Electrical Power and Energy Systems 64 (2015) 1–8

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A novel fast distance relay for series compensated transmission lines

Xuanwei Qi, Minghao Wen *, Xianggen Yin, Zhe Zhang, Jinrui Tang, Fei Cai

State Key Laboratory of Advanced Electromagnetic Engineering and Technology, Huazhong University of Science and Technology, Hubei, China

ARTICLE INFO

Article history:
Received 17 October 2013
Received in revised form 14 June 2014
Accepted 6 July 2014

Keywords:
Distance relay
Equal transfer process of transmission lines
Series capacitor
Transmission line
Differential equation

ABSTRACT

This paper presents a fast distance relay for series compensated transmission lines based on the R–L differential-equation algorithm using the theory of equal transfer process of transmission lines. The measuring distances based on the proposed algorithm can fast approach the actual value of fault distance when a fault occurs in front of the series capacitor. When a fault occurs behind of the series capacitor, the fault loop, including the series capacitor, does not match the R–L transmission line model, so the measuring distances fluctuate severely. Based on this, the relative position of the fault with respect to the series capacitor can be judged effectively according to the fluctuation range of the measuring distances, and the accurate fault location can be obtained fast. A variety of PSCAD/EMTDC simulation tests show that the new relay has fast operating speed and high accuracy when applied to the long series compensated transmission lines.

© 2014 Elsevier Ltd. All rights reserved.

Introduction

In recent years, due to various reasons, such as the rapid increase in electricity demand, delays in building new transmission facilities, the transmission lines are forced to operate close to their transfer limits [1]. Use of Series Capacitor (SC) is a widely applied solution to this problem. The benefits of installing SC include improved power system stability, increased power transfer capability, reduced system losses, and improved voltage regulation [2].

However, the employment of series compensation technique brings unique challenges to distance protection. The measured impedance at the relaying point is the basis of the distance protection operation, because the impedance of an uncompensated line is proportion to its length. But the SCs may introduce significant change in line impedances [3]. On the other hand, in a typical SC arrangement, the Metal-Oxide Varistor (MOV), which is connected in parallel to the capacitor and protects the SC from over voltage during a fault, acts nonlinearly and may also affect the apparent impedance seen by the relay. The most important singularity of series compensated lines as objects to be protected, lays, however, in the fact that the impedance measured by traditional distance relays is no longer an indicator of the distance to a fault [4].

Some research has been done to solve the aforementioned problems with the distance relay for a series compensated transmission lines.

One approach proposes to apply machine learning and intelligent technique, such as artificial neural network [5], the support vector machines [6,7], ensemble decision tree [8], pattern recognition [9], and echo state networks [10]. Although the results presented in the aforementioned articles are encouraging, the performance of these methods depends on the experience gained from the training input–output examples, which needs a large number of training sets and training times.

Another solution proposes to use fault-generated high frequency transient signals. In [11], a specialized measurement unit consisting of stack tuner and line trap are used to capture the high-frequency components of the fault signal. The wavelet transform based technique is also proposed for the fault zone identification [1,12–14]. These methods require either special hardware to realize the protection algorithm or utilize novel approaches that are not sufficiently tested nor widely accepted by relay vendors and utilities.

Some literature proposes the voltage compensation method to improve the performance of the relay [2,4,15,16]. For fault occurring behind the series capacitor, the voltage across the SC is estimated, which is subsequently subtracted from the voltage measured by the relay to enhance the accuracy of the line impedance measurement. However, this method required the complicated parameters to describe the nonlinear characteristic of SCs. Further, the current level may be of the same order at two different fault points of the transmission line (one in front of the capacitor

* Corresponding author. Tel./fax: +86 2787540945.
E-mail addresses: WilliamQi@qq.com (X. Qi), swenmh@mail.hust.edu.cn (M. Wen), xgyin@mail.hust.edu.cn (X. Yin), zz_mail2002@163.com (Z. Zhang), tangjinrui001@126.com (J. Tang), cfly513@163.com (F. Cai).

http://dx.doi.org/10.1016/j.ijepes.2014.07.028
0142-0615/© 2014 Elsevier Ltd. All rights reserved.

and the other behind it) for the same type of fault. This will bring more complexity while locating the fault point on a transmission system.

In [17], a novel fast distance protection for an uncompensated transmission line is proposed. This method can achieve faster operating speed and higher accuracy than the conventional distance protection algorithms on the basis of the R–L differential-equation algorithm [18] using the theory of equal transfer process of transmission lines (ETPTL) [19]. However, application of this method for the protection of series compensated transmission line has not been validated.

In this paper, a new fast distance protection based on the theory of ETPTL is particularly proposed for series compensated transmission line. This new algorithm can effectively identify the relative position of the fault with respect to the SC and obtain the accurate fault location within about one cycle from fault inception. A variety of PSCAD/EMTDC simulation tests show the validity. To explain the concept of this new method, the following sections deal with the proposed protection method, simulation analysis, discussions and conclusions.

Proposed protection method

Basic principle

A protected series compensated transmission line is illustrated in Fig. 1. In this system, a SC is located at one terminal of the transmission line. A moving data window occupying the local current and voltage measurement at the relay point is used to calculate the fault location based on the R–L differential-equation algorithm. In this way, we can have every fault distance calculation result for each sampling instance. For the distance relay M, when internal fault occurs, as F1 shows, the SC is not in the fault loop, so the measuring distances can fast approach the real value of fault using the theory of ETPTL. When external fault occurs, as F2 shows, the fault loop including the SC does not match the R–L transmission line model. Therefore, the measuring distances fluctuate severely. In the same way, as for the distance relay *N* which uses the line side voltage, when internal fault occurs, as F1 shows, the measuring distances can indicate the actual fault location. When backward fault occurs, as F2 shows, the measuring distances fluctuate severely. Based on this, the relative position of the fault with respect to the SC can be judged according to the fluctuation range of the calculated distance results, and the distance of the internal fault can be calculated quickly.

Low pass filter and restructuring the voltage at the fault point

During the transient course due to fault occurrence, high order harmonics in voltage and current have adverse impact on the performance of the R–L differential equation algorithm. The low-pass filter is introduced to overcome the shortcomings of distance relay due to the impact of high frequency components.

According to the theory of ETPTL [19], the voltages and the currents at the relay point and the voltage at the fault point should pass the same low-pass filter. The voltage difference between the relay location and the fault point with respect to the current

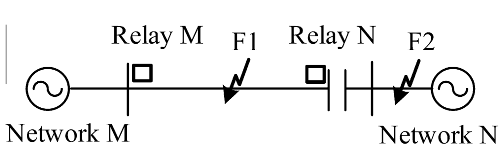

Fig. 1. The compensated system.

measured by the distance relay are still comply with the original transmission line model because they are transformed by the same linear circuit. Although low-pass filters produce the phase delay between input and output signals, the relationship between the voltage and the current does not change. Therefore, the R–L differential equation algorithm can estimate the fault distance accurately without any time delay due to the low-pass filter. In contrast, if the voltage at the fault point is not low-pass filtered, the transient error of the distance relay will possibly occur to a great extent. So it is necessary to estimate the faulty phase voltage at the fault point according to the three-phase voltages and currents at the relay location that can be measured by the distance relays.

The process of restructuring the faulty phase voltage at the fault point can be divided into two stages, namely, the pre-fault one and the post-fault one. In general, the pre-fault voltage at the fault point is a sinusoidal steady-state signal. The compensated voltage at a certain point of the protected line is used as the estimation of this voltage since the fault position is unpredictable. The post-fault voltage at the fault point can uniformly set as the product of the fault resistance and the current through the fault resistance. According to the usual realization method of distance protection, the current through the fault resistance can be replaced with the current measured by the distance relay. Therefore, the post-fault voltage can be regarded as the function of the fault resistance. The more detailed process of restructuring the voltage at the fault point can refer to literature [17].

Iterative calculations of the fault distance

The difference between the compensated voltage at a certain point of the protected line and this voltage at the fault point can cause the accuracy problem of distance relays. Iterative calculation can solve the problem.

The iterative technique, described as follows, is used to calculate the fault distance.

- Step (1) The initial value of the fault distance $l = 0.5\,D$. D is the total length of the protected line.
- Step (2) Calculate the samplings of the voltage at the fault point according to the three-phase voltages and currents at the relay location measured by the distance relays.
- Step (3) The voltages and the currents at the relay point and the voltage at the fault point are then filtered using a second-order low-pass Butterworth filter.
- Step (4) The new fault distance l can be calculated by substituting the voltages and the currents at the relay point and the voltage at the fault point into the R–L differential equation.
- Step (5) If l converged, stop the procedure; otherwise, go back to Step (2).

It is verified with the calculation results that iteration for 3 times can lead to a stable result of distance measuring.

The criterion for distance protection

According to the aforementioned method, we have every fault distance calculation result for each sampling instance during the post-fault period. In order to identify the fault zone and obtain the accurate fault location, two indexes, namely k and $t_{10\%}$, are proposed to analyze the fluctuation of the calculated fault distance results.

The index k is to describe the fluctuation range

$$k = \frac{|l_{\max} - l_{\min}|}{|l_{\max}|} \times 100\% \tag{1}$$

Download English Version:

https://daneshyari.com/en/article/6859880

Download Persian Version:

https://daneshyari.com/article/6859880

Daneshyari.com