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An adaptive algorithm to prevent distance relay overreach during CCVT transient

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ABSTRACT

In this paper, the impact of coupling capacitor voltage transformer (CCVT) subsidence transients on the performance of distance relay is investigated. The reach accuracy of distance relay is not maintained during CCVT subsidence transient and for this the responsible factors are system source-impedance-ratio (SIR), CCVT secondary burden, and fault inception angle. Relay generally overreaches during CCVT subsidence transient and in order to mitigate this problem an integrated adaptive logic is proposed. The adaptive zone-1 algorithm uses two criteria: (1) online SIR calculation using prefault and fault positive sequence voltage and current measured at relay location and (2) the maximum value of the transient monitor function obtained from the three-phase voltages to discriminate the in-zone fault from out-of-section fault. For accurate zone discrimination and to avoid relay overreach issue during end zone fault, the importance of adaptive threshold is crucial and can be set based on the online computed SIR value. The simulation study is performed using EMTDC/PSCAD. As the CCVT available in master library (ML) is not able to develop sufficient subsidence transient, a 500 kV, 60 Hz CCVT is modelled. Distance relay performance is analysed for different critical cases using the developed CCVT model and also the response of proposed method is observed. Results for different critical cases prove that the proposed method is able to maintain proper selectivity between in-zone and end-zone faults and also using the method the time-delay operation can be avoided during subsidence transient in the secondary side of CCVT

1. Introduction

Application of coupling capacitor voltage transformer (CCVT) in high or extra voltage transmission system is an economical way to produce the exact replica of primary voltage in the secondary side [1]. Reduced size and communication facility are the two major advantages of CCVT over conventional potential transformer. However, for any voltage dip during fault the CCVT output voltage may not be able to track the primary voltage due to the internal parameters of CCVT [2–6]. This may result in tripping of zone-1 element of distance relay even during out-of-section fault [7]. This is commonly known as relay overreaching. The system source impedance ratio (SIR) is also one of many causes behind relay overreach. The voltage measured by CCVT during fault is a function of the SIR [8]. The chance of relay overreach is also high for system with high SIR. The other factors such as, fault inception point on voltage wave, the design of ferroresonance suppression circuit (FSC), the composition of burden, fault resistance, and fault location are also responsible for the transient response of CCVT [9–12]. These factors indirectly influence the reach accuracy of distance relay. A complete analysis has been done on the above stated factors and reported in this paper.

In modern numerical relays, CCVT transient detection logic is applied to zone-1 protection of distance relay to delay the operation in order to avoid relay overreach [13,14]. In Ref. [13], a non-symmetrical filter which considers 1.5 power cycle window data is applied to estimate the voltage phasor during the transient period. Considering the system SIR as a reference parameter, the delay time for relay operation is computed. In this algorithm for higher system SIR, lower reach with time delay logic is provided to relay setting. By enhancing the phasor estimation process, distance relay maloperation during CCVT subsidence transient can be avoided [14,15]. An improved least squares technique uses different harmonics of voltage signal during the transient period to enhance the relay performance [15]. This technique is further utilised in Ref. [16], to determine the effect of voltage-zero subsidence transient. In this

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work, the moving average filter is applied to compute the average of the instantaneous decaying dc estimate (AIDDCE) considering once cycle data. The index obtained from calculated AIDDCE is used to determine the presence of CCVT transient.

Instead of providing time delay and reach reduction setting, application of electronic FSC is suggested in place of active and passive ferroresonance suppression circuit (FSC) to enhance the transient response of the CVT [17]. In Ref. [18], an adaptive distance relay algorithm based on transient error estimation technique is proposed for CCVT transient condition. The adaptive algorithm estimates the error between preset and measured reactance value during fault along with the apparent impedance. For higher values of estimated error, a time delay of 30 ms is provided to ensure the correct detection during out-of-section fault. A recursive digital filter (RDF) is used in Ref. [19] to estimate the primary CCVT voltage during transient. An analytical discrete Fourier transform based algorithm to eliminate the CCVT transient and estimate the correct voltage phasor is proposed in Ref. [20]. In this context, several other approaches have also been reported in the literature to filter the decaying dc offset and compensate the voltage signal mainly during CCVT transient for the enhancement of distance relaying performance [21,22].

Artificial intelligence-based algorithms are reported in the literature to solve this issue. In Ref. [23], a nonlinear multilayer recursive neural network is applied for correcting the distorted secondary voltage of CCVT with passive ferroresonance suppression circuit (FSC). A feedforward neural network based approach is presented in Ref. [24], for the compensation of CCVT secondary voltage.

In this work, a new adaptive distance relay technique is proposed to discriminate in-zone fault from out-of-section fault. The method utilises two new criteria. The first method is based on online SIR calculation using prefault and fault positive sequence voltage and current at relay location. Second method computes the maximum value of the transient monitor function obtained from three-phase voltages. The performance of the method is tested for various conditions using a 500 kV, 60 Hz, three-phase power system model simulated using EMTDC/PSCAD software. The results show that discrimination of in-zone fault from out-of-section fault using the proposed method is possible during CCVT subsidence transient.

2. CCVT modelling and comparative assessment

CCVT is common in high and extra high voltage transmission system due to reduced cost and size as compared to potential transformer. Since the secure and fast operation of protection system depends on accurate CCVT output response, proper designing of CCVT is essential. The transient response of CCVT obtained during certain system and fault conditions may cause relay overreach. This transient is termed as subsidence transient and can be defined as the transient voltage (voltage contains some oscillatory components) that appears in the secondary side of a CCVT due to sudden drop in primary voltage with the onset of fault. The subsidence transient contains decaying dc, low frequency and high frequency oscillatory and decaying dc components [15]. The transient response of CCVT depends on both internal parameters and fault conditions. With transient in secondary signal, the voltage magnitude changes abruptly and relay unwantedly operates for out-of-section fault. Such a condition is undesirable. A master library (ML) CCVT model available in EMTDC/PSCAD is unable to produce sufficient transient at the secondary side during out-of-section fault due to improper burden and FSC parameters. To study the impact of subsidence transient on distance relay performance, a CCVT model as provided in Ref. [15] is considered and modelled using EMTDC/PSCAD software. This model is also used in Ref. [25]

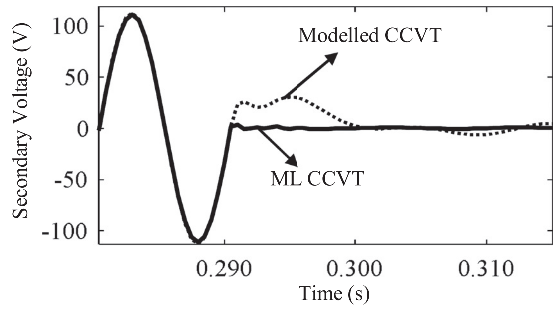

Fig. 1. Comparison between output voltages of modelled CCVT and ML CCVT.

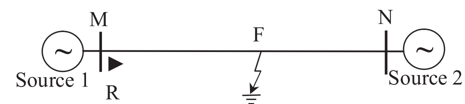

Fig. 2. The three-phase power system model.

to investigate the effect of CCVT subsidence transient on directional relaying during single-pole tripping. However, the CCVT model is used in this work to investigate the impact of subsidence transient on distance relay reach accuracy.

2.1. CCVT modelling

The considered CCVT model consists of (1) a capacitive voltage divider (CVD) which scales down the high primary voltage into desired intermediate voltage, (2) compensating reactor (CR), (3) step down transformer (SDT), (4) active ferroresonance suppression circuit (AFSC) and (5) burden. The AFSC consists of parallel resistors R_{1F} and R_{2F}, capacitor C_{1F}, series inductor L_{1F} and damping resistor R_{3F}. The passive ferroresonance suppression circuit (PFSC) based CCVT has a negligible impact on distance relay performance. However, presence of AFSC in the secondary circuit results in more severe voltage transient [16]. For analysis and to obtain required transient at the secondary side, AFSC based CCVT model is considered for the study. R_p, L_p, R_s, and L_s represents the primary and secondary resistances and inductances of SDT. The CCVT burden consists of a series R–L branch (R_{2B} and L_{1B}) in parallel with a resistor (R_{1B}). Further, the impact of higher burden on the performance of modelled CCVT is also investigated. The details of CCVT parameters are provided in Appendix A.

The output voltage generated during a low resistance far-end fault through both the ML CCVT and modelled CCVT are compared and shown in Fig. 1. After the initiation of fault, the change in voltage level obtained at the secondary side of ML CCVT is almost negligible and thus is not suitable for transient analysis. However, the voltage generated through modelled CCVT contains decaying dc components along with fundamental and other frequency components. So, for transient study and distance relay performance evaluation the modelled CCVT can be used.

2.2. Comparative assessment

Detection of in-zone fault and discrimination from out-of-section fault is a difficult task for distance relay during CCVT transient. To verify the response of modelled CCVT and for comparison with the ML CCVT different SIR conditions, fault locations and fault resistances are considered. A three-phase, 500 kV, 60 Hz Brazilian power system [8] as shown in Fig. 2 is considered for the study. The source and line parameters are provided in Appendix B. Distributed parameter line model is considered. The performance reports of both the CCVTs are provided below.