Transient Based Protection - A New Concept in Power System Protection

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Abstract - **This paper presents a new concept in power system protection, 'Transient Based Protection'. In contrast to present protection schemes applied in power systems which are based on the measurement of power frequency components, Transient Based Protection utilises the fault generated high frequency transient components to detect the occurrence of a fault. This paper outlines the advantages of the concept over existing techniques. A brief introduction to a number of new schemes under development based on the concept is included in the paper.**

Keywords: Power System Protection, Fault Transients, Transient Based protection

I. INTRODUCTION

A power system fault, when considered in the frequency domain, introduces additional transient components to the normal power frequency spectrum. These additional components contain extensive information about the fault and are spread throughout the spectrum ranging from DC to high frequency components. Power system protection has traditionally relied on the measurement of power frequency components for the detection of faults. In conventional protection schemes, the high frequency signal is considered as interference and is filtered out. However, these high frequency components contain extensive information about the fault type, location, direction and sustain time. In fact, the high frequency transient signals generated by a fault contain more information about the fault than power frequency signals. The use of high frequency transient signals enables the realisation of new protection principles that could not be implemented using only power frequency signals. The use of these high frequency transient components, only now possible due to rapid developments in microprocessor technology, has led to a new concept in power system protection, which utilises the fault generated high frequency transient components to detect the occurrence of power system faults. The transient based protection schemes operate by extracting the fault transient generated high frequency signals through specially designed detection devices and their associated algorithms. In contrast to present protection schemes based on fault generated transients, such as travelling wave based protection schemes, the new schemes are not limited by the bandwidth of the conventional transducers, and are able to accurately separate and extract the high frequency information required from the dominant power frequency signals.

This paper presents a new concept in power system protection - 'Transient Based Protection'. A brief introduction of the history of development of relaying principles which outlines the background of the concept is first given. The advantages of transient based protection schemes over the power frequency and travelling wave based schemes are illustrated by the introduction of various schemes currently under development which are based on the concept. These include applications in fault location, line protection, power apparatus protection and autoreclosure. It has been shown that the schemes based on fault generated transients provide a fast response, high accuracy, and are not affected by power frequency phenomena, such as power swing, high impedance fault, CT saturation etc. Furthermore, transient based protection offers other advantages such as simple principles, filter design and ease of setting and mastering.

II. BACKGROUND

Nearly a century has passed since the application of the first electro-mechanical induction relay (1901) in power system protection. Various new relay principles appeared within the first 3 decades. For example, the differential (1908), directional (1910), distance (1923) and unit (1927) protection. All these relay principles are based on the measurement of power frequency for fault detection. With the continuous development of modern technology and industry, the protection devices based on the above mentioned principles have advanced through the development stages of electro-mechanical, semiconductor, integrated circuit and microprocessor. Although decades of research have been put into the continue development and perfection of the relay technology, the above mentioned basic principles have not been changed, they are still playing the dominant role in the area of power system protection today.

Computer application is an important milestone in the history of power system protection. Since the concept was first raised at later 60's[1], relay technology has gone through rapid development. Digital techniques for protection of line and power apparatus[2-9] had been quickly developed. In particular, the rapid development of microprocessor technology not only enables the digital realization of conventional relay principles, but also provides the possibility to explore new and complex relaying principles.

The development of the 'ultra high speed protection' based on the travelling wave and superimposed components for protection of transmission line started in the late 70's, was the beginning of utilising the fault generated transient for the purpose of protection. With the continuous development of the EHV transmission system, the conventional protection methods could not meet the system stabilities demand for fast fault clearance. In searching for methods to increase the speed of relay response, researches found that travelling wave and superimposed components generated by fault transients can be used for fast fault detection[10-11]. A number of well-known relay manufactures produced products [12-14]. These relays have the advantage of fast response; directionality; not affected by power swing and CT saturation. The disadvantages are lack of phase selection ability; can not detect voltage zero fault; fault location not accurate. The most important of all is that these schemes require a communication link. However, the main reason that these relays were unable to reach ideal accuracy and reliability is the limitation imposed by the bandwidth of transducers.

The concept of adaptive protection developed during the 80's. Research[17,18] has shown that this concept has a wide range of application such as in the areas of distance protection, transformer protection and autoreclosure. It has many advantages such as: improved system responses, increased reliability and reduced costs. However, the basic principles of the various relays have not been changed by the adaptive technique.

Enter 90's, research work has turned to the application of artificial intelligence in protection. For instance, neural networks are used for fault identification, fault location, direction detection, and apparatus protection[20-24]. By using new mathematical means, the information of the entire frequency range of fault generated transient can be used for fault detection. This not only provides the means to enhance accuracy of fault identification, but also solve the problems which can not be identified by conventional methods based on single power frequency measurement. However, the application of artificial intelligence are also limited by the bandwidth of transducer, it is difficult to provide a significant new principle to replace conventional protection methods. The consequence is that sophisticated computation and a huge amount of work are required in exchange for a slight increase in the accuracy and reliability of fault identification.

In recent years, the newly developed 'fault generated noise based protection for transmission line' marks the start of protection using fault generated high frequency transient[25-27]. The main advantage of this scheme is the saving in costs of communication link and device. More importantly, the specially designed high frequency voltage transducer was first used for fault detection, therefore, the bandwidth limitation of conventional voltage transducers is overcome. Following the development, extensive research work has been conducted to develop new relaying principles and techniques based on the detection of fault generated transients. Thus far, the new schemes proposed have already covered many aspects of power system protection. This development has led to a new concept in power system protection - the 'Transient Based Protection' and symbolised the start of a new generation protection.

III. TRANSIENT BASED PROTECTION AND ITS APPLICATION

'Protection of power transmission system based on the detection of fault generated high frequency transients' is a concept for a new generation of protection, in short, 'Transient Based Protection'. Fault generated transient signals contain extensive information concerned with the fault type, direction, position and sustain time etc. The information is within the entire frequency domain including DC, power frequency and high frequency. In the conventional power frequency based protection scheme, the high frequency signal is considered as interference noise and filtered out. As a result, extensive research work was spent on the designing of the filters. Present protection schemes based on fault generated transients, limited by the bandwidth of the transducer, cannot separate and extract the high frequency information required from dominant power frequency signals, as a result, these protection schemes fail to offer any significantly new relay principles other than increasing the speed of fault clearance.

Since the high frequency signals generated by a fault transient contains more information about the fault than the power frequency signal does, it can be used to generate new protection methods which could not be implemented by using power frequency signals. The development of microprocessor technology has made possible the application of the transient based protection technique.

The 'Transient Based Protection' detects the occurrence of a fault by measuring of fault generated high frequency transient current or/and voltage signals. The high frequency current signals are directly extracted from the CT outputs. However, due to the bandwidth limitation of conventional CVT (VT), the voltage signals are measured by specially designed high frequency voltage transducer. Fast signal processing algorithms are then applied to the measured signals for fault identification. The basic principle of the 'transient based protection' can be best illustrated by the introduction of some of the major schemes currently under investigation as follow:

A. Fault location

The conventional fault location methods can be broadly classified into two categories: (a) impedance method; (b) travelling wave method. The impedance method determines fault position by measuring the impedance from the relay end to the fault point. Obviously, it is based on power frequency measurement and affected by many factors of power frequency phenomena, such as fault path resistance, line loading and source parameters etc. As a result, the accuracy of the impedance based fault location methods is limited to 2-3% of the line length.

The travelling wave generated by fault transient contains accurate information about fault position. However, present travelling wave based fault location methods cannot accurately separate the travelling wave which reveals the fault position from other waves of different frequencies, for example, the oscillation and multiple reflection waves generated by fault transient. This greatly affects the accuracy and reliability of the scheme, and because of this inaccuracy, the scheme can only be implemented off-line.

In the neural network based fault location method currently under development, it was found, during feature extraction, that using the power frequency signals is far more accurate in fault location than using the travelling wave frequency signals. As a result, this method is close to the impedance method based on power frequency measurement.

The fault location method based on high frequency transient is able to accurately extract the fault generated high frequency travelling signal, therefore, giving accurate fault position. Fig.1 shows the block diagram of the voltage and current based fault locator units which are used to capture the fault generated high frequency voltage or current transient signals from the faulted line/cable. The principle of the fault location technique is based on the successive identification of the fault initiated travelling high frequency voltage/current signal arriving at the location where the locator is installed; in particular, the first and the subsequent signals with reference to the first signal are used to identify the fault position. The propagation time of the high frequency components is used to determine the fault position. The technique has been proved to be immune to power frequency phenomena such as power swings and CT saturation, and insensitive to fault type, fault resistance, fault inception angle, system source parameters etc. Theoretically, the accuracy of this technique is proportional to the sampling rate of the fault locator. 1 MHz sampling rate in transmission line location can secure an accuracy of fault location of 150 meters[28,29]. A 20 MHz sampling rate corresponds to an accuracy within 10 meters in cable fault location[30].

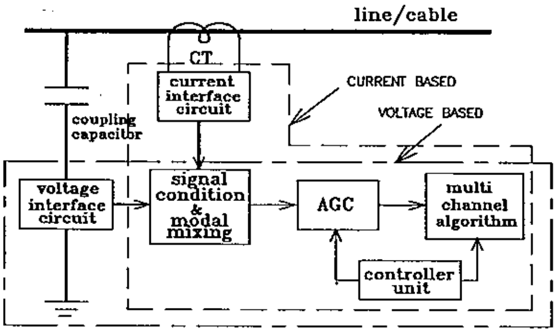

Fig.1 Fault locator unit

B. New line protection principles

1) Position and Directional Relays: A number of new protection principles for transmission and distribution line/cable have also been proposed based on the detection of fault generated transients. Firstly, due to the computation simplicity of the transient fault location method mentioned above, it could be implemented on-line to accomplish a fault position based protection technique. Studies show that the position protection techniques are faster and more accurate than conventional distance schemes[31-32]. Furthermore, a novel directional relay[33] and a new directional comparison scheme[34] were also proposed. Fig.2 shows the basic arrangement of the proposed directional relay. In the scheme, a current transient detection unit, which is interfaced to the CTs on each of the output lines connecting the busbar, is employed to capture the fault generated transient current signals. The transient signal captured from each line is first integrated to obtain its spectral energy; the level of the energy entering the busbar is then compared with that leaving it, to ascertain the direction of the fault. The main advantage of the technique over the conventional directional relay is that there is no requirement for a voltage transformer. This not only overcomes the problem of bandwidth limitation of the voltage transformer, but also offers wide application for places where a VT (CVT) may not be available.

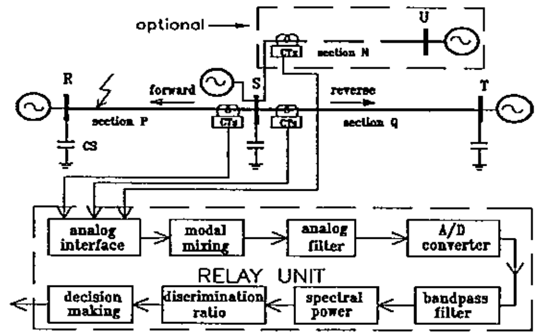

Fig.2 New directional relay

2) Non-communication Protection: Non-communication implies complete protection of transmission lines without the need for communication links. It is well known that there are mainly two protection principles for line, i.e. non-unit (such as distance scheme) and unit protection. For many years, extensive research has concentrated on the improvement of the two methods. Each method has its own limitation. The disadvantage of distance protection is that it cannot protect the entire line and setting is complicated. In contrast, unit protection can selectively trip the faulted line from both ends without delay. However, at the same time, the requirement for a communication link or device will increase the cost of this method. More importantly, the reliability of the method will also depend on the reliability of the communication link and device.

It can be concluded that a complete transmission line protection scheme without the need for communication link has obvious advantages. The first non-communication prototype relay[27] based on the detection of fault generated high frequency voltage transient signals has passed the high voltage laboratory tests. Simulation studies have also shown that the technique can be applied to different systems and configurations[35]. Fig.3 shows a novel non-communication scheme based on the measurement of fault generated high frequency current signals[36]. As shown in the figure, the conventional broadband carrier frequency line traps and coupling devices are situated as shown at each end of the protected line; these are tuned to a given band of high frequencies. The current transformers installed at line side adjacent to the line trap and coupling devices are employed to extract fault generated high frequency transient current signals. With reference to Fig.3, any fault generated high frequency current noise signal for an external fault is severely attenuated by the high impedance of the line traps and shunted to earth by the busbar capacitance and coupling devices. Therefore, within the frequency band the line traps are tuned, the signals detected by the current transformers are thus very low by comparison with those detected for a fault on the protected line. Based on the signals captured by the measurement unit, a Genetic Algorithm evolved Neural Network with is employed to solve the problem of internal and external fault identification. The convenience for interfacing CTs will make the technique attractive to protection engineers.

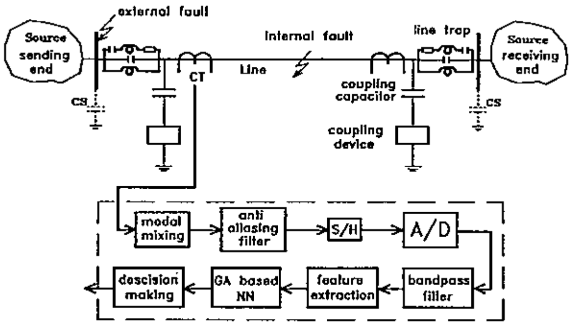

Fig.3 Current base Non-communication protection scheme

New non-communication protection schemes based on fault transient detection are also under investigation, the result of which will be reported in due time.

C. Protection of Power Apparatus

The power frequency based differential protection has been the main protection method for power apparatus (transformer, generator and busbar). Years of operation have proved its reliability. However, phenomena such as inter-turn faults inside transformer/generator, or potential faults such as partial discharge due to insulation ageing causing little change in terminal current, which are very difficult to detect using power frequency based differential protection techniques. This has been the major problem dominant apparatus protection since the application of relays in the area.

The above mentioned phenomena are high frequency transient in nature and therefore the application of protection techniques based on high frequency transient detection to power apparatus protection, could solve the long standing problem of low level fault detection[37-39]. The block diagram of the transient based protection scheme for a transformer unit is shown in Fig.4. The technique is concerned with the detection of the fault generated high frequency current transients through a specially designed relay unit. The relay, tuned to a band of high frequencies, is connected to the transformer through CTs on both the high and low voltage sides of the transformer. When a fault is detected, the transient currents from both ends of CTs are extracted by the detector; the differential and average currents between the two ends are then calculated. The spectral energies of these current signals are then extracted to produce the operate and restraint signals; a comparison between the levels of the two signals will determine whether the fault is internal or external to the protected zone. The proposed techniques cannot only discriminate power apparatus internal faults from external faults but can detect small currents and potential faults. It provides the possibility to combine functions of fault monitoring and protection.

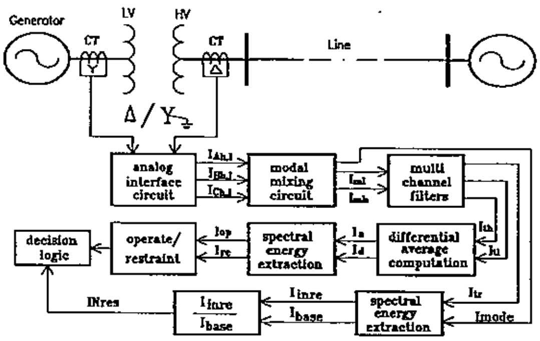

Fig.4 Protection of transformer based on the detection of fault generated transients

D. Autoreclosure

Transient based protection is mainly applied in two areas in autoreclosure: 1) phase selection and 2) transient and permanent fault identification.

1) Phase selection: Phase selection is the pre-condition for single-pole reclosure. There are many phase selection methods based on power frequency voltage, current and impedance. However, these methods cannot cover different systems and fault conditions in phase selection. Research shows that neural network based phase selection utilising fault generated high frequency transient could offer an alternative solution to a wide variety of system conditions[40].

2) Transient and permanent fault identification: Since the issue of distinguishing between transient and permanent fault was first raised[19], new identification methods using neural network [20] has been recently developed. However, the application of the technique requires extensive training data from the practical faulted transmission line system to which the technique is applied and the parameters of the neural network could vary with system configurations. As a result, the cost and the amount of work involved to implement a practical device are considerable. In contrast, a fault identification method based on fault generated high frequency transient signals is able to accurately distinguish between transient and permanent faults and the sustain time for transient faults. It is not only simple in application, but is also a method to solve the problem of transient and permanent fault identification for three phase reclosure[41-42]; which has seen no solution so far.

The basic arrangement of the transient and permanent fault identification unit is shown in Fig.5. As shown in the figure, a specially designed transient detector installed at the end of the transmission line and connected to each phase of the line through the high voltage coupling capacitors of CVTs, is employed to capture the fault generated high frequency transients; a fast data processing algorithm is then applied to the captured signals to identify between a transient and permanent fault, and also the time for which the transient fault persists. In this principle, when a fault occurs on the transmission line, the protective relay will issue tripping command to open the associated breakers. The behaviour of the primary arc after the fault inception and the secondary arc subsequent to the breaker opening, and their characteristic features, in particular its repeated temporary extinction/re-ignition features until final extinction have been well documented. It is these arcs that are responsible for the generation of the broadband high frequency noise on the transmission line; therefore, the new technique developed relies on the capturing of the high frequency noise generated by the arc to determine the nature of a fault and the arc extinction time. The signal processing unit consists of a number of elements, i.e. signal limiter and threshold, spectral energy computation, control logic, and decision making. The high frequency voltage signals captured by the transient detector is firstly clipped to a desired level by the signal limiter and a threshold is set to detect the inception of a fault; the spectral energy computation is used to convert the fault arc generated spurious noise to a continuous level of spectral energy from which the decision making unit can determine whether a fault is transient or permanent in nature and the sustain time of a transient fault; the control logic element is responsible for the control of entire operation.

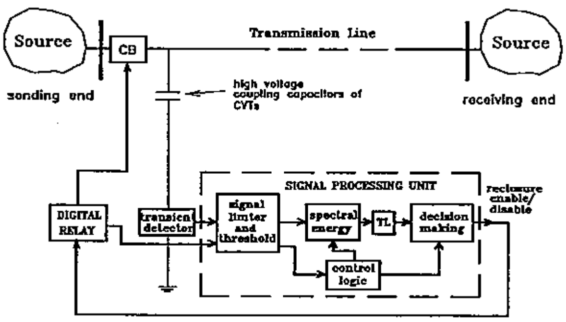

Fig.5 Novel scheme for transient and permanent fault identification

IV. CONCLUSION

It should be noted, the above introduced new protection principles and schemes are at an early stage in development. There could still be many practical problems. However, it is not difficult to predict that the transient based protection will be an important new development. With the involvements from the scientists and industries in the field, schemes currently under development will be perfected and new protection principles will surely emerge.

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