Module 2 : Current and Voltage Transformers

Lecture 8 : Introduction to VT

Objectives

In this lecture we will learn the following:

- Derive the equivalent circuit of a CCVT.
- Application of CCVT in power line communication.
- Transient response of a CCVT.
- Classification of CCVT.
- Design of CCVT.

8.1 Voltage Transformers

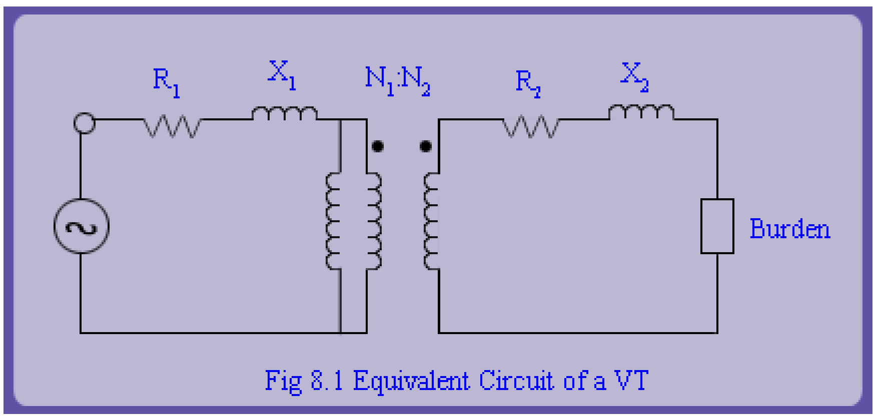

Fig 8.1 Equivalent Circuit of a VT

Many relaying applications like distance relays, directional overcurrent relays require measurement of voltages at a bus. This task is done by a voltage transformer (VT).
The principle of a voltage transformer is identical to the conventional transformer. Hence, its equivalent circuit can be represented as shown in fig 8.1.

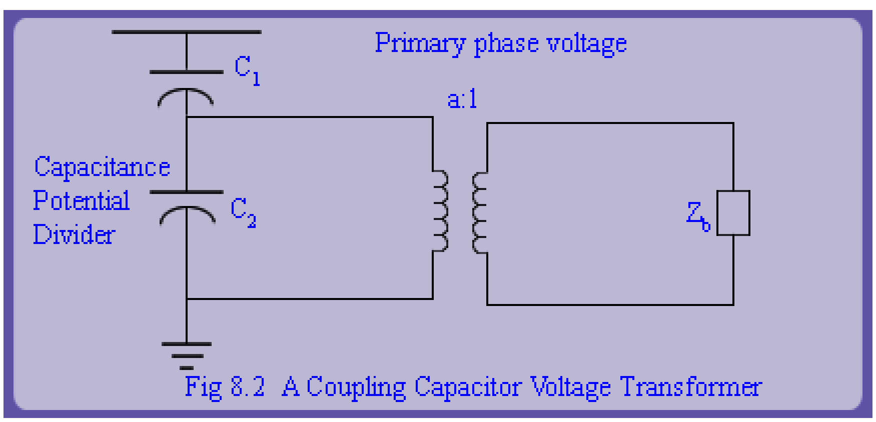

Fig 8.2 A Coupling Capacitor Voltage Transformer

Typically, the secondary voltage of the VT is standardized to 110 V (ac). Hence, as the primary voltage increases, the turns ratio $N_1:N_2$ increases and transformer becomes bulky.

To cut down the VT size and cost, a capacitance potential divider is used (fig 8.2). Thus, a reduced voltage is fed to primary of the transformer. This reduces the size of VT. This leads to development of coupling capacitor voltage transformers (CCVT).

8.1 Voltage Transformers

8.1.1 Role of Tuning Reactor

Assuming, the transformer to be ideal, the Thevenin's equivalent circuit of CCVT is shown in fig 8.3.

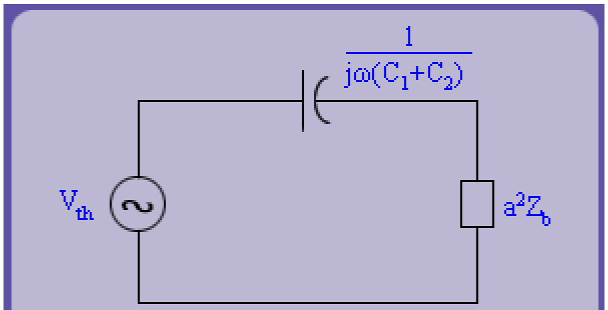

Fig 8.3 Thevenin Equivalent of CCVT as seen from Primary side of VT

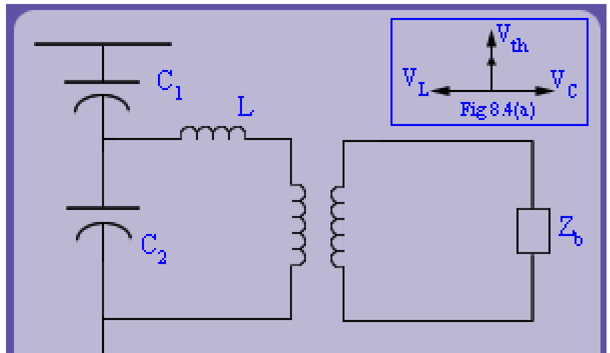

Fig 8.4 Role of Tuning Inductor

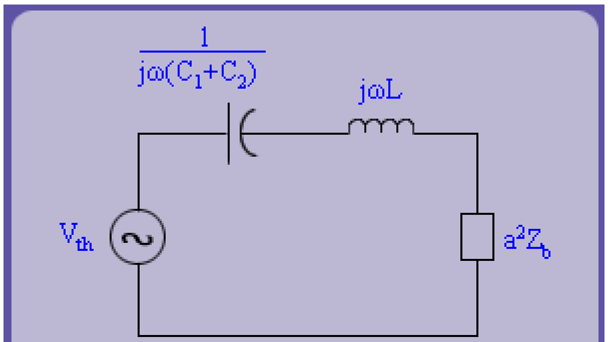

Fig 8.5 Final Equivalent Circuit of CCVT

It is now obvious that Z_{th} due to the capacitance divider, affects the voltage received by the relay. To achieve high level of accuracy, it is therefore necessary to compensate for this voltage drop by connecting a tuning inductor. The tuning inductor's value is so chosen that it compensates for the 'net C' at power frequency (50Hz in India). The phasor diagram across resistive load, is as shown in fig 8.4(a). (See fig 8.4).

From the corresponding equivalent circuit, it is apparent that, if $\omega L = \dfrac{1}{\omega(C_1 + C_2)}$, then voltage drop across C is neutralized and the relay sees the actual voltage to be measured. (See fig 8.5).

8.2 CCVT in Power Line Communication

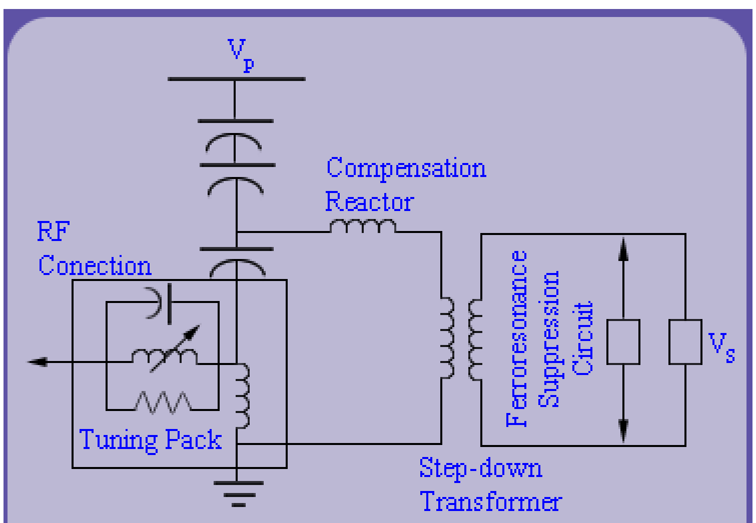

Fig 8.6 Schematic Diagram of a CCVT with RF Connection

The capacitance potential divider also serves the dual purpose of providing a shunt path to high frequency signal used in power line carrier communication. Normally, CCVT is used in HV/EHV systems where carrier line communication is used. High frequency i.e. Radio Frequency (RF) signals (50 - 400 kHz) can be coupled to power line for communication. At high frequency, the capacitive shunt impedance is very small and hence these signals can be tapped by the potential divider. To block the path to ground for the RF signal, a small drainage reactor is connected in series with the capacitance divider. At power frequencies, it has a very small impedance. Thus, the role of capacitance potential divider at power frequency is not compromised. On the other hand, at RF, the impedance of drainage reactor is large and it blocks the RF signal.

Also, compensating reactor and transformer leakage reactance by their inductive nature, block the path of RF signal. This signal is then tapped by a tuning pack which provides low impedance to the RF signal.

8.2.1 Ferro Resonance Problem in CCVT

The iron cores of the reactor and transformer will not only introduce copper and core losses but it can also produce ferroresonance caused by the nonlinearity of the iron cores. Hence a ferroresonance suppression circuit is also included in the secondary of the transformer. The dangerous overvoltages caused by ferroresonance are eliminated by this circuit. Unfortunately, it can aggravate CCVT transients.

8.3 Transient Response of CCVT

As can be seen in the fig 8.5, CCVT equivalent circuit is a R-L-C circuit. If transformer is considered ideal, it can be described by integro differential equation of the type,

$v(t) = Ri + \frac{1}{C_{eq}}\int_{-\infty}^{t} i dt + L\frac{di}{dt}$. The corresponding differential equation is given by

$\frac{dv}{dt} = R\frac{di}{dt} + \frac{1}{C_{eq}}i + L\frac{d^2i}{dt^2}$.

For a solid 3 - phase fault say near the CCVT bus at t=t_0. v(t) = 0 for $t \geq t_0$. Thus, during fault the governing differential equation is given by $\frac{d^2i}{dt^2} + \frac{R}{L}\frac{di}{dt} + \frac{1}{LC_{eq}}i = 0$.

This equation is expressed in standard form as follows: $\frac{d^2i}{dt^2} + 2\zeta\omega_n + \omega_n^2 i = 0$ where ω_n is natural frequency in radians per second and ζ is the damping constant. Thus, $\omega_n = \frac{1}{LC_{eq}}$ and $2\zeta\omega_n = \frac{R}{L}$.

Because of the property of tuning reactor, $\omega_n = \frac{1}{\sqrt{LC_{eq}}} = 2\pi \times f_0$ f_0 = 50 or 60 Hz. We know from the background in network analysis that response of such a circuit to step excitation, depends upon ζ.

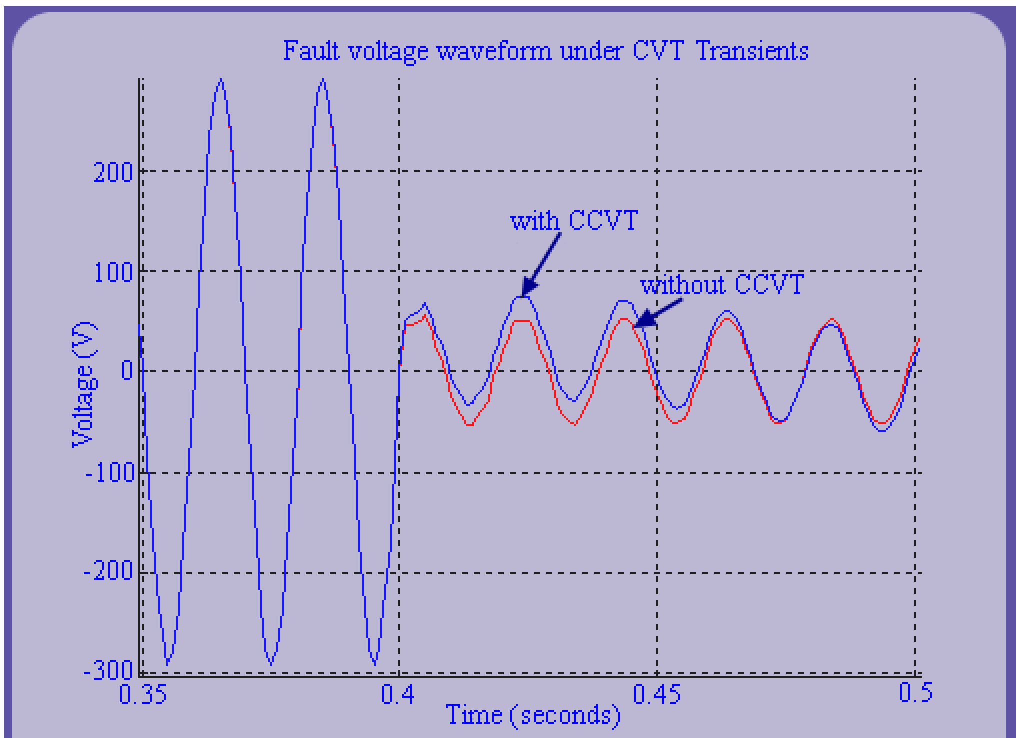

Fig 8.7 Typical CCVT Subsistence Transient

Because R is quite small, $\zeta < 1$. If $\zeta < 1$; then we expect underdamped response. The response depends upon the damping ζ and ω_n and point on the voltage waveform where the fault strikes. Such transients are known as subsistence transients. Fig 8.7 shows subsistence transients of CCVT. It can be seen that subsistence transients can reduce the accuracy of distance relays.

8.4 Classification of CCVTs

CCVTs can be classified into following two types:

- Class 1

- Class 2

Table 8.1 shows the maximum limit for the ratio and phase angle errors. It can be seen that errors of Class 2 type are double than that of class 1 type.

Table 8.1 : Limits for Ratio and Phase Angle Errors		
VT Class	Maximum ratio error	Maximum phase angle error
Class 1	$\pm 1\%$	$\pm 40\,\mathrm{min}$
Class 2	$\pm 2\%$	$\pm 80\,\mathrm{min}$

Review Questions

1. Derive the equivalent circuit of a CCVT.

2. What is the function of a tuning inductor?

3. How can CCVT be used in Pilot wire communication?

4. What is the function of ferroresonance suppression circuit?

Recap

In this lecture we have learnt the following:

- Role of VT.

- The equivalent circuit of a CCVT.

- Use of CCVT in Pilot wire communication.

- Ferroresonance problem in CCVTs.