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THE EFFECT OF VARIOUS PARAMETERS OF CVT ON ITS PERFORMANCE, AND THEIR ROLE ON POWER QUALITY

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ABSTRACT

With the advancement of technology and importance of using devices with the ability to perform complex tasks like super computers and new household appliances, Performance of these devices has had a negative impact on the power network, and lowered power quality in the system. So these days the issue of improving power quality gets more and more attention. One of the issues considered in the further development of new devices is the problem of harmonics above 50 Hz. Today, Capacitor Voltage Transformers (CVTs) are widely used to measure harmonics and transients voltages. Therefore the issue of efficiency and stability of this device against the changes of its parameters as well as changes and disturbances in the network is of great importance. In this paper, the CVT system is simulated, and then the role of changes of device and network parameters in stability and performance of the CVT are examined. Results showed that CVT is sensitive only to the changes of capacitors in low frequency response.

Keywords: Capacitor voltage transformer, parameters, power quality, performance.

INTRODUCTION

Today, the power quality issue is important. With the advancement of technology, every day new devices are invented to perform complicated operations and automatically carry out a sequence of commands chain. On the other hand, electricity distribution companies due to the adverse impact caused by power quality disturbances, always try to solve this problem and increase electricity production quality so that they can compete with other power companies. One thing that is very common in this area is isolating the components of the network where the error happened (Zhao *et al*., 2010). For this purpose, the energy provider companies try to offer several methods and devices are used to protect the network from a variety of system errors. Usually the common devices which are employed to protect the network use 50Hz frequency band. Due to limitations in the choice of frequency, these devices inevitably have lower rate on the protection of network. Popular examples of these devices are current differential, distance, and over-current relays.

If the transient error at any point in time be available, protective relays, given the available information, can be significantly faster and increase the error detection precision; however, a relay that works based on transition error is required to have a current transducer or voltage transducer, or both to have a good frequency response range of 50 Hz or higher. Today, one of the most popular voltage transducer devices is CVT. They are widely used in power distribution systems. This device helps the relay to measure transient error and thus increase the network security. CVTs have been designed to detect errors in 50 Hz by providing information for the relays. CVTs measure voltage to protect the high-voltage grid. They turn high voltage into low voltage to be used in protective measuring devices like relays and particularly, voltage transformer component of CVT has the task of isolating the high-voltage measurement devices.

A CVT is composed of various parts includes two input capacitors, a VT circuit (a reactor, VT, and the Ferro-resonance Suppressing Circuit (FSC) and a burden. Each of these parts tries to avoid entering the damaging effects of high voltage to measurement and protective devices in some ways. Although these devices are designed to have the best performance, but for various reasons, such as severe errors, longevity, aging, and etc., various parts of CVT may have problems, and much of it takes away from their normal value problems such as the change in the input capacitor due to the discharge of part or all of their capacity, and the loss or saturation effects of iron core of inductor which as a result, change normal value of inductor. Since every function of protective relays is based on information sent from the CVT unit; therefore, changes in these components can cause many problems in isolating the circuit. On this basis, famous companies manufacturing CVT provide standard tests to verify the accuracy of the performances of the CVT components so that consumers and organizations that are responsible for the maintenance of power lines and equipment every once in a while, perform periodic maintenance and examination of these devices to ensure their functionality. One of these companies is *Alstom Grid Worldwide* which has its own solutions to check each

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grid. Considering the above, the manufacturers of various CVT try to design various parts of CVT in such a way as not to be sensitive to changes in the properties of components or at least, to have a little bad effect on the output of device. In other words, the system output should be as robust as possible to the uncertainty of items, and should have the property of low sensitivity. The CVT units are designed to have the best performance with a frequency of 50 Hz; so unfortunately, accuracy of CVT is not appropriate at higher frequencies (CIGRE Working Group, 1981; IEEE Committee Report, 1981, Iravani *et al.*, 1998; Hou and Roberts, 1995). CVT also has problems of high frequency in magnitude and phase curves.

Conventional instrument voltage transformers are currently used as the essential instrument for harmonic measurement in power network. However, their frequency bandwidths are limited. As a result, they are not suitable for high frequency harmonic measurement unless their frequency responses in a concerned frequency range (e.g. 50Hz to 5 kHz) are clarified" (Senpeng *et al.*, 2014). In this section we review some studied that have been conducted associated with CVT. In a recent study, Senpeng *et al.* (2014) tested and analyzed harmonic response of High voltage instrument voltage transformers, and checked the frequency response of the system from 50 to 5000 Hz in the presence of harmonic problems. Then the harmonic response assessment of a single phase 400kV Wound-type Voltage Transformer (WVT) and a single phase 275kV Capacitor Voltage Transformer (CVT) were conducted using the developed test bed. Davarpanah *et al.* (2012) presented appropriate solutions to this problem. Their findings showed that short circuit elements of capacitor, especially low-voltage capacitors, increase error in CVT. One way to compensate the increased error is using the Auxiliary Voltage Transformer (AVT) which does not need to open the CVT components. The practical examples showed that this method affected the CVT transient response. An optimal design for minimum transient response of the CVT was given by Xie *et al.* (2011). In a study by Ghassemi *et al.* (2005), Harmonic voltage was measured by a CVT. In this study, a method is provided in which the current sensor is installed within CVT. Simulation studies and field tests have confirmed the validity and practicability of this method. In this method, the input terminal voltage is directly determined and there is no need for information about transfer function and burden. An innovative design of CVT with consideration of all the issues related to market using computer analysis was proposed by Krajtner *et al.* (2007). In this study, the CVT system is mentioned as a tool without the need for maintenance and repair which makes it vitally important to find CVT preliminary calculations. In this paper, the issues and the needs of the market and industry in various sections were also investigated, and the question of reliability was also intended in how to design it. A Novel correcting method for transient errors of CVT were presented by Xu *et al.* (2010). With this method, a transient error was reduced to an acceptable level, and the amount of voltage in the primary side was calculated correctly from the secondary-side voltage. The node voltage equations based on integral equivalence was used to simplify the computation of algorithm. Bakar *et al.* (2006) studied transient performance of Capacitor Voltage Transformer. He reported the digital-time domain and frequency domain studies on a typical 132 kV capacitor voltage transformer (CVT) model. Simulation results related to the CVT transient response under both system fault and ferro-resonance condition were also reviewed by them. a steady-state error analysis and digital correction for capacitor voltage transformers was presented by Sun *et al.* (2008). With this method, the authors have been able to address and solve the problems that affect the development of steady-state error of the system response. Transfer function of a CVT was obtained by Ghassemi *et al.* (2002). Then with the help of this transfer function, harmonic errors were resolved. Bradley *et al.* (1985) tested Harmonic Response on Voltage Transducers for the New Zealand Power System. It is also shown that the measured harmonic response of the CVT is different than that in the high voltage.

MATERIALS AND METHODS

Capacitor Voltage Transformer (CVT)

Figure1 shows a typical CVT. CVT model has been widely discussed in the literature along with details of its parameters (Zhao *et al.*, 2010; IEC, 2002; IEEE, 2003). As can be seen from Figure 1, CVT system consists of two capacitors C1 and C2 which is as a voltage divider.

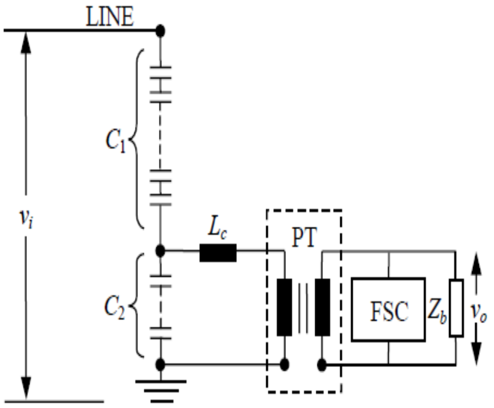


Fig. 1. Electrical diagram of a typical CVT (Fernandes Jr. *et al.*, 2003).

Assuming that the current drawn by the circuit output is negligible, the voltage can be calculated as follows:

$$Vc2 = \frac{C1}{C1+C2} \times Vin \qquad (1)$$

When the burden is high, an error in measurement of voltage ratio, phase angle, as well as input and output voltage will occur. To fix this error, an inductive reactance is connected in series with the voltage transformer which is shown in the Figure 1 with symbol Lc. After the inductive reactance, you can see PT element which is related to current transformer. The task of this element is to provide the secondary voltage for measuring devices and protective relays. Finally there is FSC element which can prevent the effect of Ferroresonance as much as possible. In harmonic or sub-harmonic frequencies, ferroresonance circuit impedance whose parameters are set for the main frequency drops sharply. This part of the circuit will act like a resistor that has the effect of damping and thereby suppressing ferroresonance oscillations.

The word “ferroresonance” includes all the oscillatory phenomena that take place in an electric circuit comprising a nonlinear inductance, a capacitance, a voltage source and low losses. That is why it is a frequent phenomenon in voltage transformers, due to their nonlinear magnetic characteristic and their operation conditions, similar to no-load ones. This phenomenon appears after transient disturbances (transient overvoltage, lightning overvoltage or temporary fault) or switching operations (transformer energizing or fault clearing). Its effects are characterized by high sustained over voltages and over currents with maintained levels of current and voltage waveform distortion, producing extremely dangerous consequences (Valverde *et al*., 2012). Careful attention must be taken when computing the ferroresonance suppression circuit (FSC) parameters to avoid numerical instabilities in time-domain simulations. The protection circuit is very effective in damping out transient voltages when a short circuit is cleared at the CCVT secondary side (Fernandes Jr. *et al*., 2003).

Simulation

In this section using MATLAB, first we simulate a schematic model of CVT in Simulink simulation environment. Figure 2 shows the results. The parameters shown in Table 1 are considered normal. Then, the effect of pure burden and inductive burden with power factor of 0.85 is examined, and in finally, the effect of changing CVT parameters on circuit performance is evaluated.

Table 1. All parameters of CVT.

Parameters	**Values**	**Parameters**	**Values**	**Parameters**	**Values**
C1	5.65nF	Lp	2.85H	Cf	9.6uF
C2	81.1nF	Rp	400Ω	Lf1	.481H
Lc	56.5H	Cp	154pF	Lf2	.247H
Rc	228Ω	Lm	1e4H	M	.163Ω
Cc	127pF	Rm	1e6Ω	Rf	37.5Ω

Source: Zhao *et al*., 2010

Bus voltage is considered as 79.674 kV (Zhao *et al*., 2010; Kezunovic *et al*., 1992; Kojovic *et al*., 1994) and the frequency response is studied in the range of 10Hz to 10 kHz. Note that the burden Z_b was set as equal to 22 ohms.

The impedance of the reactor block (reactor equivalent) is obtained as follows:

$$R_{reactor} = (j\omega.Lc + Rc)||(1/j\omega.Cc) = \frac{j\omega.Lc + Rc}{j\omega.Cc.Rc - \omega^2.Lc.Cc} \qquad (2)$$

VT equivalent which is related to the voltage transformer, converts high voltage to low voltage is in the CVT. The FSC, as can be seen, has been simulated with resistor, inductor and capacitor.

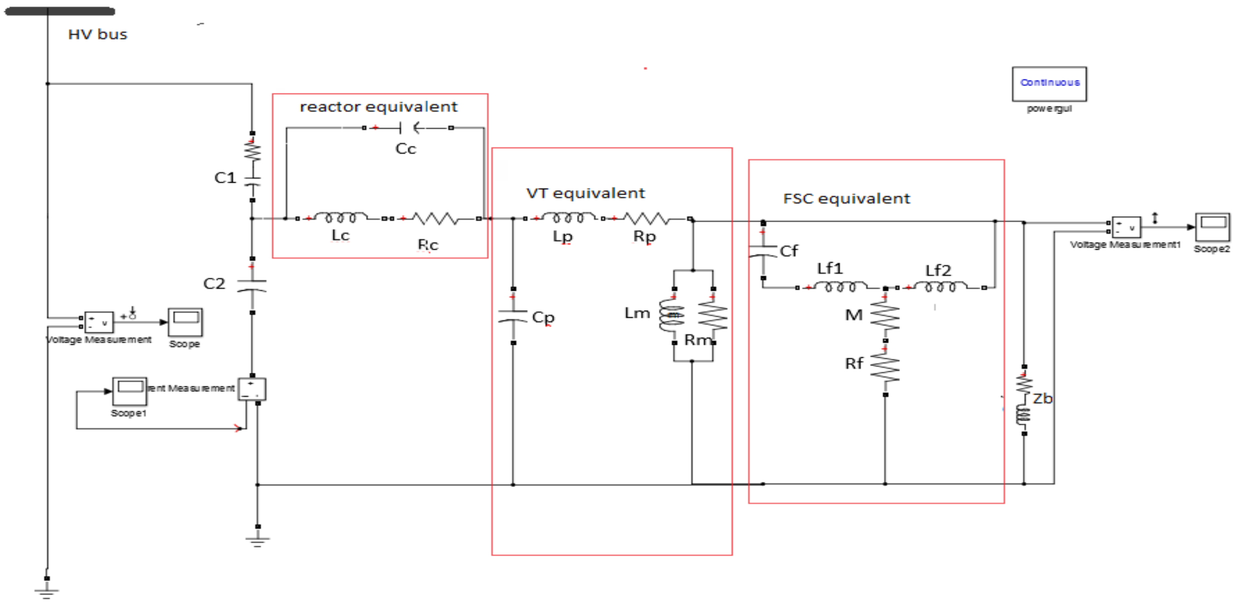
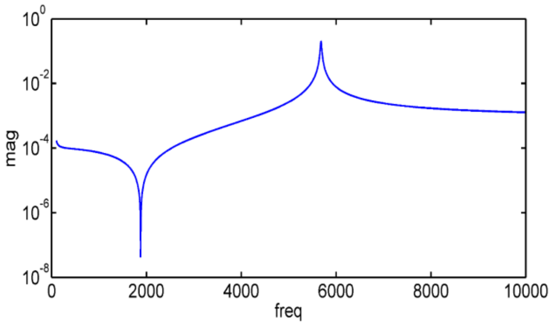


Fig. 2. CVT model simulated in MATLAB.

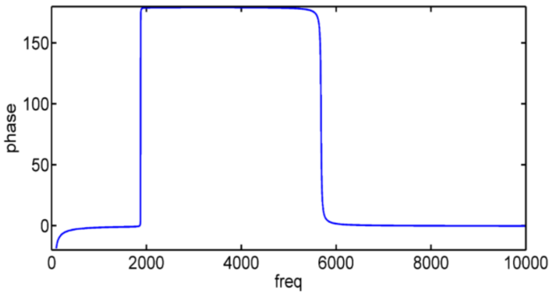
RESULTS AND DISCUSSION

CVT Performance Under Various Burdens

Here we examine the frequency response of the CVT when the frequency is changed from 10 Hz to 10 kHz under 22 Ω pure burdens. Figure 3 shows frequency response of the system.



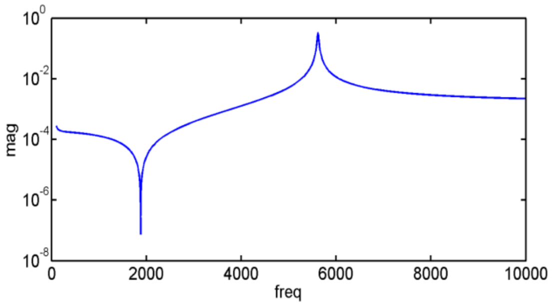
(a) Magnitude frequency response.



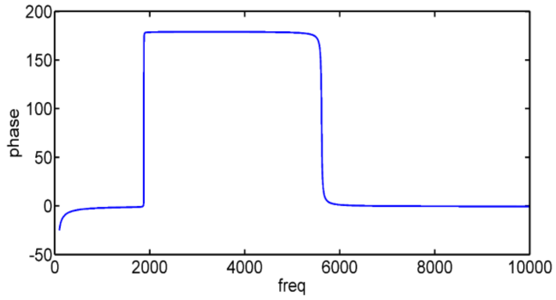
(b) Phase frequency response.

Fig. 3. Frequency response of CVT under pure burden.

As seen in Figure 3(a), CVT bandwidth is approximately 300 Hz with about 1700 Hz resonance frequency. In this frequency and bandwidth under mentioned normal conditions, phase frequency response is equal to -20 (Fig. 3(b)) which indicates that the circuit is stable in its bandwidth. Now we examine frequency response with 3 H inductor in normal conditions. Figure 4 show the measurements.



(a) Magnitude frequency response.



(b) Phase frequency response.

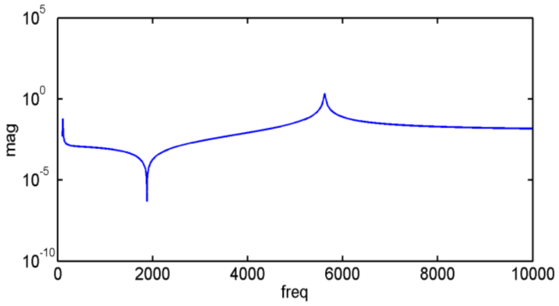
Fig. 4. CVT Frequency response under inductive burden.

As seen, again, the bandwidth of CVT is about 300 Hz, and resonance is about 1700 Hz, but the magnitude of frequency is a little different under inductive burden as well as the phase shift.

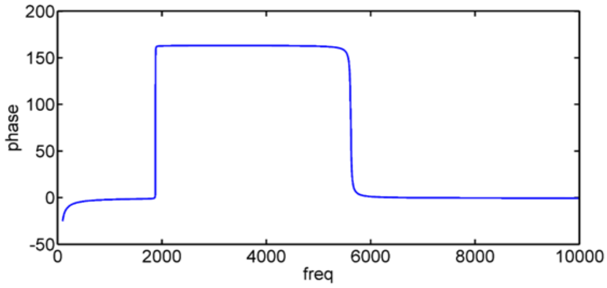
CVT Performance Under Changes of its Parameters

Input Capacitors

To examine the effects of changes of CVT capacitors on its performance, first we create a 20% uncertainty on the input capacitors, C1 and C2, and then we study magnitude and phase frequency diagrams.



(a) Magnitude frequency response.



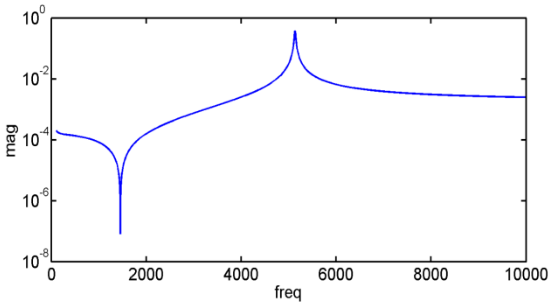
(b) Phase frequency response.

Fig. 5. CVT frequency response under changes on C1 and C2.

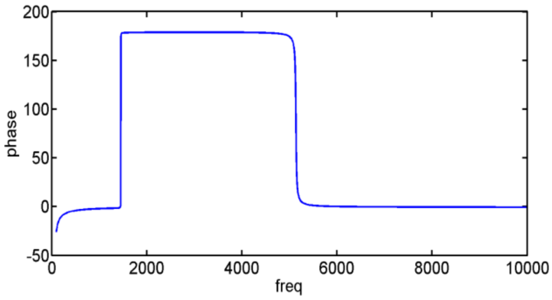
As seen in Figure 5, low frequency response of CVT has been considerably changed. Also when the frequency is low it makes the graph has a greater slope which reduces bandwidth; however, the resonance frequency has not been changed as well as phase frequency.

Reactor

Now we examine the effect of uncertainty in reactor equivalent on the frequency response of CVT. To do this, we considered Cc=180 pf, Rc=150Ω, and a 66.5 H inductor, and then we illustrated its measurements as shown in Figure 6.



(a) Magnitude frequency response.



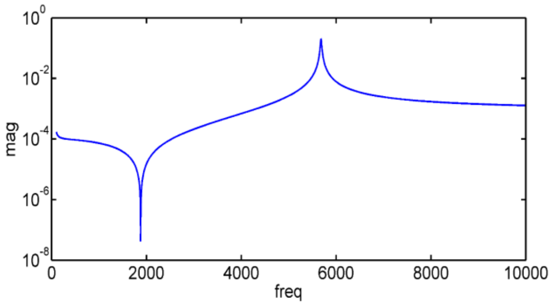
(b) Phase frequency response.

Fig. 6. CVT frequency response under changes on reactor.

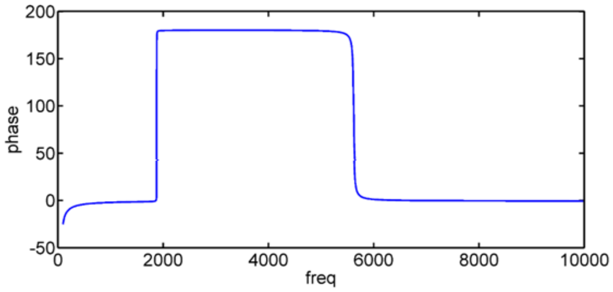
As can be seen, with uncertainty of about 20% in the reactor circuit, low magnitude frequency of CVT has not been changed, but its resonance has reached 1500 Hz.

VT

To examine the effect of VT changes on CVT performance, and to create uncertainty in VT, we set Cp value as 174 pf, Lp as 3.8 H., and Rp as 300Ω. Also Lm value is 8e4 H, and Rm= 6e6 Ω. Figure 7 shows the results.



(a) Magnitude frequency response.



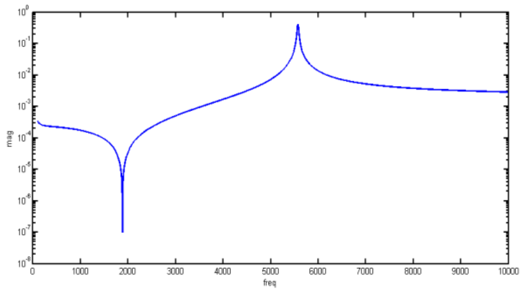
(b) Phase frequency response.

Fig. 7. CVT frequency response under changes on VT.

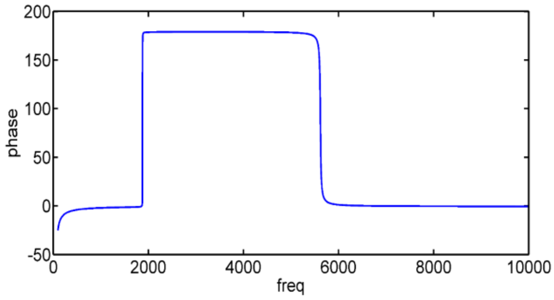
According to Figure 5, not much change is seen in magnitude frequency response, so CVT is not sensitive to changes in the parameter VT.

FSC

Finally we assess the effect of FSC on CVT performance. For this purpose, each of the parameters' value is increased up to 20 percent. Magnitude frequency response of CVT under this condition is shown in Figure 8. As can be seen, magnitude frequency response has been slightly increased which caused bandwidth value to be increased, but the resonance value was unchanged.



(a). Magnitude frequency response.



(b). Phase frequency response.

Fig. 8 (a,b). CVT frequency response under changes on FSC.

CONCLUSION

Advancement of technology and development of increasingly sophisticated consumer loads on the network, have caused power quality disturbances in power system network. To solve this, CVT circuits by measuring the error of the network can be used as an auxiliary tool to identify and isolate the error, and help the relay. Unfortunately, this circuit has many problems at high frequencies. In this study we tried to analyze the frequency response of CVT circuit, and examine the uncertainty of each circuit block in frequency analysis, and thereby investigate CVT sensitivity to changes in its parameters. Results showed that when we changed the value of input capacitors up to 20% , the low frequency response had more slop which reduced the value of bandwidth, and but had no effect on resonance frequency response. Also when we changed the value of reactor, resonance response we changed but low frequency response remained unchanged so the response speed is not changed. Moreover, our findings showed that the CVT is robust to changes in the VT, and its low frequency response was slightly changed under change son FSC. In total we can conclude that CVT is sensitive only to changes of capacitors in low frequency response.

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