Electrical Power and Energy Systems 63 (2014) 83–90

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Extra high speed hybrid protection scheme for high voltage transmission line

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ARTICLE INFO

Article history:
Received 8 May 2013
Received in revised form 15 May 2014
Accepted 19 May 2014
Available online 26 June 2014

Keywords:
Hybrid protection
Extra high speed
Traveling wave relay
Current differential relay
Polarity comparison

ABSTRACT

To improve the reliability of traveling wave protection, this paper proposes a hybrid protection scheme based on the traveling wave polarity comparison principle and current differential principle. In this scheme, the traveling wave relay is primary and the current differential relay is supplementary. Two complementary relays simultaneously operate to ensure that the hybrid protection has a good performance. For the general faults, the traveling wave relay can fast discriminate internal faults from external faults using the polarity characteristics of initial current traveling wave. For some special fault conditions, the identification result for fault is determined by the current differential relay. Therefore, the sensitivity and reliability of traditional traveling wave protection may be greatly improved. Using the same hardware platform and only requiring current signal, the hybrid scheme is easily achieved. Simulation results verify that the hybrid protection has fast speed and high reliability level.

Introduction

Extra high voltage transmission line is responsible for transporting bulks of power from the generator plants to the load centers, and it is one of the most important components in power systems. If a fault occurs on the line, the protective relay should fast and reliably clear this fault. Otherwise, the electrical equipments may be destroyed and the stability of power systems is possibly influenced. Nowadays, the widely used current differential protection and distance protection have a high reliability level, but their sensitivities are easily influenced by distributed capacitance of line, fault resistance, CT saturation, etc. Moreover, it is difficult to further improve the operation speed. In general, the operation time is about one cycle [1,2].

To improve the operation speed of line protection, many methods utilizing traveling wave signals have been proposed, such as the polarity comparison based traveling protection [3–5], the amplitude comparison based traveling protection [6–8], the traveling wave distance protection [9,10] and other protections [11,12]. However, the fast fault detection capability of traveling wave protections is tarnished by their inability to detect faults under all possible conditions [13,14]. One of those situations, although rare, is a single phase to ground fault with small inception angle. In this fault case, the transient signals generated by this fault are very weak, and the indistinct wave front will be hardly identified for the detection purpose. Therefore, the traveling wave protections may fail to detect this fault. Another situation is a fault close to the relay position. The closer the fault is to the relay, the higher the frequency of traveling wave signal is. So it is difficult for the traveling wave protections to distinguish among the arrivals of consecutive wave fronts. Moreover, some other factors, such as the special structures of busbar, the parallel lines, the disturbance of lightning stroke, can also make some negative influences on the reliability of traditional traveling wave protections. This is one of the reasons why the traveling wave protections are rarely applied in a real power system.

In order to improve the reliability of traveling wave protections, as well as maintain the capability of fast fault detection, recently several hybrid protection algorithms have been proposed in [15–17]. In [17], Pathirana and McLaren presented a combined scheme which consists of a traveling wave relay and an impedance relay, but this scheme requires both the voltage traveling wave signals and the current traveling wave signals. The conventional CT has a good response to frequency, but the finite bandwidth of the capacitance voltage transducer (CVT) is a limiting factor to the extraction of high frequency voltage signals. Therefore, implementing such a hybrid protection scheme is still difficult.

Considering the questions mentioned above, this paper proposes a novel hybrid protection scheme. This scheme is made up of two

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http://dx.doi.org/10.1016/j.ijepes.2014.05.061
0142-0615/

relays operating in parallel, namely the polarity comparison based current traveling wave relay and the instantaneous value comparison based current differential relay. Although the detection speed of current differential relay is slower than that of the traveling wave relay, it is extremely reliable. The traveling wave relay has a very fast operation speed, but its reliability is low. If the advantages of two principles can be developed, the hybrid scheme would be promising. To testify the validity of the proposed hybrid protection scheme, using the PSCAD/EMTDC software package, a 500 kV power transmission system model was constructed and the extensive simulations were carried out.

Instantaneous value comparison based current differential relay

Through comparing the instantaneous value of current signal at one terminal of the protected line with that of another terminal, the current differential relay can correctly identify an internal or external fault. To avoid the negative influence generated by the load current on the sensitivity of relay, the fault component based instantaneous value current differential method is used here [18]. The phase segregated operating criteria for a two-terminal line is as follows:

$$|\Delta i_{m\cdot\phi} + \Delta i_{n\cdot\phi}| \geq k|\Delta i_{m\cdot\phi} - \Delta i_{n\cdot\phi}| + i_{th} \tag{1}$$

where $\Delta i_{m\cdot\phi}$ and $\Delta i_{n\cdot\phi}$ are the instantaneous values of fault component current at terminals *M* and *N* of the protected line, respectively, ϕ denotes the phase A, B or C; k is a restraint coefficient and i_{th} is the threshold value.

Letting:

$$\begin{cases} i_d = \Delta i_{m\cdot\phi} + \Delta i_{n\cdot\phi} \\ i_b = \Delta i_{m\cdot\phi} - \Delta i_{n\cdot\phi} \\ i_{op} = |i_d| \\ i_{re} = k|i_b| + i_{th} \end{cases} \tag{2}$$

Then (1) can be written as:

$$i_{op} \geq i_{re} \tag{3}$$

where i_d denotes the differential quantity of fault component current; i_b is the bias quantity of fault component current; i_{op} and i_{re} represent the operating quantity and the restraint quantity, respectively.

In this criterion, the cause that i_{th} is introduced is to prevent the non-zero output of the differential quantity in those conditions of steady state operation and external faults. Item $k|i_b|$ is used to ensure the sufficient reliability for external faults, especially for the situation of CT saturation caused by an external fault. Furthermore, the settings for k must also ensure the adequate sensitivity for internal faults.

During the fault process, since the values of both $\Delta i_{m.\phi}$ and $\Delta i_{n.\phi}$ are all variable, the relationship between the operating quantity and restraint quantity in (3) is also inconstant. This means it is necessary to make comparison more times by using different sampling values when (3) is used to make a tripping decision. To achieve a high speed response to internal faults and ensure the sufficient reliability to external faults, a tripping logic is designed as follows: supposing the sampling rate is 12 points per fundamental frequency cycle, if there are 4 samples (successive or not) meeting (3) among the first 9 post-fault samples, and the zero-cross times of i_d are not more than 2 during the judging process, then the current differential relay will issue a tripping command.

Polarity comparison based traveling wave relay

Theoretical analysis

Fig. 1 shows a single phase power system, in which $i_m(t)$ and $i_n(t)$ denote the initial current wave fronts at terminals *M* and *N*, respectively. The propagation of current traveling wave generated by a fault at f_1 is shown in Fig. 2, where t_m and t_n are the arrival times of initial current traveling wave signals $i_m(t)$ and $i_n(t)$, respectively. Supposing the positive direction of current is from busbar to line, according to the propagation principle of traveling wave, the polarity relationship between $i_m(t)$ and $i_n(t)$ is listed in Table 1.

As can be seen from Table 1, for the initial current traveling waves, if $i_m(t)$ and $i_n(t)$ have the same polarity, an internal fault would be determined; on the contrary, once the polarities of $i_m(t)$ and $i_n(t)$ are opposite, this fault must be on the external of the protected line.

Wavelet transform of traveling wave signals

The traveling wave signals generated by fault contain a large amount of fault information. Therefore, the key that achieving traveling wave protection is to extract these fault information effectively, and accurately identify the fault characteristics existing in the initial wave front. As an analysis tool for signals in time-domain and frequency-domain, the wavelet transform can synchronously describe the time characteristic and frequency characteristic of transient signals. These features make the wavelet transform suitable for extracting the fault characteristics of traveling wave signals. The theories of wavelet transform and singularity detection are as follows.

Supposing function $\psi(t)$ is absolute integral and square integral, meanwhile function $\hat{\psi}(\omega)$ is a Fourier transform of $\psi(t)$, if $\hat{\psi}(\omega)$ meets the following condition:

$$C_\psi = \int_{-\infty}^{\infty} \frac{|\hat{\psi}(\omega)|^2}{|\omega|} d\omega < \infty \tag{4}$$

then $\psi(t)$ is called as a basic wavelet. Through stretching and moving, $\psi(t)$ becomes an energy normalization function

$$\psi_{a,b}(t) = \frac{1}{\sqrt{|a|}}\psi\left(\frac{t-b}{a}\right), \quad a,\ b \in R, \quad a \neq 0 \tag{5}$$

where a is the scale parameter and its value decides the center of frequency-domain, bandwidth and duration; b is the shift parameter, which decides the center of time-domain. In order to conveniently analyze, function $\psi_s(t)$ is defined as the analysis wavelet here

$$\psi_s(t) = \frac{1}{s}\psi\left(\frac{t}{s}\right), \ s \in R, \ s \neq 0 \tag{6}$$

where s is also named as the scale parameter. To achieve fast wavelet analysis, generally the parameter s is taken a series of dyadic discrete value, i.e. $s = 2^j, j \in z$.

Therefore, the dyadic wavelet transform is defined as follows:

$$(w_s f)(t) = f(t) * \psi_s(t) = 2^{-j}\int_{-\infty}^{\infty} f(\tau)\psi\left(\frac{t-\tau}{2^j}\right)d\tau \tag{7}$$

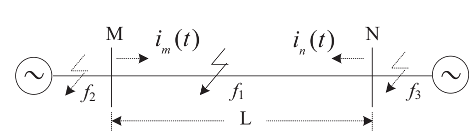

Fig. 1. Single phase power transmission system.