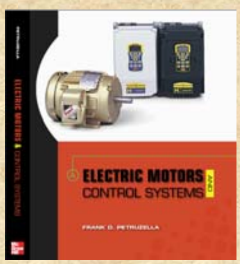


Chapter 3

Motor Transformers and Distribution Systems

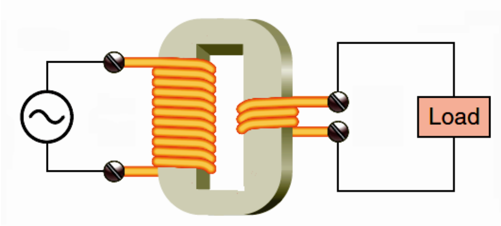
PART 2 Transformer Principles

TRANSFORMER OPERATION

A *transformer* is a static device (no moving parts) used to transfer energy from one AC circuit to another.

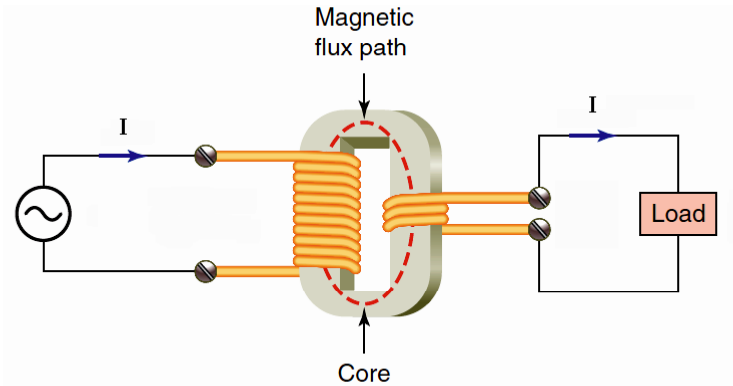
This transfer of energy may involve an increase or decrease in voltage, but the *frequency* will be the same in both circuits.

440 V
60 Hz



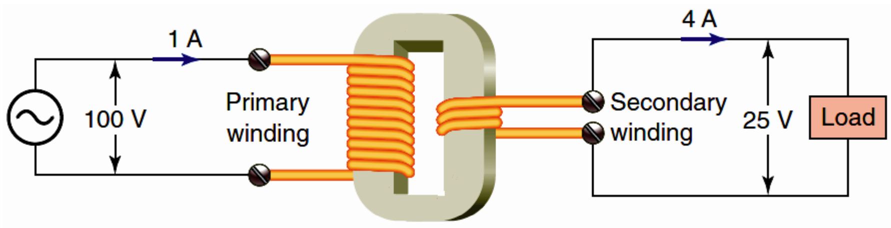
120 V
60 Hz

The two circuits of a transformer are coupled by a *magnetic field* that is linked to both instead of a conductive electrical path.



A transformer can only be operated with AC voltage because no voltage is induced if there is no change in the magnetic field.

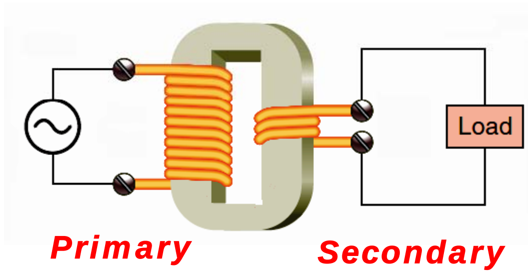
A transformer doesn't change *power* levels between circuits. If you put 100 VA into a transformer, 100 VA (minus a small amount of losses) comes out.



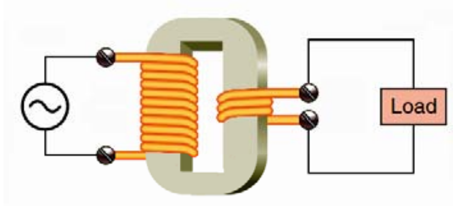
Input 100 V x 1 A = 25 V x 4 A Output

Input 100 VA = 100 VA Output

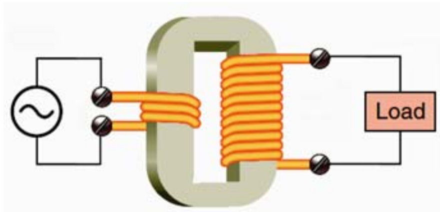
The transformer consists of two electrical conductors called the *primary winding* and the *secondary winding*. The primary winding is fed from a varying alternating current which creates a varying magnetic field around it. According to the principle of "mutual inductance", the secondary winding, which is in this varying magnetic field, will have a voltage induced into it.



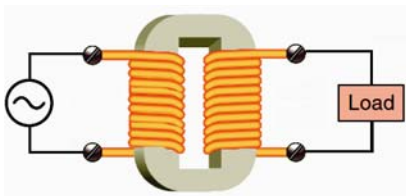
If the primary has more turns than the secondary, you have a ***step-down transformer*** that reduces the voltage.

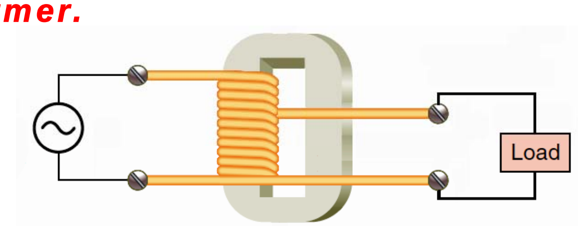


If the primary has fewer turns than the secondary, you have a ***step-up transformer*** that increases the voltage.



If the primary has the same number of turns as the secondary, the outgoing secondary voltage will be the same as the incoming primary voltage. This is the case for an ***isolation transformer.***



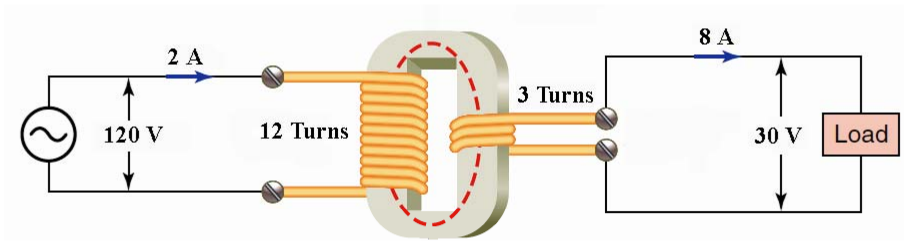


In certain exceptional cases, one large coil of wire can serve as both the primary and secondary. This is the case with ***auto-transformers.***

TRANSFORMER VOLTAGE, CURRENT, and TURNS RATIO

The ratio of turns in a transformer's primary winding to those in its secondary winding is known as the *turns ratio* and is the same as the transformer's *voltage ratio*. The voltage ratio of an ideal transformer (one with no losses) is directly related to the turns ratio, while the *current ratio* is inversely related to the turns ratio.

$$\frac{\text{Turns primary}}{\text{Turns secondary}} = \frac{\text{Voltage primary}}{\text{Voltage secondary}} = \frac{\text{Current secondary}}{\text{Current primary}}$$



$$\frac{\text{Turns primary}}{\text{Turns secondary}} = \frac{\text{Voltage primary}}{\text{Voltage secondary}} = \frac{\text{Current secondary}}{\text{Current primary}}$$

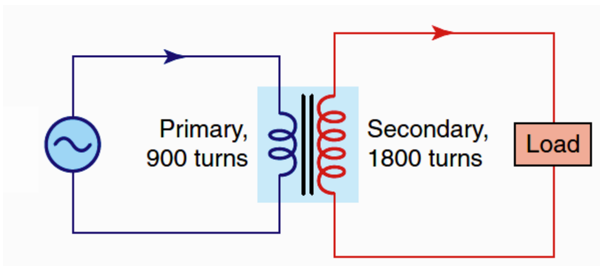
$\frac{12\ T}{3\ T}$	$\frac{120\ V}{30\ V}$	$\frac{8\ A}{2\ A}$
Turns Ratio 4:1	**Voltage Ratio 4:1**	**Current Ratio 1:4**

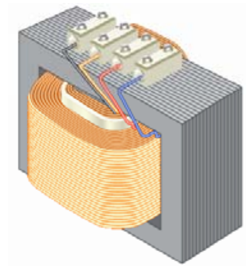
Examples of common single-phase transformer turns ratios base on primary and secondary voltage ratings.

Primary voltage	Secondary voltage	Turns ratio
480 V	240 V	2:1
480 V	120 V	4:1
480 V	24 V	20:1
600 V	120 V	5:1
600 V	208 V	2.88:1
208 V	120 V	1.73:1

The actual number of turns is not important, just the turns ratio. A *Transformer Turns Ratio Test Set* can directly measure the turns ratio.

Step-Up Transformer Equations

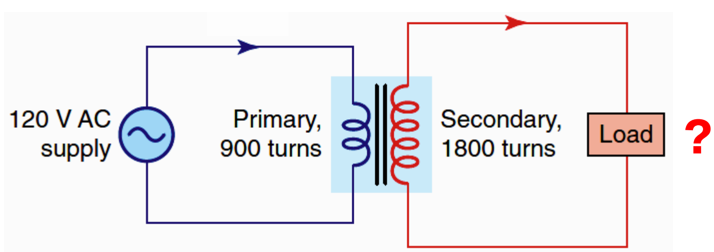




$$\text{Turns ratio} = \frac{\text{Number of turns on the primary}}{\text{Number of turns on the secondary}}$$

$$= \frac{900}{1800} = \frac{1}{2} = 1{:}2 \text{ turns ratio}$$

If the voltage of the primary winding and the turns ratio are known, the voltage of the secondary winding can be determined.

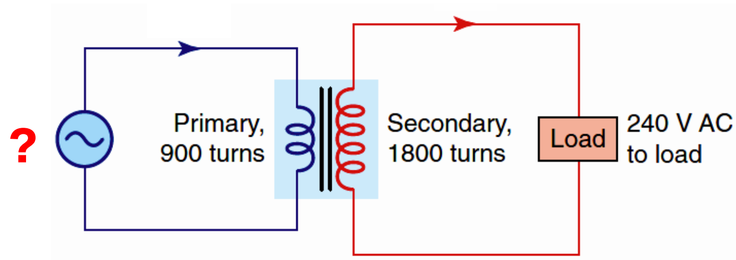


Turns Ratio = 1:2

$$\text{Secondary voltage} = \frac{\text{Primary voltage}}{\text{Turns ratio}}$$

$$= \frac{120}{\frac{1}{2}} = 120 \times 2 = 240 \text{ V}$$

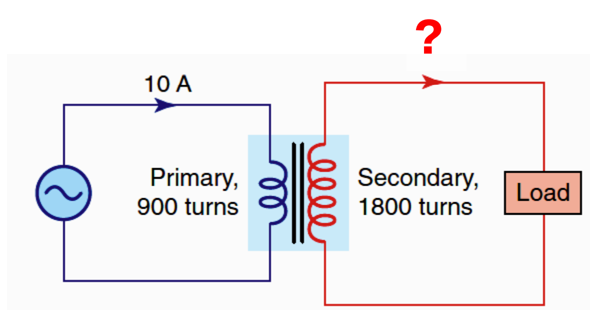
If the voltage of the secondary winding and the turns ratio are known, the voltage of the primary winding can be determined.



Turns Ratio = 1:2

$$\text{Primary voltage} = \text{Secondary voltage} \times \text{Turns ratio}$$
$$= 240\text{ V} \times \frac{1}{2} = 120\text{ V}$$

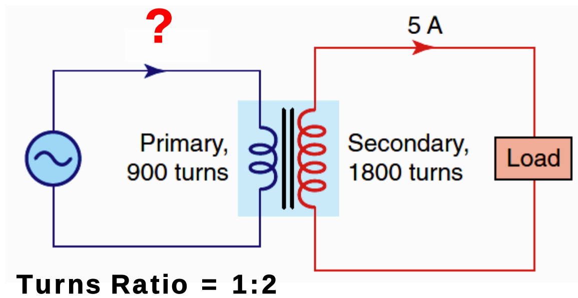
If the current of the primary winding and the turns ratio are known, the current of the secondary winding can be determined.



Turns Ratio = 1:2

$$\text{Secondary current} = \text{Primary current} \times \text{Turns ratio}$$
$$= 10\text{ A} \times \frac{1}{2} = 5\text{ A}$$

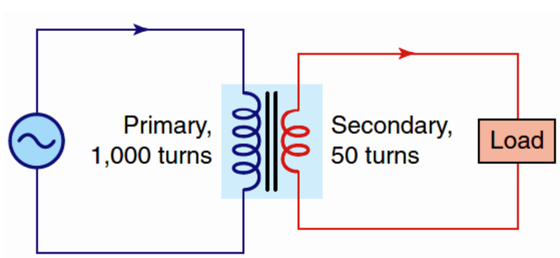
If the current of the secondary winding and the turns ratio are known, the current of the primary winding can be determined.

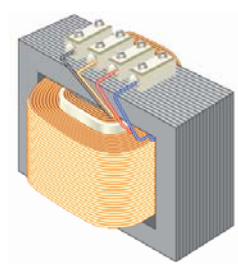


Turns Ratio = 1:2

$$\text{Primary current} = \frac{\text{Secondary current}}{\text{Turns ratio}} = \frac{5\text{ A}}{\frac{1}{2}} = 5 \times 2 = 10\text{ A}$$

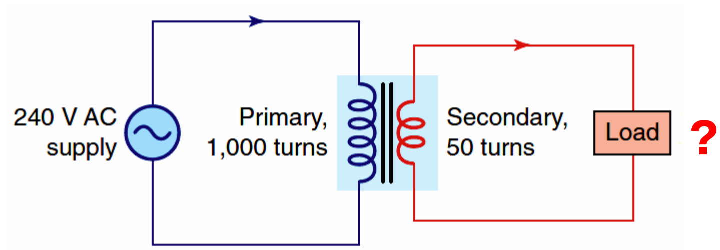
Step-Down Transformer Equations





$$\text{Turns ratio} = \frac{\text{Number of turns on the primary}}{\text{Number of turns on the secondary}} = \frac{1000}{50} = \frac{20}{1} = 20{:}1 \text{ turns ratio}$$

If the voltage of the primary winding and the turns ratio are known, the voltage of the secondary winding can be determined.

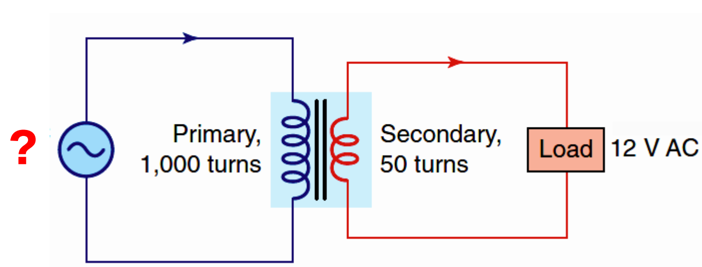


Turns Ratio = 20:1

$$\text{Secondary voltage} = \frac{\text{Primary voltage}}{\text{Turns ratio}}$$

$$= \frac{240}{\frac{20}{1}} = 240 \times \frac{1}{20} = 12\ \text{V}$$

If the voltage of the secondary winding and the turns ratio are known, the voltage of the primary winding can be determined.

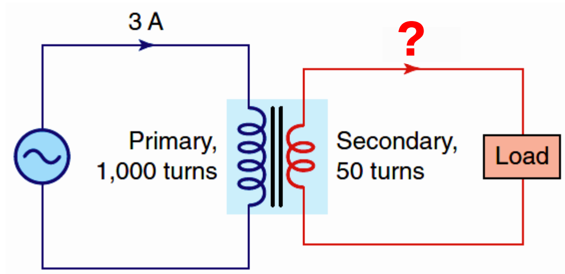


Turns Ratio = 20:1

$$\text{Primary voltage} = \text{Secondary voltage} \times \text{Turns ratio}$$

$$= 12\ \text{V} \times \frac{20}{1} = 240\ \text{V}$$

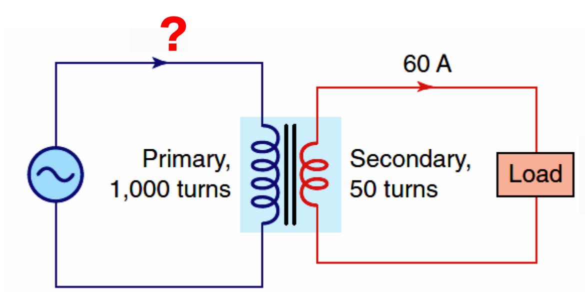
If the current of the primary winding and the turns ratio are known, the current of the secondary winding can be determined.



Turns Ratio = 20:1

$$\text{Secondary current} = \text{Primary current} \times \text{Turns ratio}$$
$$= 3\text{ A} \times \frac{20}{1} = 60\text{ A}$$

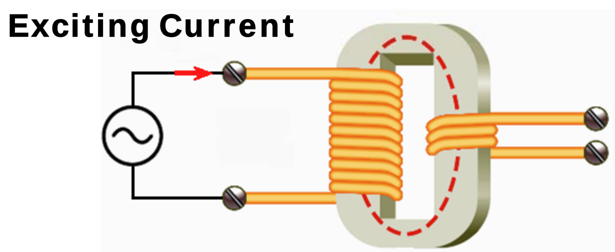
If the current of the secondary winding and the turns ratio are known, the current of the primary winding can be determined.



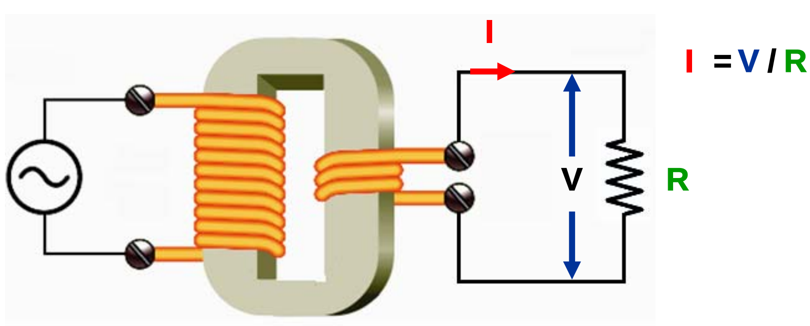
Turns Ratio = 20:1

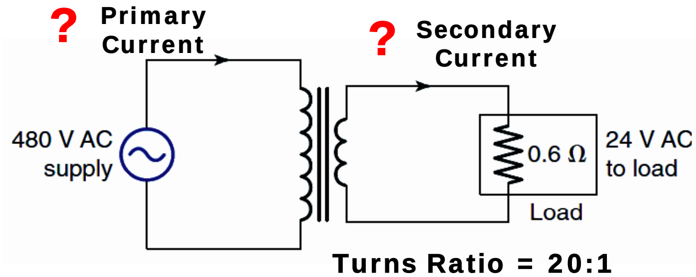
$$\text{Primary current} = \frac{\text{Secondary current}}{\text{Turns ratio}}$$
$$= \frac{60\text{ A}}{\frac{20}{1}} = 60 \times \frac{1}{20} = 3\text{ A}$$

A transformer automatically adjusts its input current to meet the requirements of its output or load current. If no load is connected to the secondary winding, only a small amount of current known as the ***magnetizing current*** or ***exciting current*** current flows through the primary winding.



For a purely ***resistive*** load, according to Ohm's law, the amount of secondary winding current equals the secondary ***voltage divided*** by the value of the load ***resistance*** connected to the secondary circuit (a negligible coil winding resistance assumed).





Turns Ratio = 20:1

$$\text{Secondary winding current} = \frac{\text{Secondary voltage}}{\text{Load resistance}} = \frac{24\text{ V}}{0.6\ \Omega} = 40\text{ A}$$

$$\text{Primary winding current} = \frac{\text{Secondary winding current}}{\text{Turns ratio}} = \frac{40\text{ A}}{\frac{20}{1}} = 40 \times \frac{1}{20} = 2\text{ A}$$

TRANSFORMER POWER RATING

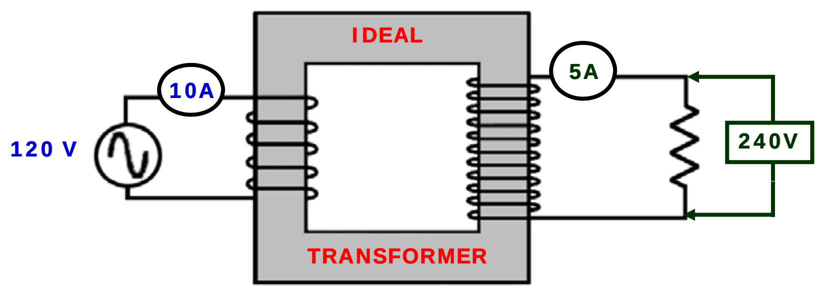
Just as ***horsepower*** ratings designate the power capacity of an electric motor, a transformer's ***kVA*** rating indicates its maximum power output capacity.

$$\text{Single-phase loads: kVA} = \frac{I \times E}{1{,}000}$$

$$\text{Three-phase loads: kVA} = \frac{I \times E \times \sqrt{3}}{1{,}000}$$

The maximum power rating of a transformer can be found on the transformer's nameplate.

There is no gain or loss in energy in an *ideal transformer* when energy is transferred. This means that the volts multiplied by the amperes of the primary circuit equal the volts multiplied by the amperes of the secondary circuit.



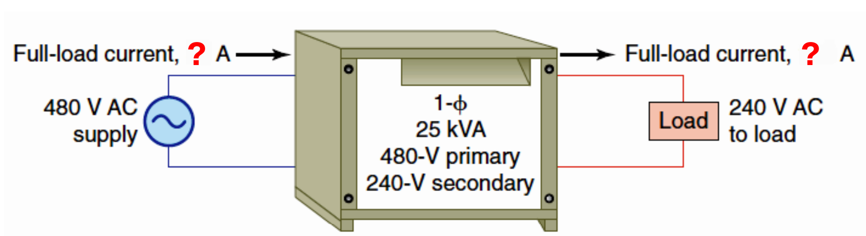
VA (primary) = 120 x 10
= 1200 VA

VA (secondary) = 2400 x 5
= 1200 VA

Transformers are rated in volt-amperes (*VA*) or kilovolt-amperes (*kVA*). You may recall that volt-amps (VA) is the total power supplied to the circuit from the source, and includes real (Watts) and reactive (VAR) power. The primary and secondary full-load current usually are not given but can be calculated using the power rating as follows:

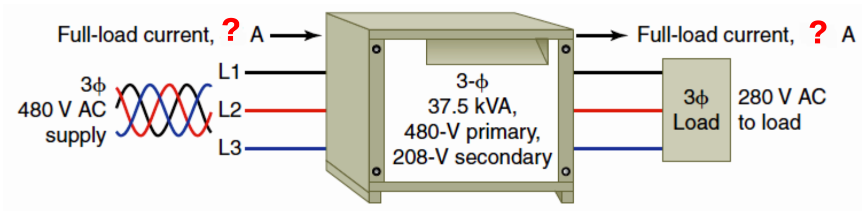
$$\textbf{Single-phase: } \text{Full-load current} = \frac{\text{VA}}{\text{Voltage}} \text{ or } \frac{\text{kVA} \times 1{,}000}{\text{Voltage}}$$

$$\textbf{Three-phase: } \text{Full-load current} = \frac{\text{kVA} \times 1{,}000}{1.73 \times \text{Voltage}}$$



$$\text{Primary full-load current} = \frac{\text{kVA} \times 1{,}000}{\text{Voltage}} = \frac{25 \text{ kVA} \times 1{,}000}{480 \text{ V}} = 52 \text{ A}$$

$$\text{Secondary full-load current} = \frac{\text{kVA} \times 1{,}000}{\text{Voltage}} = \frac{25 \text{ kVA} \times 1{,}000}{240 \text{ V}} = 104 \text{ A}$$



$$\text{Primary full-load current} = \frac{\text{kVA} \times 1{,}000}{1.73 \times \text{Voltage}} = \frac{37.5\ \text{kVA} \times 1{,}000}{1.73 \times 480\ \text{V}} = 45\ \text{A}$$

$$\text{Secondary full-load current} = \frac{\text{kVA} \times 1{,}000}{1.73 \times \text{Voltage}} = \frac{37.5\ \text{kVA} \times 1{,}000}{1.73 \times 208\ \text{V}} = 104\ \text{A}$$