6. AC power supplies and basic transformer theory and operation

Overview

Purpose

The gas technician/fitter requires a basic understanding of 120-volt alternating (ac) circuits typically present in a residential application. Additionally, proper sizing, connection, and troubleshooting of various types of transformers e in the gas industry require knowledge of transformer theory and operation.

Objectives

At the end of this Chapter, you will be able to:

- describe basic component identification characteristics in a 120-volt ac circuit; and
- describe the principles of transformer operation.

Terminology

Term	Abbreviation (symbol)	Definition
Transformer		Electrical device that transfers energy between two or more circuits through electromagnetic induction and commonly helps increase or decrease the voltages of alternating current in electric power applications

AC power supplies

Electrical distribution

An electrical distribution system allows generation and delivery of electricity at various voltages. Voltages are either stepped-up or stepped-down with transformers.

120 volt AC receptacles

By the time electricity reaches a standard receptacle, such as that found in your home, the voltage has decreased to 120 volts ac from a much higher distribution voltage. Generally, electricity arrives at the receptacle inside a two-conductor cable and includes a ground wire.

Generally, the colour of insulation identifies each wire:

Colour	Is used for...
White or natural grey	Insulated, neutral conductors
Black (sometimes red or blue)	Insulated live or hot conductors
Green	Only for ground conductors

Each outlet must have at least 6 inches (150 mm) of free conductor for making joints or for the connection to receptacles.

You usually identify the terminals on receptacles to indicate which conductor is to be connected. For example, the neutral wire terminal has a metallic coating for identification, is made of metal that is substantially white (silvery) in colour, or has a "W" or "WHITE" marking adjacent to the terminal. The colour of the ground terminal (screw head, nut, or clamp) is green.

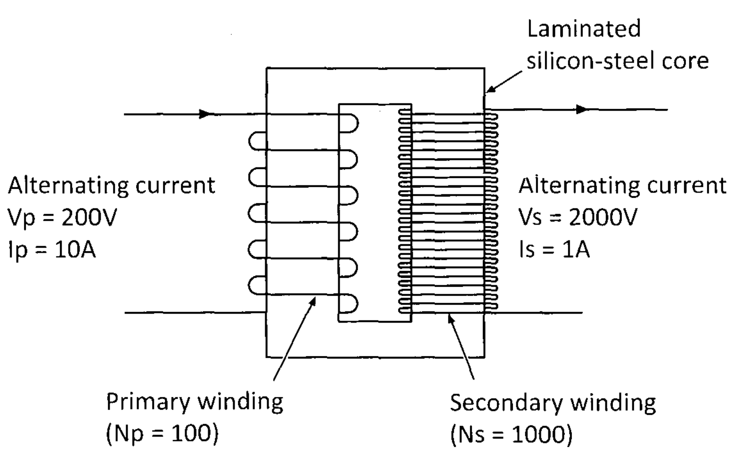
Principles of transformer operation

Single-phase transformer operation

Although most large-current transformers are three-phase, for simplicity this section discusses only single-phase. The principle is the same for three phase, except that there are three sets of windings instead of just one.

Figure 6-1 shows a transformer core with a primary winding and a secondary winding. The windings are actually wound around each other on a real transformer. However, for simplicity of understanding, the figure shows two separate windings. The current is supplied to the primary winding and the output is from the secondary winding. In this example, there are 100 turns (N_p = 100) in the primary and 1000 turns (N_s = 1000) in the secondary.

Figure 6-1
Single-phase transformer



When the primary winding of this transformer takes an alternating voltage, a current flows and a magnetic field develops around the winding. Since the alternating current flow is fluctuating at 60 Hz, the magnetic field will likewise fluctuate. With alternating current, the current increases to a peak value, then decreases to zero for each fluctuation. The magnetic field associated with this current fluctuates at the same frequency.

The flux lines cut through the secondary winding and induce a voltage into the winding. This is the same electromagnetic induction that takes place in a generator.

If the number of turns in the secondary winding equals the number of turns in the primary winding, the secondary voltage would equal the primary voltage. Since the secondary winding in this step-up transformer has more turns than the primary, the secondary voltage is greater. This is due to the flux lines cutting through a greater number of secondary winding turns. The greater the number of turns, the greater the voltage generated.

Transformer output calculation

You can calculate the secondary (output) voltage of a transformer by multiplying the primary voltage by the ratio of turns in the secondary to primary coils.

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

where

V_S = secondary voltage

V_P = primary voltage

N_S = turns in secondary coil

N_P = turns in primary coil

In Figure 6-1, the secondary coil has 1000 turns and the primary has 100 turns. This means that the secondary voltage is 10 times the primary voltage (1000 ÷ 100). Since the primary voltage is 200 V, then the secondary voltage will be 2000 V (200 x 10).

Transformer efficiency is very high, so the output power is very close to the input power. Since power is a function of the voltage times the current, you can calculate the secondary current if you know the primary current.

$$V_p I_p = V_s I_s$$

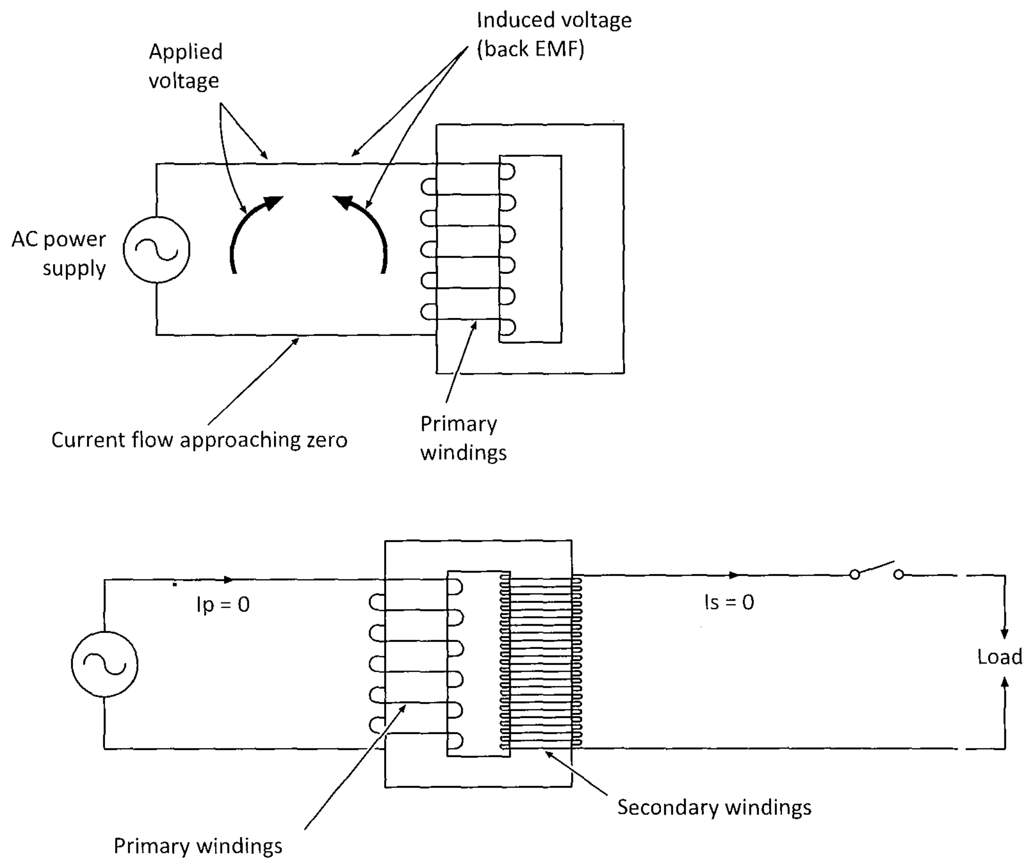
Therefore: $I_S = \frac{V_P}{V_S} x I_P$

In the example, the primary current is 10 A. Since output voltage increases by ten times and the power remains the same, the current must decrease by ten times. The current in the secondary winding must therefore be 1 A. Since the secondary current is lower than the primary current in a step-up transformer, the size of the conductor in the secondary winding can be smaller. Therefore, you can make the winding with the most turns of smaller-diameter wire.

In a step-down transformer, the operation is exactly the same. However, the secondary winding has fewer turns than the primary winding so the secondary voltage is less than the primary voltage. Also, the secondary current is greater than the primary current. Figure 6-1could also represent a step-down transformer with the primary and secondary windings reversed.

Transformers are also self-regulating. This means that, as the current flow through the secondary winding changes, the primary current also changes. If opening a switch or circuit breaker stops the secondary current, the primary current flow also stops.

Figure 6-2
Transformer with open secondary circuit



In the upper portion of Figure 6-2 is a simple coil of conductor that wraps around a steel core. An ac voltage applied to the coil normally results in a flow of current through the wire. In fact, since there are no resistors in this circuit, a large current flow results. This is the case in a dc circuit. But in a properly designed alternating current circuit, very little current will flow.

The alternating current is again causing a magnetic field to build up and collapse around the coils 120 times per second. As the lines of flux pass through the primary winding, they induce a voltage in that winding. This induced voltage is the opposite of applied voltage and acts to limit applied voltage. For example, if a 60 Hz supply is connected to the coil with a voltage of 220 V, the fluctuating magnetic field induces a voltage in the winding that is equal to the applied voltage, but in the opposite direction.

The two voltages (applied and induced) very nearly cancel each other out, so only a very small current flows. The induced voltage is often what you call back emf. Another term for source voltage is electromotive force (emf). Back emf plays an important part in limiting the current flow through electric machines.

The bottom part of Figure 6-2 shows a simple transformer with the secondary circuit open at the switch. Since no current flows through this circuit, it has no effect on the transformer, which operates as though there were only one coil. Thus, when the secondary circuit is open, the primary current flow decreases to a very small value. Although there is no current flow in the secondary circuit, the field produced by the very small primary current maintains the terminal voltage of the transformer's secondary winding's terminal voltage.

When the switch is closed and a small load is placed across the secondary circuit, enough current flows to supply this load. This current flow in the secondary winding now produces a magnetic field of its own. This is alternating current, so the magnetic field builds up, collapses, and passes through the winding coils. The magnetic field that the secondary winding current produced is opposite the magnetic field that the primary winding current produced.

Because the secondary field opposes the primary field, the primary field is reduced. This is the magnetic field that produced the back emf. Since the primary field is reduced, the back emf is reduced in the primary winding. The reduction in the back emf causes more current to flow in the primary winding.

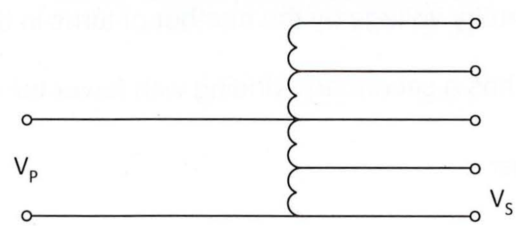
As the secondary load increases, the current flow through the secondary winding increases. This increase in current strengthens the secondary field which, in turn, weakens the primary field. This further reduces back emf and increases primary current flow. To simplify, any increase in the secondary current flow results in a proportional increase in primary current flow. For this reason, transformers are said to be self-regulating.

Auto-transformers

An autotransformer differs from the transformer described above in that it consists of a single coil, arranged as shown in Figure 6-3.

An autotransformer is a power transformer with one continuous winding, part of which serves as the primary winding and all of which serves as the secondary winding, or vice versa. Secondary voltages are supplied across any pair of a series of connections (taps).

Figure 6-3
Autotransformer connections



An important thing to note is that there is no electrical isolation between the primary and secondary of an autotransformer. For this reason, autotransformers are more economical to manufacture than other types and, for the same reason, are also more vulnerable to catastrophic failure.

Assignment Questions – Chapter 6

1) Normally, what color is the insulation on the live conductor in a 120 V ac circuit?
   a) Black
   b) Green
   c) White
   d) Red

2) Complete the following statement with the appropriate word(s) provided:
   A conductor having white insulation is normally connected to the ______________ colored terminal on a 120 V ac receptacle.
   a) Darker or Gold
   b) Black
   c) White or silvery
   d) Green

3) To which winding of a transformer is the current supplied?
   a) The primary winding
   b) The secondary winding
   c) Both the primary and secondary winding

4) If the number of turns on a secondary winding of a transformer is greater than the number of turns on a primary winding, is the secondary voltage greater or lesser than the primary voltage?
   a) Lesser
   b) Greater

5) How is the secondary voltage of a transformer calculated?
   a) By dividing the primary voltage by the ratio of turns in the secondary to primary coils.
   b) By multiplying the primary voltage by the ratio of turns in the secondary to primary coils.
   c) By multiplying the primary voltage by the number of turns in the primary coil.

6) What type of transformer has a secondary winding with fewer turns than the primary winding?
   a) Step-down transformer
   b) Step-up transformer

7) Indicate True or False:
   "Self-regulating" means that as the current flow to the secondary winding changes, the primary current flow also changes
   a) True
   b) False