36

Voltage Transformers and their Applications

Introduction — Theory of voltage transformers — Specification of VT's — Terms and definitions — Accuracy class of VT's — Burdens on VT's — Connections of VT — Residually connected VT — Electromagnetic voltage transformers — Capacitor voltage transformer — CVT as Coupling capacitor for carrier current applications — Choice of capacitance for CVT — Transient behaviour of CVT — Ferro resonant (FR) in CVT — Testing of voltage transformer — Summary.

36.1. INTRODUCTION

Voltage transformers (potential transformers) are used for measurement and protection. Accordingly, they are either measuring type or protective type voltage transformers. They may be either single phase or three phase units. Voltage transformers are necessary for voltage, directional, distance protection. The primary of voltage transformer is connected to power circuit between phase and ground. The voltampere rating of voltage transformers is smaller as compared with that of power transformer.

There are two types of construction :

— electromagnetic potential transformer, in which primary and secondary are wound on magnetic core like in usual transformer.

— capacitor potential transformer, in which the primary voltage is applied to a series capacitor group. The voltage across one of the capacitors is taken to auxiliary voltage transformer. The secondary of auxiliary voltage transformer is taken for measurement or protection.

— CCVT combines function of coupling capacitor and VT.

36.2. THEORY OF VOLTAGE TRANSFORMERS

Symbols : V_p = primary applied voltage

V_s = secondary output voltage

K_n = nominal ratio $\dfrac{\text{primary turns}}{\text{secondary turns}}$

K_v = actual voltage ratio, $\dfrac{\text{primary volts}}{\text{secondary volts}}$

I_p = primary current

I_s = secondary current

θ = phase angle error of VT, angle between V_p and reversed V_s

I_o = exciting current (no load primary current)

I_m = magnetizing component of I_0 in phase with flux ϕ, which sets up flux ϕ

I_e = component of I_0 in quadrature witb ϕ which caters for iron loss, eddy current loss in core.

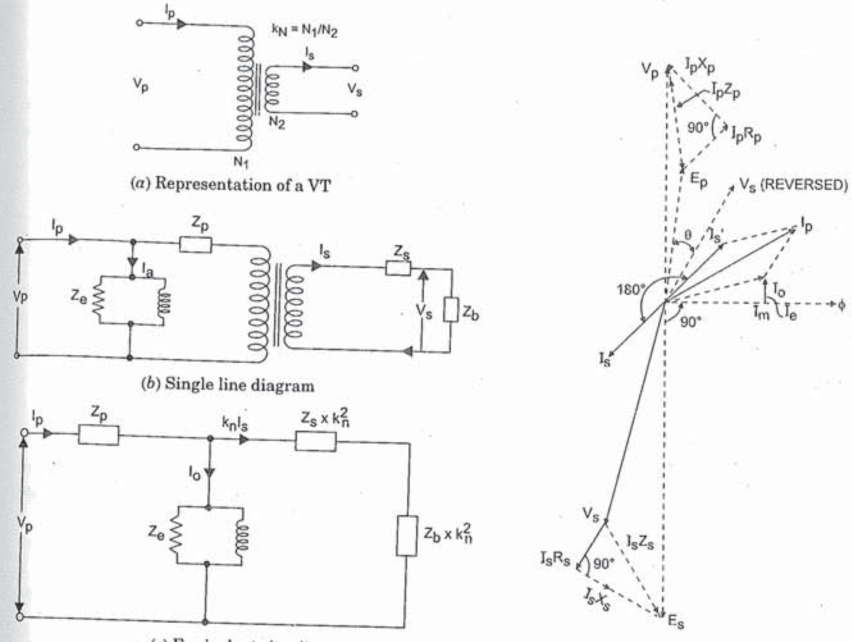
Z_p = primary impedance

Z_s = secondary impedance

Z_b = impedance of burden

Z_s = impedance of excitation circuit.

Ref. Fig. 36.1 (*a*) represents a single line reactance diagram of the VT. The secondary quantities can be referred to Primary by multiplying impedances by K_n^2 and voltages by K_n and equivalent diagram can be drawn [Fig. 36.1 (*c*)]. Fig. 36.1 (*d*) gives the vector relations.



(*a*) Representation of a VT

(*b*) Single line diagram

(c) Equivalent circuit

(*d*)

Fig. 36.1. Development of equivalent diagram of a VT.

Primary current I_p is a vector sum of exciting current I_o and equivalent secondary current referred to primary (I_s'). The primary current sets-up flux ϕ. The induced secondary voltage E_s opposes the induced primary voltage E_p.

The secondary voltage is given by :

$$V_s = E_s - I_s\,(Z_s + Z_b)$$

where $Z_s + Z_b$ is impedance on secondary side.

Primary voltage is given by

$$V_P = E_p + I_p\,(Z_p).$$

In case of ideal VT

$$I_o = 0$$

$$I_P Z_P = 0$$

$$\frac{V_P}{V_r} = K_n$$

V_P and V_s are 180° apart.

In case of actual VT

The voltage drop in primary impedance and secondary voltage drop introduce errors in ratio.

Hence $V_p \neq K_n V_s$

This error is expressed as a ratio error as follows :

$$\% \text{ Ratio error} = \frac{100\,(K_n V_s - V_p)}{V_p}$$

The secondary voltage V_s, when reversed has a phase angle θ with respect to primary voltage. This is mainly due to exciting current I_e of the VT. This angle is called phase angle error of the VT.

36.3. SPECIFICATIONS FOR VOLTAGE TRANSFORMERS

The following aspects should be determined while selecting the current transformer :

1. Rated primary voltage. 2. Rated secondary voltage.
3. Rated burden. 4. Supply frequency.
5. Number of phases. 6. Class of accuracy.
7. *Insulation level.* Power frequency and impulse voltage withstand.
8. Limits of dimensions, type of construction etc.

36.4. TERMS AND DEFINITIONS

(*a*) **Rated Primary voltage.** The voltage primary voltage marked on the rating plate of the voltage transformer. The method of connection of primary winding to system and system voltage should be considered while selecting the VT of correct primary voltage rating.

There are several values of standard primary voltages. These have a reference to standard system voltages.

(*b*) **Rated Transformation Ratio.** The ratio of rated primary voltage to rated secondary voltage.

(*c*) **Rated Secondary Voltage.** *e.g.* $100/\sqrt{3} = 63.5$ V or $110/\sqrt{3} = 190$ V. It is the value of secondary voltage marked on the rating plate.

(*d*) **Residual voltage.** Vector sum of three line to earth voltages, *i.e.*

$$V_{RD} = V_{RN} + V_{YN} + V_{ZN}$$

(*e*) **Residual VT.** A three phase VT or a group of 3 single phase residually connected VT's in which residual voltage appears across secondary terminals when three-phase voltages are applied to primary windings.

(*f*) **Ratio Error.** Percentage ratio error sometimes called percentage voltage error is given in (*h*) below.

(*g*) **Voltage factor.** The upper limit of operating voltage (primary) is given by

Rated primary voltage × Voltage factor, is specified for certain time. *e.g.*, 1.1 continuous, 1.5 for 60 sec., 1.9 for 30 sec.

(*h*) $$\%\text{R.E.} = \frac{100\,(K_n V_s - V_p)}{V_n}$$

where K_n = Nominal ratio

V_s = Secondary voltage

V_P = Primary voltage.

R.E. = Ratio error.

As alternate method describe the ratio is to specify the voltage ratio factor (V.R.F.)

$$\text{V.R.F.} = \frac{K_v}{K_n}$$

$$K_n = \text{Nominal ratio } \frac{V_n}{V_s}$$

$$K_v = \text{Voltage ratio } \frac{V_p}{V_s} \text{ actual.}$$

$$\text{V.R.F.} \cong 1 - \frac{\%\text{R.E.}}{100}.$$

36.5. ACCURACY CLASSES AND USES [B.S. 3914 (1965)]

Standard specify the following limits of errors for voltage transformers and protection for measurement.

Table 36.3. Limits and Phase Errors for Voltage Transformers

Accuracy Classes	*0.9 to 1.1 times rated primary voltage 0.25 to 1.0 times rated output at 0.8 lag p.f.*		*Application*
	Voltage error % (per cent) (+ or −)	*Phase error minutes (minutes) (+ or −)*	
0.1	0.1	5	Measurement
0.2	0.2	10	
0.5	0.5	20	
1.00	1.0	40	
3.0	3.00	120	Protection
5.0	5.00	300	
10.0	10.00	—	Residual VT only

Applications of VT's Depending Upon Accuracy Class

Accuracy Classes	*Application*
0.1	Precision testing in standard laboratories
0.2	Sub-standard instruments in laboratories.
0.5—1	Industrial metering
3.00	Voltmeters
5.00	Under voltage relays, overvoltage relays, other relay where phase angle is not important
10.00	Directional relays where phase angle is important.

Note. (1) Class 3.0 and 5.0 VT's are recommended for protection.
2. Class 5.00 and 10.00 is recommended only in Residual VT's.

36.6. BURDENS ON VOLTAGE TRANSFORMER

Burdens are specified in voltamperes at a rated secondary voltage at a particular power factor. Let rated secondary voltage be V_s. The ohmic impedance of burden be Z_b. Volt-ampere burden = P.

$$Z_b = \frac{V_s^2}{P} \text{ ohms.}$$

Let burden power factor be cos ϕ

$$R_b = Z_b \cos\phi$$

$$X_b = Z_b \sin\phi$$

$$Z_b = \sqrt{R_b^2\, X_b^2}.$$

The total burden on a VT should be less than the rated burden of VT.

Table 36.4 gives rated burdens of bushing type potential transformer device. The capacitor voltage transformer output is upto about 200 VA. While that of wounded type is upto about 500 VA. The standard values being 10, 25, 50, 75, 100, 150, 200, 500 VA.

Example 36.3. *A voltage transformer with rated secondary voltage of 110 V has nominal output of 1 A, lead loop resistance is 0.1 ohm. Calculate the voltampere output of the voltage transformer when the relay takes 0.1 ampere at 110 volts.*

Solution. Total voltamperes = Voltamperes for relay + Voltamperes or leads

$$= 110 \times 0.1 + (0.1)^2 \times 0.1 = 11 \text{ VA.} \quad \textbf{Ans.}$$

Table 36.4. Reference Voltage of Burdens on VT's

Rated Voltage KV		*Rated Burden Volt-ampere*
Phase to phase	Phase to ground	
115	66.4	25
138	9.74	35
161	93	45
230	133	80
287	166	100

Table 36.5

Typical Values of Burdens imposed by different measuring instruments and relays on Voltage Transformers

Voltmeter	5 VA
Voltage coil of Wattmeter	5 VA
Voltage coil of kWh meter	7.5 VA
Voltage coil of Synchroscope	15
Under voltage/over voltage Relay	5 VA
Voltage coils of electromagnetic relays	3—10 VA
Static relays	0.02—0.2 VA

The total burden on a VT is vector sum (r and jX) of component burdens on secondary *e.g.*, burden on a VT for under voltage protection would be the sum of burden of relay coil, pilot wires. The VA rating should be such that the total burden is about 10% less than rated burden, for pick-up condition. If the VT is overloaded beyond its rated burden, the error will increase. The burden of a relay varies for various settings. The VA rating of VT should not be far greater than the burden. Because the accuracy of VT at very low burdens (25% rated burden) is not guaranteed.

36.7. CONNECTIONS OF VT'S

There are three types of connections, V-V, Star-Star and Star Open Delta. (Residually Connected) VT.

1. V.V. Connection

This connection is used only for measurement and usually not for protection. Two VT's are used. Primaries are connected V, secondaries also in V. There is no path for zero sequence voltages arising from earth faults.

2. **Star-Star Connections.** (Fig. 36.2)

Either three separate transformers or a single three limb transformer are used. Primaries are connected in star, secondaries also connected in star.

Each primary phase winding is connected phase to earth Voltage of supply circuit is transformed into secondary.

The neutral point of load is connected to neutral point of secondaries. The neutral point of primary is solidly earthed with such connections (Ref. Fig. 36.3).

If primary neutral is not earthed, the zero sequence component of voltages (due to earth fault) cannot flow through primary windings. Hence phase to earth voltages of system which contain zero sequence component do not get truly transformed. Measured voltages are distorted.

Hence the earth fault on the system cannot be sensed on the secondary side of VT.

In voltage restrained overcurrent fault protection (Fig. 36.3), in impedance protection for earth faults, the VT connection should be such that zero sequence component of voltage is reflected on secondary. Hence the neutral of primary should be earthed.

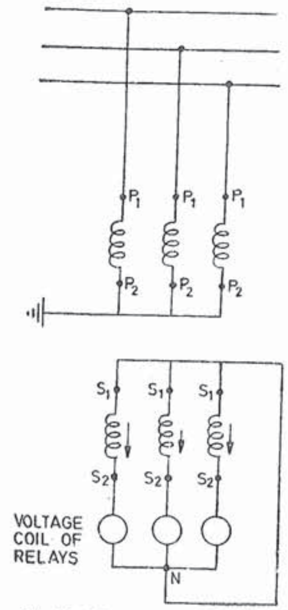


Fig. 36.2. Connection of VT's with star-star connection.

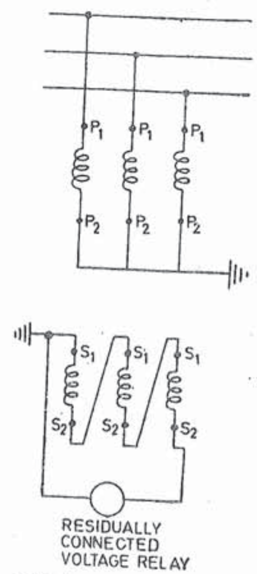


Fig. 36.3. Connection of Residually connected, VT.

When electromagnetic type of VT is used for star-star connections, it should be of 5 limb construction, to provide path for zero sequence component of magnetic flux. The zero sequence component of flux ϕ_0 in three limbs is in one direction. In three limb construction, there is no return path for flux.

In five limbed transformer, the outer two limbs provide a path for zero sequence component of magnetic flux. Thereby the zero sequence voltages are transformed.

36.8. RESIDUALLY CONNECTED VT (ZERO SEQUENCE VOLTAGE FILTER)

The primary windings are connected in star and star point is earthed. The secondaries are connected in series with the load [Fig. 36.3 (*a*)].

$$V_{SR} + V_{SY} + V_{SB} = 3V_{SO}$$

where, V_{SR}, V_{SY}, V_{SB} = Secondary voltages

V_{SO} = Zero sequence voltage on secondary.

The voltage appearing across broken delta ($3V_{SO}$) is proportional to zero sequence component of voltage on primary.

Under no-earth fault

$$V_{PR} + V_{PY} + V_{PB} = 0$$

$$V_{PO} = 0$$

Hence $$V_{SR} + V_{SY} + V_{SB} = 0$$

$$V_{SO} = 0$$

(Subscript *P* for primary, *S* for secondary, *RYB* for respective phases and *O* for zero sequence).

Hence output of residually connected VT secondaries is zero under earth fault condition.

$$V_{PR} + V_{PY} + V_{PB} = 3V_{PO}$$

Hence, $$V_{SR} + V_{SY} + V_{SB} = 3\,V_{SO}$$

$$3\,V_{SO} = \frac{3V_{PO}}{K_n} = V_r$$

V_r = Residual voltage flowing through the load connected across residually connected VT secondary.

K_n = Voltage ratio.

The residually connected VT, the star point of primary must necessarily be earthed.

Residually connected VT is used for supplying :

1. Voltage coil of voltage restrained overcurrent earth fault protection.
2. Restricted earth fault protection.
3. Directional earth fault protection.
4. Distance earth fault protection.
5. Earth-fault alarm relays.

One point on secondary is necessarily earthed for safety. In case the primary comes in contact with secondary.

The residually connected VT may have three single phase units or one three phase five limbed unit.

Accuracy class of residually connected VT is 5.00 or 10.00.

Types of Construction of VT's

1. Electromagnetic Voltage Transformer, oil filled/epoxy resin encapsulated.
2. Capacitor voltage Transformer. (CVT).

36.9. ELECTROMAGNETIC VOLTAGE TRANSFORMER

Potential transformer is similar to a conventional transformer with additional care taken to minimise errors of transformation, and the power transformed is low. The construction of a PT largely depends on the rated primary voltage. For voltage upto 3.3 kV dry type transformers with varnish impregnated taped windings are quite satisfactory. For higher voltages it is a practice to immerse the core and winding in oil. Recently windings are impregnated and encapsulated in synthetic resins. With this development, dry type PT's are available for voltages higher than 3.3 kV. Cast resin insulated PT's are available for voltages upto 66 kV.

The core of a smaller voltage transformer is usually made up of normal *T*, *U*, *E*, *I*, *L* shaped laminations when hot rolled steel is employed. For smaller PT's shape of Fig. 36.4 is generally used.

For larger single phase units cut *C* core is used of oriented sheet steels.

The electromagnetic VT's are either indoor or outdoor. Porcelain enclosure is necessary for outdoor VT's.

The electromagnetic VT for residual connections should have five limbs.

For voltages above 66 kV, electromagnetic PT's are generally in cascade connections. They employ a number of series connected primary coils on separate cores, with coupling coils to link primary coils so as to keep the effective leakage inductance at a low value. Such an arrangement is conveniently housed in a porcelain enclosure. However, capacitor Type PT is more economical. For high speed distance protection, electromagnetic voltage transformer is preferred.

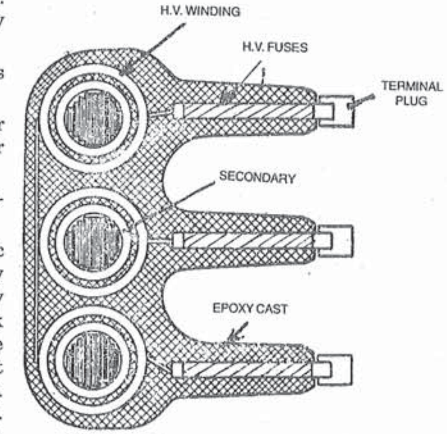


Fig. 36.4. Cross-section of a resin cast VT.

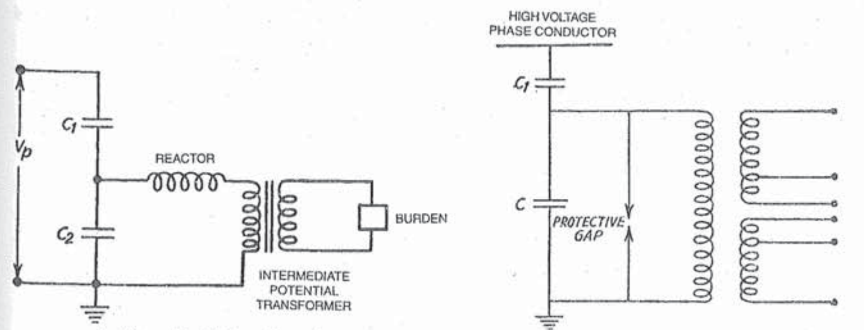
The secondary leads should have low impedance to reduce voltage drop.

36.10. CAPACITOR VOLTAGE TRANSFORMERS (CVT)

Capacitor voltage transformer are used for line voltmeters, synchroscopes, protective relays, tariff meter, etc.

The performance of capacitor voltage transformer is inferior to that of electromagnetic voltage transformer. Its performance is affected by the supply frequency, switching transients, magnitude of connected burden, etc. The capacitor voltage transformer is more economical than an electromagnetic voltage transformer when the nominal system voltage increases above 66 kV.

The carrier current equipment can be connected *via* the capacitor of the Capacitor Voltage Transformers. Thereby there is no need of separate coupling capacitors.



(*a*) Capacitor Voltage Transformer. (*b*) Capacitor voltage transformer—basic diagram.

Fig. 36.5.

Capacitor type VT is used for voltages 66 kV and above. At such voltages cost of electromagnetic type VT's tends to be too high. The capacitors connected in series act like potential dividers provided the current taken by the burden is negligible compared with the current passing through the series connected capacitors. However, the burden current becomes relatively larger and ratio error and also phase error is introduced. Compensation is carried out by 'tuning'. The reactor connected in series with the burden is adjusted to such a value that at supply frequency it resonates with the sum of two capacitors. This eliminates the error. The construction of capacitor type VT depends on the form of capacitor voltage divider. Generally, h.v. capacitors are enclosed in a porcelain housing. A large metal sheet box at the base encloses the tuning coil intermediate transformer.

36.10.1. CVT with Stepped Output

When the same CVT is used for various applications, it is likely to be subjected to a variation of burden. The CVT for such applications should have stepped output range. The number of steps and output range depend upon the choice of user and recommendations of manufacturer. The sum of outputs of the steps should be one of the following values :

10, 25, 50, 75, 100, 150, 200, 500 VA.

36.10.2. Protection of Voltage Transformers

— HRC fuses on primary side for VT's rated upto 11 kV.

— HRC fuses on secondary side for overcurrent protection of electromagnetic unit.

— spark gaps or lightning arresters in parallel with intermediate capacitor for overvoltage protection.

36.11. CVT AS COUPLING CAPACITOR FOR CARRIER CURRENT APPLICATIONS

The carrier current equipment is connected to the power line *via* coupling capacitor. The coupling capacitor Voltage Transformer (CCVT) combines the functions of coupling capacitor and Voltage Transformer. Fig. 36.6.

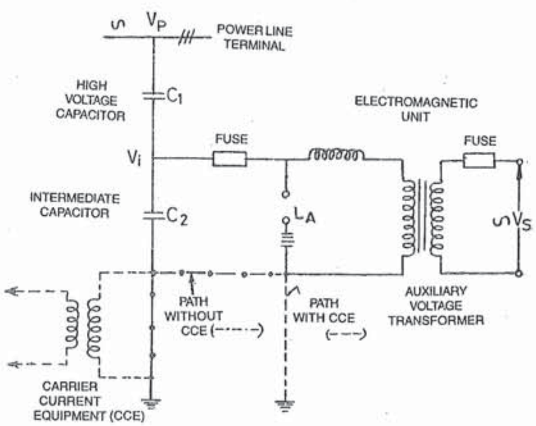


Fig. 36.6. Connection of CVT and carrier current equipment.

36.12. CHOICE OF CAPACITANCE VALUES FOR CVT

The maximum output from a capacitor voltage transformer is governed by the range of frequency over which the accuracy has to be maintained. The change in error with variation of frequency is mainly a change in phase when the burden is of unity power factor. The permissible rated output may be derived from the expression :

$$W = K (C_1 + C_2) V_i^2 \theta_c \quad ...(36.11)$$

where W = output in VA ;

K = constant depending on frequency, losses, etc. ;

C_1 = capacitance of primary voltage capacitor in farads ;

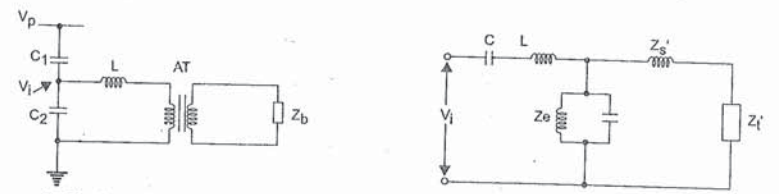
C_2 = capacitance of intermediate voltage capacitor in farad ;

V_i = intermediate (tapping point) voltage in volts ; and

θ_e = phase angle error change in minutes per Hz.

It is apparent from the above expression that, for a given accuracy over a given frequency range, the rated output is proportional to the total capacitance at a fixed tapping point voltage, but the capacitance required may be reduced to the economic limit by a suitable selection of the intermediate voltage. On the other hand, when the capacitance values are fixed by other considerations, for example, carrier current requirements, the rated output may depend entirely on the permissible phase-angle error change (θ_c) per Hz.

Consider the single line diagram of a CVT (Fig. 36.7) and its equivalent circuit as referred to primary voltage V_P [Fig. 36.7(*b*)]. At normal power frequency C and L are in resonance, therefore, offer zero impedance. Therefore, the CVT behaves like conventional VT.



(*a*) Single line diagram of CVT (*b*) Equivalent diagram of (*a*)

Fig. 36.7. Equivalent diagram of CVT.

However, this resonance is at a particular frequency (50 Hz). At other frequencies, I_C and I_L do not get cancelled and the reactive component present introduces phase angle error in measurement. This error depends on the power factor of burden.

The phase angle error changes with frequency. If reactive voltage across C and L is small compared with V_P, the error introduced is small and change in error with frequency is not excessive.

However, choice of frequency depends upon whether the capacitor is used as a coupling capacitor for carrier channel or not.

(*a*) The typical values of C_1 is 2000 pf. It offers 1.5 mega-ohms impedance to 50 Hz and 150 ohms to 500 kHz carrier frequency.

(*b*) The value of C_2 depends upon the required nominal ratio.

$$\frac{V_p}{V_i} = \frac{C_1}{C_2}$$

Suppose V_i is 12 kV and V_P is $132/\sqrt{3} = 75.6$ kV.

$$C_2 = \frac{132}{\sqrt{3}} \times \frac{1}{12} \times 2000 = 1200 \text{ pf.}$$

(*c*) The output is of the order of 150 VA.

(*d*) θ_c has a following range :

50 minutes for 132 kV, CVT
25 minutes for 220 kV, CVT
15 minutes for 400 kV, CVT

From Eq. 36.11 large C_1 and C_2 permit higher rated VA output. To reduce cost, the CVT's are designed for larger regulation (variation in secondary voltage) with variation of burden Z_b. VT is provided with taps which should be selected for required value of burden. Alternatively CVT's can be "Full Range Type" , without taps and suitable for burdens in a range of 25 to 100% of rated output. Such CVT's would require larger C_1 and C_2 and are costly.

(*e*) **Effect of Supply Frequency.** CVT's perform within accuracy limits for frequencies of 77 to 103% of rated frequency for protective VT's and 99 to 101% for measuring VT's.

The variation in the primary side power frequency has significant influence on the accuracy of a CVT. Normally a capacitor voltage transformer is turned to achieve the required accuracy at rated frequency (50 Hz). When the operating frequency deviates beyond the reference range of frequency, the accuracy limits are likely to be exceeded. Coincident influential factors are the power factor and the magnitude connected burden. Where accuracy is important as in tariff metering applications. It is desirable to obtain accuracy curves for the capacitor voltage transformer corresponding to the limiting operating frequencies.

These curves (supplied by manufacture of CVT) give the ratio error and phase angle error for various frequencies. The power factor of burdens is also indicated on the same graph.

36.13. TRANSIENT OF BEHAVIOUR OF CVT

The transient performance of CT's discussed in Sec. 35.16 was related to saturation of core due to d.c. and a.c. components in transient over-currents.

The transient performance of CVT's is influenced by transient over-voltages and resulting distortion in secondary voltage waveform, and duration of overvoltage.

When an impulse wave is applied to primary of CVT, oscillations of various frequencies take place and will continue for a duration which depends upon the resistive damping in the equivalent circuit [Fig. 36.7 (*b*)]. Increased resistance reduces the time constant of transient oscillations. However initial amplitude increases.

For high speed protection, transient oscillations should be minimum. Hence cascade type electromagnetic voltage transformers are preferred. They have a less ratio error even under short-circuit condition.

36.14. FERRO-RESONANCE (FR) IN CVT

(*a*) **Principle.** Ref. Fig. 36.7. The excitation impedance Z_e and equivalent C of voltage divider may form a resonant circuit which may oscillate at a lower frequency than 50 Hz.

If such a circuit is subjected to a impulse voltage due to switching transient voltage oscillations of variable frequency do occur. These can pass through a range of frequencies due to non-linear nature of inductance of auxiliary VT.

If natural frequency of this circuit is somewhat less than 50/3 ; it is possible that the oscillations build-up by taking energy from system. When the variable oscillations reach the natural frequency resonance condition occurs. This causes increased flux density in auxiliary transformer core and thereby bringing the natural frequency to exactly 50/3.

This results in progressive build-up of third harmonic oscillations which are stabilized for indefinite time. The third harmonic component increases the secondary voltage to 1.2 to 1.5 times rated secondary voltage. The waveform of secondary voltage containing third harmonic is also non-sinusoidal. Hence ferro-resonance should be prevented.

Good design of CVT will not exhibit ferro-resonance for resistive burdens. However, non-linear inductive burdens (such as auxiliary voltage transformers in protective systems) are likely to cause ferro-resonance. Auxiliary VT's should have a large core so as to maintain flux density at a low value (0.2 to 0.4 Wb/m^2) to prevent saturation.

(*b*) **Methods for Minimising FR in CVT.** The ferro-resonance arises due to the interchange of energy between the equivalent capacitance of the voltage divider and the non-linear inductance of the magnetic unit. It results in a severe distortion of the secondary voltage. It can also result in sustained sub-harmonic oscillations. This can be avoided by taking suitable precautions while designing the CVT. Some of the methods are given below.

— Maintaining the working flux density of the electromagnetic units at much lower levels as compared with the conventional voltage transformers (*e.g.* 0.2 to 0.4 Wb/m^2 only).
— Greater utilization of the linear position of the magnetisation curve by using strip would cores, thus avoiding local saturation effects.
— Providing an air gap in the magnetic circuit of auxiliary VT to maintain the linearity of magnetising inductance over a wide range of operating conditions.
— Connecting a suitable damping resistance permanently across the secondary.
— Spreading out (deploying) auxiliary tuning and damping networks in the electromagnetic unit. In this case it is necessary that additional precautions are taken to avoid introduction of additional transients in the process of damping ferro-resonance.

(*c*) **Method of Testing FR in CVT**

In case of CVT's, it is necessary to check that the ferro-resonance does not occur and the transient oscillations die down quickly after removal of secondary short-circuits.

While testing CVT, the secondary is temporarily shorted. A voltage of 120% rated value is applied to primary. The short-circuit on secondary is suddenly removed. The peak value of secondary voltage is recorded. The peak secondary voltage should not differ from 110% normal value, after 10 Hz. Ferro-resonance should not sustain for more than 2 sec.

36.15. TESTING OF VOLTAGE TRANSFORMER (BRIEF)

(*a*) **Error Measurements.** The errors are generally measured by comparison method, *i.e.* comparing the voltage transformer under test with a sub-standard voltage transformer of high accuracy and known errors. Errors are measured for various primary voltages, for rated burdens.

(*b*) **Core losses.** Measurement of core loss and exciting current are made to check the quality of core material and short-circuits in winding between turns.

(*c*) **Insulation Tests.** Routine insulation tests are of two kinds, applied and induced overvoltage tests. In applied tests, the primary winding is short-circuited and test voltage is applied between primary winding and earth, for specified time and of specified value.

Induced voltage tests are made to test inter-turn and inter-layer insulation of the windings. The supply is usually applied to the secondary winding at a frequency two to four times normal frequency to prevent core saturation and excessive exciting current. The secondary insulation is tested by applying 50 Hz. 2 kV for one minute type tests on voltage transformer include impulse tests.

(*d*) **High voltage tests.** Power frequency with stand tests and impulse withstand tests. (Ref. Sec. 12.8, 12.11).

(*e*) **Polarity Test.** These are similar to the test on CT's (Refer Sec. 35.8).

36.16. APPLICATION OF CAPACITOR TYPE VOLTAGE TRANSFORMER FOR PROTECTIVE RELAYING

The requirements of protective voltage transformers depend upon the application.

1. For capacitor type voltage transformer used for residual connection, accuracy class 10 is generally preferred.

2. In applications of voltage transformers where phase relationship between current and voltage is important, accuracy class 3 is preferred. These applications include directional over-current relaying, reverse power protection, distance protection, etc.

3. In applications, where phase angle is not significant; accuracy class 5 is preferred. Such applications include under-voltage overvoltage, voltage restrained protection.

4. For high speed distance relays, electromagnetic voltage transformers are preferred.

For potential transformer for protection purposes it is a common practice to measure the primary and secondary volts in terms of line-to-line. In other words, 110 volts is generally line-to-line voltage in terms of the secondary. Where relays are line-to-neutral voltage, their coils are generally at $110/\sqrt{3}$, V.

5. Protective relays operate under system fault conditions. As the faults are associated with voltage drops, a protective voltage transformer is required to maintain its accuracy within the specified limits from 5 per cent of the rated voltage to voltage factor time the rated voltage.

6. Capacitor voltage transformers may be of full range or of stepped range design.

7. Composite transformers used for protection and measurement, are normally of full range design. Although adjustment of the ratio and series inductance of the electromagnetic unit is usually necessary to enable capacitors with commercially practical tolerances to be employed, once the adjustment setting to suit a particular set of capacitors has been determined, no further adjustments are necessary in service. Such full range devices may thus be employed in service in the same manner as electromagnetic voltage transformer and power factor corrections for inductive burdens are not necessary.

(8) When same VT is used for both protection and measurement (Dual propose) separate secondary winding may be used. The rated burden of each winding may be separately specified.

(9) Actual VA burden on VT should be about 90% of rated VA burden of VT.

SUMMARY

Voltage transformers are used for protection are generally different from those for metering with reference to their accuracy class. Generally class 3.0, 5.0 is used for voltage transformers connected in star-star and class 10.0 for residually connected VT's.

There are two types of construction : 1. Electromagnetic VT (2) CVT. Electromagnetic VT's are more accurate than CVT's. CVT's are used for voltages above 66 kV.

Transient performance of VT's is important in protection. CVT should not give ferro-resonance and secondary over-voltages. Electromagnetic VT is superior to CVT in this respect.

QUESTIONS

1. Illustrate with clear sketches the following :
   (*a*) Connections of VT's in V-V for measurement of voltages.
   (*b*) Connections of VT's in star-star for under-voltage/over-voltage protection.
   (*c*) Residual connection of VT's.

2. Draw a vector diagram of VT and discuss the causes of ratio error and phase angle error. State the preferred accuracy classes for protective relays.

3. The power consumption of each voltage relay coil used in a over-voltage protection is 5 VA. The lead resistance if 0.1 ohm per lead. There is no other burden. Draw diagram of over-voltage protection for a 132 kV, there phase bus-bar illustrating VT and relay coil connections.

4. Describe the construction of Capacitor Voltage Transformer and discuss the factors affecting the choice of capacitors, auxiliary electromagnetic VT, spark gaps, arrangement of coupling of carrier current equipment.

5. Describe the applications of VT's in the following applications :
   — distance protection
   — direction earth fault protection.
   Illustrate √T connections and CT connections in these.

6. Describe the residual connections of VT. Why a five limb core is essential for each electromagnetic residual VT.

7. Describe the phenomena of ferro-resonance in capacitor voltage transformer and the methods adopted to minimise the same.

8. Fill in the gaps :
   (*a*) Electromagnetic VT is ...... accurate than CVT.
   (*b*) Ratio Error of a VT is given by ......
   (*c*) In residually connected VT, the three secondaries are connected in .....
   (*d*) Ferro-resonance occurs in ...... type VT.
   (*e*) There are two categories of VTs. 1 .... (2)
   (*f*) Ohmic value of burden Z_b is given by the expression Z_b = ...
   (*g*) Accuracy classes recommended for VTs are as follows :
      1. Measuring VT ......
      2. Protective VT ......
      3. CVT only ......