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Delta Directional Comparison Principle Enhances Transmission Line Protection

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Superimposed components, Directional determination, distance relays.

1 INTRODUCTION

Transmission line protection faces increasing challenges when protecting modern power systems. One of the main problems is the correct detection of fault direction. By using the fault generated changes in the current and voltage quantities which are called the superimposed components or the delta components, the direction of a fault in the power system can be determined correctly. Forward and reverse fault decisions are made by comparing the angle between the delta voltage and the delta currents. By comparing the directional decisions of the relays at the protected line ends with the help of a signaling channel, an in-zone fault in the protected line unit can be cleared.

Often in transmission line systems, protective relays using distance principles encounter problems in dealing with evolving faults, high resistance faults, transient fault on lines compensated by series capacitors or shunt compensation devices. Under such conditions the delta directional comparison principle will provide accurate direction determination of the fault, thus complementing the distance protection. Superimposed currents are also used to assist correct selection of the faulted phase or phases. Delta directional comparison principles can also be used with signaling schemes such as blocking, the permissive overreach scheme, and the permissive overreach scheme with weak infeed features. Delta direction comparison can be used in single or three pole tripping schemes. Delta-based currents and voltages also find advanced application in detection of power swings and out of step conditions, particularly as they do not necessitate the need for additional settings for power swing detection.

Dedicated delta direction comparison protection schemes using delta currents for phase selection, are complementing main distance protections in many EHV systems today. The author's company has significant operational experience using delta based directional principles especially on long transmission lines, both with or without series capacitors, uncompensated lines adjacent to series capacitors, shunt compensated lines, lines that require high sensitivity for ground faults, parallel lines with high mutual coupling, and lines with mixed overhead and underground conductors.

The paper is organized as follows: In section two the principle of directional determination by delta technique is covered. In section three, fault detector and phase selectors are discussed and how they work along with delta directional determination is covered. In section four performance of delta directional determination technique available in a commercial relay from the author's company was tested in the power system environment of RTDS for various system fault types and their results recorded, along with other practical experience will be shared with the attendees of the conference and readership of the paper. Final section concludes with the works carried out in this paper to bring out the salient features of delta directional technique.

2 PRINCIPLE OF DELTA DIRECTIONAL TECHNIQUE

When subtracting a value of the signal, before a change (due to a disturbance or fault) from its corresponding value after the change will produce a signal that represents the change. In the case of a change occurring in a periodic signal such as a sinusoid, the corresponding value before the change is the value measured exactly one or more cycles earlier. Figure 1 shows an example of a change in a sinusoidal wave and the effect of subtracting values separated in time by one cycle. Change signal produced in this way are known as superimposed components. When a fault occurs on a power system, changes occur in the current and voltage signals which produce superimposed components as shown in Figure 2. Before the fault, when no changes are occurring, these superimposed components are zero.

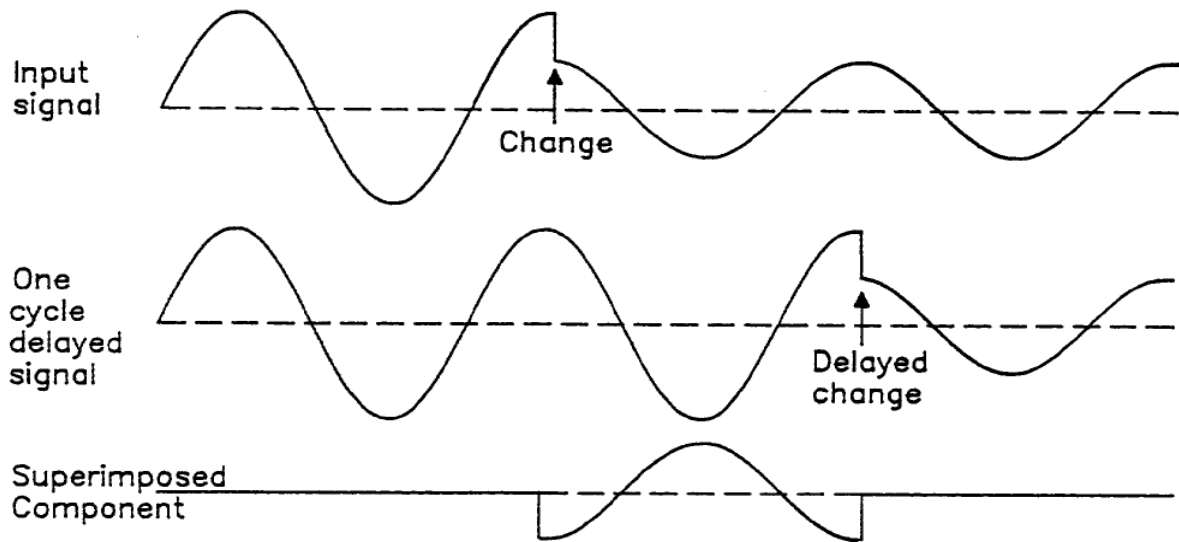


Fig. 1: Superimposed component

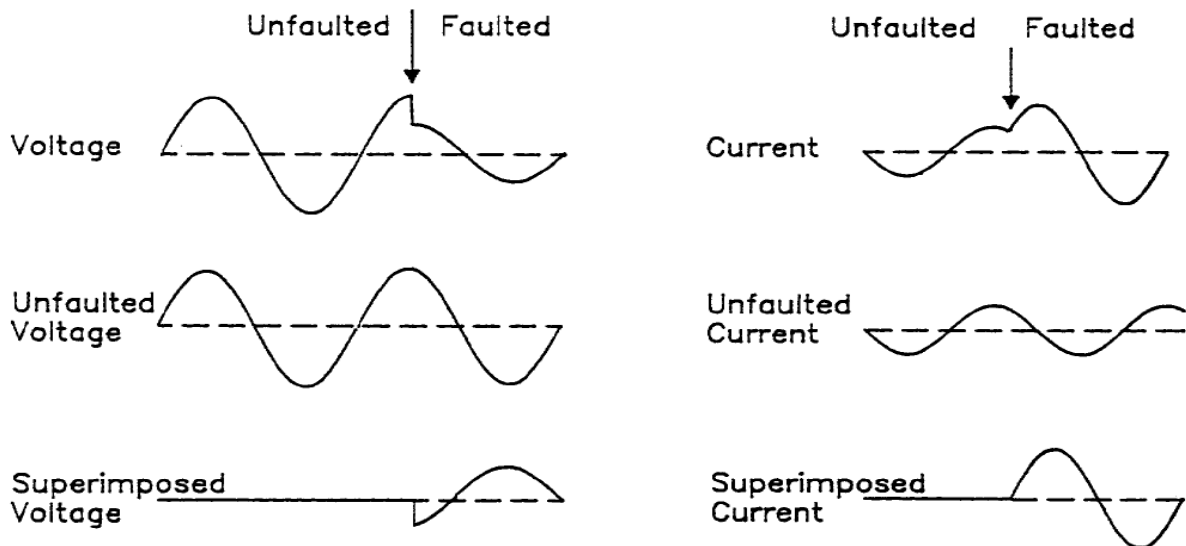


Fig. 2: Superimposed component currents and volts

The forward and reverse fault directions determination can well be explained by an example. Consider a protected line section AB, a fault occurs external to the protected circuit, both forward and reverse directional measurement is demonstrated using the same fault. The difference between unfaulted and faulted circuit is an equivalent circuit in which all signals are superimposed components. This shows that the superimposed components of current and voltages can be considered to be produced by an equivalent source of superimposed voltage at the fault point. The fault

occurrence is represented by closing of the switch S which connects the superimposed voltage source ΔE , whose magnitude is the change in voltage at the fault point. This causes a superimposed current ΔI to flow in the superimposed circuit. ΔV_r and ΔI_r are the positive directions of superimposed voltage and current as defined for each relay position. In Figure 3 the superimposed components flowing for an external fault is shown. In Figure 4 the superimposed signals for forward and reverse fault are shown.

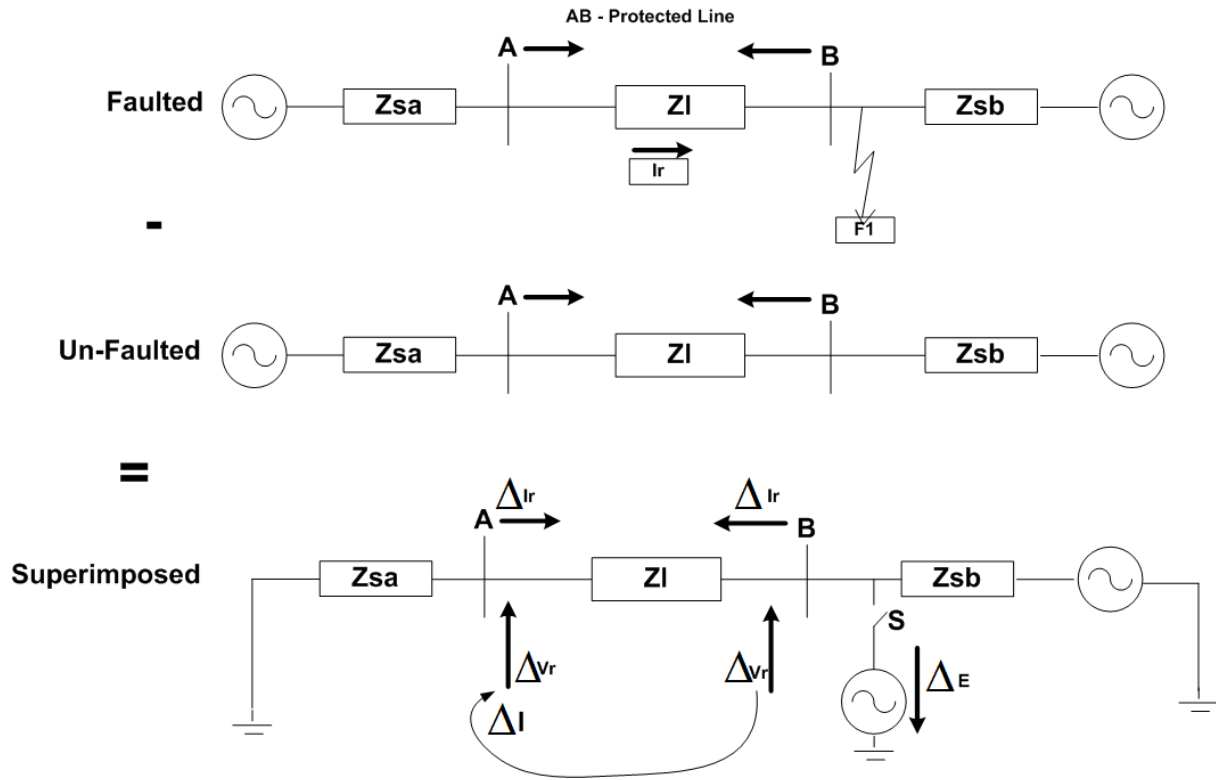


Fig. 3: Superimposed components External fault

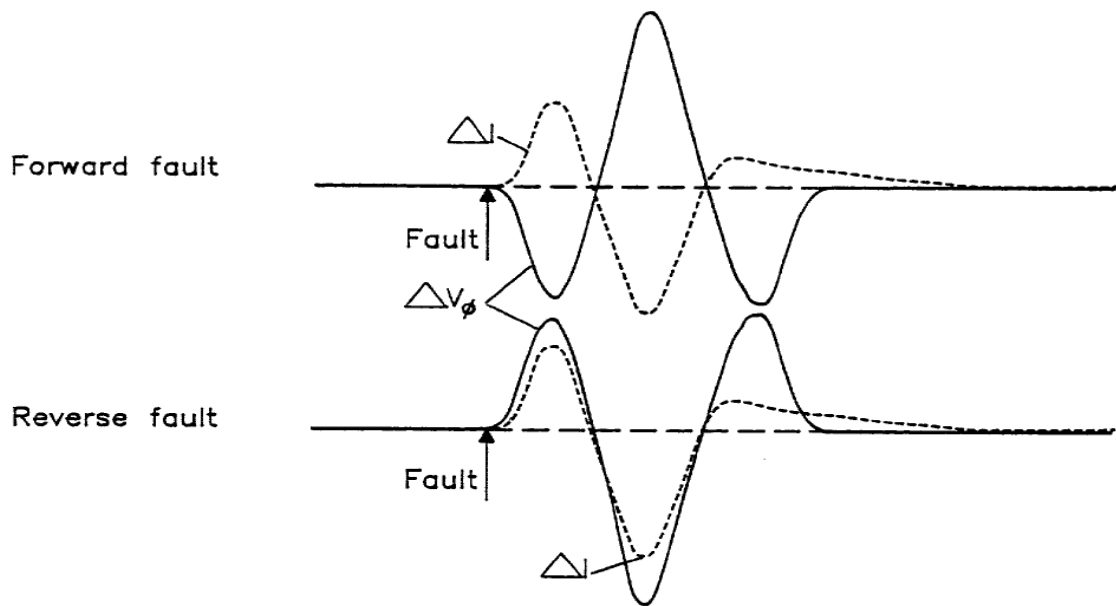


Fig. 4: Superimposed signals

Consideration of this equivalent circuit for the relay at 'A' shows that the superimposed signals ΔV_r and ΔI_r are related by the equation,

$$\Delta I_r = \frac{-\Delta V_r}{Z} \dots\dots\dots \text{Equation 1}$$

Where, Z is the impedance (Z_{sa}) of the source behind the relay location.

Similarly for the relay at 'B' this relationship is,

$$\Delta I_r = \frac{\Delta V_r}{Z} \dots\dots\dots \text{Equation 2}$$

Where, Z is the impedance ($Z_{sa} + Z_l$) of the source plus the line in front of the relay location. It should be noted that the positive direction of current for the relay at 'A' is towards 'B' and the positive direction of current for the relay at 'B' is towards 'A'.

This means that, for forward faults (location A), the superimposed signals of ΔI_r and $\Delta V_r / Z$ is of opposite polarity and for reverse faults (location B) the superimposed signals of ΔI_r and $\Delta V_r / Z$ are of same polarity. Compensation for the phase angle of impedance Z will then allow directional decisions to be made based on the relative polarity of the two superimposed signals. The method of determining fault direction is similar to that used by the conventional amplitude comparison directional relay [1].

A directional operating signal (Dop) is generated from the superimposed signals using the magnitude equation,

$$Dop = |\Delta V \phi - \Delta I| - |\Delta V \phi + \Delta I| \dots\dots\dots \text{Equation 3}$$

For forward fault the superimposed signals are of opposite polarity. This means that $|\Delta V \phi - \Delta I|$ is greater than $|\Delta V \phi + \Delta I|$ and the operating signal is positive.

For reverse fault the superimposed signals are of same polarity. This means that $|\Delta V \phi - \Delta I|$ is smaller than $|\Delta V \phi + \Delta I|$ and the operating signal is negative.

3 FAULT DETECTORS AND PHASE SELECTORS

3a Fault detectors:

Any changes to the directional decisions made by superimposed components (delta quantity) are monitored by the fault detectors elements. Fault detectors are basically over-reaching Mho type characteristic elements which are six forward and six reverse elements. The six forward elements are three phase-ground and three phase-phase and the same with the reverse elements.

Fault detector forward element operates as follows,

$$Dop = |IZ_m + V_{pol}| - |V - IZ_m + V_{pol}| \dots\dots\dots \text{Equation 4}$$

Where I is the fault current, V_{pol} is the un-faulted voltage and V is the fault voltage.

The fault detector reverse element operates as follows,

$$Dop = |-IZ_m + V_{pol}| - |V + IZ_m + V_{pol}| \dots\dots\dots \text{Equation 5}$$

3b Phase selectors:

Similar to directional determination by superimposed component, phase selection can also work with superimposed quantities. The three superimposed current signals produced for the directional

elements could be used for phase selector too. An example of how superimposed component detect phase to Ground fault and Phase to phase fault are shown below in Figures 5 and 6 respectively.

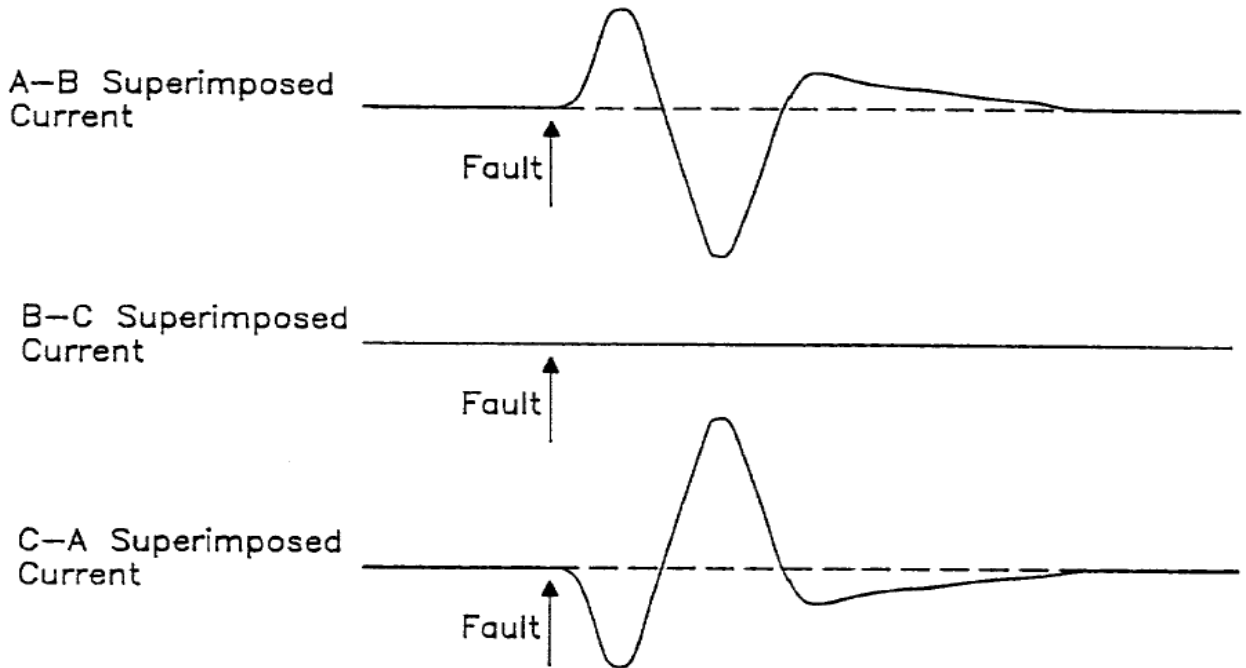


Fig. 5: Superimposed current A-G Fault

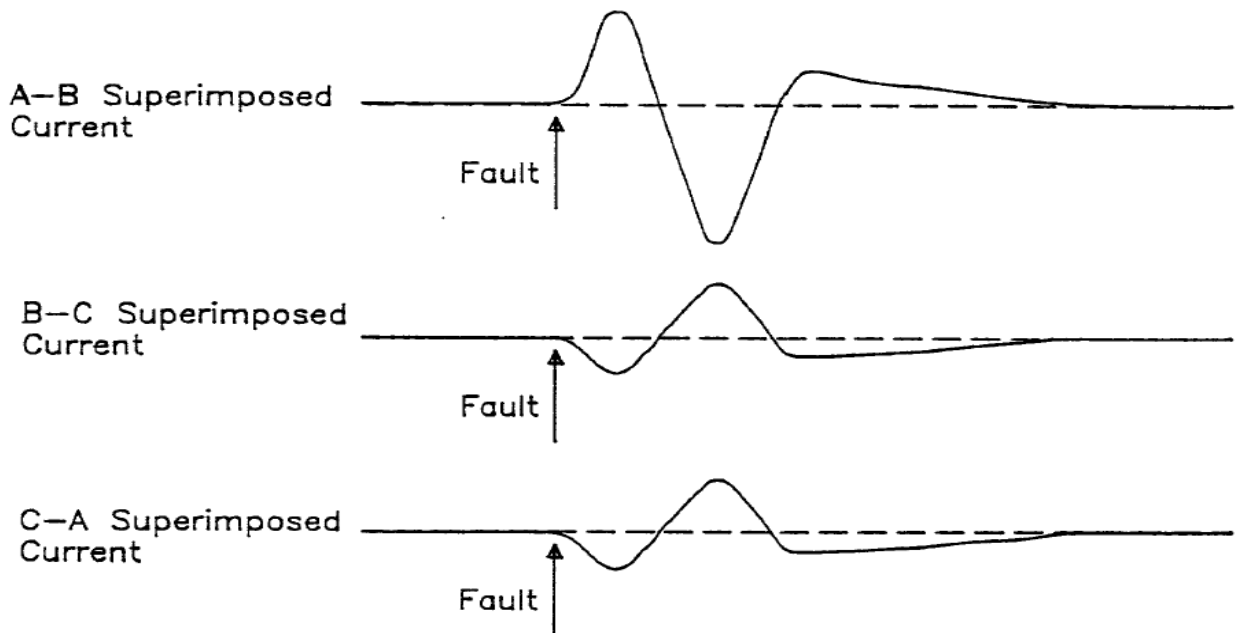


Fig. 6: Superimposed current A-B Fault

4 PERFORMANCE OF DELTA DIRECTIONAL TECHNIQUE FROM A COMMERCIAL RELAY

The performance of delta directional technique in a commercial relay from the author's company has been tested in RTDS power system environment for various types of faults and scenarios. The fault types were repeated on strong and weak sources.

4a Forward Fault:

Figure 7 below, is the disturbance record from the relay showing the correct operation of the relay for a Forward A phase to Ground fault. The relay operates in sub-cycle, as shown from the record below.

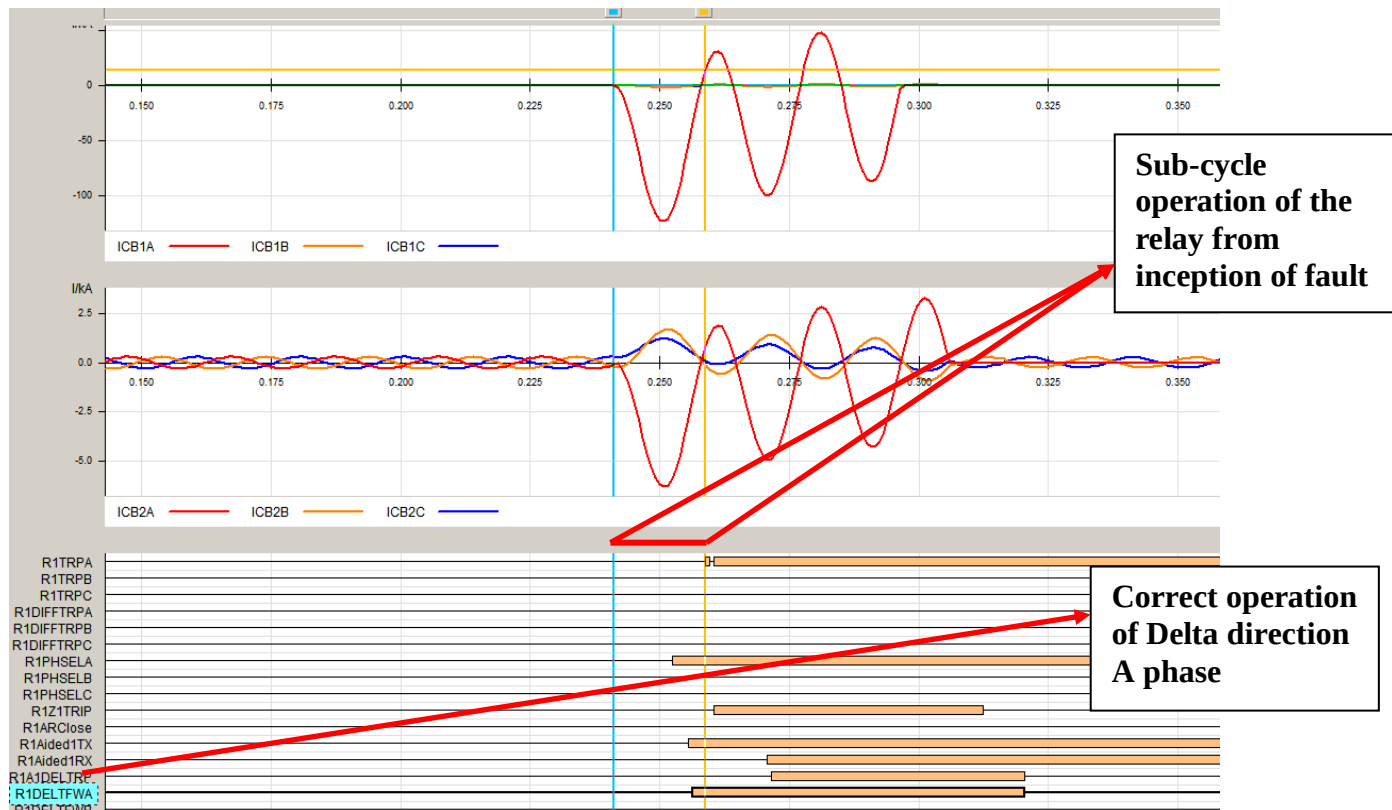


Fig. 7: FORWARD AN fault – Correct operation of Delta directional element & sub-cycle relay operation

4b) Evolving Fault:

Forward A phase to ground fault evolved into a B phase to ground fault after two cycles the relay directionality correctly operated firstly on Forward A phase and 2 cycles later operated on AB superimposed directional element. Figure 8 below shows correct operation of relay on directional element and phase selection both based on superimposed components (delta quantity).

4c) Simultaneous Fault:

Forward A phase to ground fault and reverse B phase to ground fault was simulated in RTDS simultaneously the relay correctly operated for forward AN fault and not-operated for reverse BN fault. Disturbance record from Figure 9, shows correct operation of phase selector on phase A and correct operation of directional element on AN, both phase selector and directional elements are based on superimposed components (delta technique).

5 CONCLUSION

Superimposed components (delta) based directional determination has been used in commercially available relays from the author's company and have been successfully protecting the transmission lines for more than a decade. The delta directional techniques have been complimented by the delta based phase selectors both of which provide fast and secure operations for most faults in the power system even when protecting the complex power systems and compensated transmission lines.

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Fig. 8: FORWARD evolving faults – Correct operation of Delta directional element & phase selectors



Fig. 9: Simultaneous fault - Forward AN and Reverse BN – correct operation of Delta directional element & phase selectors