International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Research Article

Design of Gas Tungsten Arc Welding Power Supply using Power Electronic Transformer for Steel and AluminiumWelding

R.Shiju Kumar[a] and T.Ruban Deva Prakash[b*]

[a]Sathyabama University, Chennai ,Tamilnadu India
[b]Sree Narayana Gurukulam College of Engineering, Kollenchery, Kerala

Accepted 10 October 2013, Available online 19 October 2013, **Vol.3, No.4 (October 2013)**

Abstract

Welding power supply is a device that supplies high current at low voltages in the range of 50V. Gas tungsten arc welding draws low current in the range of 5A. Gas tungsten arc welding machine operates with dc supply for steel welding and operates with 150Hz rectangular wave ac supply for aluminium welding to avoid oxidation and better welding quality. Welding power supply has constant current or constant voltage operation. This paper deals with constant voltage welding power supply. Conventional welding power supplies are transformer style or IC engine/motor driven generator style or inverter style devices. Harmonics, low power factor and transient disturbance are the major problems with conventional welding power supply. Recently, power electronic transformer gains importance due to reduced size and weight in many applications. Traditional power electronic transformer with its power quality analysis is presented in this paper. This paper also proposes a novel modular power electronic transformer based dc welding power supply for gas tungsten arc welding of steel. Modular topology based on dc-dc buck converter is used for the design. Also matrix converter power electronic transformer based ac welding power supply for gas tungsten arc welding of aluminium is proposed in this paper. DC link in input side is eliminated using 3-phase to 1-phase matrix converter. A simple control method for the matrix converter is explained in this paper. Performance is validated by simulation studies. It if found that the input voltage and current has some harmonics, but much less than that of traditional power electronic transformer topologies.

Keywords: *Power quality, welding power supply, power electronic transformer, high frequency transformer, gas tungsten arc welding, steel and aluminium welding.*

1. Introduction

A welding power supply is a device that provides an electric current to perform welding. Welding usually requires high current (over 80 amperes) and it can need above 12,000 amperes in spot welding. Low current can also be used; welding two razor blades together at 5 amps with gas tungsten arc welding is a good example. A welding power supply can be as simple as a car battery and as sophisticated as a modern machine based on silicon controlled rectifier technology with additional logic to assist in the welding process. Welding machines are usually classified as constant current (CC) or constant voltage (CV); a constant current machine varies its output voltage to maintain a steady current while a constant voltage machine will vary its output current to maintain a set voltage. Shielded metal arc welding and gas tungsten arc welding will use a constant current source and gas metal arc welding and flux-cored arc welding typically use constant voltage sources but constant current is also possible with a voltage sensing wire feeder.

The nature of the CV machine is required by gas metal arc welding and flux-cored arc welding because the welder is not able to control the arc length manually. If a welder attempted to use a CV machine to weld with shielded metal arc welding the small fluctuations in the arc distance would cause wide fluctuations in the machine's output. With a CC machine the welder can count on a fixed number of amps reaching the material to be welded regardless of the arc distance but too much distance will cause poor welding. A transformer style welding power supply converts the high voltage and low current electricity from the utility mains into a high current and low voltage, typically between 17 to 45 volts and 55 to 590 amps. A rectifier converts the AC into DC on more expensive machines. Welding power supplies may also use generators or alternators to convert mechanical energy into electrical energy. Modern designs are usually driven by an internal combustion engine but older machines may use an electric motor to drive an alternator or generator. In this configuration the utility power is converted first into

*Corresponding author: **T.Ruban Deva Prakash**

mechanical energy then back into electrical energy to achieve the step-down effect similar to a transformer. Since the advent of high-power semiconductors such as the insulated gate bipolar transistor (IGBT), it is now possible to build a switched-mode power supply capable of coping with the high loads of arc welding (Huang. N *et al*., 2005). These designs are known as inverter welding units. They generally first rectify the utility AC power to DC; then they switch (invert) the DC power into a step-down transformer to produce the desired welding voltage or current. The switching frequency is typically 10 kHz or higher. Although the high switching frequency requires sophisticated components and circuits, it drastically reduces the bulk of the step down transformer, as the mass of magnetic components (transformers and inductors) that is required for achieving a given power level goes down rapidly as the operating (switching) frequency is increased. The inverter circuitry can also provide features such as power control and overload protection (Khairy Sayed *et al*., 2011). The high frequency inverter-based welding machines are typically more efficient and provide better control of variable functional parameters than non-inverter welding machines (Jinhong Zhu *et al*., 2008). The IGBTs in an inverter based machine are controlled by a microcontroller, so the electrical characteristics of the welding power can be changed by software in real time, even on a cycle by cycle basis, rather than making changes slowly over hundreds if not thousands of cycles.

N.R. Mandal explained the distortion created by welding power supply (Mandal.N.R, 2009). Harmonics, low power factor and transient disturbance are the major problems with conventional welding power supply (ZHANG E.F. de Silva *et al*., 2011). Power factor corrected converter based welding power supply is also proposed in literature (Huang. N *et al*., 2005 and Khairy Sayed *et al*., 2011). Power quality improvement using three phase modular converter for welding power supply is proposed by Singh (Singh.B et.al., 2012). Recently power electronic transformer gains importance due to reduced size and weight (Hosseini.S.H *et al*., 2008). It is applied for electric traction, smart grid, wind electric generation, ship power supplies, welding power supplies etc (Wrede.H *et al*., 2002). Some topologies of power electronic transformer themselves act as source of power pollution (Sabahi.M *et al*., 2009). Power flow control, bidirectional power flow and power quality mitigation are added features of power electronic transformers. In this paper we propose a novel power electronic transformer based welding power supply for gas tungsten arc welding of steel and aluminium. Gas tungsten arc welding machine operates with dc supply for steel welding and operates with 150Hz rectangular wave ac supply for aluminium welding to avoid oxidation and better welding quality. Welding power supply has constant current or constant voltage operation. This paper deals with constant voltage welding power supply.

2. Power Electronic Transformer

Power electronic transformer gains importance due to its reduced size and weight. The principle of power electronic transformer is converting 50Hz ac to high frequency ac and given as input to a high frequency transformer and its output is converted back to 50Hz ac. It gains the advantage of reduction in size and weight due to high frequency transformer which also gives galvanic isolation and voltage transformation. Power flow control, bidirectional power flow and power quality mitigation are added features of modern power electronic transformers.

Different topologies of power electronic transformers are under research. In one approach 50Hz ac is converted into dc using diode bridge rectifier. The next stage consists of IGBT 3-leg, 6- pulse inverter which converts dc into 50 KHz ac. In between the two stages there is a dc link capacitor. A high frequency transformer is used for galvanic isolation and changing voltage levels. The 50 KHz ac output is converted to dc using diode bridge rectifier.

This is followed by dc link capacitor and inverter stage. The IGBT based voltage source inverter converts the dc to 50 Hz ac. The conventional welding transformer can be replaced by such power electronic transformer which reduces size and weight. Also it eliminates the current unbalance problem. The simulink model of this power electronic transformer is shown in Fig.1.

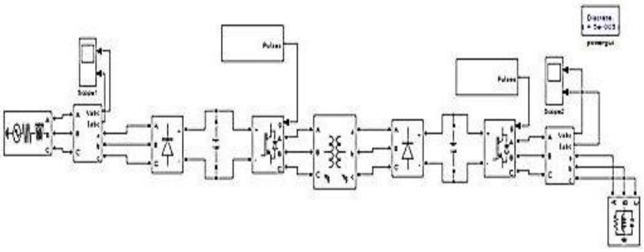


Fig. 1. Simulink model of power electronic transformer

3. Power Quality Analysis Of Power Electronic Transformer

The voltage and current waveform at the input side of the power electronic transformer explained in section-II is shown in Fig. 2.

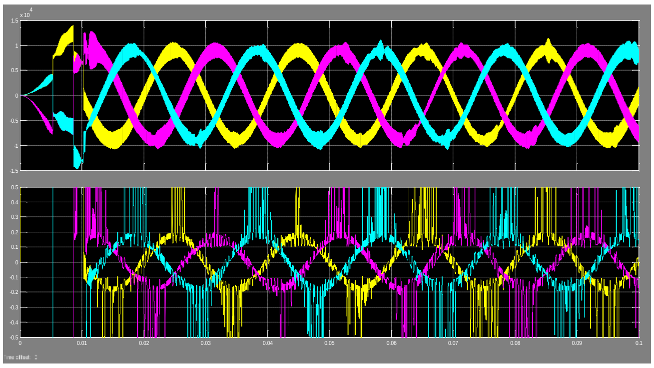


Fig. 2. Input voltage and current of power electronic transformer

From the figure, it is evident that the transient disturbances due to high frequency switching are very high especially in current waveform. The FFT analysis of the waveforms is shown in Fig. 3.

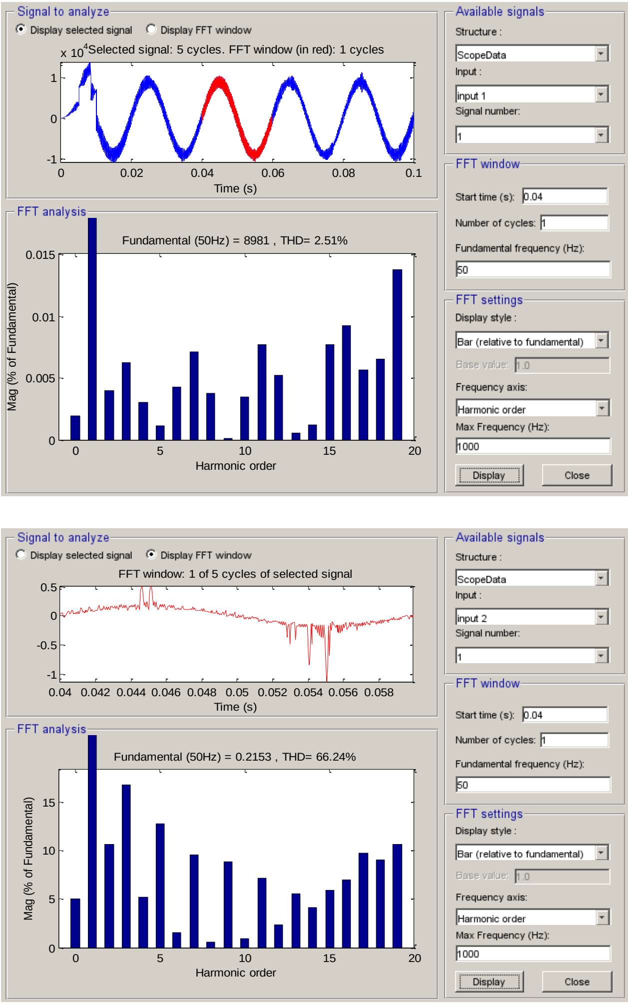


Fig. 3. FFT analysis of input voltage and current

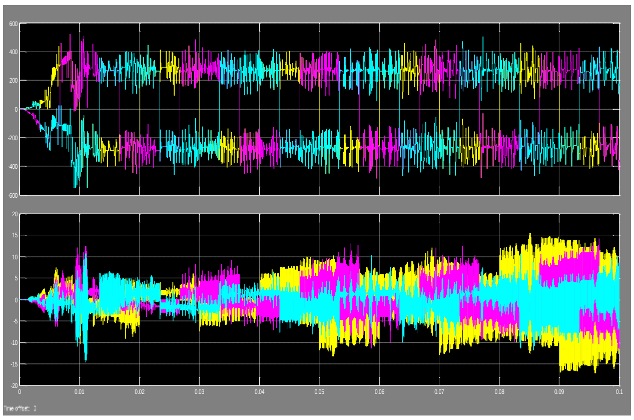


Fig. 4. Output voltage and current of power electronic transformer

The FFT analysis shows that THD of voltage is 2.51% which is within the limits, but the THD of current is 66.24% which is very high. Thus the traditional topology of power electronic transformer produces input current harmonics. The voltage and current at the output side is shown in Fig. 4. Both voltage and current are non sinusoidal with very high distortion index (DIN).

The FFT analysis (Fig.5) shows that THD of voltage and current are 53.65% and 155.59% respectively which are very high.

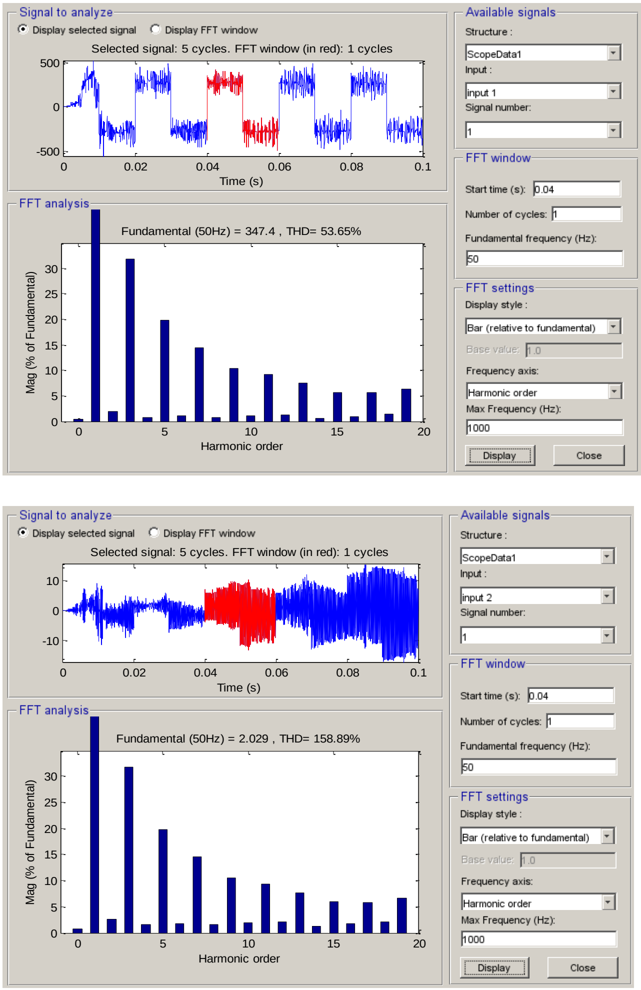


Fig. 5. FFT analysis of output voltage and current

Thus the traditional topology of power electronic transformer produces output voltage and current harmonics. The above topology of traditional power electronic transformer can replace the conventional 50Hz welding transformer but it suffers from power quality problems. Also this topology requires three phase high frequency transformer which is costly.

4. Proposed Power Electronic DC Welding Power Supply

The Gas tungsten arc welding machine operates with dc supply for steel welding. Welding power supply has constant current or constant voltage operation. Simulink model of power Electronic transformer based constant voltage welding power supply is shown in Fig. 6.

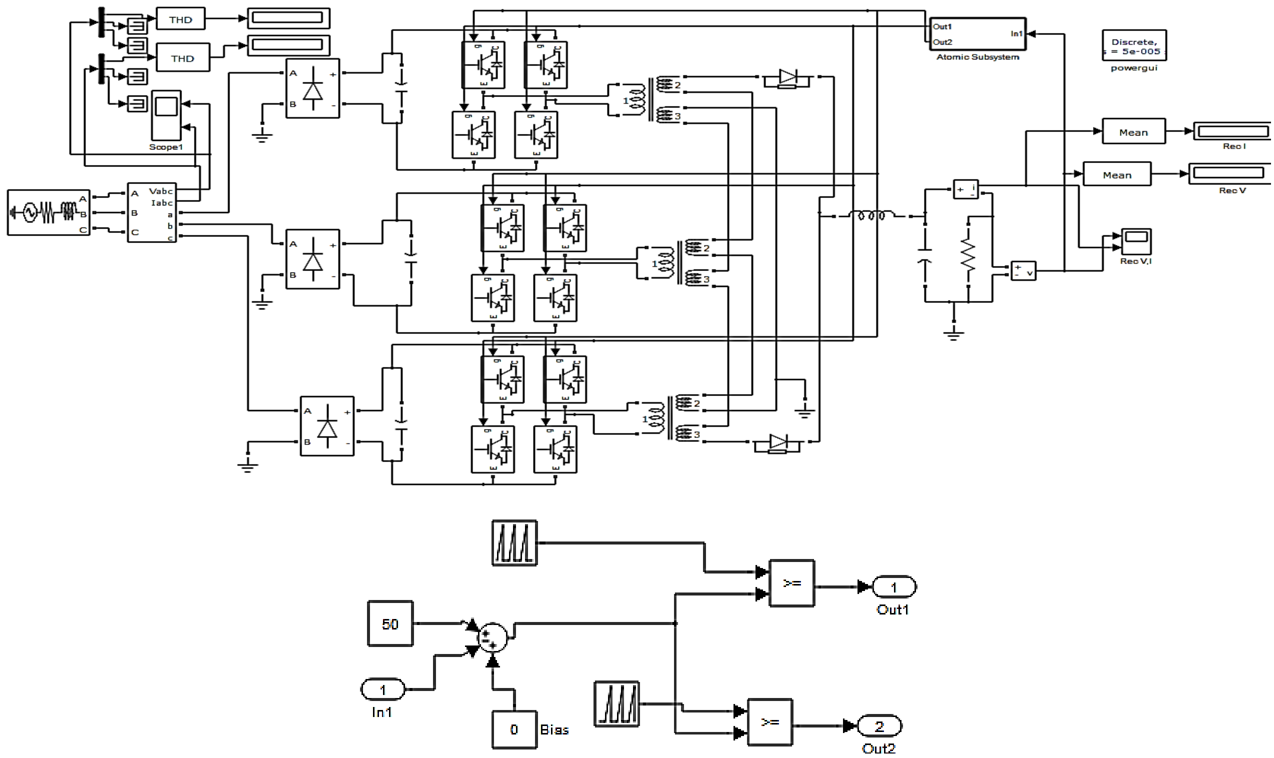


Fig. 6. Simulink model of proposed dc welding power supply

Three phase 50Hz ac supply is the input of the modular power electronic transformer which is fed from a 3-phase generator. The power electronic transformer consists of three single phase diode bridge rectifier. Phase voltages are fed as input to the rectifiers and the output side of rectifiers has dc link capacitors. The dc is converted to high frequency ac using three, 2-leg IGBT inverter. Output voltage is kept constant at 50V by a closed loop controller which produces gating pulses for the 2-leg IGBT inverters. The high frequency outputs from the three inverters are fed to single phase three winding high frequency transformers. All the upper secondary windings are connected in series. One end of the series connected windings is grounded and the other end has rectifier diodes which gives rectified output during positive half cycle. All the lower secondary windings are connected in series. One end of the series connected windings is grounded and the other end has rectifier diodes which gives rectified output during negative half cycle. This dc output is fed to welding electrodes through series inductor and parallel capacitor. The topology is similar to dc-dc buck converter if we exclude the input rectifiers. The output voltage is kept constant at 50V using a closed loop controller. The difference between the desired voltage (50V) and the actual output voltage is compared with a saw tooth waveform of high frequency to generate the gating pulses to IGBT inverter.

5. Power Quality Analysis of Power Electronic Transformer Based DC Welding Power Supply

The input voltage and current of proposed welding power supply is shown in Fig. 7. During the first few cycles transient disturbances prevails due to switching. The voltage and current are balanced and the unbalance factor is zero.

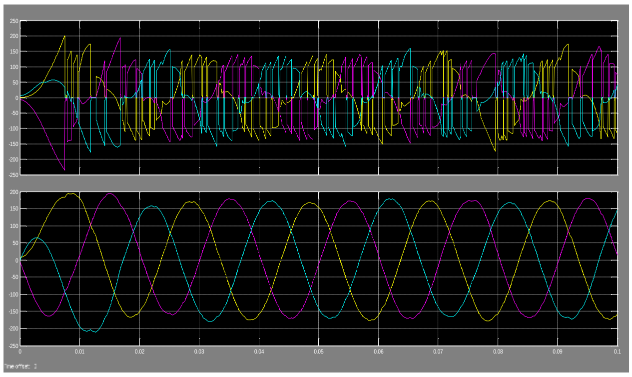
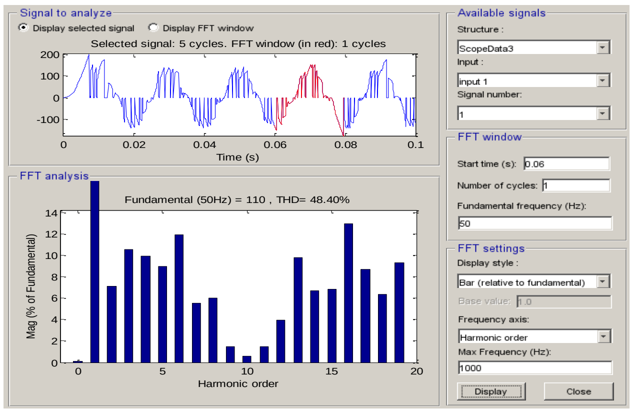


Fig. 7. Input voltage and current of proposed dc welding power supply



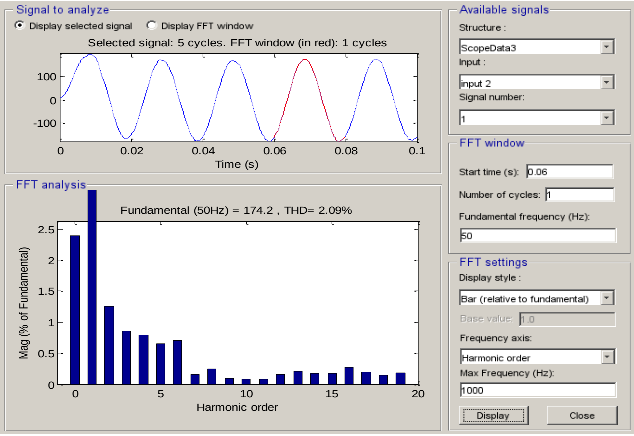


Fig. 8. FFT analysis of input voltage and current

The FFT analysis of input voltage and current are shown in Fig. 8. The THD of voltage and current are 48% and 2% respectively which are much less than the THD level in traditional power electronic transformer. THD of current is well below the limits specified in IEEE standards.

The output voltage and current of proposed welding power supply is shown in Fig. 9. The output voltage is kept constant at 50V by the closed loop controller.

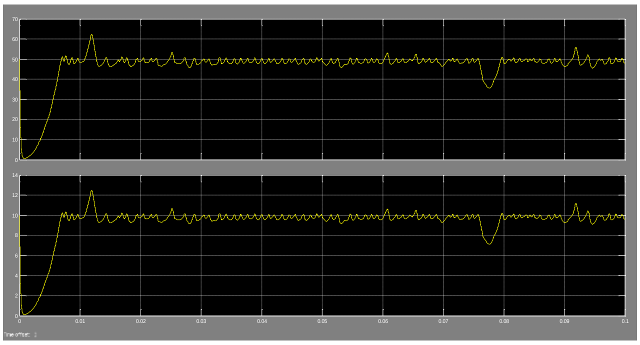


Fig. 9. Output voltage and current of proposed dc welding power supply

6. Proposed Power Electronic AC Welding Power Supply

Before the advent of inverter-based gas tungsten arc welding (GTAW) machines, frequency control was rarely thought of as a way to improve aluminum welding. The current that came from the wall—50 hertz—was the same current that went into the weld. Since then countless manufacturers have sworn off this mentality after seeing firsthand the benefits of adjustable output frequency. In alternating current (AC) GTAW, frequency refers to the number of times that the direction of the electrical current completes a full cycle every second, expressed in hertz. Frequency is represented by a sine wave, which depicts the current flow rising and falling as it reverses direction.

Direct current (DC) cannot be used with nonferrous metals because of the oxide layer that forms on the surface of the base material. In direct current electrode negative (DCEN) GTAW, the current flows from the tungsten electrode to the work surface, and the positively charged argon gas ions flow from the work surface to the tungsten. DCEN works well for steel and other common ferrous metals, but the oxide layer that forms on nonferrous metals such as aluminum and magnesium melts at a higher temperature than the base metal. Trying to weld with this process causes the base metal underneath the oxide layer to liquefy while the surface remains hard and impenetrable. Direct current electrode positive (DCEP) solves the oxide problem because the current flows from the work-piece to the tungsten, lifting the oxide off the material in the arc zone. DCEP alone provides the oxide cleaning action and very little penetration. Because the heat is concentrated on the tungsten instead of the work-piece, DCEP also causes the tungsten to ball up at the end.

AC power supply combines DCEN and DCEP to provide good heat penetration with cleaning action. Historically, though, AC has posed an obstacle to GTAW because the arc frequently extinguishes itself as the current reaches a zero point before reversing directions. Without any current passing between the tungsten and the base metal, the arc simply goes out. Improvements in transformer-based GTAW machines created the square wave, which increased the amount of time the arc spends at full-current flow in both DCEN and DCEP. Square-wave technology eliminated the tendency for the arc to extinguish when the current came to a halt as it reversed directions by making the transition very quickly. This greatly improved the stability of the arc and made square-wave technology the preferred method for GTAW of aluminum and other materials that form an oxide layer, such as magnesium. The second major revolution in frequency technology came with the invention of the inverter, which created the ability to increase or decrease output frequency beyond the standard 60 Hz, which is the standard frequency delivered to every outlet in the U.S. (other countries, such as Germany, England, and France, deliver AC power at 50 Hz). The inverter also allowed for the development of the advanced square wave, which decreases the time it takes for the current to reverse directions, increasing arc stability even more and eliminating the need for continuous high frequency (Tae-Jin Kim *et al*., 2006). The proposed power electronic ac welding power supply produces square wave output with 150Hz frequency for better welding quality. The simulink model of the proposed power electronic ac welding power supply and its control strategy are shown in Fig. 10. Three phase 50Hz supply is first converted to 50KHz single phase ac using 3-phase to 1-phase matrix converter. The next in the link is the single phase high frequency three winding transformer. There are two output windings with same voltage rating. The second terminal of the first output winding and the first terminal of the second output winding are connected to the ground. The first terminal of the first output winding and the second terminal of the second output winding are connected together through two rectifier diodes. One diode will be conducting during positive half cycle and the other diode during negative half cycle. This is followed by a dc link capacitor and two leg IGBT inverter which converts the dc to 50Hz ac output.

The control strategy of matrix converter is comparing the phase voltages with a rectangular wave. The rectangular wave is generated with the desired output frequency of matrix converter and magnitude equal to half of maximum value of nominal phase voltage of input supply. During the positive half cycle of rectangular wave, gating pulse for IGBT based bipolar switch is produced when the corresponding phase voltages are greater than rectangular wave. During the negative half cycle of rectangular wave, gating pulse for IGBT based bipolar switch is produced when the corresponding phase voltages are lesser than rectangular wave. The bipolar switches of the matrix converter are realized using one IGBT and four diodes with configuration shown in Fig.10.

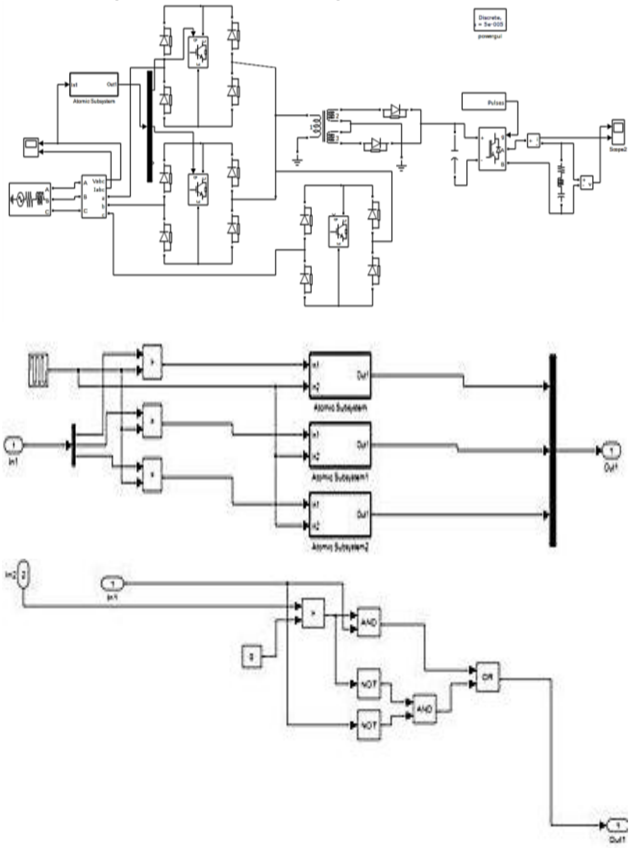


Fig. 10. Simulink model of proposed ac welding power supply

7. Power Quality Analysis of Power Electronic Transformer Based Ac Welding Power Supply

The input voltage and current of proposed ac welding power supply is shown in Fig. 11. The distortion index (DIN) which is the ratio between the rms value of harmonic component to rms value of current/voltage is very high for both voltage and current, but the input power factor is almost unity.

The FFT analysis of input voltage and current are shown in Fig. 12. The THD of voltage and current are 56% and 75% respectively which are far above the limits specified in IEEE standards. Efforts can be taken in future designs for limiting the same.

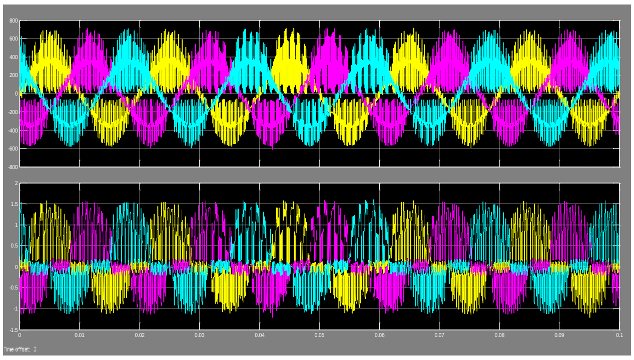


Fig. 11. Input voltage and current of proposed dc welding power supply

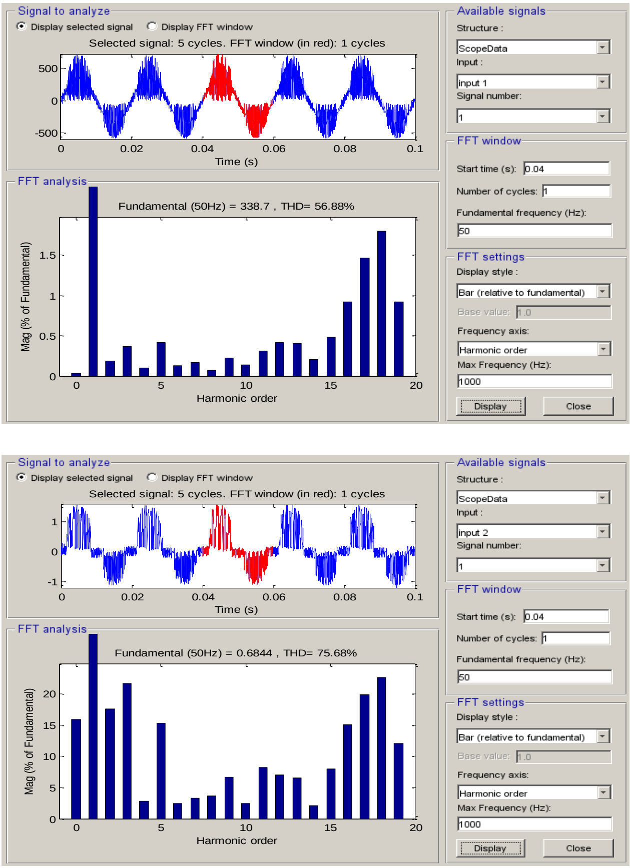


Fig. 12. FFT analysis of input voltage and current

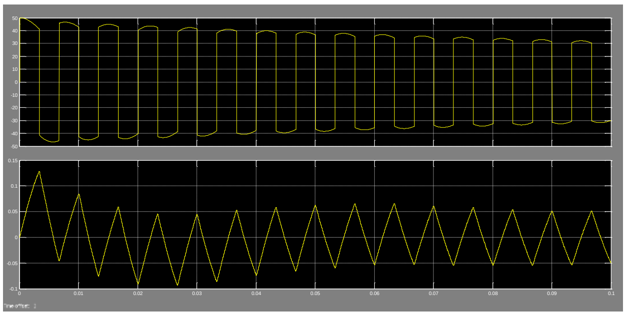


Fig. 13. Output voltage and current of proposed dc welding power supply

The output voltage and current of proposed ac welding power supply is shown in Fig. 13. The output voltage is a square wave with 150Hz frequency. Thus the welding quality will be very good for welding aluminium using gas tungsten arc welding machine.

Conclusion

Harmonics, low power factor and transient disturbance are the major problems with conventional welding power supply. It is suggested to replace conventional welding transformer by power electronic transformer. The power quality issues in traditional power electronic transformer are analyzed in this paper by simulation. Traditional topology of power electronic transformer produces input current harmonics, output voltage and output current harmonics. Also this topology requires three phase high frequency transformer which is costly. Hence this paper proposed a novel power electronic transformer based dc welding power supply for gas tungsten arc welding of steel. Modular topology based on dc-dc buck converter is used for the design. Also a novel power electronic transformer based ac welding power supply for gas tungsten arc welding of aluminium is proposed. DC link in input side is eliminated using 3-phase to 1-phase matrix converter. A simple control method for the matrix converter is explained in this paper. Performance of the proposed power electronic transformer based welding power is validated by simulation. However the input voltage and current are having some harmonics, but much less than that of traditional power electronic transformer topology. Efforts can be taken in future designs for limiting the same.

References

Hosseini.S.H, M. B. Sharifian, M. Sabahi, A. Yazdanpanah, and G. H. Gharehpetian (May 2008), Bidirectional power electronic transformer for induction heating systems, in *Proc. Can. Conf. Electr. Comput. Eng.*, May 4–7,pp. 347–350.

Huang. N, D. Zhang, T. Song, M. Fan, Y. Liu and Y. Zhao (2005), A 10 kW single-stage converter for welding with inherent power factor correction, in *Proc. of IEEE APEC'05*, vol. 1, pp. 254-259.

Jinhong Zhu, Shuzhong Song, Hongxin Shi and Kang Yong Lee (2008), Investigation on control strategies for pulse gas metal arc welding process, in *Proc. of IEEE Industrial Electronics and Applications (ICIEA)*, pp. 1276-1281.

Khairy Sayed, Keiki Morimoto, Soon-Kurl Kwon, Katsumi Nishida and Mutsuo Nakaoka (2011), DC-DC converter with three-phase power factor correction for arc welder, in *Proc. of IEEE ICPE-ECCE Asia*.

Mandal.N.R (2009), Welding Techniques, Distortion Control and Line Heating, *Narosa Publication House Pvt. Ltd.*, India.

Sabahi.M, S. H. Hosseini, M. B. Sharifian, A. Yazdanpanah, andG. H. Gharehpetian (Mar. 2009), A three-phase dimmable lighting system using a bidirectional power electronic transformer, *IEEE Trans. Power Electron.*, vol. 24, no. 3, pp. 830–837,

Singh.B, Narula.S, Bhuvaneswari.G (Dec 2012), Power quality improvement using three phase modular converter for welding power supply, *Power India Conference, 2012 IEEE Fifth* , pp. 1-6

Tae-Jin Kim, Jong-Pil Lee, Han-Woong, Park Kim and Cheul-U Kim (2006), Development of a power supply for the pulse MIG arc welding with a wire melting rate change, in *Proc. of IEEE PESC'06*, pp. 1-4.

Wrede.H, V. Staudt, and A. Steimel (2002) Design of an electronic power transformer, in *Proc. IEEE 28th Annu. Conf. Ind. Electron. Soc*., vol. 2, pp. 1380–1385.

Zhang E.F. de Silva, R.M. Jose, A. Scotti and J.C. de Oliveira (2011), Power quality analysis of gas metal ARC welding process operating under different drop transfer modes, in *Proc. of IEEE COBEP*, pp. 129-135,