# A New Directional Comparison Technique For Line Protection Based On the Measurement of Fault Current Transients

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Abstract - **This paper presents a new directional comparison technique for line protection by utilising fault generated transient current signals. A specially designed relay is used to extract fault generated high frequency transient current signal from the faulted line. The polarity of the fault generated transient current signal detected at each end is then sent over to the line remote end through the communication link. Comparison between the polarities detected at both ends will determine whether a fault is inside the protected zone. Studies show that the scheme is insensitive to fault type, fault position, fault path resistance and fault inception angle. It is also able to detect lower level, intermittent and other contingencies, not readily detected using present technology, and totally immune to CT saturation, power swings and heavy loading.**

Keywords: Transient Based protection, Directional relay, High frequency current signal

## I. INTRODUCTION

The demand for increasing power transfer and improved transient stability of a power system has resulted in research into protection techniques with high speed fault clearance schemes. Among these techniques, the use of travelling wave components for fast protection has been a major area of interest for the past decade. In particular, the travelling wave based directional comparison schemes[1-4] in which the direction of the fault with respect to the relay location is determined from the first travelling waves of current and voltage. A communication link is used to send information between the relays situated at both ends of the protected line, and as a result the fault is determined as internal or external to the protected zone.

Studies have revealed that the travelling wave based protection is able to produce very fast relay operation for most system and fault conditions. However, the scheme does have shortcomings; for example, a fault does not generate significant travelling wave components when it occurs at a voltage inception angle close to zero degrees. Moreover, the bandwidth limitation of the transducers, particularly the CVT, limits the applicability of such techniques, particularly for close-up faults which generate very high frequency travelling waves that are outside the bandwidth of receptibility of conventional CVTs.

This paper presents a new directional comparison technique for line protection by utilising fault generated transient current signals. Fault current transient detectors, connected to the CTs at both ends of the protected line, are used to extract fault generated transient current signals. The polarity of the fault generated transient current signal detected at each end is then sent to the lines remote end through the communication link. Comparison between the polarities detected at both ends will determine whether a fault is inside the protected zone. In contrast to previous research based on the measurement of the fault generated power frequency signals and initiated travelling waves, this technique pays more attention to the fault generated signals under arcing faults and their associated high frequency signals. With this approach, the problem of low fault inception angle is effectively solved since the fault arc signals vary little with the inception angle. In addition, the scheme does not require voltage transformers, therefore, solving the bandwidth limitation problems, and opening the way for application where VT's may not be available. A 400 kV EHV transmission system is modelled by EMTP software, the faulted responses of which are examined with respect to different system configurations and fault conditions. The results show that the scheme is able to give correct response under various system and fault conditions.

## II. BASIC PRINCIPLE

The principle of the proposed technique is based on the detection of the initial fault generated high frequency transient current signals at both ends of the protected line. Subsequently the comparison between the polarities of the signals detected at both ends will decide whether a fault is inside or outside the protected line.

Fig.1 can be used to illustrate the proposed technique. This is a multi-section transmission system, the length of the line and source parameters are as shown in the figure.

The proposed directional comparison relays are installed at both ends of the protected line P and linked by a communication channel.

When a fault occurs on the protected line section P, for example, at the point F1 as shown in Fig.1, a high frequency transient current signal will be initiated, which travels towards both busbar S and R. In time, the signals ($I_S$ and $I_R$) will arrive at busbar S and R respectively. As shown in Fig.1, for an internal fault, the polarities of the two transient signals $I_S$ and $I_R$ detected by the CTs at both ends will be the same. However, for a fault outside the protected zone, for example at F2, the transient current signals detected at both ends will be of opposite polarities. Subsequently, the information about the polarities of the fault generated transient current signals are sent to their far ends respectively through the communication link, comparison at each end will decide whether a fault is inside the protected zone or not.

## III. RELAY DESIGN

As shown in Fig.1, the proposed relay unit essentially consists of the analog interface, modal mixing, transient detector, directional comparison and a communication channel. The modal transformation method[5] is employed to decouple the phase signals into their respective aerial modes. The modal mixing circuits receive the current signals from the analog interface circuit and combine the three phases to form Mode 2 & 3 signals.

The centre part of the relay is the transient detector which works as a bandpass filter. Over the range of frequencies to which the filter is tuned, the relay effectively extracts a band of fault generated transient current signal from the faulted line signal, from which the polarity of the signal can be derived. By this arrangement, the response of the scheme is not significantly affected by the power frequency short-circuit level at the terminating busbar or the precise configuration of the source side networks. This contrasts sharply with conventional protection which, in general, has a performance that is often significantly affected by changes within the source side networks. The communication channel is used to send the polarity of the signal detected at its end to the other end of the protected line. In the studies, the centre frequency of the detectors is tuned to 1 kHz.

## IV. SYSTEM RESPONSE EVALUATION

The response of the complete system is evaluated by digitally modelling the transmission line system together with the directional relay units. As shown in Fig.1, the transmission system is based on a typical 400 kV EHV vertical construction line of the type widely used on the UK supergrid system. There are three sections of line in the system, the lengths of which are 80 km, 100 km and 120 km for line section N, P and Q with short circuit levels of 35 GVA, 10 GVA , 20 GVA, 5 GVA at the ends U, S, R and T respectively. The simulation of the faulted power system was carried out using the Electromagnetic Transient Programme (EMTP). A non-linear fault arc model is also included in the simulation. When the fault occurs at voltage zero point, the scheme relies on the detection of fault arc generated high frequency signals. The simulation studies presented herein investigate the scheme responses to: a) fault position, b) fault inception angle, c) fault type and d) fault path resistance. The sampling frequency used is 20 kHz.

For ease of explanation, the results are examined by considering the signals derived for the mode-2 channel at point x in Fig.1.

### *A. Typical Internal and External Responses*

Fig.2 shows the system responses to a typical internal 'a'-earth fault at 70 km from end S on the line. Fig.2a shows the primary system currents on all phases at both ends in the immediate post-fault period. It is evident that the magnitude of the faulted phase current is significantly higher than that of the unfaulted phases; the travelling wave components are produced on the faulted and unfaulted phases and are swamped by the dominant power frequency components.

Fig.2b shows the outputs of the current transient detectors at both ends of line section P. As shown in the figure, although the signals arrive at end S and R at different time instances due to the travelling time of the current wave, the polarities of the signals detected at two ends are the same indicating that the fault is inside the protected zone.

Fig.3 shows the corresponding responses for a fault on the busbar R outside of the protected zone. As expected, the polarities of the signals detected are of opposite signs at end S and R respectively (Fig.3b), which clearly indicted that this is an external fault.

### *B. Relay Responses to Different Fault Conditions*

Fig.4 shows the responses of the detectors to an "a"-earth fault at inception angle of 0°, the fault being on section P near busbar S. It can be seen from the figure that signals detected at both ends are of the same polarity, which indicates that the fault is inside the protected zone.

It can also be observed from the figure that the level of the signal is comparatively small; this is somewhat as expected because in the case of a fault at a higher inception angle, the high frequency signals (which are a combination of the components generated by the very non-linear behaviour of the fault arc and those due to travelling waves) are augmented by a significant travelling wave component; this is not the case for voltage zero faults. In the latter case, the signals generated are primarily due to the non-linear behaviour of the fault arc. This clearly shows that the detector does not suffer from the aforementioned sensitivity limitations of the zero voltage point on wave fault condition, as in the case of travelling wave relays.

Fig.5 shows the detector responses, for an 'a'-'b'-earth fault on line P near busbar R. Fig.6 shows a 'b'-'c' phase fault on line N at 60 km from busbar S. In both cases, the detector gives correct responses, indicating that the scheme is not affected by a variation in fault type.

Fig.7 shows the effect of fault resistance on relay performance for an 'a'-earth fault on line Q at 40 km from busbar R, the fault path resistor is 300Ω. In this respect, the results have shown that the relative magnitudes of the detected signals diminish as the fault resistance increases. This is expected and can be attributed to the fact that damping of the signals increases with an increase in fault resistance. However, the important point to note is that the scheme gives a correct response.

## V. CONCLUSION

This paper presents a new direction relaying principle. The technique relies on the detection of fault generated high frequency current transient signals. Comparison between the polarities of the captured current transient signals from the CT outputs at both ends of the protected line will determine whether a fault is inside the protected zone. Simulation studies show that the scheme is insensitive to fault type, fault position, fault path resistance and fault inception angle, and totally immune to CT saturation, power swings and heavy loading.

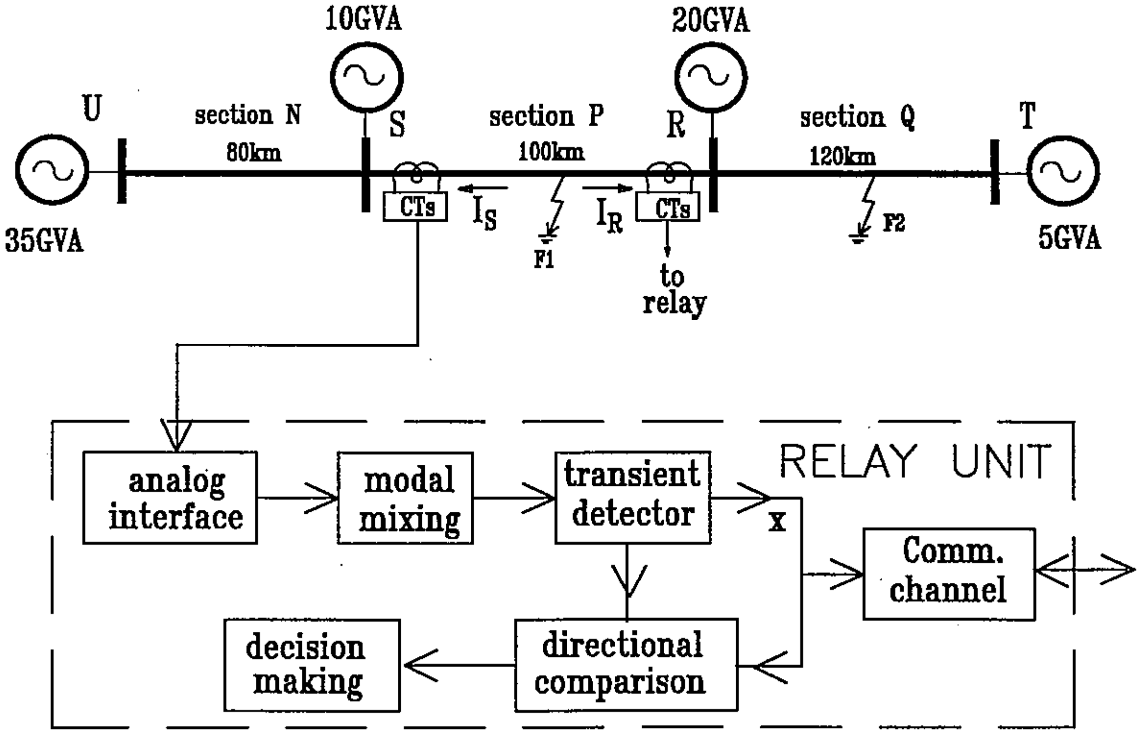

Fig.1 A typical system configuration with directional relay units

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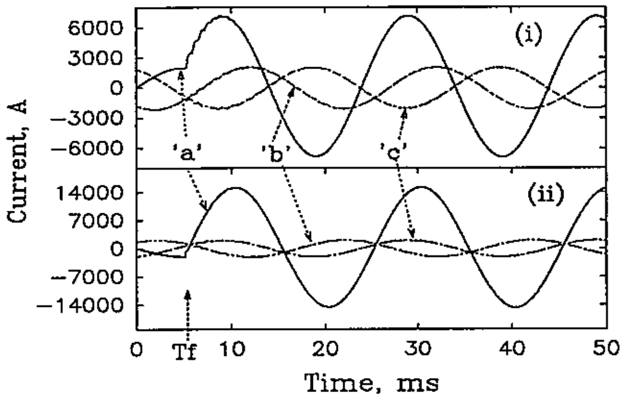
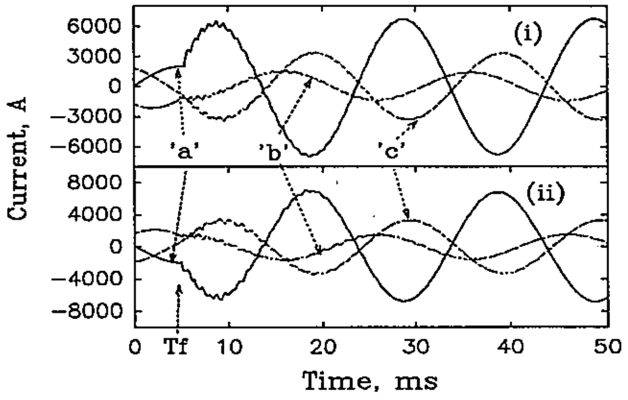
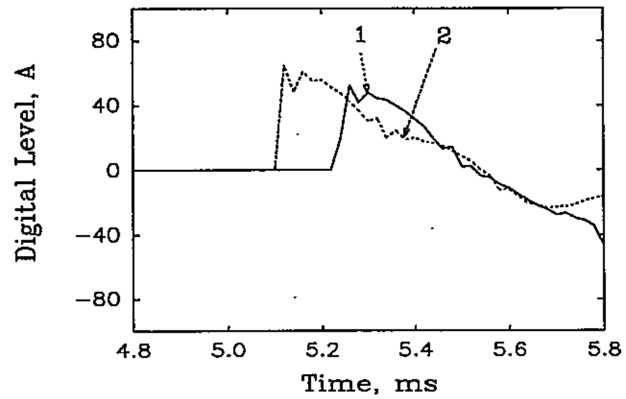


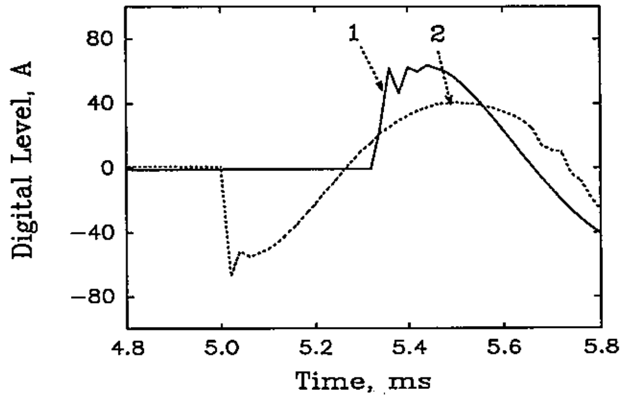
2a primary system currents
fault inception Tf=5ms; (i) end S; (ii) end R



3a primary system currents
fault inception Tf=5ms; (i) end S; (ii) end R



2b transient currents detected, 1 - end S; 2 - end R
Fig.2 Responses for an 'a'-earth fault on line P at 70 km from the end S



3b transient currents detected, 1 - end S; 2 - end R
Fig.3 Responses for an 'a'-earth fault on the busbar R outside the protected zone

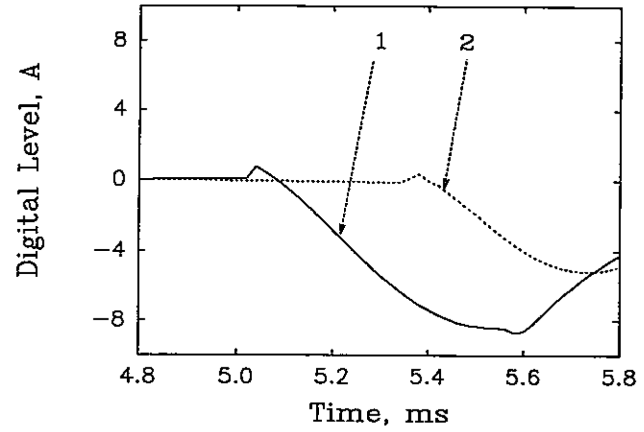


Fig.4 Responses for an 'a'-earth voltage near zero fault on line P near busbar S, 1 - end S; 2 - end R, fault inception Tf=5ms

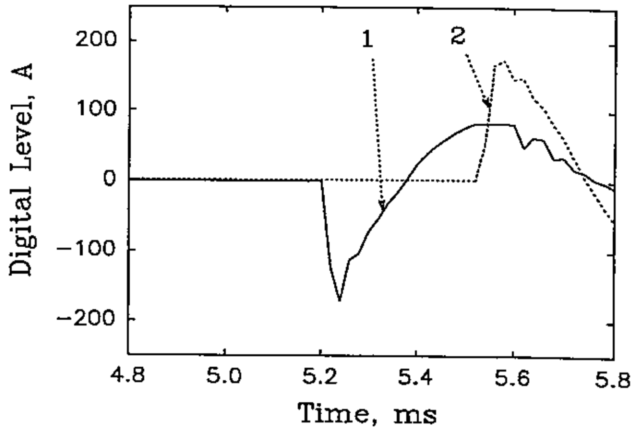


Fig.6 Relay response for a 'b'-'c' phase to phase fault on the line N at 60 km from busbar S, 1 - end S; 2 - end R, fault inception Tf=5ms

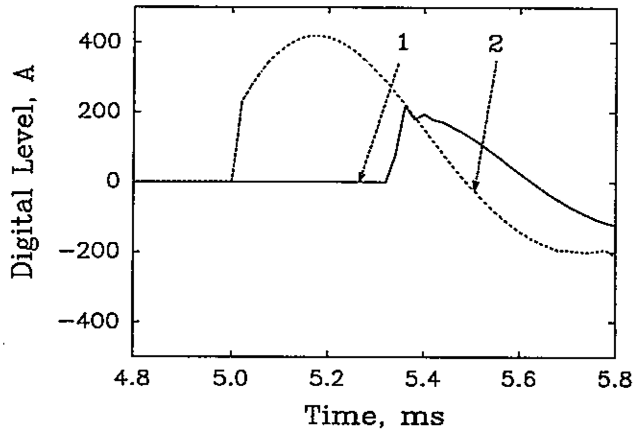


Fig.5 Responses for an 'a'-'b'-earth fault on line P near busbar R inside the protected zone, 1 - end S; 2 - end R, fault inception Tf=5ms

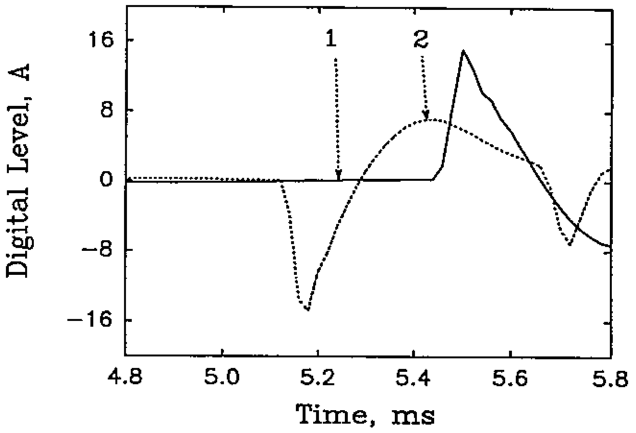


Fig.7 Relay response for an 'a'-earth fault on the line Q at 40 km from Busbar R, fault path resistance 300Ω, 1 - end S; 2 - end R, fault inception Tf=5ms