The Current Transformer

Many seem to think that a current transformer defies all the rules of a 'normal' transformer. This is completely untrue, it does obey all the rules that apply to any transformer, it is just that – in the loosest possible terms – it operates the wrong way round.

Comparing Voltage and Current Transformers

Voltage Transformer	Current Transformer
Specified by input and output voltages and power (VA) rating	Specified by input and output currents and power (VA) rating
Primary winding usually has many turns, secondary winding usually has few turns	Primary winding usually has only one turn, secondary winding has many turns
Primary winding is finer gauge wire, secondary winding is heavy gauge wire	Primary winding is the circuit conductor, secondary winding is finer wire
Works when secondary is open circuited, no damage sustained	Works when secondary is short-circuited, no damage sustained
Damaged by excess current, e.g. because of an overloaded or short-circuited secondary	Damaged by excess voltage, e.g. because of a lightly loaded or open-circuited secondary
Secondary output voltage is proportional to primary voltage (*see the following text for full details*)	Secondary output current is proportional to primary current (*see the following text for full details*)
Has a maximum power output	Has a maximum power output

Circuit symbol

The primary winding–and the rest of the primary circuit–is often drawn thicker to emphasise the fact that a higher current is expected.

Construction

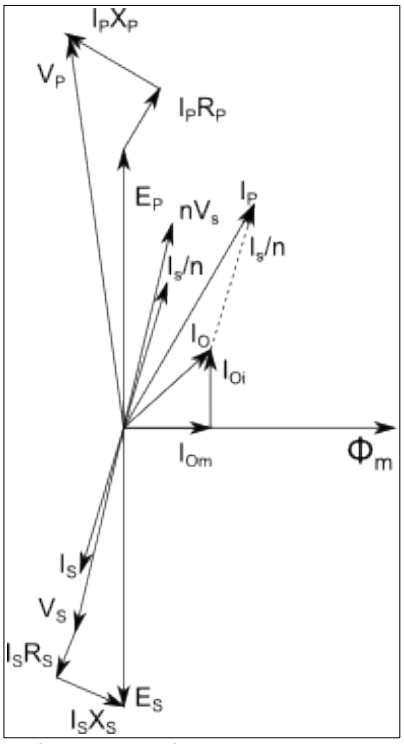
The usual construction for energy monitoring is the “split-core” type. In this, the magnetic core material – either high permeability steel stampings or a moulded ferrite material – is made in two parts that can be separated to allow the core to fitted around the primary conductor without breaking the primary circuit. Whilst this is convenient for installation, this form of construction noticeably increases the errors associated with the c.t. The secondary winding will be formed on a bobbin on the centre limb of one of the 'U'-shaped pieces. Where higher accuracy is demanded, or when installation conditions permit, the 'ring-core' construction is preferred. In this, a (usually) steel tape is wound in many layers into a doughnut shape. Often, the secondary winding is distributed evenly around the entire circumference of the core.

Specifying a Current Transformer

The c.t. is specified in terms of the ratio of currents (not turns) and the maximum power (in VA) that it can handle. In the smaller c.t's, the maximum secondary voltage, or the maximum burden (load) resistor value is often specified instead of a VA rating.

Operating Principles of a Voltage Transformer and Current Transformer

In a familiar voltage transformer, the primary winding is connected to a source of alternating voltage – typically the mains supply. A current flows that sets up a magnetic flux Φ_m in the core, which in turn generates a magnetomotive force (mmf) E_p that almost completely opposes the applied voltage V_p, leaving just the voltage drops due the current in the primary resistance I_pR_p and reactance I_pX_p.
With no load on the secondary, the primary current is equal to the excitation current I_o, and serves only to magnetise the core. This too has two components, the magnetising component that produces the flux I_{om}, and the iron loss component I_{oi}.

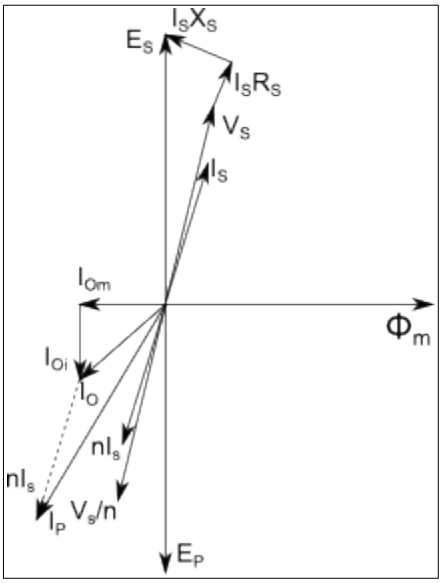


Voltage Transformer Phasor Diagram

The flux also generates a balancing mmf in the secondary winding E_s that will cause a secondary current I_s to flow. This current similarly causes voltage drops in the secondary winding resistance I_sR_s and the reactance I_sX_s, but this time these subtract from the emf to give the secondary voltage V_s.

Small voltage transformers are normally specified by the primary and secondary voltages at full load and the power rating in VA. When lightly loaded, I_p will be small as there is no I_s/n component, so E_p will rise also. E_s will rise to balance the mmfs. The secondary terminal voltage will rise to become very nearly E_s because the voltage drops due to I_sR_s and I_sX_s are absent. The total of these changes is the regulation, normally expressed as a percentage.
The phase error is the angle between the reversed secondary voltage nV_s and the primary voltage V_p, n being the turns ratio.

In the current transformer, the principal difference is that the primary current is set not by the winding impedance and the core mmf, but by the external circuit, and the secondary effectively operates into a short circuit.
The primary current generates the primary mmf which again has a magnetising component and a core loss component and must again be balanced by the secondary mmf E_s.
The secondary mmf leads the magnetic flux Φ_m by 90° and the secondary current I_s produces the same voltage drops I_sR_s and I_sX_s due to the winding resistance and reactance that reduce the terminal voltage V_s.
The phase error is the angle between the reversed



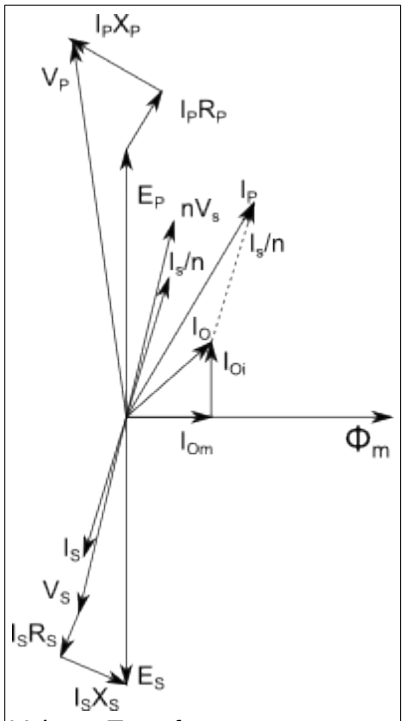
Current Transformer Phasor Diagram

secondary current nI_s and the primary current I_p, n being the turns ratio. The phase error will reduce as the magnetising loss and the core loss become smaller. (For clarity, these are drawn considerably larger than scale.)
There is also a small ratio error due mainly to the core loss. Unfortunately, the magnetising and the core loss components of current reduce less quickly than the primary current, therefore the errors increase at low currents. The turns ratio can be reduced to partially compensate for this error.

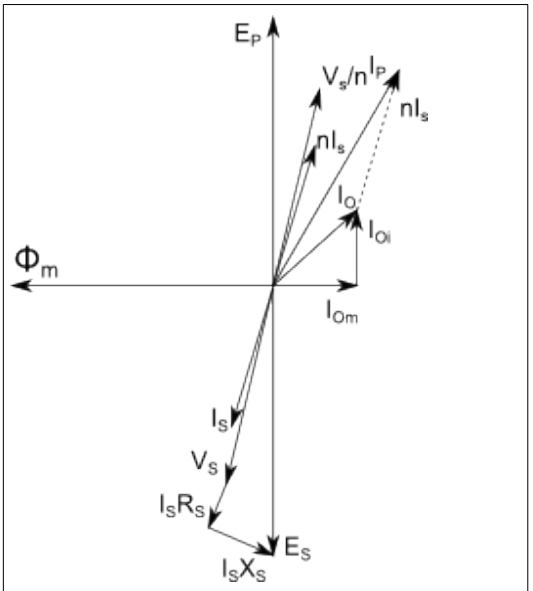
Dangers

If the secondary winding is open-circuited, there is no secondary current and no secondary mmf. The whole of the primary mmf must therefore be used to magnetise the core – I_o becomes equal to I_p. The flux will increase to a large value and core losses will increase, resulting in overheating. The emf induced in the secondary will become very high, possibly dangerously so, and the insulation may be damaged if flash-over occurs. Some core materials may become permanently magnetised, and must be demagnetised before the transformer can be used again.

To emphasise the similarity to the voltage transformer, here are the two side by side, but with the phasor diagram of the current transformer rotated through 180°.



Voltage Transformer Phasor Diagram



Current Transformer Phasor Diagram