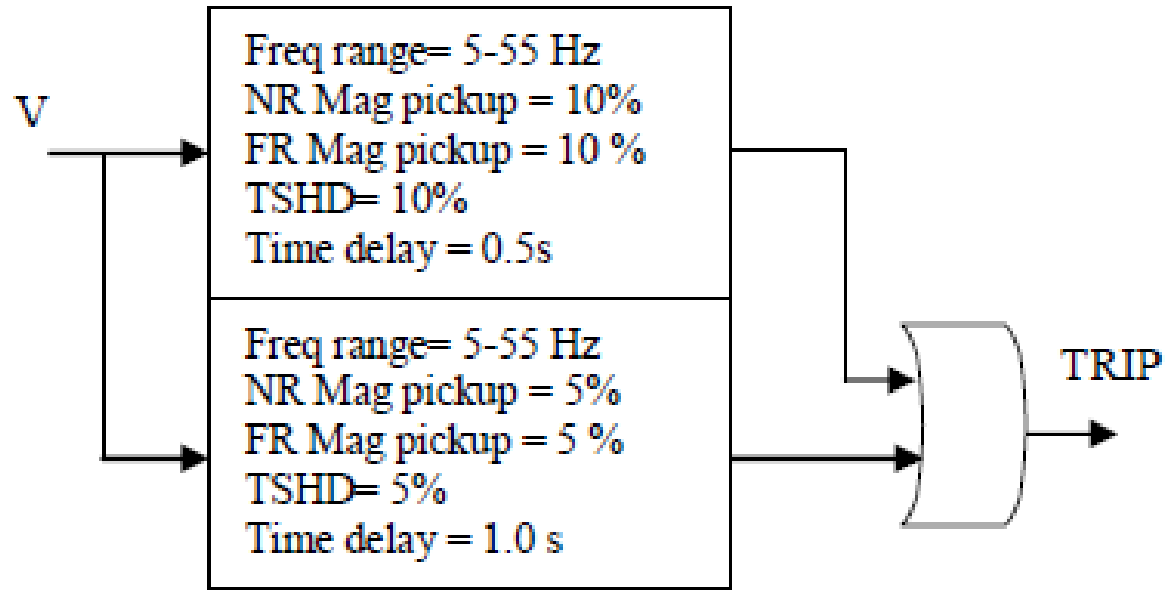
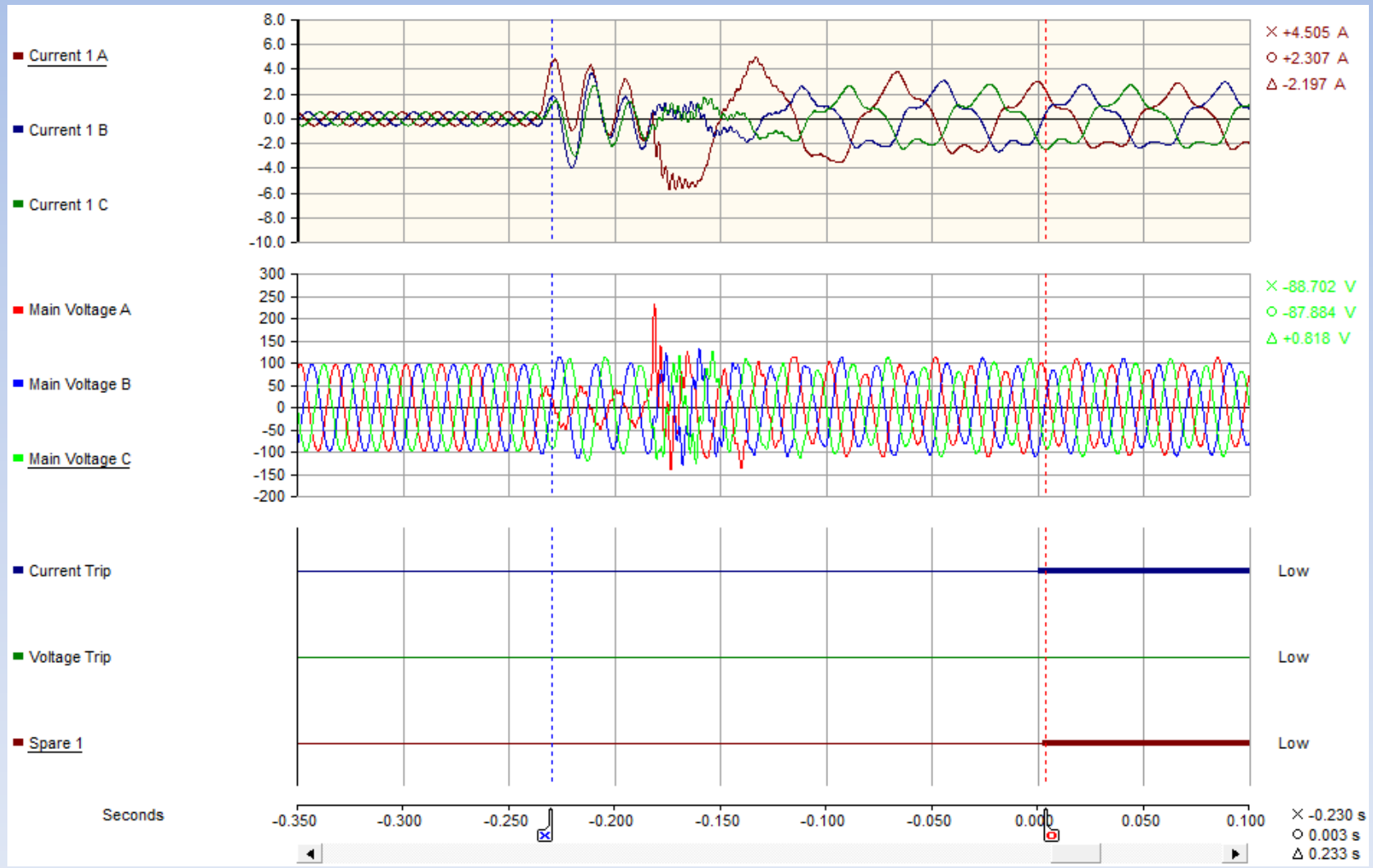


Fig. 8. Standard settings for voltage detection

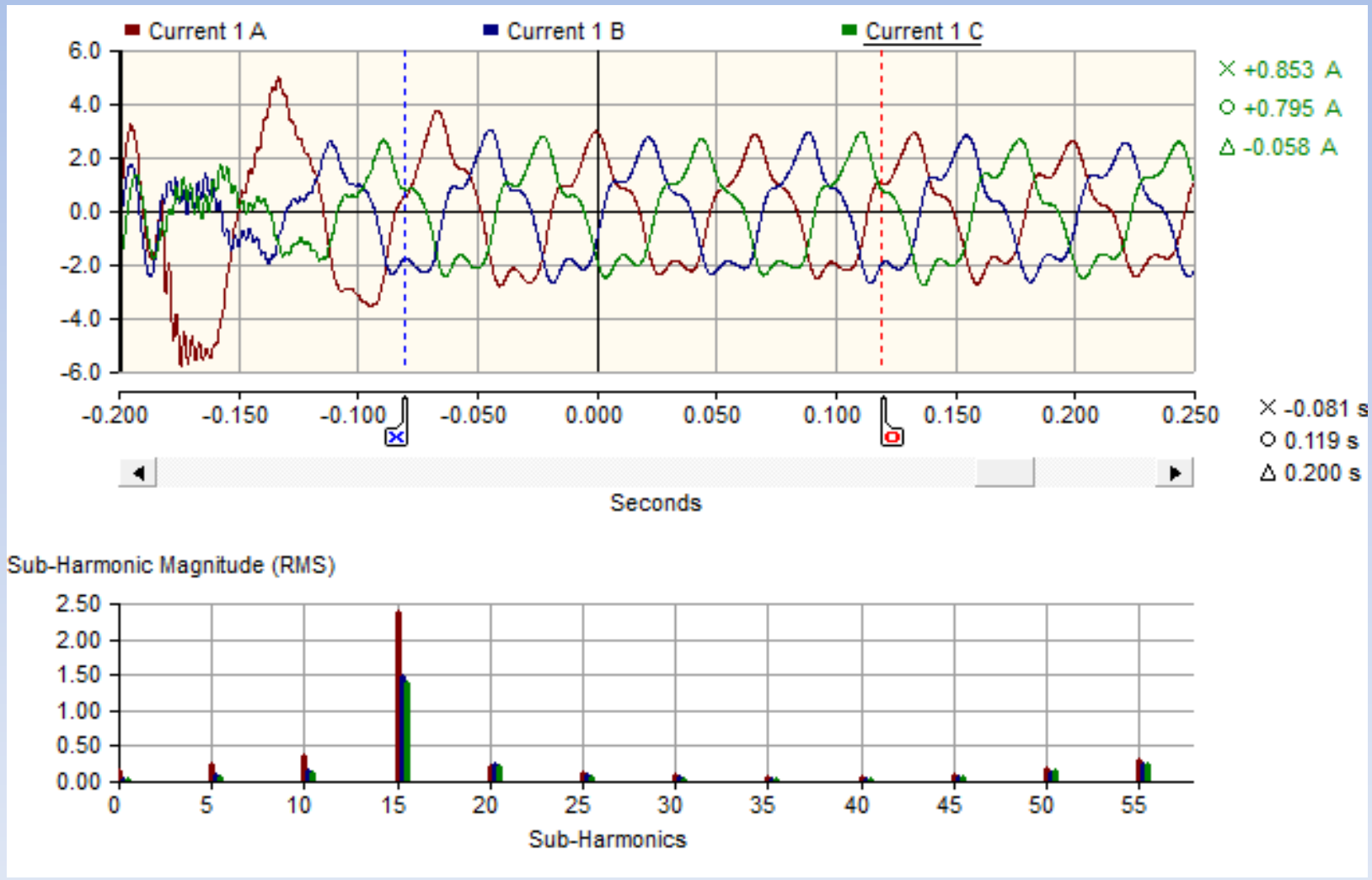
Case Study-1: Single Mode

- Relay Operation



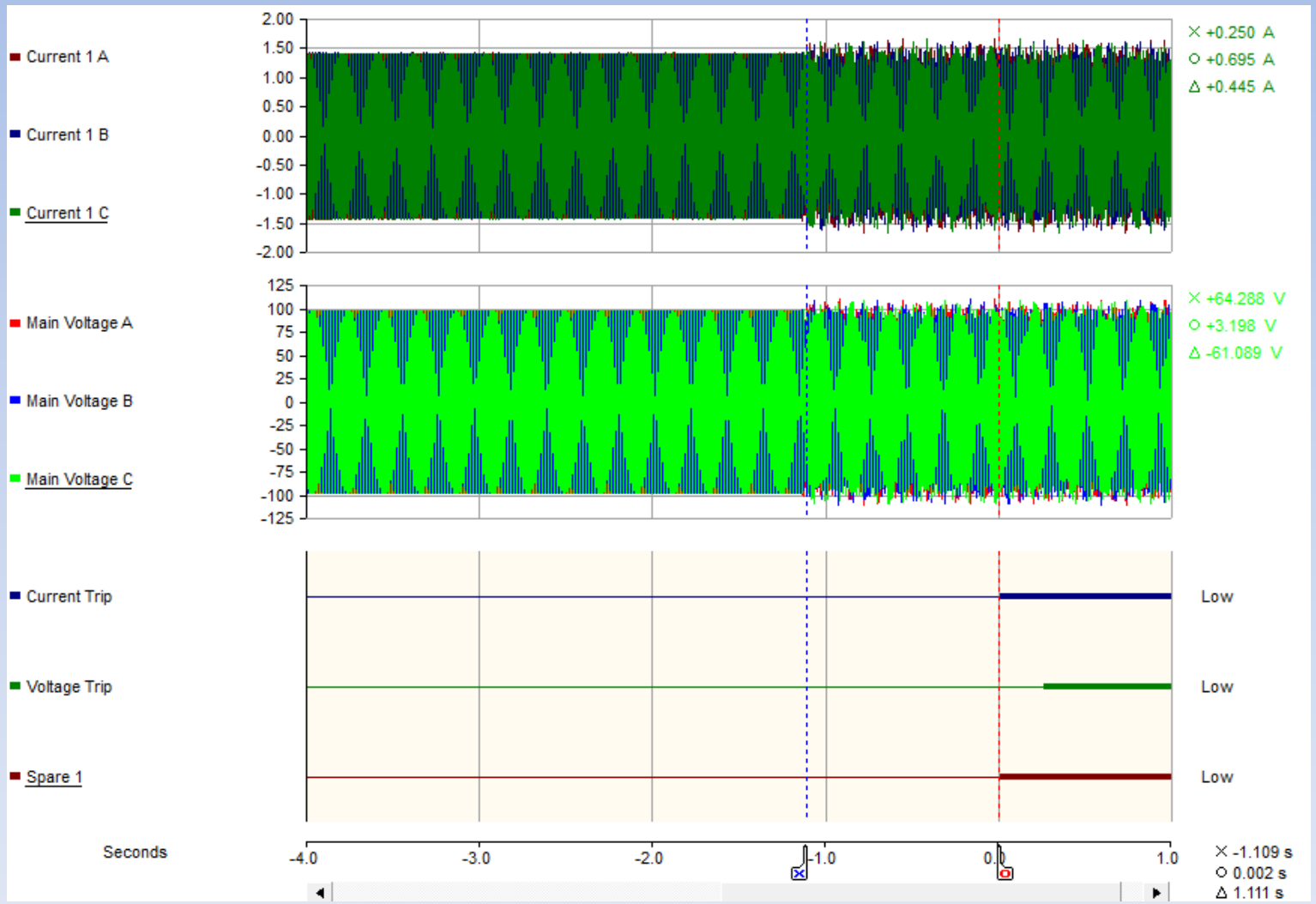
Case Study-1: Single Mode Cont..

- Sub-harmonics View



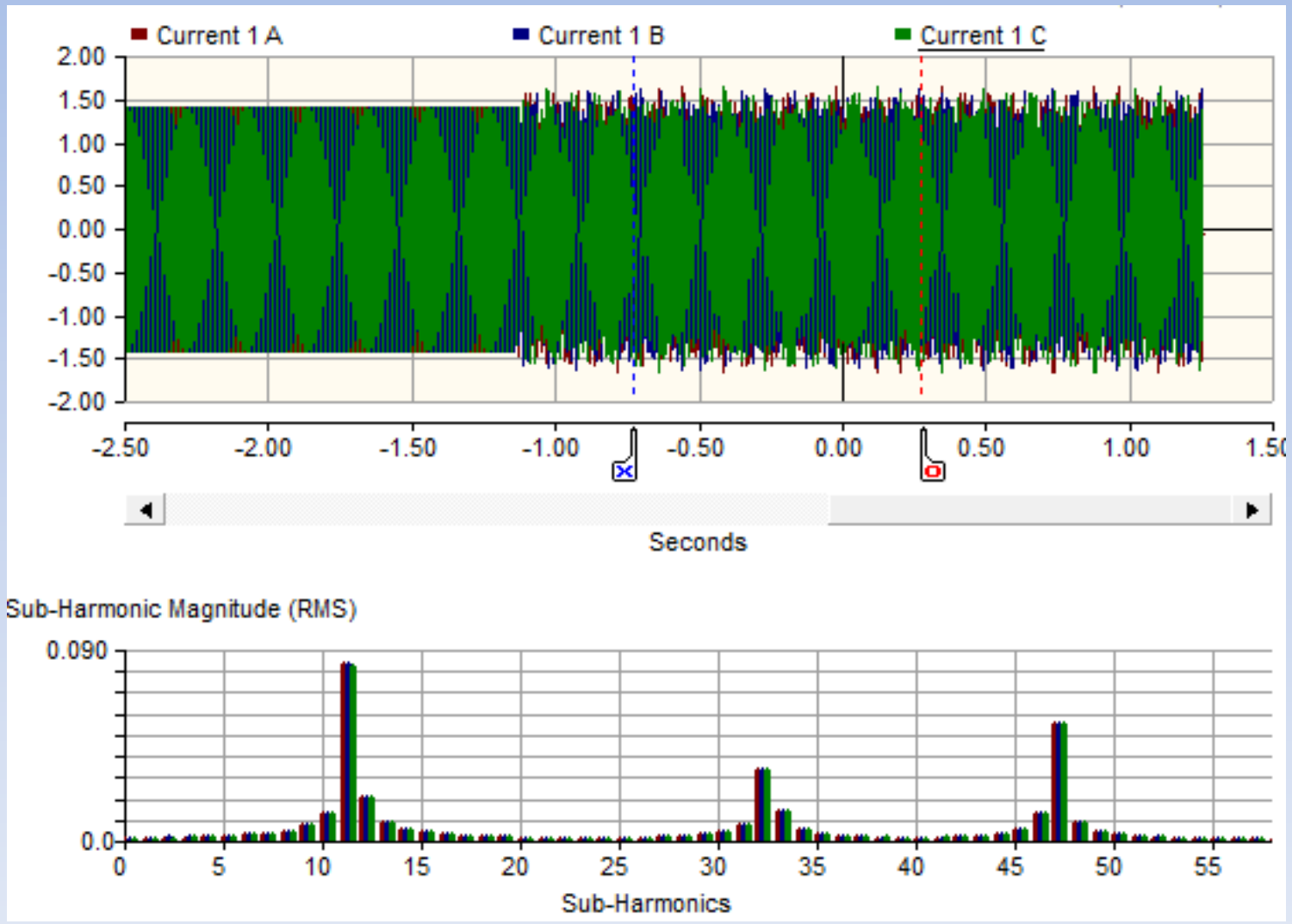
Case Study-2: Multi Mode

- Relay Operation



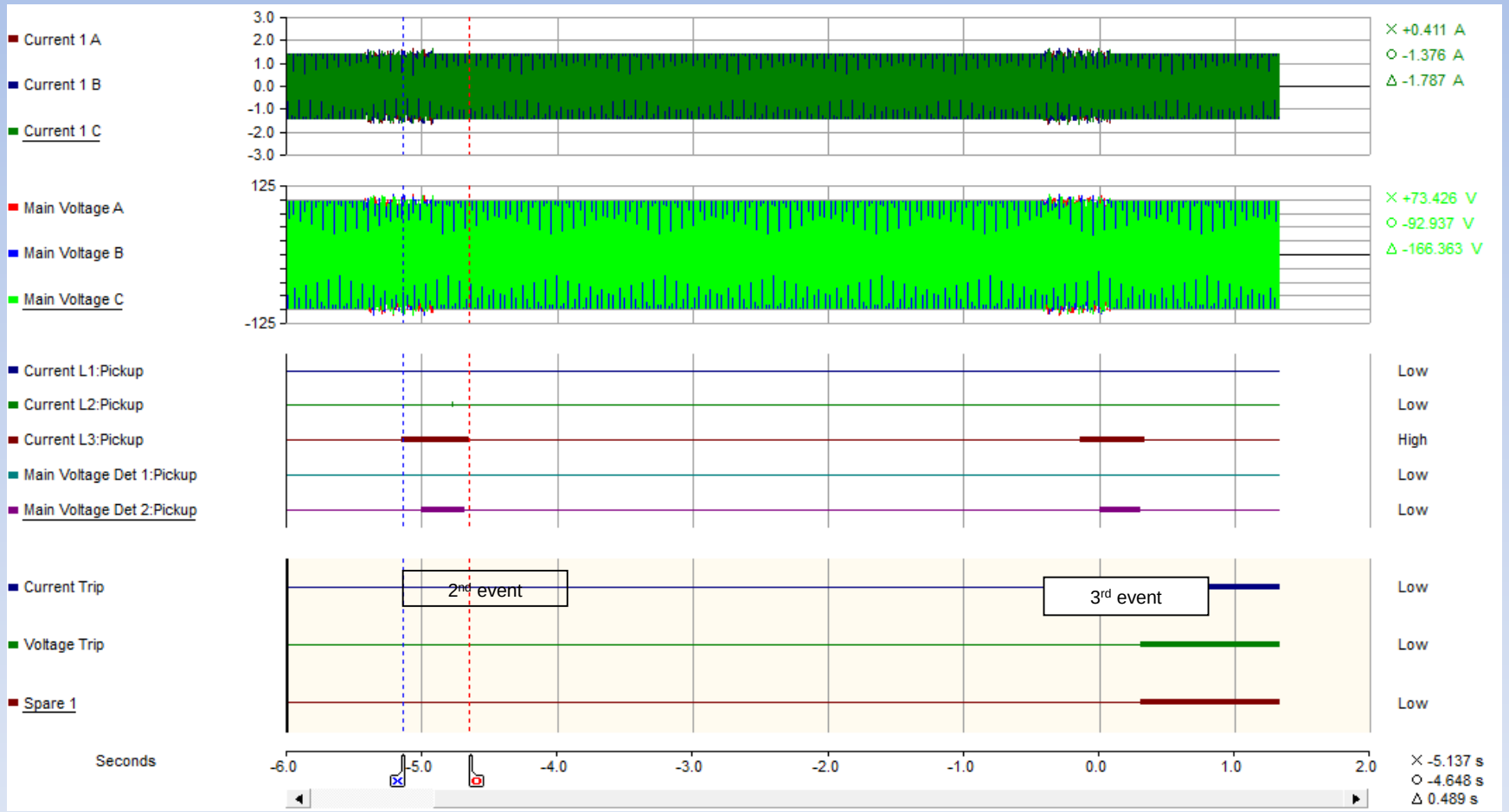
Case Study-2: Multi Mode Cont..

- Sub-harmonics View



Case Study-3: Operation per Duration

- Relay Operation



Conclusions

- An brief introduction on SSTI conditions was presented.
- A protection setting structure that provides the flexibility for user to select basic setting, even during the situations where limited information or no information is available from system studies was proposed.
- Applicability of the proposed setting structure was verified using various SSTI conditions simulated in PSCAD/EMTDC simulation program.
- Results presented in this paper demonstrate the capability of the relay in providing adequate protection against SSTI conditions

Thank you !
Questions ?