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Gas Metal Arc Welding – Simplified Perspective of Power Sources (Part I)

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Abstract

Gas Metal Arc Welding (GMAW), also known as Metal Inert Gas (MIG) Welding, has evolved over the years and a significant volume of welding is carried out by this process. The AC/DC transformer-rectifier with different control systems have been the most sought-after power sources and has served majority of the manufacturing requirements in recent times. The latest inverter based GMAW power sources with enhanced features have led to more advancements in welding technology, be it functional efficiency or welding of relatively difficult materials, joint configurations, and weld positions. This article intends to give a clarity about some of the modern power sources, their design and characteristics, and some special features that are aligned to industry needs. Part I of the article would essentially cover welding machine systems, while the subsequent parts would delve with the benefits that modern welding machines provide in to address material and manufacturing issues.

Keywords: GMAW, Power Sources, Transformer-Rectifier, Flat Characteristics, Metal Transfer

1.0 Introduction

The gas metal arc welding (GMAW) process has been in use since World War II. In the early years the primary tap AC transformers and DC generators were the main power sources used for GMAW. The AC/DC transformer-rectifier power sources became attractive after 1970. The power source is the most vital part of the welding system that produces the electrical conditions by which sufficient heat is generated at the weld joint. A stable arc ensures metal transfer from the consumable electrode to the job for proper welding to take place. As welding happens at high current values in the range of 50-600A and at relatively low voltages of 10-40V, the power sources are designed to reduce the mains voltage of 440V to operational levels. Over several years the DC output has been preferred for high quality weld joints (**Fig. 1**). While DC generators are still used for certain applications, the AC/DC rectifiers are cost effective and meet most weld quality and operational requirements [1]. The current generation of GMAW machines has been able to overcome several limitations that the primary tapped machines had with restricted tuning options for controlling the output power fluctuations. The arc stability and transfer mechanism in GMAW is enabled by the flat (i.e., constant voltage) characteristics of the power source. All variants of transformer-rectifier or the more recent inverter machines are designed and build to deliver flat characteristics. A variety of sophisticated solid state control devices have been introduced to maintain the output parameters very close to the theoretical current-voltage (I-V) characteristic line, particularly at low current values.

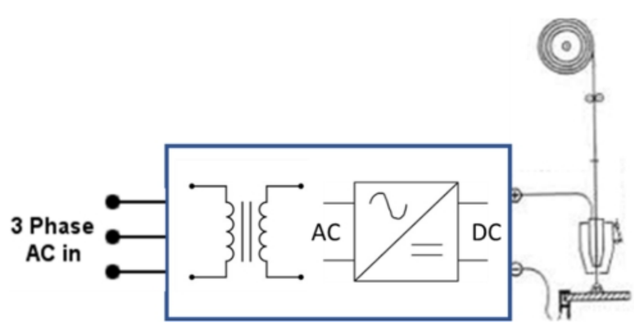


Fig. 1 : A GMA welding transformer rectifier

In the early years of transformer-rectifier sets there were certain process limitations for wider variety of applications. The critical points of concern were: (i) excessive spatter during short circuit mode of metal transfers, (ii) erratic arc stability at low current values, (iii) structural and metallurgical joint quality, (iv) tolerance to large joint gaps, and (v) ability for positional welding. Several of these points are interrelated. Subsequently, power source developments have happened to address these issues. Some of the available variants, particularly the inverter systems with high-speed core electronics technology, demonstrate superior performance. To have better clarity about welding machine technology, it is key to discuss in a simple manner some of the basic electrical design features, output characteristics and their role with respect to metal transfer that has led to significant improvement in weld quality.

2.0 Classification of AC/DC Power Sources

These power sources can be broadly classified as [2]:

(i) Transformer-Rectifier (with different controls viz. saturable reactor, thyristor).

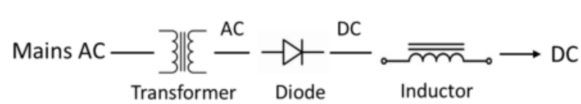
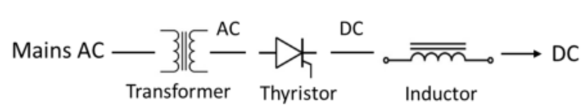
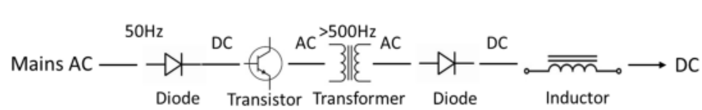
(ii) Inverter

The AC/DC transformer rectifiers are extensively used in fabrication industry as they cost less and produce stable arc with good quality welds. The type of electronics components in different type of rectifiers are shown schematically in **Table 1** [3]. While diodes are used for rectification purpose, inductors stabilize the arc by restricting large current variations during different modes of metal transfer, i.e., different output current values. Types of control, such as saturable reactor, or thyristor, are critical entities of a power source. Saturable reactor, also called magnetic amplifiers, is a controller that proportionally and remotely controls the AC output of the transformer by a DC current passing through a coil wound around the magnetic core during welding. The control winding is well isolated from the AC power. Saturable reactors have multiple taps as the inductance is varied based on output current requirements. Small inductance for higher current and large inductance for small current output. Since these reactors are bulky and expensive, they have been replaced by thyristor control. Thyristors provide solid state AC phase control, by which the output voltage and current are continuously adjusted and is independent of any variations in the mains input voltage.

Inverter power sources offer all the advantages of thyristor control and provide additional performance. Aided by a series of electronic components, they are light in weight and have high efficiency [4]. Rectifiers and semiconductors (IGB transistors) are used to convert mains AC current of 50Hz to medium frequency (>500Hz) AC current, as shown against inverter in **Table 1**. The high frequency current is then transformed down to a suitable voltage and then rectified to DC output for welding purpose. The solid-state power circuits used for regulating the output parameters have replaced the reactors used in conventional power sources.

IGBTs, the latest in transistor technology, are high-speed switching devices which facilitate voltage regulation and are the heart of all world class welding inverters. They are less vulnerable to mains fluctuations, more reliable and robust ensuring long term performance with negligible failure. In modern inverter machines, an interfacing software accurately controls the parameters and offers multi-process capability. The transistors act as variable resistance in response to command signals and allow feedback control for regulating the parameters. The quick response of inverters allows for high frequency pulsing (up to microseconds) required for pulsed GMAW and continuous high-speed feedback to control metal

Table 1 : Simplified circuit diagram of modern AC/DC power sources

Type of m/c	Circuit
Transformer – Rectifier	
Transformer – Rectifier (Thyristor)	
Inverter	

transfer in short circuit mode, details of which is discussed in the next section. The inductor in the circuit helps controls the dynamic characteristics by moderating the current rise as the voltage changes instantaneously, particularly when short circuiting happensas schematically demonstrated in **Fig. 2**.

with the flat characteristics. Synergic curve has been developed to make it operator friendly so that the output current value is automatically assigned by setting the wire feed speed.

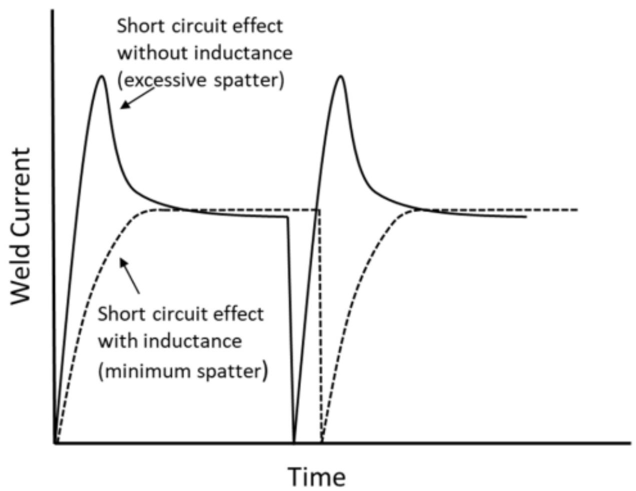


Fig. 2 : Role of inductance during short circuit metal transfer [5]

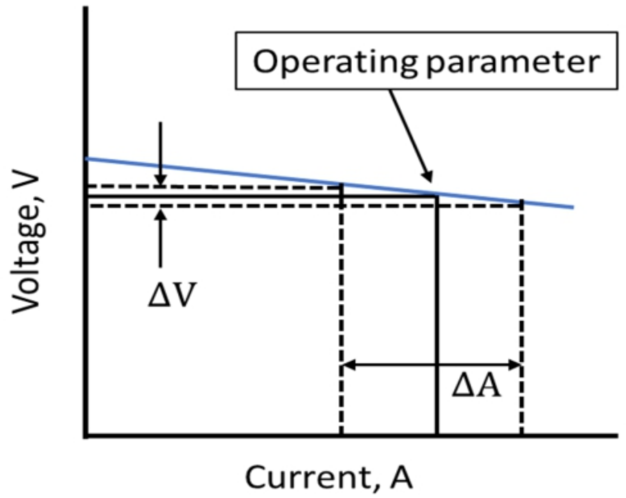


Fig. 3 : Flat characteristic (constant voltage) in GMAW power source

3.0 Power Source Characteristics and Metal Transfer Modes

Static Characteristics

The GMAW machines are designed to deliver flat (or constant voltage) output characteristics to meet the requirements of the process [6]. The I-V relationship is given in **Fig. 3**. The said characteristic is the vital feature that ensures a wide range of welding current with a very small variation in voltage (2-5V). Such characteristics ensure precise control on the arc length with continuously fed filler wire at constant speed. The voltage can be set in the control panel of the power source and the current varied by changing the wire speed.

When such a power source is used in conjunction with a wire feeding system, a self-regulating mechanism is set in to keep the arc length constant. Any change in welding parameters due to fluctuating outputs will either increase or decrease the melting rate at the wire tip and maintain the necessary arc length for stable welding. Good flat characteristics have a shallow slope, which allows for bulk of the heat variation required for melting of the consumable wire by appropriate adjustment of current rather than the voltage. Most available GMAW systems have synergic software control, wherein the microprocessor in the welding set uses the wire speed to select the optimum voltage from a database of I-V value agreement

The GMAW process has gone through several technological advancements in equipment design primarily to address the issues mentioned earlier. Most of the focus has been to control the transfer of molten metal from the consumable wire to the weld pool. The mode of transfer depends on the operating features of the machine. The three principal metal transfer modes linked to static characteristics are:

i. Short circuiting
ii. Droplet
iii. Spray

The metal transfer modes have been extensively covered in numerous papers and books [2, 7-8]. Spray and droplet transfer were the primary discussion points in the initial times of GMAW process as it was mostly used for welding thick steel plates under high heat input conditions. Later, the need for low heat input welding was felt necessary, thereby short-circuiting (or dip) mode of transfer has assumed great importance [1]. The welding current heats the wire until it begins to melt in the arc. At the lower current regimes, the arc is weak and hence melting is delayed. As a result, when the electrode tip touches the weld pool short circuiting occurs and the arc extinguishes. Consequently, the voltage decreases and the current increases causing the molten droplet to be released by the surrounding electromagnetic force. Subsequently, the arc reignites when the contact between the wire and the weld pool is broken. The cycle is repeated with frequency of 50 to 150Hz. Low current (i.e., low heat input) and a small wire diameter together with repeated short-circuiting makes the process suitable for joining thin sheet and positional welding. However, for this precise control of the welding current is necessary. Conventional power sources result in high spatter level associated with the fluctuations of the current and voltage cycle at low heat-inputs. The most recent digitally controlled power sources deliver precise output parameter, which has helped to overcome these problems and have brought in major improvements in GMA welding capabilities.

Dynamic Characteristics

For certain applications a combination of all the transfer modes were thought to be beneficial in one setting, and that led to the development of pulse welding with pulse mode of metal transfer. The new generation machines demonstrate dynamic characteristics, where many of the newer waveform control technology is made possible using a combination of software and hardware interfacing. Dynamic characteristic represents the rapid transient variation of output current and voltage and is reflected through a pulsed profile given in **Fig. 4**. As a matter of fact, power sources with good dynamic characteristics continuously monitor at extremely fast rates the rapidly changing voltage and current to produce very stable arc welding conditions. Thus, melting, metal transfer and metal deposition happen in an appropriate manner. Feedback control is an essential feature for maintaining a consistent and precise output through in-process corrective action using solid state electronic devices.

In GMAW pulsed welding, spray transfer takes place at current values above the transition current. However, the pulse parameter sort of regulate spray transfer in a restrained manner as the waveform varies in from a high peak level to a low background level, and the pattern is repeated constantly for the period of welding. Although the current amplitude is high with a low operating voltage, the low average current helps in maintaining a significantly low heat-input as compared to normal GMAW. The surface tension of the molten metal at the electrode tip associated with weakening magnetic force (i.e., pinch effect) leads to droplet formation that is transferred through the pulsed arc. Pulse current and current density must be sufficiently high to enable spray transfer of droplets for positional welding. During pulse welding a single droplet is projected through the arc gap at a frequency of 50-300 pulses. Pulse spray with high current amplitude and low background current has finger type high penetration and facilitates complete fusion even while welding thick plates [8-9].

In pulsed mode the current is varied between the background current and peak current at a specific time interval. The background current ensures that the metal remains in molten state under nominal arc ignition condition with no metal transfer between electrode and job. Melting occurs as the current is increased to peak values. This makes it suitable for joining thin sheet and positional welding, where precise control of the arc is essential.

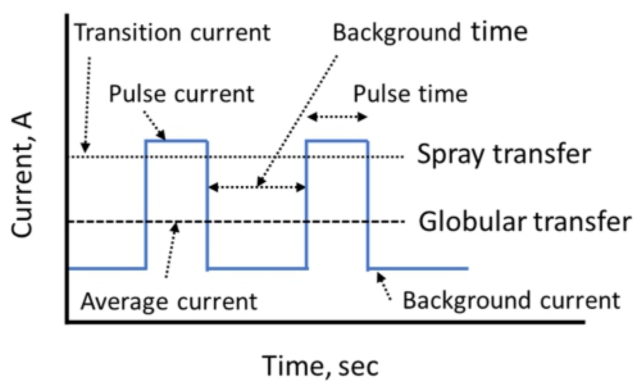


Fig. 4 : Pulsed spray transfer current waveform

Table 2 : Summary of metal transfer

Sl. No.	Mode of Metal Transfer	Description
1	Spray	Fine uniform droplets; high heat-input
2	Globular	Coarse droplets; medium heat-input
3	Short-circuit	Irregular coarse droplets; low heat-input
4	Pulsed	Fine droplets; low heat-input

In more recent times the evolution of adaptive pulse GMAW, the power sources are designed to adjust parameter variations through high-speed electronics. This enables a broad range of spray and short circuit metal transfer, and close control of heat-input has improved the weld quality and process efficiency [10-11].

4.0 Inverter Power Sources and Associated Technology

Recent developments in inverter technology with electronic control have enhanced process capability for producing high quality welds. While conventional GMAW machines rely on large transformers to regulate the voltage of identical frequency as the mains, inverter machines use diodes and transistors to convert the power into medium frequency AC waves prior to converting through the step-down transformer. This has been the game changing technology of inverter machines. On further rectification the output voltage is precisely controlled and experiences negligible disturbances. Much use of advanced electronic devices has significantly lowered the weight of the welding machines, increased efficiency because of smaller transformer size, enhanced the duty cycle, delivers consistent DC output, has superior performance, and provides additional functions.

There have been many developments by welding machine manufacturers to improve process stability and reduce spatter. Spatter is associated with droplet detachment with rise of current rise; the rate of current rise at that stage being critical. Therefore, equipment manufacturers have attempted to resolve this issue by closely maintaining the current profile, and thereby lowering heat input variation. Most digital power sources precisely regulate the waveform through subtle variation of the electronic circuit design with the help of an interfacing software. Few examples of such systems include the Cold Metal Transfer (CMT), ColdArc, Surface Tension Transfer (STT), Regulated Metal Deposition (RMD), FastROOT and QSet processes [11]. Whilst each demonstrates specific current profile characteristics, all rely on arresting the current increase soon short circuiting takes place. As a result, arc re-ignition takes place in a more controlled manner than conventional short-circuiting mode of transfer [12]. Therefore, thin sheets as low as 0.3 mm can be joined by reducing the heat input by 5-30% with negligible spatter. Also, large gap up to 4.8mm can be bridged using similar parameters (1).

Recent inverter machines come with anti-interference and have a lower probability of temperature changes and voltage

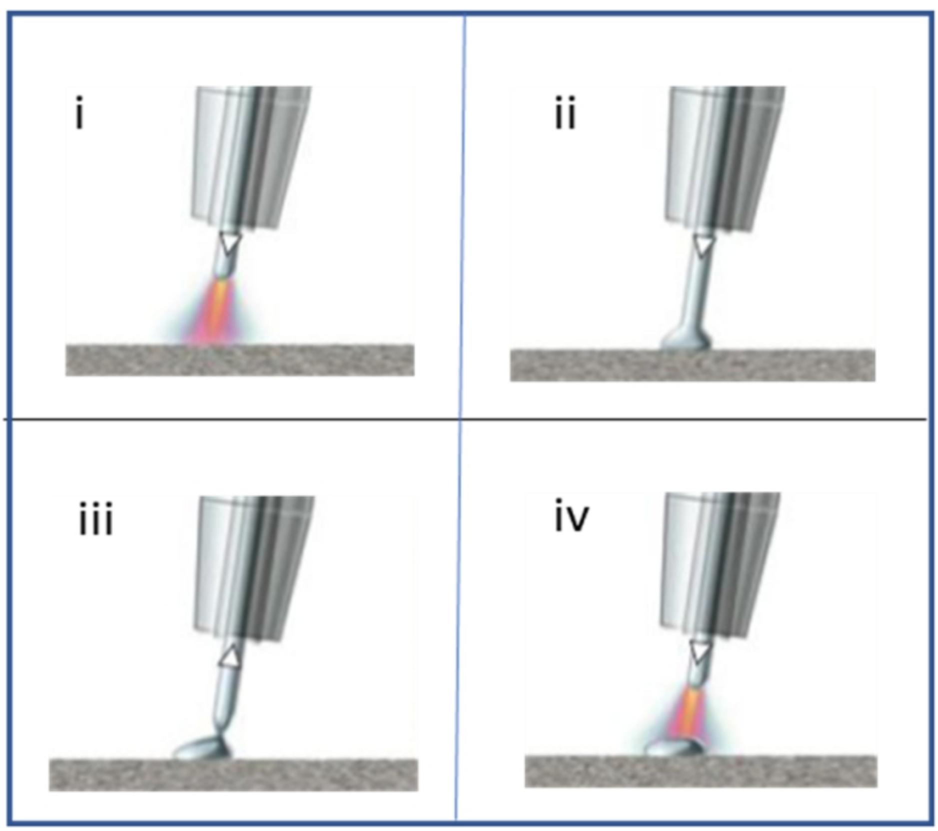


Fig. 5 : Wire feed control stages in the CMT process [13]

fluctuations. They can maintain a constant current flow and therefore produces a more stable arc. Inverter machines, with IGBT, can quickly gather power using insulated gate bipolar transistor technology. The inverter switch also operates fast and uses less energy during welding, which makes it effective. When compared to a transformer welder, an inverter welding machine uses half the amperes to get similar voltage, i.e., flat characteristics with shallow slope.

Along with the inverter power sources, development of other hardware parts have largely improved the performance of the system. The second generation CMT system, which combines motion control of the wire through a specially designed push-pull welding gun aids in droplet formation and disassociation (**Fig. 5**). As the arc is ignited, the wire is fed towards the job [**Fig. 5(ii)**]. The wire is momentarily withdrawn by the gun mechanism soon short circuiting occurs [**Fig. 5(iii)**]. The surface tension of the liquid droplet during detachment in the molten pool results in fall of current to very low levels with reduced heat input. Hence spatter generation is minimized. Once the short circuit is broken and the arc re-established, the wire is again fed into the weld pool at normal speed [**Fig.5(iv)**]. As the wire feeding is synchronized with the electrical parameters, a random process cycle causes oscillation of around 70Hz [1]. This is an add-on to power source capability and has enhanced the scope of large number of welding applications.

5.0 Summary

1. Electrical design with advanced electronic hardware, viz. diode-rectifier, transistor, and inductor, in modern AC/DC power sources has prevented large current variation during different modes of metal transfer. Control hardwares, like thyristor, adjust the output parameters independent of the mains voltage in transformer-rectifier machines.
2. An inverter welding machine converts alternate current to a lower usable voltage output. The primary power supply frequency is increased from low (50Hz) to medium values (10-20khz) by diodes and transistors prior to transformer entry, and therefore precise output regulation after rectification becomes convenient. This has been a game changing technology in the development of adaptive GMAW power sources.
3. Modern power sources are equipped with synergic software control, which helps to select the appropriate welding current (I) and voltage (V) combination from a I-V data base corresponding to constant voltage characteristics just by assigning a wire feed speed in the power source panel. For pulse welding, waveform control technology is adopted by interfacing the user software with the machine hardware.
4. Maintaining a stable arc by restricting rapid rate of current increase during short circuit metal transfer to minimize spatter has been a key development in the latest adaptive GMAW power sources. This has enabled in producing high quality welds using low heat-input in thin sheets. Further, ability of large gap and positional welding has improved by applying short circuit mode parameters.
5. Push-pull technology in the welding torch controls the motion of electrode wires in sync with the processing parameters for precise molten metal droplet formation, detachment, and release during low heat-input welding by the CMT process. Thereby, spatter, burn-through and heat effects to the work piece material are significantly reduced.

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