ARC WELDING POWER SOURCES

Photograph courtesy of NASA

Prepared by the Welding Handbook Chapter Committee on Arc Welding Power Sources:

S. P. Moran, Chair
Miller Electric Manufacturing Company

D. J. Erbe
Panasonic Factory Automation

W. E. Herwig
Miller Electric Manufacturing Company

W. E. Hoffman
ESAB Welding and Cutting Products

C. Hsu
The Lincoln Electric Company

J. O. Reynolds
Miller Electric Manufacturing Company

Welding Handbook Committee Member:

C. E. Pepper
ENGlobal Engineering

Contents

CHAPTER 1

ARC WELDING POWER SOURCES

INTRODUCTION

This chapter presents a general overview of the electrical power sources used for arc welding. It explores the many types of welding power sources available to meet the electrical requirements of the various arc welding processes.

Welding has a long and rich history. Commercial arc welding is over a hundred years old, and scores of processes and variations have been developed. Over the years, power sources have been developed or modified by equipment manufacturers in response to the changes and improvements in these processes. As welding processes continue to evolve, power sources continue to provide the means of controlling the welding current, voltage, and power. This chapter provides updated information on the basic electrical technologies, circuits, and functions designed into frequently used welding power sources. Topics covered in this chapter include the following:

1. The volt-ampere (V-A) characteristics required for common welding processes,
2. Basic electrical technologies and terminology used in power sources,
3. Simplified explanations of commonly used power source circuits, and
4. An introduction to useful national and international standards.

A basic knowledge of electrical power sources will provide the background for a more complete understanding of the welding processes presented in the other chapters of this book.

FUNDAMENTALS

This section introduces the fundamental functions of welding power sources and the concepts of constant-voltage (CV) and constant-current (CC) characteristics required for welding processes.

The voltage supplied by power companies for industrial purposes—120 volts (V), 230 V, 380 V, or 480 V—is too high for use in arc welding. Therefore, the first function of an arc welding power source is to reduce the high input or line voltage to a suitable output voltage range, 20 V to 80 V. A transformer, a solid-state inverter, or an electric motor-generator can be used to reduce the utility power to terminal or open-circuit voltage appropriate for arc welding.

Alternatively, a power source for arc welding may derive its power from a prime mover such as an internal combustion engine. The rotating power from an internal combustion engine is used to rotate a generator or an alternator for the source of electrical current.

Welding transformers, inverters, or generator/alternators provide high-amperage welding current, generally ranging from 30 amperes (A) to 1500 A. The output of a power source may be alternating current (ac), direct current (dc) or both. It may be constant current, constant voltage, or both. Welding power sources may also provide pulsed output of voltage or current.

Some power source configurations deliver only certain types of current. For example, transformer power sources deliver ac only. Transformer-rectifier power sources can deliver either alternating or direct current, as selected by the operator. Electric motor-generator power sources usually deliver dc output. A motor-alternator delivers ac, or when equipped with rectifiers, dc.

Power sources can also be classified into subcategories. For example, a gas tungsten arc welding power source might be identified as transformer-rectifier, constant-current, ac/dc. A complete description of any power source should include welding current rating, duty cycle rating, service classification, and input power

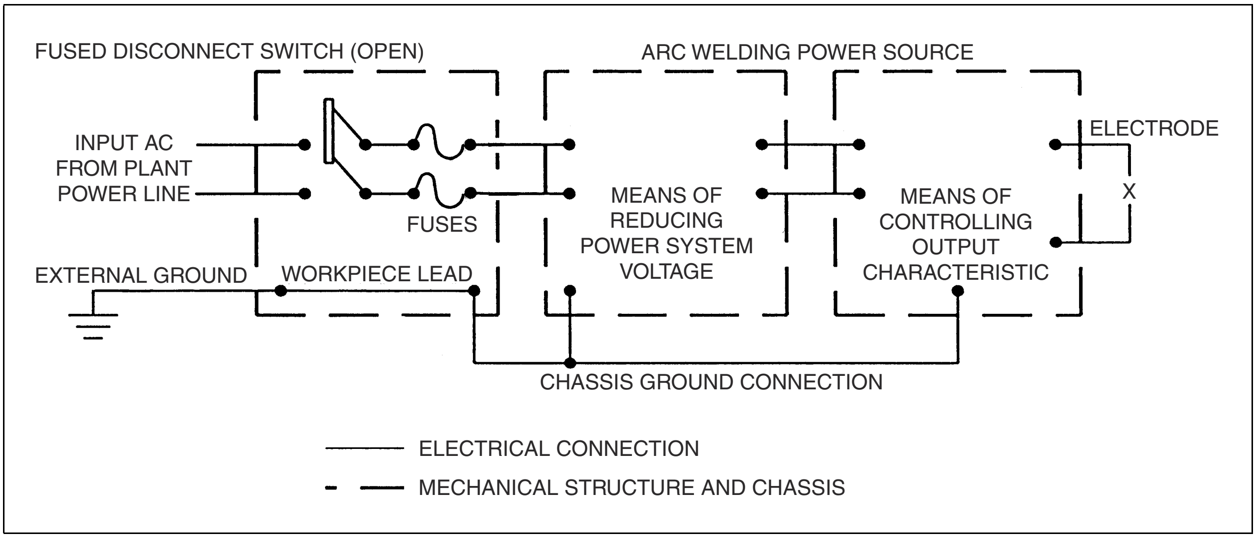

Figure 1.1—Basic Elements of an Arc Welding Power Source

requirements. Special features can also be included such as remote control, high-frequency stabilization, current-pulsing capability, starting and finishing current versus time programming, wave balancing capabilities, and line-voltage compensation. Conventional magnetic controls include movable shunts, saturable reactors, magnetic amplifiers, series impedance, or tapped windings. Solid-state electronic controls may be phase-controlled silicon-controlled rectifiers (SCRs) or inverter-controlled semiconductors. Electronic logic or microprocessor circuits may control these elements.

Figure 1.1 shows the basic elements of a welding power source with power supplied from utility lines. The arc welding power source itself does not usually include the fused disconnect switch; however, this is a necessary protective and safety element.

An engine-driven power source would require elements different from those shown in Figure 1.1. It would require an internal combustion engine, an engine speed regulator, and an alternator, with or without a rectifier, or a generator and an output control.

Before the advent of pulsed current welding processes in the 1970s, welding power sources were commonly classified as constant current or constant voltage. These classifications are based on the static volt-ampere characteristics of the power source, not the dynamic characteristic or arc characteristics. The term *constant* is true only in a general sense. A constant-voltage output actually reduces or droops slightly as the arc current increases, whereas a constant-current output gradually increases as the arc length and arc voltage decrease. In either case, specialized power sources are available that can hold output voltage or current truly constant. Constant-current power sources are also known as *variable-voltage* power sources, and constant-voltage power sources are often referred to as *constant-potential* power sources. These fast-response, solid-state power sources can provide power in pulses over a broad range of frequencies.

CONSTANT-CURRENT ARC WELDING POWER SOURCES

The National Electrical Manufacturers Association (NEMA) standard *Electric Arc-Welding Power Sources*, EW-1: 1988 (R1999), defines a constant-current arc power source as one "which has means for adjusting the load current and which has a static volt-ampere curve that tends to produce a relatively constant load current. At a given load current, the load voltage is responsive to the rate at which a consumable metal electrode is fed into the arc. When a tungsten electrode is used, the load voltage is responsive to the electrode-to-workpiece distance."[1,2] These characteristics are

1. National Electrical Manufacturers Association (NEMA), 1988 (R1999), *Electric Arc-Welding Power Sources*, EW-1: 1988, Washington, D.C.: National Electrical Manufacturers Association, p. 2.
2. At the time this chapter was prepared, the referenced codes and other standards were valid. If a code or other standard is cited without a date of publication, it is understood that the latest edition of the document referred to applies. If a code or other standard is cited with the date of publication, the citation refers to that edition only, and it is understood that any future revisions or amendments to the code or standard are not included; however, as codes and standards undergo frequent revision, the reader is advised to consult the most recent edition.

such that if the arc length varies because of external influences that result in slight changes in arc voltage, the welding current remains substantially constant. Each current setting yields a separate volt-ampere curve when tested under steady conditions with a resistive load. In the vicinity of the operating point, the percentage of change in current is lower than the percentage of change in voltage.

The no-load, or open-circuit, voltage of constant-current arc welding power sources is considerably higher than the arc voltage.

Constant-current power sources are generally used for manual welding processes such as shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), plasma arc welding (PAW), or plasma arc cutting (PAC), where variations in arc length are unavoidable because of the human element.

When used in a semiautomatic or automated application in which constant arc length is required, external control devices are necessary. For example, an arc-voltage-sensing wire feeder can be used to maintain constant arc length for gas metal arc welding (GMAW) or flux cored arc welding (FCAW). In GTAW, the arc voltage is monitored, and via a closed-loop feedback, the voltage is used to regulate a motorized slide that positions the torch to maintain a constant arc length (voltage).

CONSTANT-VOLTAGE ARC WELDING POWER SOURCES

The NEMA EW-1 standard defines a constant-voltage power source as follows: "A constant-voltage arc welding power source is a power source which has means for adjusting the load voltage and which has a static volt-ampere curve that tends to produce a relatively constant load voltage. The load current, at a given load voltage, is responsive to the rate at which a consumable electrode is fed into the arc."[3] Constant-voltage arc welding is generally used with welding processes that include a continuously fed consumable electrode, usually in the form of wire.

A welding arc powered by a constant-voltage source using a consumable electrode and a constant-speed wire feed is essentially a self-regulating system. It tends to stabilize the arc length despite momentary changes in the torch position. The arc current is approximately proportional to wire feed for all wire sizes.

CONSTANT-CURRENT/CONSTANT-VOLTAGE POWER SOURCES

A power source that provides both constant current and constant voltage is defined by NEMA as follows: "A constant-current/constant-voltage arc welding power source is a power source which has the selectable characteristics of a constant-current arc welding power source and a constant-voltage arc welding power source."[4]

Additionally, some power sources feature an automatic change from constant current to constant voltage (arc force control for SMAW) or constant voltage to constant current (current limit control for constant-voltage power sources).

PRINCIPLES OF OPERATION

The basic components of welding power sources—transformers, series inductors, generators/alternators, diodes, silicon-controlled rectifiers, and transistors—are introduced in this section. Simple circuits of reactance-controlled, phase-controlled, and inverter power sources are discussed as examples.

Most arc welding involves low-voltage, high-current arcs between an electrode and the workpiece. The means of reducing power-system voltage, as shown in Figure 1.1, may be a transformer or an electric generator or alternator driven by an electric motor.

Electric generators built for arc welding are usually designed for direct-current welding only. In these generators, the electromagnetic means of controlling the volt-ampere characteristic of the arc welding power source is usually an integral part of the generator and not a separate element. Unlike generators, alternators provide ac output that must be rectified to provide a dc output. Various configurations are employed in the construction of direct-current generators. They may use a separate exciter and either differential or cumulative compound winding for selecting and controlling volt-ampere output characteristics.

WELDING TRANSFORMER

A transformer is a magnetic device that operates on alternating current. As shown in Figure 1.2, a simple transformer is composed of three parts: a primary winding, a magnetic core, and a secondary winding. The primary winding, with N_1 turns of wire (in Equation 1.1), is energized by an alternating-current input voltage, thereby magnetizing the core. The core couples the alternating magnetic field into the secondary winding, with N_2 turns of wire, producing an output voltage.

3. See Reference 1, p. 3.

4. See Reference 1, p. 2.

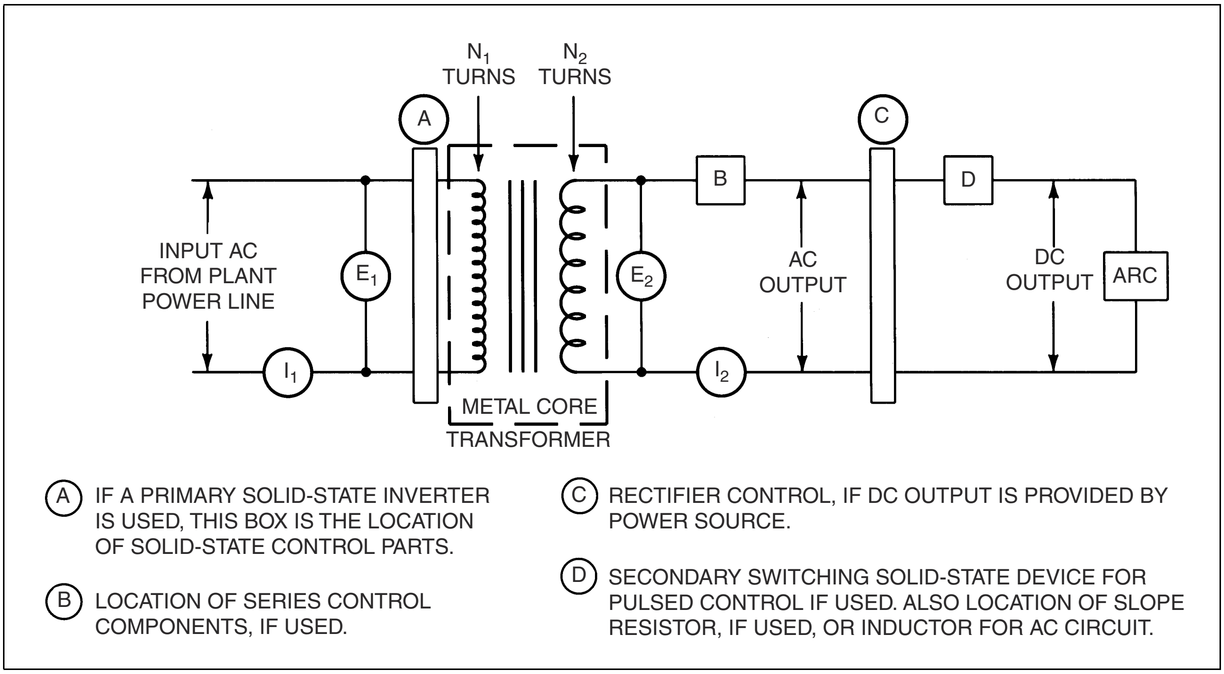

Figure 1.2—Principal Electrical Elements of a Transformer Power Source

Figure 1.2 also illustrates the principal elements of a welding transformer, with associated components. For a transformer, the significant relationships between voltages and currents and the turns in the primary and secondary windings are as follows:

$$\frac{N_1}{N_2} = \frac{E_1}{E_2} = \frac{I_2}{I_1} \qquad (1.1)$$

where

N_1 = Number of turns on the primary winding of the transformer;
N_2 = Number of turns on the secondary winding;
E_1 = Input voltage, V;
E_2 = Output voltage, V;
I_1 = Input current, A; and
I_2 = Output (load) current, A.

Taps in a transformer secondary winding may be used to change the number of turns in the secondary winding, as shown in Figure 1.3, to vary the open-circuit (no-load) output voltage. In this case, the tapped transformer permits the selection of the number of turns, N_2, in the secondary winding of the transformer. When the number of turns decreases on the secondary winding, output voltage is lowered because a smaller proportion of the transformer secondary winding is in use. The tap selection, therefore, controls the ac output voltage. As shown in Equation 1.1, the primary-secondary current ratio is inversely proportional to the primary-secondary voltage ratio. Thus, large secondary welding currents can be obtained from relatively low line input currents.

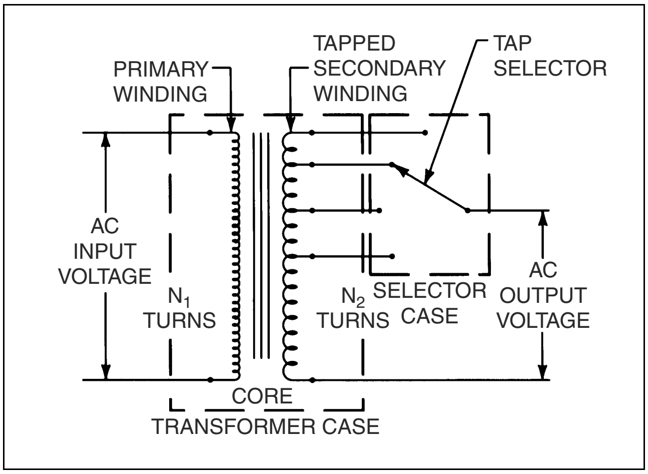

Figure 1.3—Welding Transformer with Tapped Secondary Winding

SERIES REACTOR

A transformer may be designed so that the tap selection directly adjusts the output volt-ampere slope characteristics for a specific welding condition. More often, however, an impedance source is inserted in series with the transformer secondary windings to provide this characteristic, as shown in Figure 1.4. The impedance is usually a magnetic device called a *reactor* when used in an ac welding circuit and an *inductor* when used in a dc welding circuit. Reactors are constructed with an electrical coil wound around a magnet core; inductors are constructed with an electrical coil wound around a magnet core with an air gap.

Some types of power sources use a combination of these arrangements, with the taps adjusting the open-circuit (or no-load) voltage, E_O, of the welding power source and the series impedance providing the desired volt-ampere slope characteristics.

In constant-current power sources, the voltage drop across the impedance, E_X (shown in Figure 1.4) increases greatly as the load current is increased. This increase in voltage drop, E_X, causes a large reduction in the arc voltage, E_A. Adjustment of the value of the series impedance controls the E_X voltage drop and the relation of load current to load voltage. This is called *current control*, or in some cases, *slope control*. Voltage E_O essentially equals the no-load (open-circuit) voltage of the power source.

As shown in Figure 1.5, the series impedance in constant-voltage power sources is typically small, and the transformer output voltage is very similar to that required by the arc. The voltage drop, E_X, across the impedance (reactor) increases only slightly as the load current increases. The reduction in load voltage is small. Adjustment in the value of reactance gives slight control of the relation of load current to load voltage.

This method of slope control, with simple reactors, also serves as a method to control voltage with saturable reactors or magnetic amplifiers. Figure 1.5 shows an ideal vector diagram of the relationship of the alternating voltages for the circuit of Figure 1.4, when a reactor is used as an impedance device. The no-load voltage equals the voltage drop across the impedance plus the load voltage when these are added vectorially. Vectorial addition is necessary because the alternating load and impedance voltages are not in time phase. In Figure 1.5, the open-circuit voltage of the transformer is 80 V, the voltage drop across the reactor is 69 V and the arc load voltage is 40 V.

The voltage drop across the series impedance, E_X, in an ac circuit is added vectorially to the load voltage, E_A, to equal the transformer secondary voltage, E_O. By varying the voltage drop across the impedance, the load or

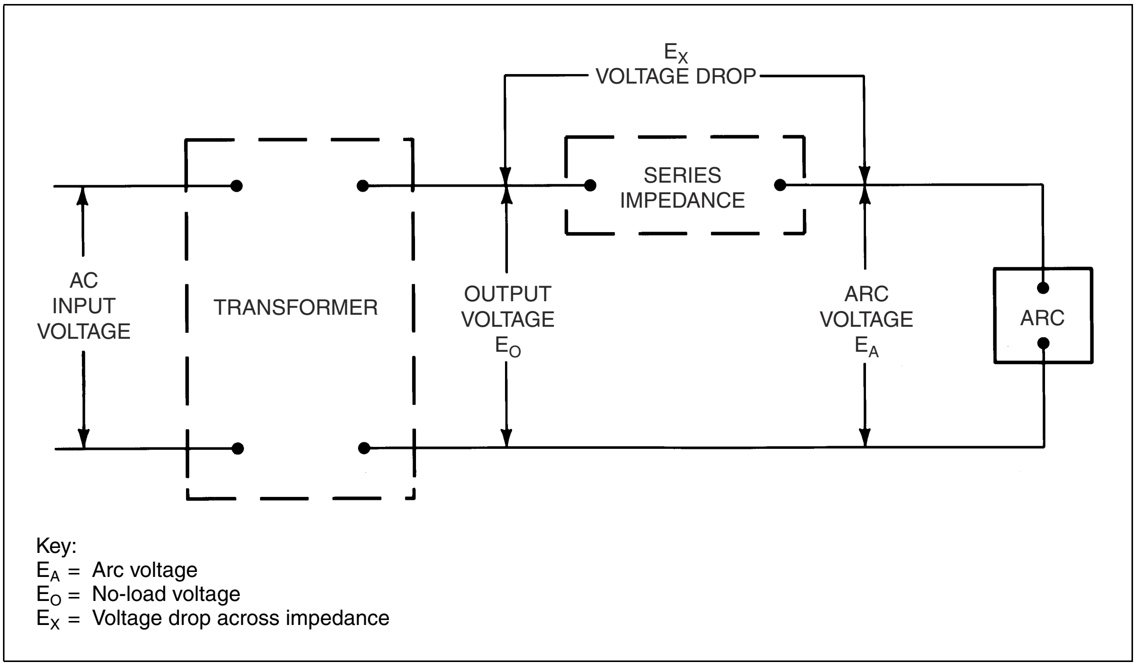

Figure 1.4—Typical Series Impedance Control of Output Current

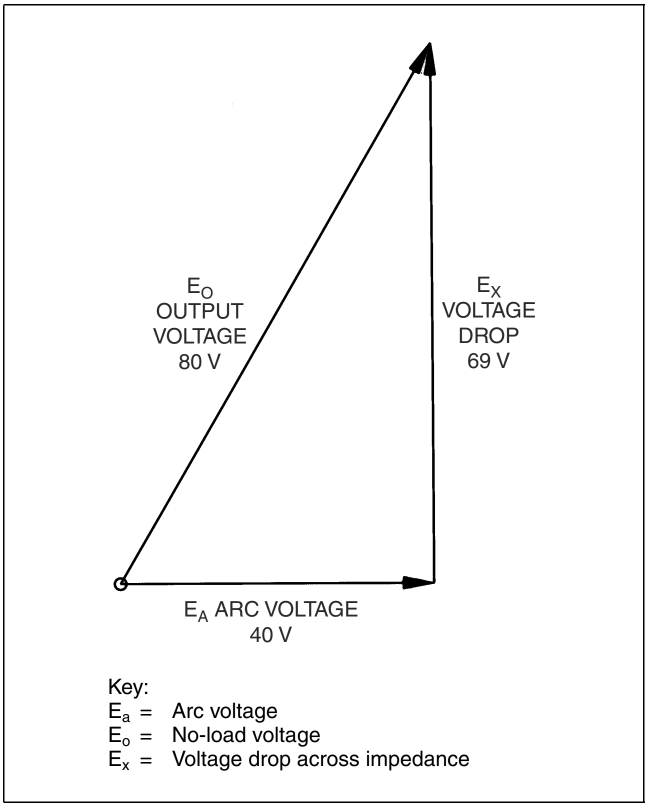

Figure 1.5—Ideal Vector Relationship of the Alternating-Voltage Output Using Reactor Control

arc voltage may be changed. This distinctive characteristic of vectorial addition for impedance voltages in ac circuits is related directly to the fact that both reactance and resistances may be used to produce a drooping voltage characteristic. An advantage of a reactor is that it consumes little or no power, even though a current flows through it and a voltage is developed across it.

When series resistors are used, power is lost and the temperature of the resistor rises. Theoretically, in a purely resistive circuit (no reactance), the voltage drop across the resistor could be added arithmetically to the load voltage to equal the output voltage of the transformer. For example, a power source with an approximately constant-current characteristic, an 80-V open circuit, and powering a 25-V, 200-A arc would need to dissipate 55 V 200 A, or 11,000 watts (W), in the resistor to supply 5000 W to the arc. The reason is that the voltage and current are in phase in the resistive circuit. A resistance and reactance circuit phase shift accounts for the greatly reduced power loss.

Another major advantage of inductive reactance is that the phase shift produced in the alternating current by the reactor improves ac arc stability for a given open-circuit voltage. This is an advantage with the GTAW and SMAW processes.

The inductive reactance of a reactor can be varied by several means. One way is by changing taps on a coil or by other electrical or mechanical schemes. Varying the reactance alters the voltage drop across the reactor. Thus, for any given value of inductive reactance, a specific volt-ampere curve can be plotted. This creates the required control feature of these power sources.

In addition to adjusting series reactance, the mutual inductance between the primary and secondary coils of a transformer can also be adjusted. This can be done by moving the coils relative to one another or by using a movable magnetic shunt that can be inserted or withdrawn from between the primary and secondary windings. These methods change the magnetic coupling of the coils to produce adjustable mutual inductance, which is similar to series inductance.

In ac/dc welding power sources incorporating a rectifier, the rectifier is located between the magnetic control devices and the output terminal. In addition, transformer-rectifier arc welding power sources usually include a stabilizing inductance, or choke, located in the dc welding circuit to improve arc stability.

GENERATOR AND ALTERNATOR

Rotating machinery is also used as a source of power for arc welding. These machines are divided into two types—generators that produce direct current and alternators that produce alternating current.

The no-load output voltage of a direct-current generator can be controlled with a relatively small variable current in the winding of the main or shunt field. This current controls the output of the direct-current generator winding that supplies the welding current. The output polarity can be reversed by changing the interconnection between the exciter and the main field. An inductor or filter reactor is not usually needed to improve arc stability with this type of welding equipment. Instead, the several turns of series winding on the field poles of the rotating generator provide more than enough inductance to ensure satisfactory arc stability. These generators are described in greater detail in following sections of this chapter.

An alternator power source produces alternating current that is either used in that form or rectified into direct current. It can use a combination of the means of adjustment previously mentioned. A tapped reactor can be employed for gross adjustment of the welding output, and the field strength can be controlled for fine adjustment.

SOLID-STATE DIODES

The term *solid-state* is related to solid-state physics and the study of crystalline solids. Methods have been developed for treating crystalline materials to modify their electrical properties. The most important of these materials is silicon.

Transformer-rectifier and alternator-rectifier power sources rely on rectifiers, or groups of diodes, to convert alternating current to direct current. In earlier times, welding circuits relied on vacuum tube and selenium rectifiers, but most modern rectifiers are made of silicon for reasons of economy, current-carrying capacity, reliability, and efficiency.

A single rectifying element is called a *diode*, which is a one-way electrical valve. When placed in an electrical circuit, a diode allows current to flow in one direction only, when the anode of the diode is positive with respect to the cathode. Using a proper arrangement of diodes, it is possible to convert alternating current to direct current. An example of a diode symbol and a stud diode is shown in Figure 1.6.

As current flows through a diode, a voltage drop across the component develops and heat is produced within the diode. Unless this heat is dissipated, the diode temperature can increase enough to cause failure. Therefore, diodes are normally mounted on heat sinks (aluminum plates, many with fins) to remove the heat.

Diodes have limits as to the amount of voltage they can block in the reverse direction (anode negative and cathode positive). This is expressed as the voltage rating of the device. Welding power-source diodes are usually selected with a blocking rating at least twice the open-circuit voltage in order to provide a safe operating margin.

A diode can accommodate repetitive current peaks well beyond its normal steady-state rating, but a single high reverse-voltage transient will damage it. Most rectifier power sources have a resistor, capacitor, or other electronic devices, commonly called *snubber networks*, to suppress voltage transients that could damage the rectifiers.

SILICON-CONTROLLED RECTIFIER (THYRISTOR)

Solid-state devices with special characteristics can also be used to control welding power directly by altering the welding current or voltage wave form. These solid-state devices have replaced saturable reactors, moving shunts, moving coils, and other systems as control elements in large industrial power sources. One of the most important of these devices is the silicon-controlled rectifier (SCR), sometimes called a *thyristor*.

The SCR is a diode variation with a trigger, called a *gate*, as shown in Figure 1.7. An SCR is non-conducting until a positive electrical signal is applied to the gate. When this happens, the device becomes a diode and conducts current as long as the anode is positive with respect to the cathode. However, once it conducts, the current cannot be turned off by a signal to the gate. Conduction ceases only if the voltage applied to the anode becomes negative with respect to the cathode. Conduction will not take place again until a positive voltage is applied to the anode and another gate signal is received.

Silicon-controlled rectifiers are used principally in the phase-control mode with isolation transformers and in some inverter configurations. The output of a welding power source can be controlled by using the action of a gate signal to selectively turn on the SCR. A typical single-phase SCR circuit is shown in Figure 1.8.

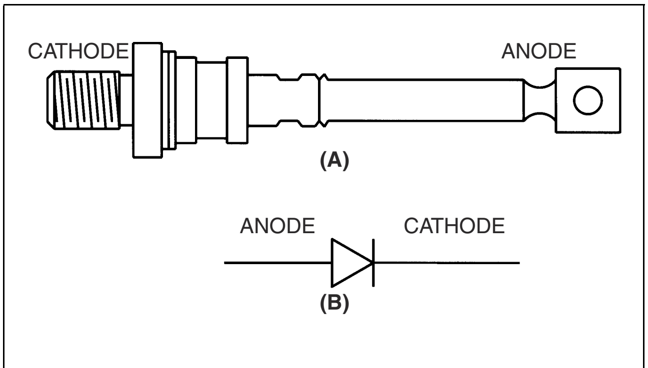

Figure 1.6—Stud Diode (A) and Diode Symbol (B)

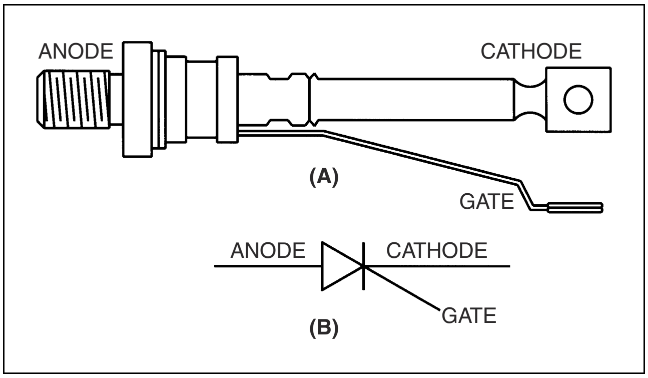

Figure 1.7—Silicon-Controlled Rectifier (A) and Silicon-Controlled Rectifier Symbol (B)

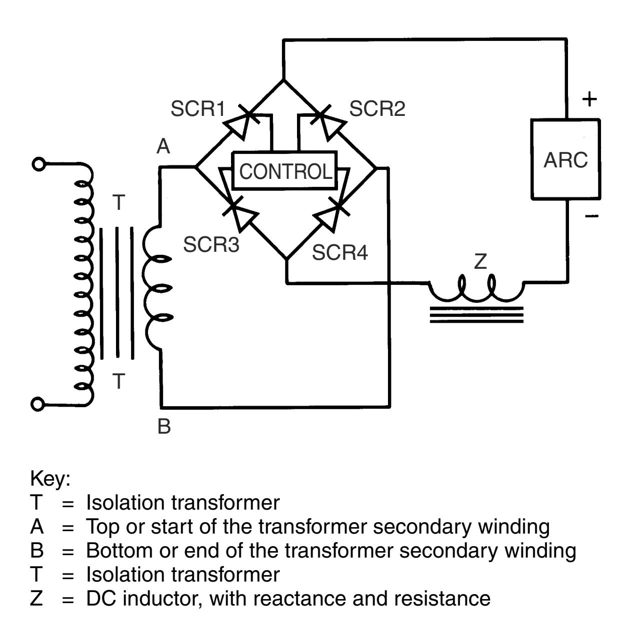

Figure 1.8—Single-Phase Direct-Current Power Source Using an SCR Bridge for Control

In Figure 1.8, during the time that Point A is positive with respective to Point B, no current will flow until both SCR 1 and SCR 4 receive gate signals to turn on. At that instant, current will flow through the load. At the end of that half-cycle, when the polarity of A and B reverses, a negative voltage will be impressed across SCR 1 and SCR 4, and they will turn off. With Point B positive relative to Point A, gate signals applied to SCR 2 and SCR 3 by the control will cause these two to conduct, again applying power to the load circuit. To adjust power in the load, it is necessary to precisely time when, in any given half-cycle, the gate triggers the SCR into conduction. With a 60-hertz (Hz) line frequency, this arrangement produces direct current with a 120-Hz ripple frequency at the arc or load.

The timing of the gate signals must be precisely controlled. This is a function of the control block shown in Figure 1.8. To adapt the system satisfactorily for welding service, another feature, feedback, is necessary. The nature of the feedback depends on the welding parameter to be controlled and the degree of control required. To provide constant-voltage characteristics, the feedback (not shown) must consist of a signal that is proportional to arc voltage. This signal controls the precise arc voltage at any instant so that the control can properly time and sequence the initiation of the SCR to hold a voltage pre-selected by the operator. The same effect is achieved with constant current by using feedback and an operator-selected current.

Figure 1.8 shows a large inductance, Z, in the load circuit. For a single-phase circuit to operate over a significant range of control, Z must be a large inductance to smooth out the voltage and current pulses. However, if SCRs were used in a three-phase circuit, the non-conducting intervals would be reduced significantly. Since three times as many output pulses are present in any time period, the inductance would also be significantly reduced.

When high power is required, conduction is started early in the half-cycle, as shown in Figure 1.9(A). If low power is required, conduction is delayed until later in a half-cycle, as shown in Figure 1.9(B). This is known as *phase control*. The resulting power is supplied in pulses to the load and is proportional to the shaded areas in Figure 1.9 under the wave form envelopes. Figure 1.9 illustrates that significant intervals may exist when no power is supplied to the load. This can cause arc outages, especially at low power levels. Therefore, wave filtering is required.

Most intermediate-sized or commercial SCR phase-controlled welding power sources are single-phase. Larger industrial SCR phase-controlled power sources are three-phase. Single- and three-phase power sources are the constant-current or constant-voltage type. Both constant-current and constant-voltage types have distinct features because the output characteristics are controlled electronically. For example, automatic line-voltage compensation is very easily accomplished, allowing welding power to be held precisely as set, even if the input line voltage varies. Volt-ampere curves can also be shaped and adapted for a particular welding process or its application. These power sources can adapt their static characteristic to any welding process, from one approaching a truly constant voltage to one having a relatively constant current. They are also capable of producing a controlled pulsed arc voltage and a high initial current or voltage pulse at the start of the weld.

An SCR can also serve as a secondary contactor, allowing welding current to flow only when the control allows the SCRs to conduct. This is a useful feature in rapid cycling operations, such as spot welding and tack welding. However, an SCR contactor does not provide the electrical isolation that a mechanical contactor or switch provides. Therefore, a primary circuit breaker or some other device is required to provide isolation for electrical safety.

Several SCR configurations can be used for arc welding. Figure 1.10 depicts a three-phase bridge with six SCR devices. With a 60-Hz line frequency, this arrangement produces direct current, with a 360-Hz ripple frequency at the load. It also provides precise control and quick response; in fact, each half-cycle of

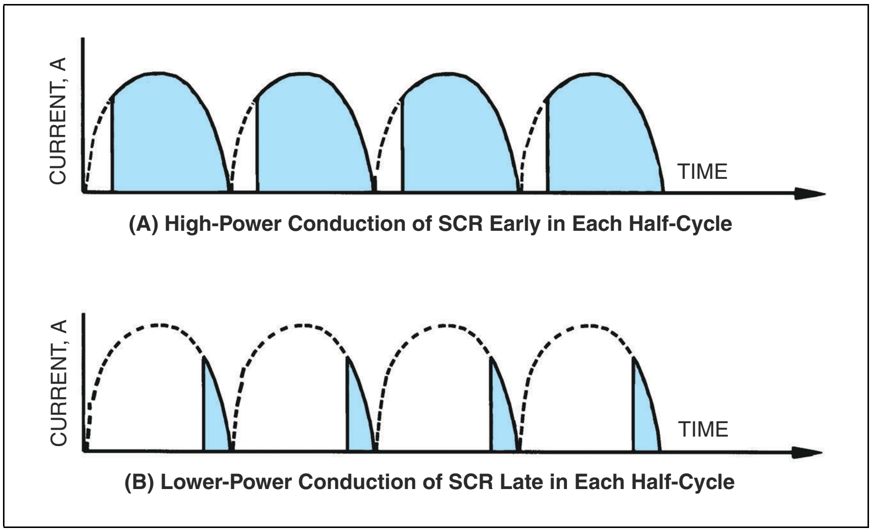

Figure 1.9—Phase Control Using an SCR Bridge

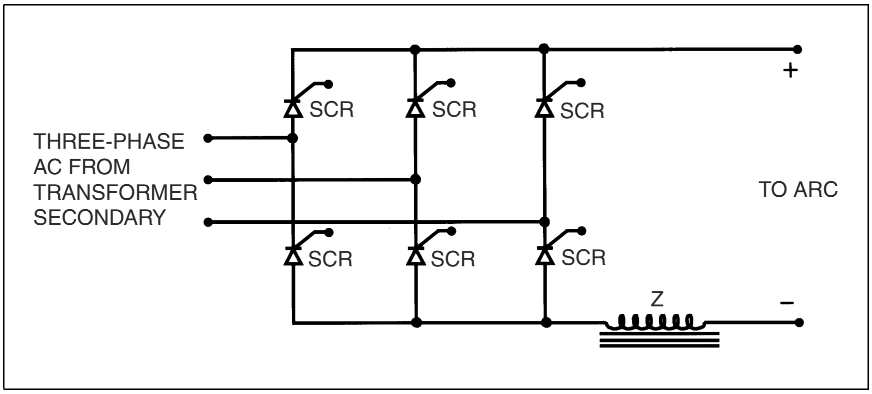

Figure 1.10—Three-Phase Bridge Using Six SCRs (Full-Wave Control)

each of the three-phase output is controlled separately. Dynamic response is enhanced because of the reduced size of the inductor needed to smooth out the welding current.

Figure 1.11 is a diagram of a three-phase bridge rectifier with three diodes and three SCRs. Because of greater current ripple, this configuration requires a larger inductor than the six-SCR unit. For that reason it has a slower dynamic response. A fourth diode, termed a *freewheeling diode*, can be added to recirculate the inductive currents from the inductor so that the SCRs will turn off, or commutate. This offers some economic advantage over the six-SCR unit because it uses fewer SCRs and a lower-cost control unit.

TRANSISTORS

The transistor is another solid-state device used in welding power sources. Transistors differ from SCRs in several ways. First, conduction through the device is proportional to the control signal applied. With no signal, no conduction occurs. The application of a small signal from base to emitter produces a correspondingly small conduction; likewise, a large signal results in a correspondingly large conduction. Unlike the SCR, the control can turn the device off without waiting for polarity reversal or an off time. Since transistors lack the current-carrying capacity of SCRs, several may be required to yield the output of one SCR.

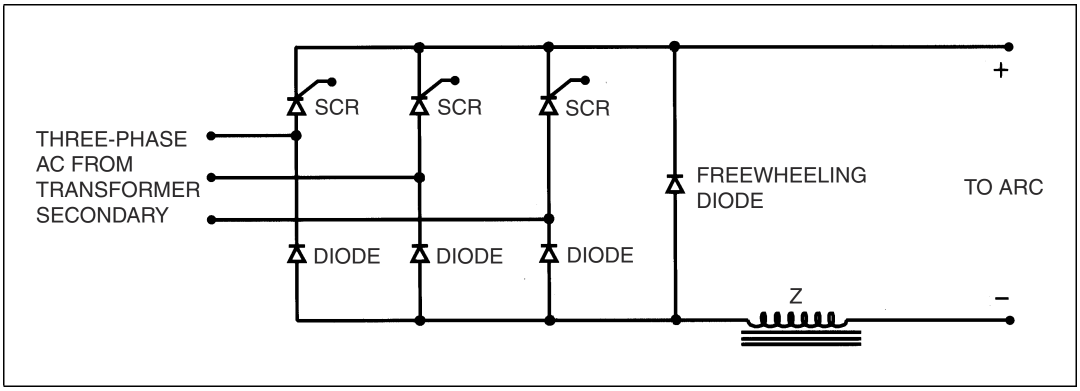

Figure 1.11—Three-Phase Hybrid Bridge Using Three SCRs and Four Diodes (Half-Wave Control)

Several methods can be used to take advantage of transistors in welding power sources. These include frequency modulation or pulse-width modulation. With frequency modulation, the welding current is controlled by varying the frequency supplied to a high-frequency transformer. Since the frequency is changing, the response time varies also. The size of the transformer and inductor must be optimized for the lowest operating frequency. With pulse-width modulation, varying the conduction time of the switching device controls welding current output. Since the frequency is constant, the response time is constant and the magnetic components can be optimized for one operating frequency.

Inverter circuits control the output power using the principle of time-ratio control (TRC) also referred to as *pulse-width modulation* (PWM). The solid-state devices (semiconductors) in an inverter act as switches; they are either switched on and conducting, or switched off and blocking. The function of switching on and off is sometimes referred to as *switch-mode operation*. *Time-ratio control* is the regulation of the on and off times of the switches to control the output. Figure 1.12 illustrates a simplified TRC circuit that controls the output to a load such as a welding arc. It should be noted that conditioning circuits include components such as a transformer, a rectifier, and an inductor, as represented previously in Figure 1.8.

SOLID-STATE INVERTER

An inverter is a circuit that uses solid-state devices called *metal oxide semiconductor field effect transistors* (MOSFETs), or *integrated gate bi-polar transistors* (IGBTs), to convert direct current into high-frequency ac, usually in the range of 20 kHz to 100 kHz. Conventional welding power sources use transformers operating from a line frequency of 50 Hz or 60 Hz.

Since transformer size is inversely proportional to line or applied frequency, reductions of up to 75% in power source size and weight is possible using inverter circuits. Inverter power sources are smaller and more compact than conventional welding power sources. They offer a faster response time and less electrical loss.

The primary contributors to weight or mass in any power source are the magnetic components, consisting of the main transformer and the filter inductor. Various efforts have been made by manufacturers to reduce the size and weight of power sources, for example, substituting aluminum windings for copper.

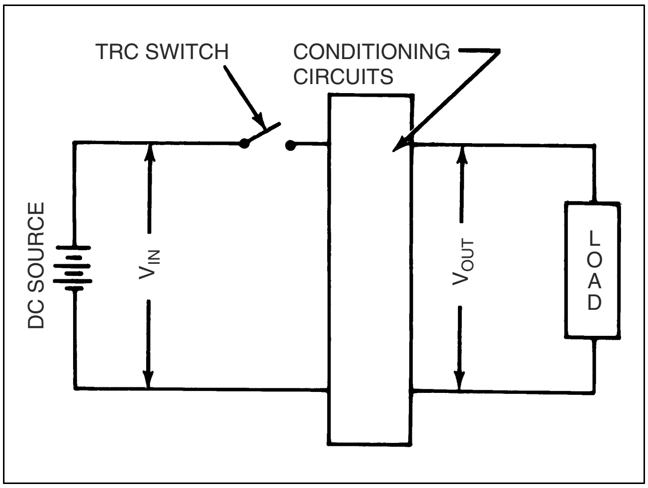

Figure 1.12—Simplified Diagram of an Inverter Circuit Used to Demonstrate the Principle of Time-Ratio Control (Pulse Width Modulation)