Transients phenomena in capacitive voltage transformers – distance protection point of view.

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***Abstract* – This paper presents problems of distance protection due to transients in capacitive voltage transformers (CVT's). CVT is a basic equipment which sends information to relay about voltages in protected system. During transmission lines faults severe transients can occur. As a result we can obtain mal-operation of distance protection.**

I. Introduction

Operation of distance relays with capacitive voltage transformers meets problems. They are directly connected to transients states of capacitive voltage transformers which appear during transmission lines faults. In this case mal-operation can occur. Relay may not recognize fault place. Moreover it's difficult for distance relay to distinguish quickly between fault within protection zone and fault at the reach point. Another problem is a low speed and worse accuracy of distance protection. Therefore these problems have to be taken into consideration.

II. CVT Transients

A. Equivalent circuit of CVT

Main components of a generic CVT are: tuning reactor, step-down transformer , ferroresonance suppression circuit and a capacitive voltage divider. It consists also many additional devices which are not important in point of view transients phenomena. There are two important diagrams below. Figure 2 is a simplification of equivalent circuit of CVT from figure 1.

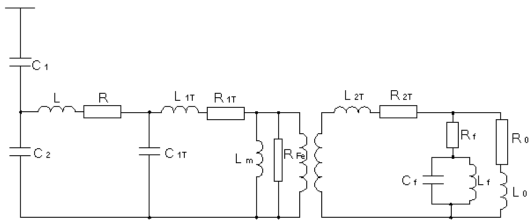

Figure1. Equivalent circuit diagram of a CVT

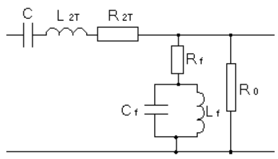

Figure 2. Simplified model of a CVT from Figure 1

Diagram from figure 2 consists following parameters:
C – sum of the stack capacitances
L,R – equivalent inductance and resistance of the tuning reactor and the step down transformer
R_0 – burden resistance
R_f, C_f, L_f, - parameters of anti-resonance circuit

B. Nature of transients

During line faults primary voltage of CVT collapses. Energy stored in stack capacitances and tuning reactor need to be dissipated. This produce a severe transients for distance relays. These transients can have different nature. It can be forecasted by analysis of CVT transfer function (1), where factors A and B in nominator and denominator are functions of parameters marked on simplified CVT diagram in figure 2.

$$G_{CVT}(s) = \frac{A_3 s^3 + A_2 s^2 + A_1 s}{B_4 s^4 + B_3 s^3 + B_2 s^2 + B_1 s + B_0} \qquad (1)$$

Eigenvalues of (1) determine nature of transient. Analysis of CVT transient nature [1], shows that induced transient can be:

- Combination of four aperiodically decaying dc components
- Combination of two oscillator decaying components
- Combination of one oscillatory decaying component and two aperiodically decaying dc components (general case)

C. High SIR problem

Drastic problems can be created by CVT transients during high System Impedance Ratios. It is proved (ref. [1]) that for higher SIR the fault voltage at the reach point drops to very small values. Also another problem appears. It is extremely unfavorable signal to noise ratio. It's illustrated at figure 3.

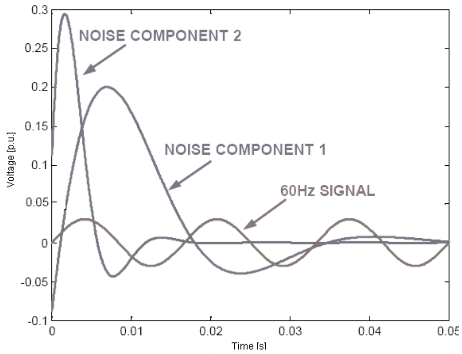

Figure 3. Signal-to-noise ratio for the CVT transients and high System Impedance Ratio

As illustrated in Figure 3, the magnitude of the noise components may be 10 times larger than the magnitude of the 60Hz operating signal. Noise dominates for 1.5 to 2 cycles.

Noise component frequency can be close to 60Hz in some part of time axis. Moreover noise vector can be in opposition to operating signal. In this case both signals cancel mutually to certain extend. Thus the phasor estimator tends to underestimate the magnitude.

III. Control of Transients

Transients are basically controlled by the following factors (reference [1]):

- Sum of stack capacitances
- Shape and parameters of the ferroresonance suppression circuits
- CVT burden
- Point on wave when a fault occurs

A. Sum of stack capacitances

Magnitude of the transients is lower when the sum of stack capacitances is higher. It is true that behavior of a distance relay doesn't depend only on magnitude of fault signal. Price of stack capacitance is quite high. Therefore transient's magnitude takes secondary importance for transient overreach and speed of operation.

B. Ferroresonance suppression circuit

A ferroresonance suppression circuit is designed to prevent subsynchronous oscillations. They appear when there is saturation of the core of a step-down transformer during overvoltage conditions. This circuit has significant impact on the characteristic of the CVT transients because it creates an extra path (apart from the burden) for dissipating energy.

C. CVT load

Better CVT performance is obtained when it is fully loaded. Contemporary digital relays introduce a very low burden tor CVT (100-400VA). As a solution we use often artificial load.

D. Point on wave when a fault occurs

The most severe transients appear at the zero crossing of the primary voltage. In this case transients can reach 40% of the nominal voltage magnitude.

IV. Distance protection problem

Distance relays measure impedance to determine location of a fault. Due to transients in CVT's , voltage signal can be underestimated. Moreover current can be overestimated. These problems often lead to error in impedance measurement. It results in mal-operation of distance protection.

Nowadays there are known methods of control a current overestimation. As a solution we use mimic filter or band-pass differentiating filter. Unfortunately problems connected to voltage underestimation due to CVT transients are still significant. Series of simulation show that voltage estimation error can be equal even 90%. If we assume that current was estimated correctly, still we have 90% of impedance measure error.

There are a lot of methods to improve distance protection during CVT transients. One idea is pre-filtering voltage with non-symmetrical FIR filter. Another ideas are e.g. to use artificial intelligence techniques or testing new algorithms.

References

[1] B. Kasztenny, D. Sharples, V. Asaro, M. Pozzuoli, "Distance relays and capacitive voltage transformers – balancing speed and transient overreach," 55th *Annual Georgia Tech Protective Relaying Conference Atlanta,* May 2001.

[2] J. Izykowski, B. Kasztenny, E. Rosolowski, M.M. Saha, B. Hillstrom "Dynamic compensation of capacitive voltage transformers," *IEEE Transactions on Power Delivery, Vol. 13,* No. 1, January 1998