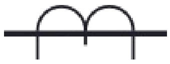
The Current Transformer

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 simply 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 fine wire, secondary winding is heavy gauge wire.	Primary winding is the circuit conductor, secondary winding is fine 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 a short-circuited secondary.	Damaged by excess voltage, e.g. because of an open-circuited secondary.
Secondary output voltage is proportional to primary voltage *(with an unvarying resistive load)*.	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 high 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 usually be formed on a bobbin on the centre limb of a 'U'-shaped piece, with either a second 'U' or a straight bar to complete the magnetic circuit.
Where higher accuracy is demanded, or when installation conditions permit, the 'ring-core' construction is preferred. In this, circular stampings are stacked, or a steel tape is wound in many layers, to give a doughnut shape. Often, the secondary winding is distributed evenly around the entire circumference of the core.

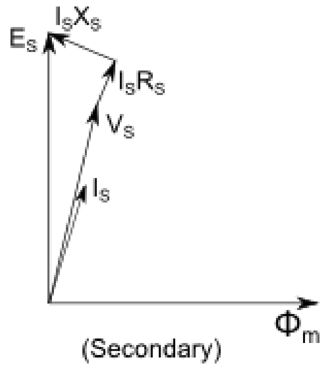
Specifying a Current Transformer

The c.t. is specified in terms of the primary and secondary currents (not the turns ratio) and the maximum power (in VA) that it can handle. In the smaller c.t's, the maximum secondary voltage at rated current is often specified instead of a VA rating.

Operating Principles of a Current Transformer

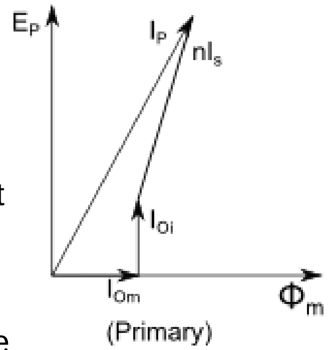
In the current transformer, the principal difference from the familiar voltage transformer is that the primary current is set not by the internal properties of the transformer and its load, but by the external circuit.

The easiest way to understand the operation is to think about the primary and secondary separately, and start with the secondary.



The induced e.m.f. E_s leads the flux in the core Φ_m by 90°, and the secondary voltage at the terminals V is less than this by the resistive and reactive voltage drops in the secondary winding I_sR_s and I_sX_s.
The angle between V_s and the secondary current I_s is the phase angle of the burden, which should be very close to zero.
The secondary burden is virtually a short circuit, and the current transformer operates under short-circuit conditions.

The link between the secondary side and the primary side is the shared flux Φ_m.



Turning now to the primary, the primary current I_p sets up the magnetic flux Φ_m in the core, which in turn generates a magnetomotive force (mmf) E_p. This has a magnetising component I_{om} that produces the flux, and a core loss component I_{oi}, and it must balance out the secondary mmf nI_s copied down from the upper diagram (n is the turns ratio).

Although the loss components I_{om} and I_{oi} are drawn larger than scale for clarity, clearly I_p can never equal nI_s so the ratio of currents is never exactly equal to the turns ratio. This is called the ratio error. At the same time, there is always a small angle between I_p and I_s and this is the phase shift between the primary and secondary currents.

The phase error will reduce as the magnetising loss and the core loss become smaller. Unfortunately, the magnetising and the core loss components of current reduce less quickly than the primary current, therefore the ratio error increases at low currents. The turns ratio can be altered slightly to partially compensate for this error.
At very high currents, the core will start to saturate and the losses will increase rapidly, again leading to increasing ratio and phase errors.

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 flux will switch rapidly between saturation in one direction and saturation in the other, therefore 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 will need to be demagnetised before the transformer can be used again.