Factors Influencing The Frequency Response Of Capacitive Voltage Transformer

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ABSTRACT: Instrument transformers are the integral components of power system protection and metering. The objective of instrument transformers is to provide scaled down replicas of high voltages and currents of the power system. In case of high voltage transmission network (≥132KV), capacitive voltage transformers are widely used as an alternative to electromagnetic voltage transformers due to their techno economic advantages. They transform higher voltages to lower values which are easily measurable and can be directly used for metering, protection and control applications. During the system transient conditions, there is a deviation in the scaled down secondary voltage signal from the actual signal which comprises of wide range of frequencies, due to energy storing elements of capacitive voltage transformer. There are several practices in the industry to mitigate the deviation in the secondary voltage signal of capacitive voltage transformer. For satisfactory operation of capacitive voltage transformer, better frequency response is desirable. The simulation study to determine the effect of various factors influencing the frequency response of capacitive voltage transformer are presented in this paper.

KEYWORDS:- Frequency response, capacitive voltage transformer, magnitude response, phase response.

I.INTRODUCTION

In case of high voltage systems, the cost, design and manufacturing complexity of the conventional inductive voltage transformer is high due to more insulation requirement. Capacitive Voltage Transformers (CVTs) are extensively used to convert the line voltages of transmission and sub-transmission networks to low voltages which can be directly used as input to protection, measurement and control equipments in the system. The CVTs also meet the basic requirment of instrument transformers by providing electrical isolation and protection to the low voltage substation equipment from the high voltage lines[1,2,3]. The coupling capacitors of CVT can be used in Power Line Carrier(PLC) communication which is an uniuqe feature.

The secondary voltage of a CVT mirrors the scaled down primary voltage with predefined ratio during the steady state. The output signal of the CVTis no longer a replica of the primary voltage during the system transient conditions due to the presence of energy storage elements in the CVT. The distortion in the output singal of the CVT under system transient condition consists of various frequency components which last for short duration. This paper presents a review of the CVT frequency response with parametric varaition and explains the effect of various design parameters on the inaccuracies at non fundamental frequencies.

II.CAPACITIVE VOLTAGE TRANSFORMER MODEL

The main components of CVT (as shown in Fig. 1.) are
    i.   stack capacitance which functions as a voltage divider to scale down the line voltage to an intermediate voltage
    ii.   tuning (compensating) reactor to compensate the reactance of the stack capacitance to avoid phase shift between the primary and secondary voltages at system operating frequency
    iii.   step-down transformer(SDT) to further reduce the intermediate voltage to lower level which is fed to the relays and other equipment and
    iv.   ferroresonance suppression circuit to mitigate the ferroresonance oscillations [4,5,6,7].

Fig.1.Basic CVT model

FSC: Ferroresonance Supression Circuit
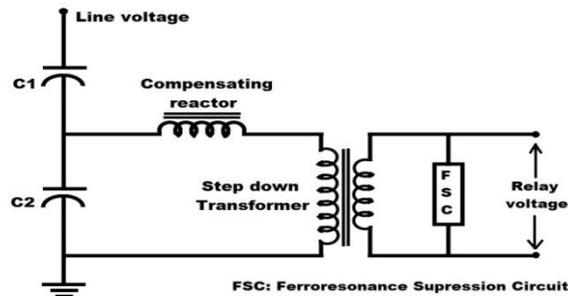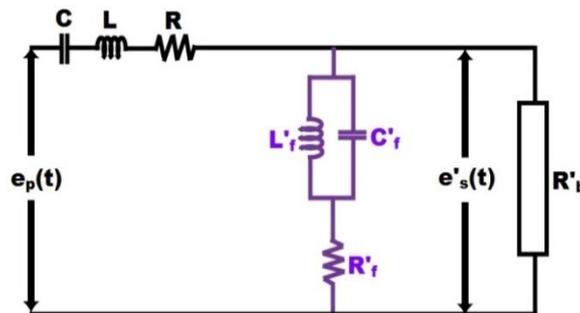

Fig.2. Equivalent circuit of CVT

The equivalent circuit of CVT is shown in Fig. 2., in which all the components are reflected to the primary side of the step-down transformer. Where $e'_s(t) = ne_s(t)$; $R'_b = n^2R_b$; $C'_f = C_f/n^2$; $R'_f = n^2R_f$; $L'_f = n^2L_f$; n: primary to secondary turns ratio of SDT, R, L and C are the corresponding resistance, inductance of the tuning reactor and capacitance of the voltage divider respectively. R'_f, L'_f and C'_f, are the resistance, inductance and capacitance of ferroresonance suppression cirucit referred to the primary. R'_b is the burden referred to the primary and $e'_s(t)$ is the secondary terminal voltage referred to the primary. L_f and C_f will act as parallel resonance circuit [5,6].

The following are the parameters of the CVT considered in this paper.

Table 1 CVT Parameters

C	80nF
L	126.65H
L'_f	4562.5 H
C'_f	2.22 nF
R'_f	62499.99 Ω
R'_b	83333.33 Ω
Burden	100VA(Rb= 83333.33Ω)
Turns Ratio	200:1

III. CVT FREQUENCY RESPONSE

The frequency response of CVT is represented by its gain (in decibels or dB) and phase angle (in radians or degrees) plotted against frequency (in radians/sec or Hertz). These plots are known as the magnitude or amplitude response and the phase angle response respectively. In general, a magnitude gain of unity (1.0) and phase angle shift of zero (0°) degrees for the wide range of frequencies is an ideal frequency response. For CVT, it is difficult to obtain the ideal frequency response.

The gain curve is obtained by plotting the gain values at different frequencies according to the relationship: *gain dB* = 20*log10(*gain*), the unity *gain* (1.0) of ideal response is equivalent to zero gain in dB as 20*log10(*1*)= 0. The magnitude response of the CVT varies with the frequency, i.e. the gain is not constant at all frequencies. The gain curve is flat and represents the unity gain at normal operating frequency. Hence, the performance is good under the steady state condition. However, the response of CVT is deviating from unity gain for other frequencies. Therefore, the output signal is not an exact replica of the input signal for other frequencies. In this paper, to care of switching transients occuring in the system, the frequency response of CVT is considered up to 10kHz.

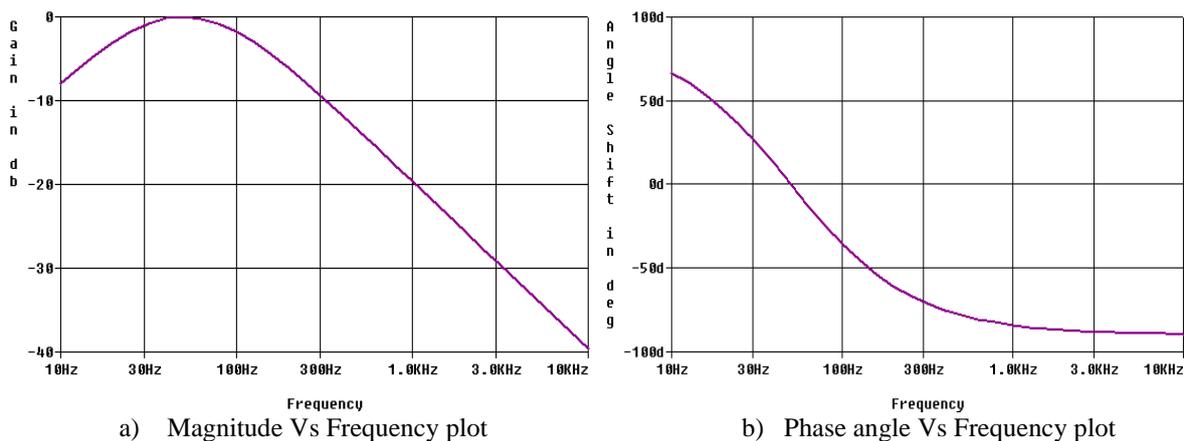| a)   Magnitude Vs Frequency plot | b)   Phase angle Vs Frequency plot |

Fig.3. Typical CVT frequency response

The typical magnitude response of the CVT is shown in Fig. 3(a). At normal operating frequency, the gain curve is flat and unity i.e, the output signal is same as the scaled down input signal. For the sub synchronuos frequencies, the gain is less than unity i.e., the output signal is less than the input signal in terms of magnitude. There is attenuation in the output signal for DC and sub synchronous components of the signal. For the higher order frequencies the attenuation is more.

The phase response of the CVT is shown in Fig. 3(b). The phase response of the CVT varies with the frequency. For the rated frequency there is no phase difference between the input and output signal i.e., zero phase shift(0°). In case of sub synchronuos frequencies, the output signal leads the input signal in phase. In case of higher order frequencies, the output signal lags the input signal. The phase curve is almost linear till 300Hz and it remains almost constant for frequencies above 300 Hz.

IV. FACTORS INFLUENCING THE CVT FREQUENCY RESPONSE

There are three major factors that influence the CVT frequency response [4,5]:
  i.   Ferroresonance Suppression Circuit (FSC)
  ii.   CVT Design parameters
  iii. Burden.

A) Ferroresonance Suppression Circuit

The FSC is one of the major components which affects the frequency response of CVT. There are two types (active FSC and passive FSC) of FSC designs widely used [1, 6]. The active type of FSC comprises of inductance, capacitance and loading resistor. This forms an LC parallel circuit in series with resistor tuned to fundamental frequencies at which it offers very high impedance. The permanent connection of the active type FSC gives undesirable frequency response for other system harmonic frequencies. The passive FSC consists of saturable inductor (150% of normal voltage) and loading resistor which remains inactive, i.e. "passive", for all conditions other than the ferroresonance. Therefore, the frequency response of passive FSC is better than active FSC.

The resistance value of the ferroresonance suppression circuit is another factor that influences the frequency response of CVT. Generally, the value of ferroresonance suppression resistance (R_f) is less than the burden. Hence, it will have loading effect on the CVT. The active FSC is considered for studying the effect of R_f on the CVT frequency response. The Fig. 4(a). shows the magnitude response of the CVT with different ferroresonance suppression resistances.The lower value of R_f results in more attenuation of the output signal and the magnitude curve improves with the increase in the R_f value, i.e., the loss of signal is reduced with higher value of R_f.

The output singnal leads the input signal for the sub synchronous frequencies and it lags the input signal for higher order frequencies as shown in Fig. 4(b). The phase response of CVT is comparitively better with increase in R_f value for non fundamental frequencies. It is observed that the magnitude and phase responses of the CVT improves with increase in the value of the ferroresonance suppression resistance. However, the change in the phase response is minimal with the change in R_f value.
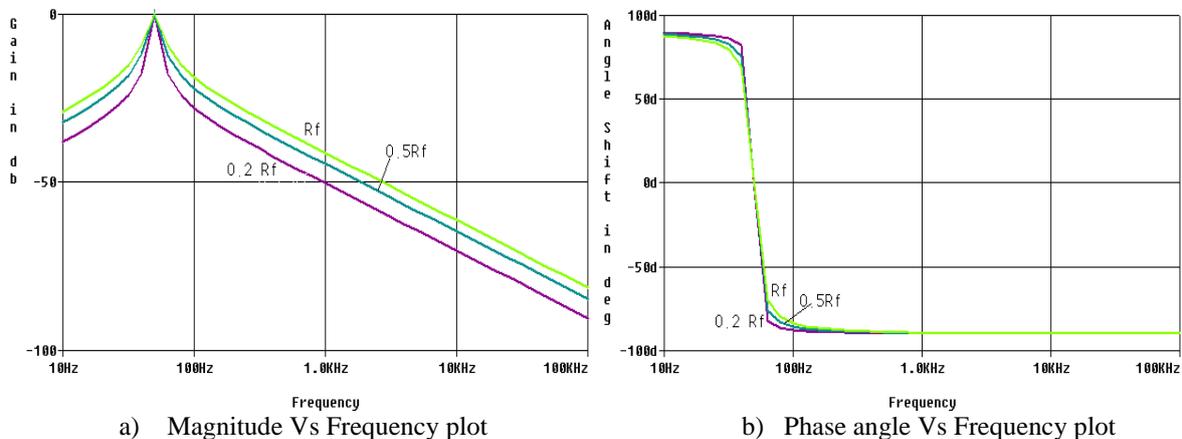

a) Magnitude Vs Frequency plot   b) Phase angle Vs Frequency plot

Fig.4. CVT frequency response with varaition of Ferroresonance suppression resistance

B) CVT Design parameters

The various design parameters of CVT that have influence on its frequency response are:

A. *Ratio of Step Down Transformer*

The increase in the turns ratio of the step down transformer will result in higher value of secondary current for a given burden impedance and increase in the loading of step down transformer[4]. Therefore, for a given burden, the increase in the turns ratio results in better magnitude response.

B. Stack capacitance

The frequency response with the variation of the value of capacitance is shown in Fig. 5. For sub synchronous frequencies, the magnitude response is better with increase in the value of capacitance as shown in Fig. 5(a). The increase in the capacitance value gives better phase response for sub synchronous frequencies as shown in Fig. 5(b). It is observed that there is no change in the magnitude and phase response with the variation of capacitance for the higher order frequencies.
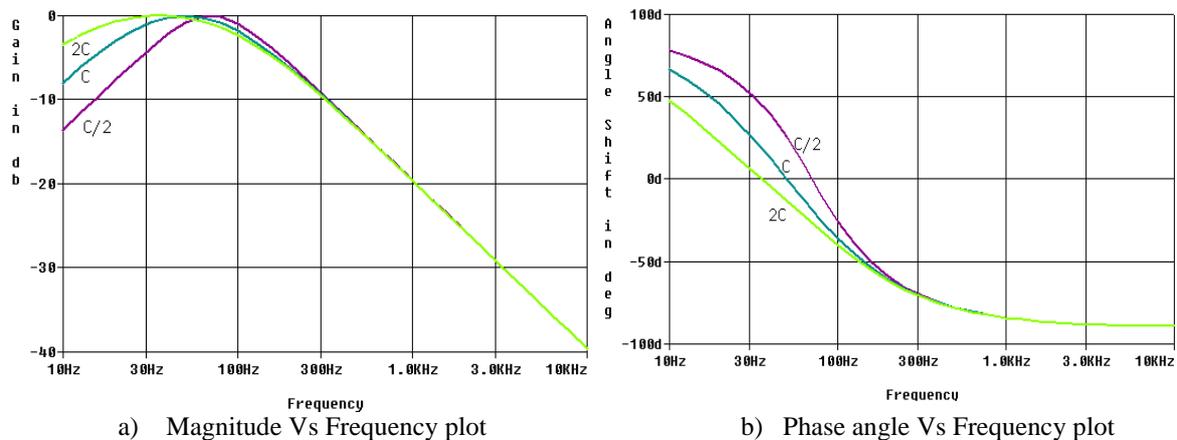

| a) Magnitude Vs Frequency plot | b) Phase angle Vs Frequency plot |

Fig.5. CVT frequency response with varaiton of capacitance

C) BURDEN

The burden which is generally connected external to the CVT is also plays a significant role in determining its frequency response [1,6,8]. The effect of composition (power factor) and magnitude of the burden are considered for study.

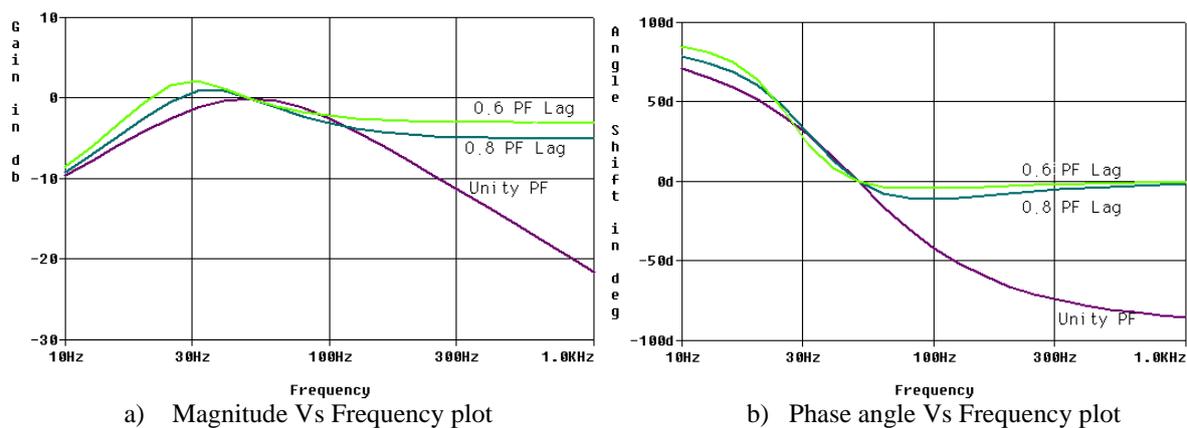| a) Magnitude Vs Frequency plot | b) Phase angle Vs Frequency plot |

Fig.6. CVT frequency response with variation of burden power factor

The effect of the burden power factor on frequency response of the CVT is shown in Fig. 6. Generally, the unity power factor burdens or 0.8 lagging power factor burdens are used in the field. The 0.6 lagging power factor burden is considered for illustrative purpose only. The magnitude response is better in case of burden with lower power factor as shown in Fig.6.(a). The phase response improves with the increase in burden power factor for sub synchronous

frequencies but the phase response worsens with increase in burden power factor for higher order frequencies as shown in Fig.6(b).

In case of 0.8 lagging power factor burden for certain range of sub synchronous frequencies, the gain curve crosses the zero dB point i.e. the gain is more than unity. The gain curve is becoming flat for frequencies more than 50Hz. In case of unity power factor burden, the gain curve is flat and unity for the normal operating frequency and the attenuation is more for higher frequencies compared to other power factor burdens.

In case of unity power factor burden there is comparitively lower phase shift for sub synchrnous frequencies but the phase shift is comparitively more for higher order frequencies. For 0.8 lagging pf burden, there is comparatively more phase shift observed for sub synchronous frequencies but the phase shift is comparitively lesser and remains almost constant for higher frequencies.

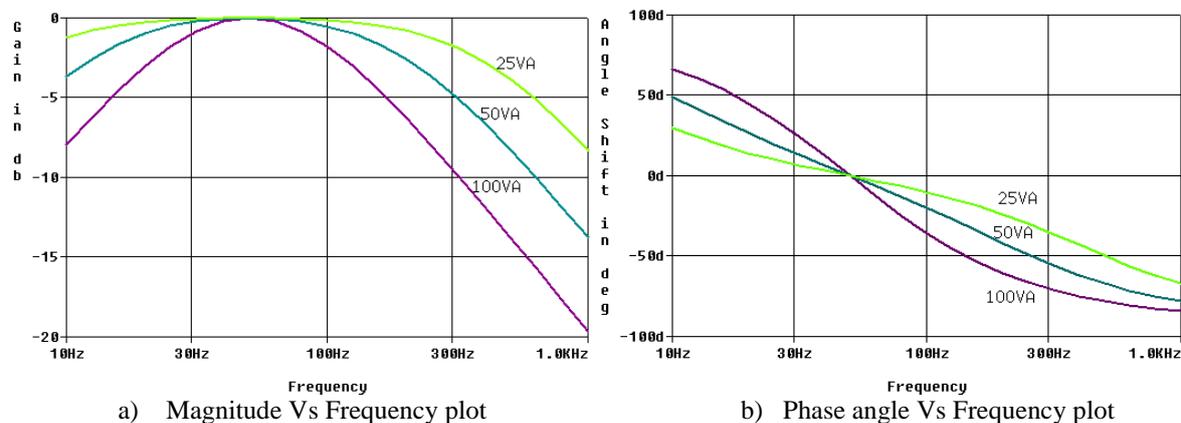a)   Magnitude Vs Frequency plot   b)   Phase angle Vs Frequency plot

Fig.7. CVT frequency response with variation of burden magnitude

The effect of burden magnitude (VA with unity power factor) on frequency response of the CVT is shown in Fig. 7. The Fig.7(a) infers that the magnitude response of the CVT is becoming flat for wide frequency band near the rated frequency by decrease in the burden VA. The Fig. 7(b) infers that the shift in the phase angle is decreasing and becoming flat near the rated frequency by decrease in the burden VA. The magnitude and phase responses of the CVT are improving with decrease in the VA of the burden as shown in Fig.7(a) and Fig. 7(b).

V.CONCLUSION

This paper demonstates the detailed response of the CVT in frequency domian and the effect of various factors influencing its frequency response. The factors which influence the CVT frequency response are type of ferroresonance suppression circuit and its damping resistance value, transformation ratio of SDT, value of stack capacitance and the composition and magnitude of burden. From the simulation study in this paper, we can conclude that the passive FSC with high value of ferroresonance suppression resistance, high SDT transformation ratio and stack capacitance, lower burden VA can aid in the better frequecny response of CVT. The 0.8 lagging power factor burden gives better frequency response for higher order frequencies than unity power factor burden.

VI. ACKNOWLEDGEMENTS

REFERENCES

[1] Dharmesh Yelamanchi, Jawahar Annabattula and T.S.Sirish, "Analysis of Transient Performance of Capacitive Voltage Transformer", Proceedings of National High Voltage Engineering Conference-2014,CPRI,Hyderabad, March,2014.

[2]"Transient Response of Coupling Capacitor Voltage Transformers IEEE Committee Report", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-100, No. 12, December 1981, pp. 4811-4814.

[3] Manual of Capacitor Voltage Transformer, Trench Limited, Instrument Transformer Division, Ontario, Canada, 2004.

[4] Sweetana, A., "Transient Response Characteristics of Capacitive Potential Devices", *IEEE Transactions on Power Apparatus and Systems*, Vol. PAS-90,September/October 1971, pp. 1989-2001.

[5] Kezunovic. M., Fromen. C.W. and Nilsson. S.L., "Digital Models of Coupling Capacitor Voltage Transformers for Protective Relay Transient Studies", IEEE Transactions on Power Delivery, Vol. 7, No. 4, Oct 1992, pp. 1927-1935.

[6] Kojovic. LJ., Kezunovic. M. and Fromen. C.W., "A New Method for the CCVT Performance Analysis Using Field Measurements, Signal Processing and EMTP Modeling", IEEE Transactions on Power Delivery, Vol. 9, No. 4, Oct 1994, pp.1907-1915.

[7] Lucas. J.R., McLaren. P.G., Keerthipala. W.W.L. and Jayasinghe. R.P., "Improved Simulation Models for Current and Voltage Transformers in Relay Studies", IEEE Transactions on Power Delivery, Vol. 7, No. 1, January 1992, pp.152-159.

[8] Kasztenny. B., Sharples. D., Asaro. V. and Pozzuoli. M., "Distance Relays and Capacitive Voltage Transformers – Balancing Speed and Transient Overreach", General Electric Company, GER-3986, 2000.

BIOGRAPHIES

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