A WAVELET TRANSFORM BASED NEW DIRECTIONAL RELAY USING TRANSIENT CURRENT SIGNALS

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Abstract: This paper presents a new directional relaying algorithm to provide a distribution system with effective fault protection which has advantages of high speed and good selectivity. The specially designed protective relays, based on the transient fault protection technique, are installed at the ends of protected feeders which are the boundary of protected zoom. In the presence of feeder fault, the relays capture the system fault and then take advantage of wavelet transform to extract the transient component from the fault signals. Comparing the polarities of transient signals at two ends of a feeder, the relays are able to distinguish an internal fault from an external one so as to trip the switchgear if the fault falls within the protected zone.

Keywords: Transient based protection(TBP), distribution system, directional protection, wavelet transform.

1. INTRODUCTION

A directional comparison protection system is a very widely used versatile and flexible differential protection system. It is not only useful for single lines but also applicable for multi-terminal lines. In principle, the directions/polarities of currents at line terminals are detected, the information of signals is then transmitted from one end to the other via communication link and the comparison between the two ends currents by use of directional relays is able to assess whether a fault is internal or external. For an internal fault, the currents at two ends inwards the protected zone permit the simultaneous high speed tripping at the terminals.

With increasing of power demand and complexity of a modern system, a protective system with high speed fault clearance is necessitated in order to minimise the effect of fault on system and improve the system transient stability. As a result, a number of high speed protective techniques have been developed, for example, the differential relaying scheme and the travelling wave based directional comparison algorithm which employs the first travelling waves of fault currents and voltages to detect the location of the fault with respect to those of relays. The travelling wave based protection can provide very fast relay operation for most of EHV/UHV transmission systems. However, some drawbacks of this scheme such as requirement of high frequency bandwidth of the transducers and significant travelling wave signals, limit its application. As to the most of the transducers, particularly the CVT, the very high frequency travelling waves generated by system fault are beyond the bandwidths of transducers. In the application, the low level of travelling wave components due to the occurrence of a fault close to the voltage zero crossing makes it difficult to detect the fault.

This paper addresses a new directional comparison scheme for distribution feeder protection which is based on fault generated transient current signals[1] and Wavelet transform. In the new scheme, fault generated transient detectors, which are connected to the CTs situated at the two ends of protected feeder, are used to detect the current flow directions at the terminals. The extraction of high frequency transient components is accomplished by virtues of signal conditioning and processing. Then the polarity of extracted transient current signals at each terminal is transferred to the remote end of protected feeder via the communication link. Consequently comparison between the polarities of transient fault currents at the two ends of line will determine whether the fault is internal or external. If an internal fault is detected, relay will issue the command to trip the circuit breakers at both ends and isolate the fault rapidly. Application of wavelet transform in the protection scheme makes it possible to capture the transient components selectively and accurately[2-3]. Here wavelet transform on the detected fault current functions as a serial of band-pass filters with variable central frequencies. This implies that the interested transient fault signal can be easily extracted. In addition, wavelet transform is capable of providing different frequency bandwidth of signals with desired resolution.

The new proposed directional protection scheme is evaluated in an 11kV distribution system that is simulated by means of EMTP program. In the study, the different system fault conditions are utilised to examine the operational performance of relaying system. The analyses mainly focus on the fault generated signals under arcing faults and their associated high frequency signals. The analytic results indicate that the new scheme is able to protect the system from different system faults under the various operational conditions. In contrast to the travelling wave based relay that uses super imposed components with a frequency bandwidth varying from 50 Hz up to a few kHz, the proposed protection relay focus on the fault generated transient signals which ranging from a few hundreds Hz to about 20 kHz. More importantly, the new method can detect the low level fault, which overcomes the problem the travelling wave based protection encounters.

2. LAYOUT OF PROPOSED RELAY

The main function of the proposed directional relay is to detect fault current directions at two ends of a feeder in order to identify the type of faults, i.e. internal or external. Unlike a conventional directional relay that is designed to operate at power frequency, the relay in this paper concentrates on the transient components in system fault current. As a result, the new technique possesses many advantages such as the high speed operation and good discrimination. In addition, the relay is insensitive to CT saturation, fault type and supply sources. Even when a voltage zero crossing fault occurs, the relay is capable of diagnosing the system fault rightly.

The schematic of the protected distribution system is illustrated as in Fig.1. It is a typical overhead 11kV distribution system with its neutral solidly earthed. The system consisting of three feeders intakes the power from different supply sources. The parameters of system components are also shown as in Fig.1. As seen in the figure, the proposed relays are installed at both ends of each feeder and connected to the system through CTs. Under the normal system operation, only power frequency current flows through the feeders. However once a fault happens on one feeder, for instance, feeder 2, flashover and fault arcing at point 'F1' as shown in Fig. 1 initiate transient signals which superposed on the power frequency fault current. Those transient signals travel towards the ends of feeder 2 where the proposed relays capture the fault current via CTs. To extract the transient signals from captured fault current, fault current signals are processed through the signal conditioning and processing units as depicted in block diagram of Fig.1. It is noticeable that there are two specially designed units in the relay, that is, modal mixing unit and wavelet transform unit. The primary functions of modal mixing unit are to cope with different type of faults and eliminate any common mode interference as well. The wavelet transform unit is implemented to dynamically focus on the interested transient signals[4-5]. Here wavelet transform provides a powerful means to localise the non-stationary transients in both time and frequency.

Wavelet transform plays very important role in the proposed protection scheme. Here, it acts as a sort of mathematical microscope through which interested parts of transient signals can be zoomed in by scaling and shifting a single prototype function named as "mother wavelet". Since mother wavelet itself is a non-stationary signal, scaling and shifting mother wavelets can be utilised to capture and measure the different transient components of a non-stationary signal. One of major advantages of WT over Windowed Fourier Transform is that the former allows a more accurate local description and separation of signal characteristics while the latter can only represent signal components for all time. One typical application of wavelet transform in discrete signal processing is filter banks which are widely utilised to obtain the wanted non-stationary signals[6]. In this paper, the relay applies two-level Daubechies wavelet transform to attain and then transmit fault generated transient signal to the relay installed at the other end of feeder. By comparing the polarities of transient signals in first cycle, the relays are able to identify whether the captured fault is internal or external. If a detected fault occurs within the protected zone, the relays will issue the command to trip corresponding circuit breaks and isolate the fault from the remaining healthy system.

3. RESPONSES OF RELAY TO DIFFERENT FAULTS

In this section, simulation analyses are conducted on the system as given in Fig.1 in order to examine the performance of proposed relay under the different faults. The proposed relays are installed at both ends of each feeder to function as a unit protection. For the purpose of illustration, only relays installed at two ends of feeder 2 are drawn in the simulation system. The system fault conditions are created by virtues of EMTP program. An EMTP based CT model was included in the simulation program[7,8]. In the following study, based on two categories of faults: internal and external the characteristics of relay are investigated in the aspects of (1) fault type, (2) fault locations, (3) fault initial phase angle and (4) fault resistance.

Fig.2 shows the transient signals generated by a phase 'a' -to-earth fault within feeder 2 at 4km from bus 'S'. When fault occurs at point 'F1' as shown in Fig.2, the fault transient travels towards buses 'S' and 'R' in two opposite directions. Then transients are extracted from the captured signals by two proposed relays at two ends of feeder 2. The results as illustrated in the figure show that the transient signals detected by two relays have the same polarities within the first cycle. Therefore, the fault belongs to an internal fault and consequently two relays will issue the command to trip the circuit breakers and isolate the feeder fault.

To evaluate the selectivity of proposed relay, two typical faults occurring near the boundary of protected zone are simulated to examine whether or not the relays are able to distinguish between the internal and external faults. The first fault is a phase 'a'-to-earth fault at location 'F2' on bus 'S' outside the protected zone as shown in Fig.3. From the response of relay to the fault 'F2' in Fig.3, it can be noted that the signal polarity in first cycle detected by the relay at bus S differs from that at bus R. As a result, the detected fault is beyond the protected zone and no tripping will happen. In contrast, another fault is simulated at point 'F3' on feeder 2 near bus R as indicated in Fig.4. The onset of fault is close to the zero voltage point. As seen clearly in Fig.4 , although the magnitudes of transient signals are attenuated due to the zero voltage fault the transient signals extracted at buses 'S' and 'R' possess the same polarities. Consequently the relays have detected the internal fault and accordingly trip circuit breakers. Contrasting the results in Fig.3 with those in Fig.4, it is apparent that fault generated transient signals arrive at the locations of relays at different time. As for the fault at point 'F2', the transient signal arrives at bus S prior to that at bus R. On the other hand, the transient generated by the fault at 'F3' travels to bus R in shorter time than to bus S. It is important to note that the above time difference due to signal travelling will not affect the polarities of transient signals.

The forgoing discussions are attained with respect to low impedance fault. Fig. 5 explains graphically the characteristic of proposed relay under a high impedance fault at point 'F4' on feeder 2. For this case, all fault conditions but the fault path resistor of 300Ω are the same as those of fault at 'F1'. It is seen from Fig.5 that the transient signals extracted by relays indicate the same polarities within the first cycle even though the high fault path resistance diminishes the transient signals.

Figs 6 and 7 show the analytic results with regards to two external faults, i.e. (1). A phase 'a'-phase 'b'-earth fault on feeder 3 at 2 km from bus R and (2) a phase 'b'-phase 'c' fault on feeder 1 at 5km from bus S. Both figures illustrate that the transient signals captured by two relays have different polarities within the first cycle. Therefore it is evident that the proposed relay is able to derive correct response to the above external faults.

4. CONCLUSION

This paper introduces a new directional protection scheme for a distribution system. The proposed relay, based on the transient protection technique, is designed to capture and extract the fault generated transients. The fault signal processing is mainly accomplished using two-level Daubechies discrete wavelet transform. Then the relays installed at two ends of feeder compare the polarities of captured transient signals mutually via their communication link so as to discriminate an internal fault from an external one. Since the new protection scheme utilises only transient signals instead of power frequency fault current, its operations are insensitive to fault type, fault locations, fault path resistance and onset of fault voltage. In addition, the performance of relay is not affected by CT saturation, load conditions and system configuration.

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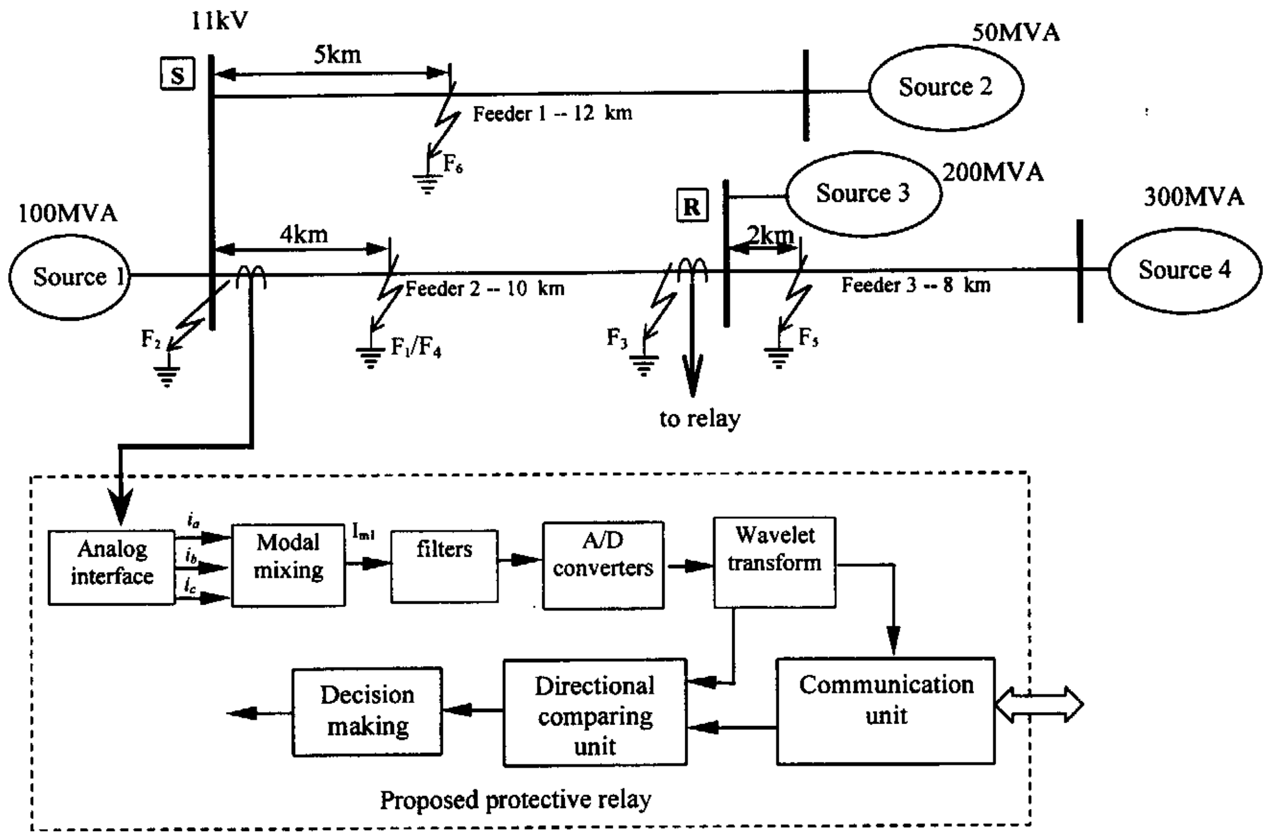

Fig. 1 The schematic of 11kV distribution system for simulation study

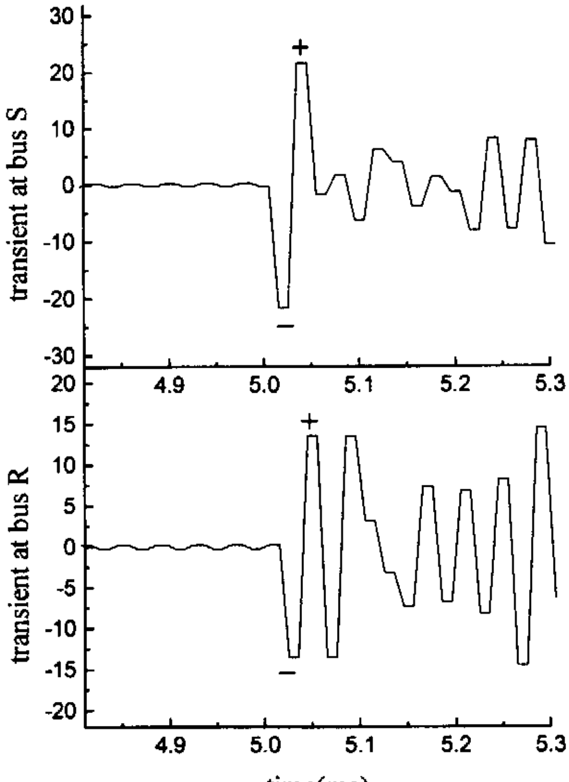

Fig. 2 Response of relay to a phase 'a'-to-earth fault on feeder 2 at 4km from bus S

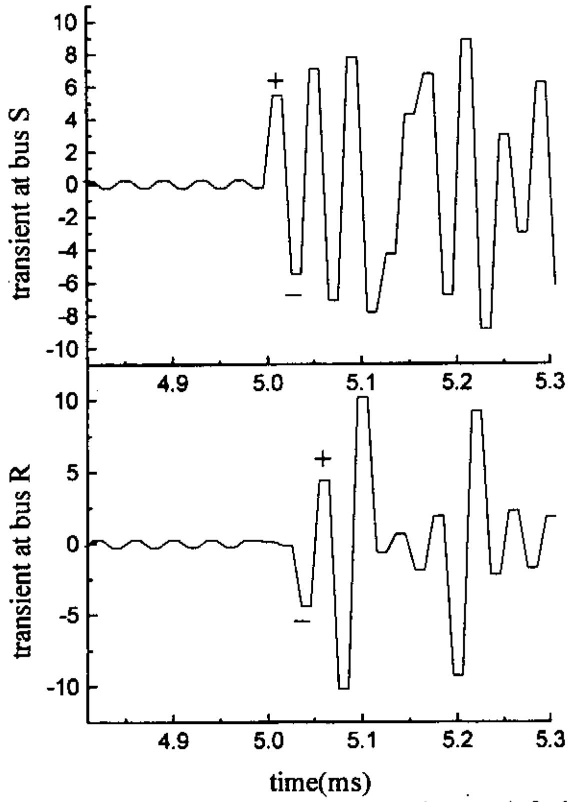

Fig. 3 Response of relay to a phase 'a'-to-earth fault on bus S outside protection zoom of feeder 2

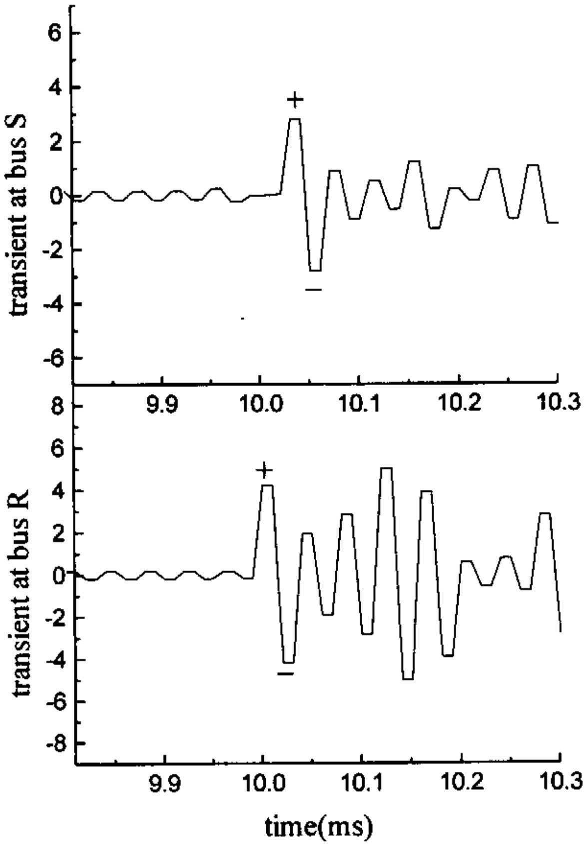

Fig. 4 Response of relay to a phase 'a'-to-earth fault on feeder 2 near bus R ; the onset of the fault is close to zero voltage.

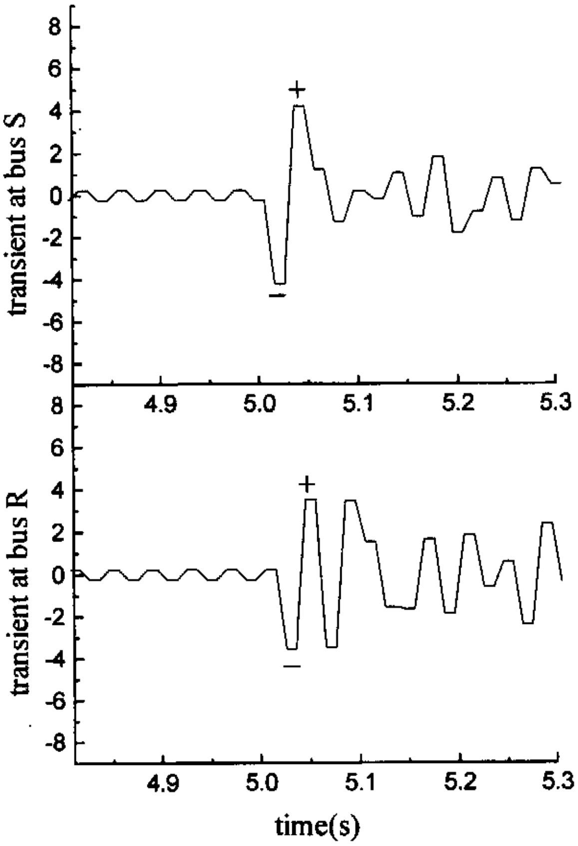

Fig. 5 Response of relay to a phase 'a'-to-earth fault on feeder 2 at 4km from bus S; the resistance of fault path is 300 Ω

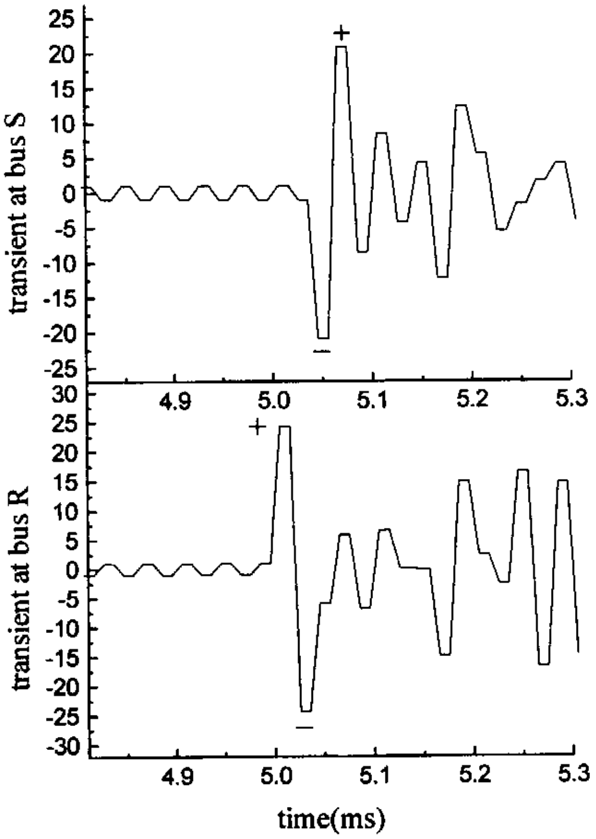

Fig. 6 Response of relay to a phase 'a'-to-'b'-earth fault on feeder 3 at 2km from bus R

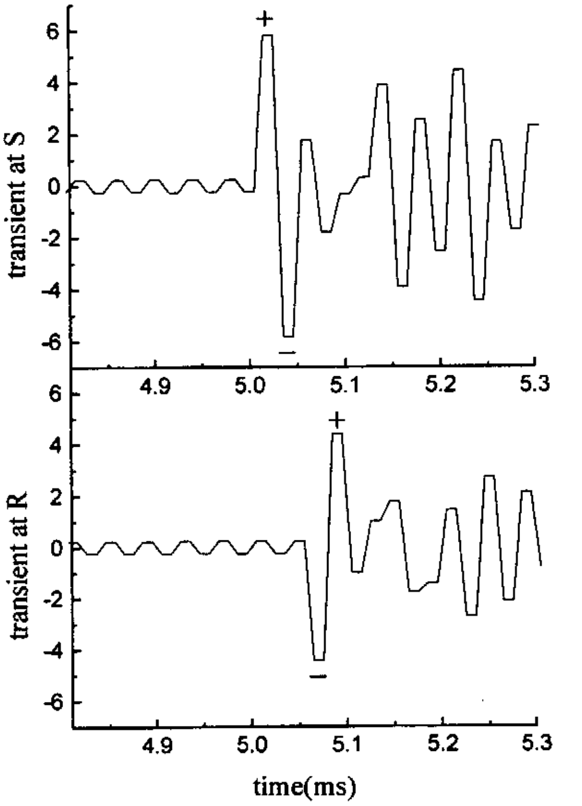

Fig. 7 Response of relay to a phase 'b'-to-'c' fault on feeder 1 at 5km from bus S