Electrical Equipment - Course 230.2

ELECTRICAL METERING: PART 1

VOLTAGE AND CURRENT TRANSFORMERS

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1. OBJECTIVE

The student must be able to:

1.1 State the purpose of electrical metering.

1.2 State the purpose of each of the following equipment:

(a) Voltage Transformers (VT's),
(b) Current Transformers (CT's),
(c) VT Primary and Secondary Fuses,
(d) CT Secondary Links.

1.3 Describe the normal operation of the items stated in section 1.2 above.

1.4 State the:

(a) Four safety precautions associated with VT's.
(b) The two safety precautions associated with CT's.

1.5 Explain the significance of VT and CT polarity markings.

2. INTRODUCTION

Electrical metering is provided to inform the operator the magnitudes of voltage, current and power flows (active and reactive) in electrical circuits.

Simple electrical systems, which operate at low voltage (120 V and below) and low current (20 A and below), have their voltage, current and power meters directly connected to the main electrical conductors.

At higher voltages and currents, it would be dangerous (from the high voltage point of view) and uneconomic (from the high current and large conductor point of view), for the meters to be directly connected to the conductors. This lesson explains how voltages and currents are **proportionally** reduced before being applied to the voltage, current and power meters. The lesson also explains the safety precautions that must be adopted with electrical metering circuits.

Transformer polarities are also explained.

3. VOLTAGE AND CURRENT TRANSFORMERS

3.1 Voltage Transformers

A voltage transformer (VT), sometimes called a potential transformer (PT), is provided to **proportionally** reduce the supply voltage to a safe value, typically 120 V or 120 V/$\sqrt{3}$. At the same time, the voltage transformer, due to it having separate windings, electrically isolates the primary winding (high voltage) from the secondary winding or windings (low voltage).

As far as construction is concerned, a wound voltage transformer, (as distinct from other types covered in the next lesson) resembles a small power transformer. The two windings are wound around a common core.

Voltage transformers are usually connected between line and ground. Occasionally, with low voltage circuits, for example 600 V, VT's are connected line-to-line.

Figure 1 shows a 3 phase high voltage circuit operating at 24 kV with voltage of 24 kV/$\sqrt{3}$ to ground.

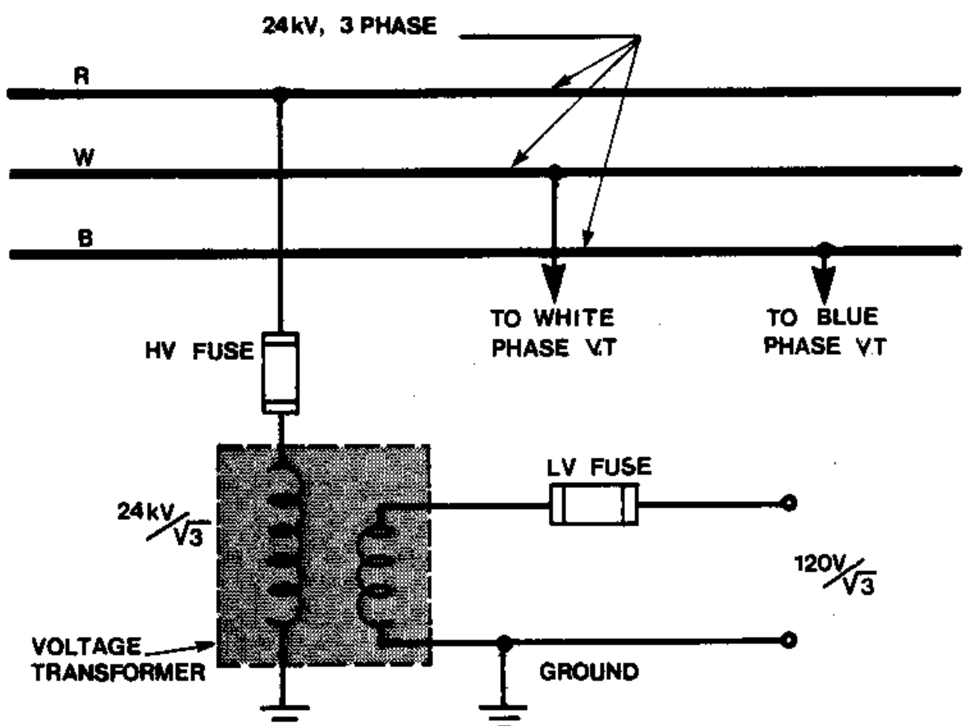

Figure 1: Voltage Transformer Supplying a Voltmeter.

Voltage transformers obey the basic transformer equation, ie,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

Taking the example of the VT's for the Pickering generators, the primary voltage is 24 kV/$\sqrt{3}$ and the secondary voltage is 120 V/$\sqrt{3}$. The turns ratio, N_1/N_2 is:

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{24\ 000/\sqrt{3}}{120/\sqrt{3}}$$

The ratio of each transformer is quoted as 24 000/$\sqrt{3}$ V:/120/$\sqrt{3}$ V and not 2 000 V:1 V, because 24 000/$\sqrt{3}$ V and 120/$\sqrt{3}$ V are the rated voltages. When each VT is operating at its rated voltage of 24/$\sqrt{3}$ kV it will give its rated output of 120/$\sqrt{3}$ V. An output of 120 V is obtained by connecting the secondaries in star.

Because the voltage output from a VT is proportional to the input voltage, a voltmeter scaled to read 0-24 kV (but supplied with 0-120 V), will at all times, give an accurate reading of the primary voltage.

3.1.1 Precautions with VT's. There are four precautions to be observed with VT's. These are:

(a) A VT is provided with a primary fuse to protect the circuit in the event of a short circuit occurring within the VT.

(b) VT's are provided with secondary fuses. In the event of a secondary circuit short-circuit, these fuses protect the VT.

(c) VT's are provided with a ground connection which is connected between the secondary wiring and ground. It is important that, before a VT is energized, this ground connection is complete. If the ground connection is left open, there is the danger that a high voltage, due to static or induction, can occur on the secondary wiring.

(d) When isolating circuits, it is common practice to remove the VT secondary fuses. This ensures, that due to testing or an accidental backfeed, the VT cannot be back-energized and produce a dangerous voltage on the HV side. The fuses are replaced before the circuit is restored to service.

3.2 Current Transformers

A current transformer (CT) is provided to **proportionally** reduce the current in the supply conductors to a convenient value for metering purposes. At the same time, the current transformer, due to it having two separate windings, electrically isolates the HV primary from the secondary.

Figure 2 shows the construction of a CT. The primary conductor, carrying the load current, is passed through the centre of a laminated iron core. The secondary winding is wound around the iron core. For simplicity, only 4 secondary turns are shown; in practice there are many more turns.

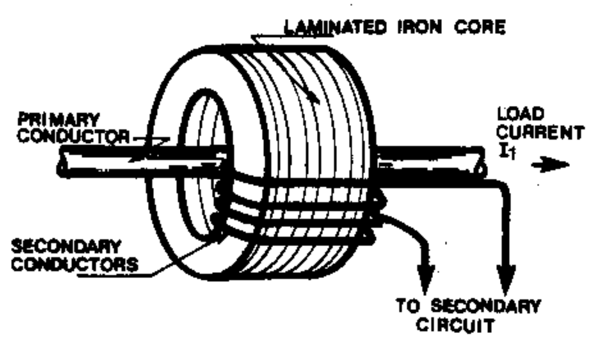

Figure 2: Current Transformer: Construction.

Current transformers obey the basic transfomer equation:

$N_1 I_1 = N_2 I_2$;

I_1 = primary current
I_2 = secondary current
N_1 = primary turns
N_2 = secondary turns

Taking the example of the CT's for the Pickering generators, the primary current is 16 000 A and the secondary current is 5 A. The CT primary has 1 turn, ie, 1 turn passes through the centre of the CT, see Figure 2. The secondary winding has N_2 turns and from the above formula,

$$N_2 = \frac{N_1 I_1}{I_2} = 1 \times \frac{16\ 000}{5}$$

$$= \underline{\underline{3200 \text{ turns}}}$$

The CT ratio is quoted at 16 000 A/5 A, and not 3 200 A/1 A. This is because the 16 000 A and the 5 A denote the full load current ratings of the primary and secondary windings. Ontario Hydro, as a standard, uses CT's with a secondary rating of 5 A. 1 A secondary CT's are used in special instances.

Figure 3 shows a three phase high voltage circuit operating at 24 kV and carrying 16 000 A. The current transformers have a ratio of 16 000 A/5 A.

Because the current output from a CT is proportional to the current input, an ammeter scaled to read 0-16 000 A (but supplied with 0-5 A) will, at all times, give an accurate reading of primary current.

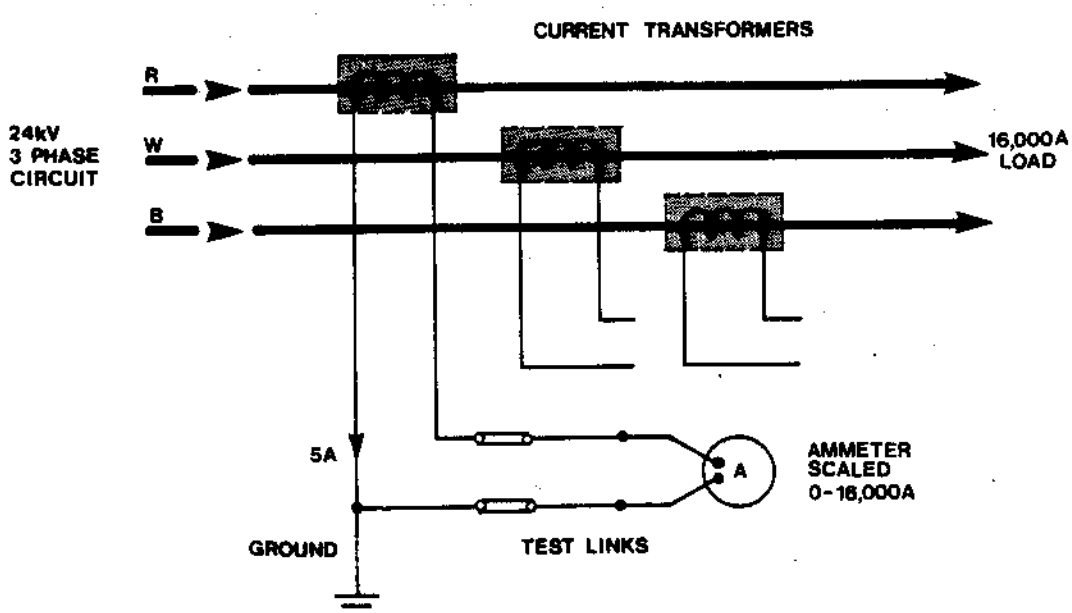

Figure 3: Current Transformer Supplying an Ammeter.

3.2.1 Precautions with CT's. There are two precautions to observe with CT's. These are:

(a) In Figure 4, current is flowing in the primary winding producing ampere-turns (mmf) which produces the primary flux Φ_p in the iron core. The secondary circuit has been open circuited and because no secondary current is flowing, no mmf and no secondary opposing flux Φ_s is produced. Consequently, the core has a large flux Φ_p. This flux Φ_p cuts the secondary winding and induces a large voltage in this winding. The induced voltage, typically several thousand volts, appears across the CT secondary terminals and across the point where the CT secondary circuit is broken.

It follows that when a CT primary is carrying current, its secondary must never be open circuited. Failure to observe this precaution may result in **ELECTROCUTION.**

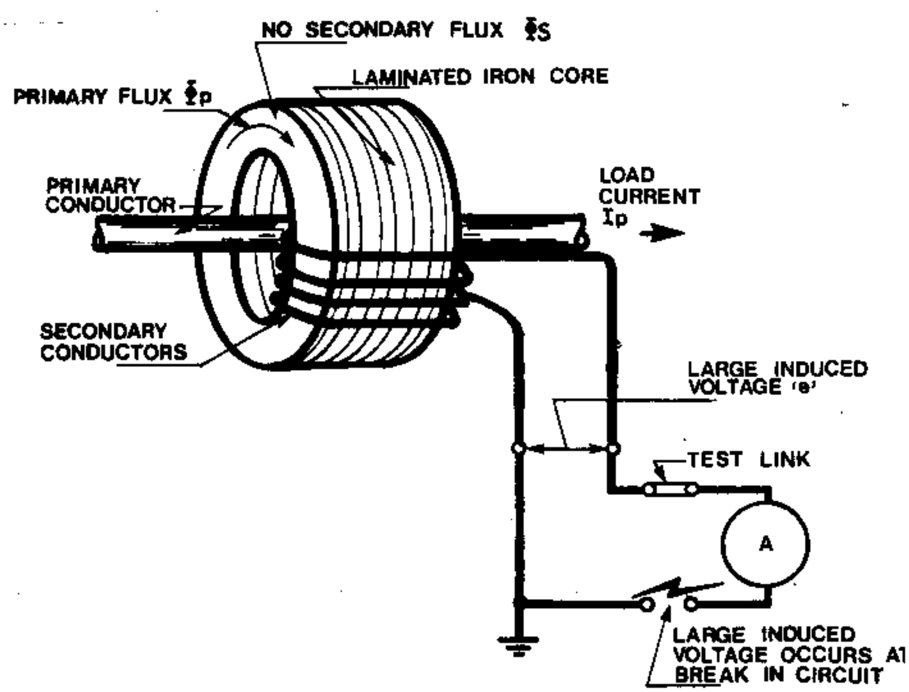

Figure 4: CT on Open Circuit.

In Figure 5, the CT is supplying an ammeter. Current is flowing in the primary producing ampere turns (mmf) which produces the primary flux Φ_p in the core. Current is also flowing in the secondary winding producing an mmf which produces a secondary flux Φ_s in the core. Due to Lenz's law, these fluxes oppose each other giving a very small value of resultant flux and hence a very small voltage across the CT secondary terminals. The value of voltage induced in the secondary winding (typically less than 2 volts) is just sufficient to circulate the secondary current I_s.

Test links are provided in CT secondary circuits. A test instrument must be connected across a test link **before** it is opened. This will ensure the CT secondary current flows through the series connected test instrument. The link must be closed **before** the test instrument is removed.

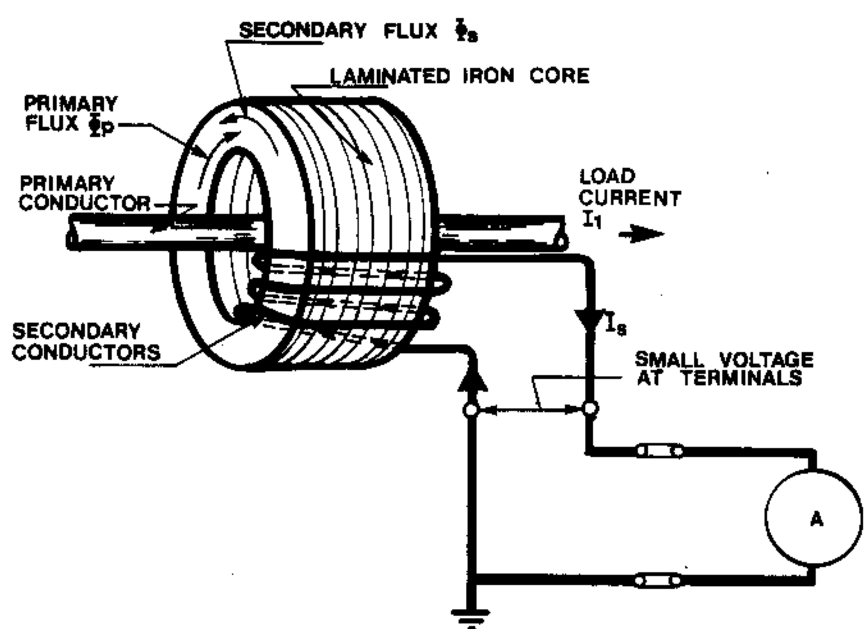

Figure 5: CT Operating Normally.

(b) CT's, like VT's are provided with a ground connection which is inserted between the secondary wiring and ground. It is important that before primary current is passed through the CT, its ground connection is complete. If the ground connection is left open, there is the danger that a high voltage, due to static or induction, can occur on the secondary wiring.

4. VT AND CT POLARITIES

When a VT is used to supply a voltmeter or a CT is used to supply an ammeter, there is no need to consider the polarity of the VT or CT. However when voltages and currents are compared (as in a wattmeter, see the next lesson) or currents are compared (see 235 course), it is vital that VT and CT polarities are taken into consideration. This section explains VT and CT voltage polarities, current flows and terminal markings.

The instantaneous polarity of the voltage and the instantaneous flow of current in a transformer secondary winding is dependent upon:

(a) the direction of the windings,

(b) the instantaneous polarity of the supply voltage and current.

Before examining transformer polarities, it is helpful to consider the dc analogy. Figure 6 shows a battery being charged and at the same time carrying a load. Current flows from the charger into the positive ⊕ terminal of the battery. Current also flows out of the positive ⊕ terminal of the battery into the load. Note, as far as the battery is concerned, the **charger** is the **source** and the battery is the **load**. As far as the **load** is concerned, the battery is the **source**.

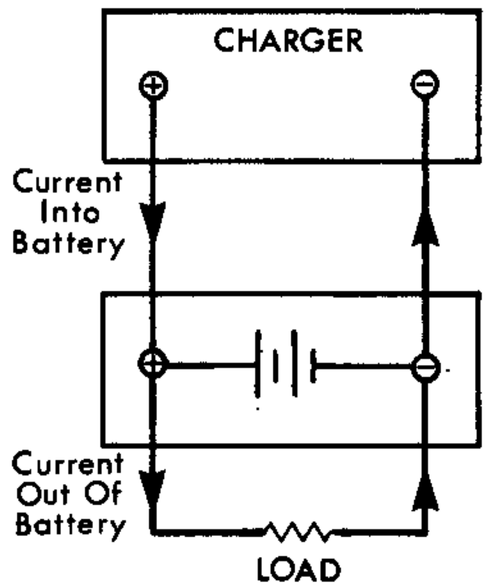

Figure 6: Polarities and Current Flows Associated with a Charger, Battery and Load.

Figure 7 shows the ac condition. The transformer is supplied with ac, which in turn, feeds the load. At the instant the supply left hand terminal is positive, a current flows from the supply positive terminal to the positive terminal on the primary of the transformer. At the same instant, one of the transformer secondary terminals will be positive. Current will flow from this positive terminal to the load. It would be possible to mark this secondary transformer terminal (+) but as the system is alternating, it is usual to mark both the positive terminals with a dot •. The dots indicates the instant the primary terminal with a dot • is positive and the instant the secondary terminal with a dot •, is also positive.

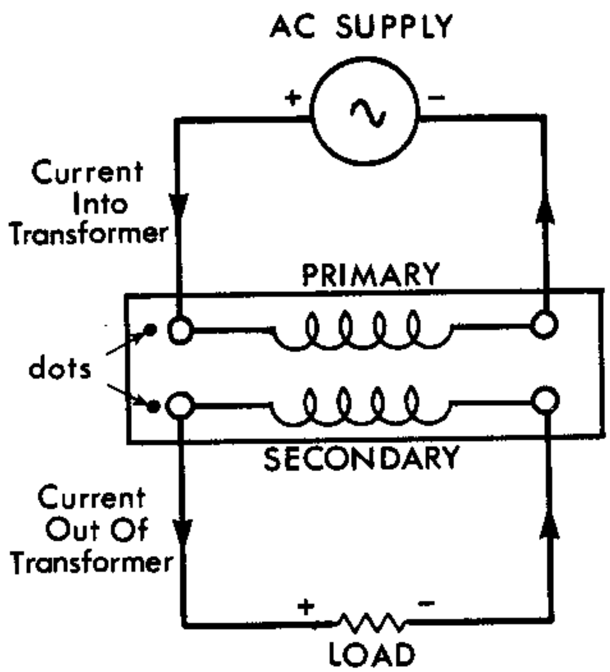

Figure 7: Polarities and Current Flows Associated with an ac Supply, Transformer and Load.

Figure 8(a) shows a VT feeding a load and Figure 8(b) shows a CT feeding a load. The instantaneous voltage polarities and instantaneous directions of current flow are shown together with the dot • markings.

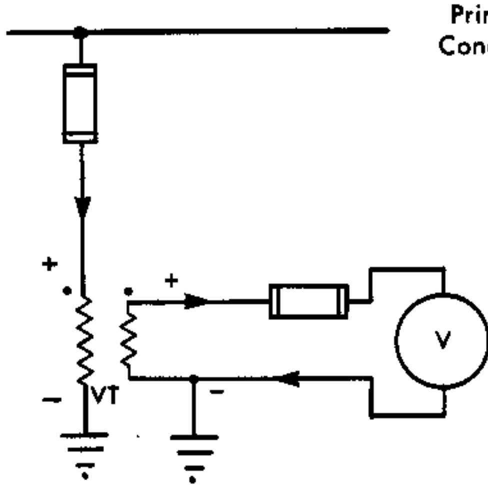

Figure 8(a): VT Supplying a Load.

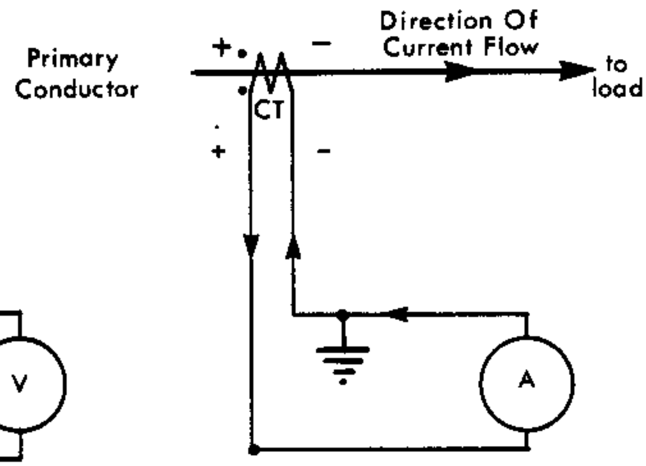

Figure 8(b): CT Supplying a Load.

ASSIGNMENT

1. State the purpose of electrical metering. (Section 2)

2. State the purposes of each of the following parts of metering equipment.

   (a) Voltage Transformers (VT's). (Section 3.1)
   (b) Current Transformers (CT's). (Section 3.2)
   (c) VT Primary and Secondary Fuses. (Section 3.1.1)
   (d) CT Secondary Links. (Section 3.2.1)

3. Describe the normal operation of:

   (a) VT's. (Section 3.1)
   (b) CT's. (Section 3.2)
   (c) VT primary and secondary fusing. (Section 3.1)
   (d) CT secondary links. (Section 3.2)

4. (a) State the four safety precautions associated with VT's. (Section 3.1.1)

   (b) State the two safety precautions associated with CT's. (Section 3.2.1)

5. Draw and label a VT feeding a load and a CT feeding a load. Show instantaneous voltage polarities, instantaneous directions of current flow and the VT and CT terminal markings. (Section 4)

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