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Strengths and limitations of a new phasor estimation technique to reduce CCVT impact in distance protection

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ABSTRACT

This paper evaluates the performance of a new least squares approach that improves the accuracy and speed of convergence of the voltage phasors estimated during CCVT transient conditions. A justification of the validity of the linear mathematical model for the CCVT used is provided together with a short study about the risk of transient ferroresonance. Also, a discussion is presented about operating times of numerical distance relays and the importance of the new phasor estimation considered. The methodology followed to achieve a realistic evaluation in a variety of scenarios is presented. The results show the improvements achievable in most conditions, but also highlight an example scenario where the new method has limitations.

1. Introduction

The coupling capacitor voltage transformer (CCVT) is typically used to obtain a scaled down replica of high voltage signals from the power system for use by measurement and protection systems. The behavior of a CCVT during fault conditions is not as good as desired, because distortions are introduced in the voltage signals. This behavior is temporary and is known as CCVT transient response. This transient response presents some characteristics that are dependent on the internal CCVT circuit and components. In this work, a new least squares method that uses the knowledge of this internal configuration of the CCVT to overcome the difficulties imposed by this transient behavior is considered.

Distance protection relays use the information from voltage and current signals to identify the presence of a faulted condition in certain area of the power system. The state of the art relays are based on microprocessor architectures, and are known as numerical relays. Numerical distance relays use in most cases information from the fundamental frequency voltage and current to make the protective decision. To obtain this fundamental frequency information typically phasor estimation methods are used.

The CCVT transient behavior in many cases has a negative impact on the accuracy and speed of convergence of typical phasor estimator methods. In other words, the CCVT transient may cause a temporary phasor estimation error. This error affects the numerical distance relays by causing a transient overreach or underreach condition. In this paper, a new phasor estimation method based on the knowledge of the CCVT [1] is first briefly described and then evaluated.

Also in this paper, the validity of the linear CCVT model used is emphasized, based on other models from the literature. To reinforce this point a short study is included to clarify any concern about the risk of ferroresonance for overvoltage caused by line reclosures. Also, a discussion is presented about operating time on distance relays, the variables involved and the importance of the new phasor estimation method on this subject.

Also in this paper, the methodology followed to evaluate the new phasor estimation method is presented. The purpose of this evaluation is not only to verify the improvements achievable, but also to find any limitations of the new method. The conditions under which the method has limitations are of particular importance and they should be avoided. Results from the evaluation are presented, showing one case of improvement and one case where it has limitations.

2. CCVT characteristics

The CCVTs perform three main functions: scale down the power system voltage to the secondary voltage level required by protection, measurement and control equipments in a substation; provide electrical isolation from the high power system voltage; and normalize the secondary voltage to a range typical from 100 to 120 V according to the standards [2] in use.

A CCVT, as shown in Fig. 1, consists of three main elements: capacitive divider, series inductance, and intermediate potential transformer (PT). The capacitive divider scales down the high pri-

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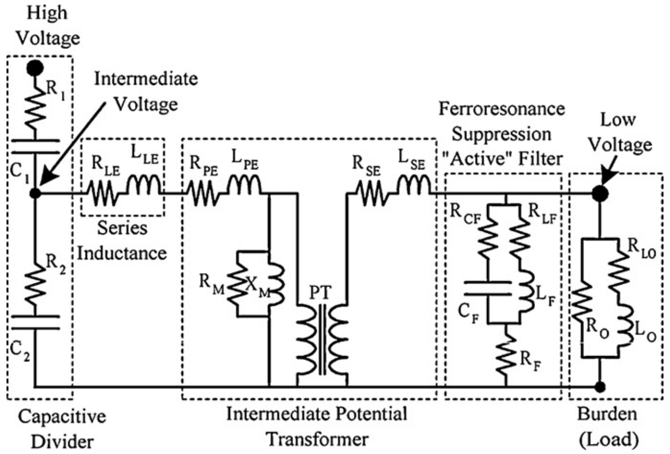

Fig. 1. Detailed circuit of a typical CCVT.

mary voltage to an intermediate level in the range of 5–20 kV. The series inductance compensates the net capacitive reactance of the divider at the power system frequency to minimize the net impedance seen by the intermediate PT. The intermediate PT performs the final voltage reduction to the normalized secondary voltage desired.

The steady state accuracy of a CCVT is acceptable even for the most demanding applications. The CCVT performance, however, is far from ideal when it is subjected to power system voltage transients, such as the fault conditions in the power system. The voltage output signal produced in these conditions contains transient components not present at the CCVT input, i.e. the CCVT introduces distortions in the voltage signal [3–5].

2.1. CCVT model

A model focused on the CCVT performance during faulted conditions has been presented by Pajuelo et al. [1]. In this study, we will first briefly justify the validity of that model which is used for this work. The same frequency response is plotted in Fig. 2, but using logarithmic scale for the frequency axis. A logarithmic scale is easier for comparing with similar plots in the existing literature [6–9], and also allows observing a broader range of frequencies. The linear range is better suited for the limited frequency range used in this study.

The time response of the CCVT is shown in Fig. 3. The response clearly shows the distortion introduced by the CCVT in the voltage signal. Three types of subsidence transients have been reported in the literature [3], i.e. high frequency component, low frequency component, and DC component. The CCVT model used in this work produces all three of them, and they are also shown in Fig. 3.

The CCVT response can be described mathematically using a Laplace transfer function as shown in (1). In previous literature [10], a 4th order transfer function has been used because the model of the burden was simplified. The composition of the burden has a significant impact on the form of this transfer function. The additional detail used in our model results in an additional DC decaying pole, and thus a 5th order transfer function is obtained.

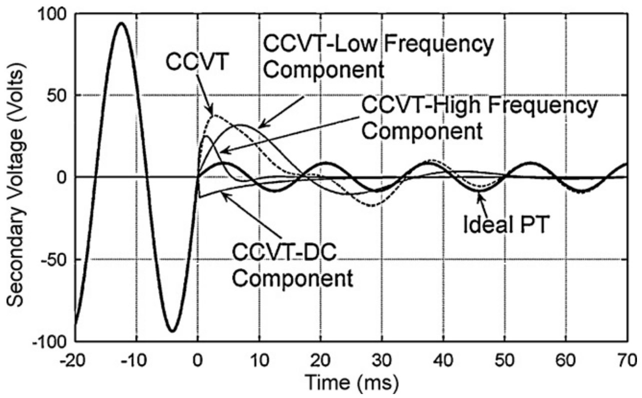

Fig. 3. Typical time response of a CCVT showing transient components.

$$G(s) = \frac{K_{\text{CCVT}}(s-z_1)(s-z_1^*)(s-z_2)(s-z_3)}{(s-p_1)(s-p_1^*)(s-p_2)(s-p_2^*)(s-p_3)} \qquad (1)$$

where

$p_1 = \sigma_1 + j \cdot \omega_1$; high frequency poles
$p_2 = \sigma_2 + j \cdot \omega_2$; low frequency poles
$p_3 = \sigma_3$; dc pole

2.2. Ferroresonance conditions

The presence of ferroresonance is unlikely during faulted conditions, because these are typically voltage drops that remain in the linear region of the magnetic core of the intermediate PT [11,12]. Thus a linear model is justified here. However, the sudden voltage increase produced during reclose or energization conditions raises concern about the presence of ferroresonance. To clarify this issue, a preliminary study is performed with the CCVT model used. The results are presented in this section.

The CCVT model used in this study includes an active ferroresonance suppression filter because it produces larger distortions in the voltage signal compared to the passive ferroresonance filter. The ATP/EMTP method is used to model the CCVT because it allows representation of the non-linear magnetic characteristics of the intermediate PT. For comparison, two CCVT models are used: one with linear magnetic core, and one with non-linear magnetic core. All other parameters of the two CCVT are identical.

The test cases are selected to produce overvoltage conditions because the risk of entering the non-linear region of the magnetic core is higher. To verify the presence of ferroresonance, the

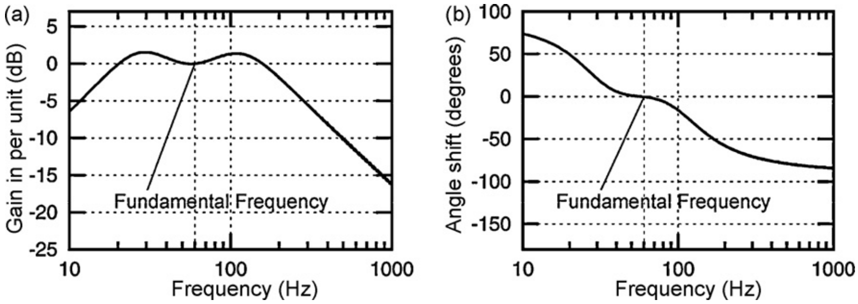

Fig. 2. Typical CCVT frequency response: (a) magnitude and (b) angle.