ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

# Comparative Study of Welding Power Supplies

Anju A Nair[1], Rajan P Thomas[2], Babu Paul[3]

M.Tech Student, M. A.College of Engineering, Kothamangalam, Kerala, India[1]

Professor, M. A. College of Engineering, Kothamangalam, Kerala, India[2]

Professor, M.A. College of Engineering, Kothamangalam, Kerala, India [3]

**ABSTRACT**:- Single phase and three phase Gas Metal Arc Welding power supplies are compared. An efficient arc welding process requires high current source with constant voltage supply. There are many problems associated with existing welding power supplies like low power factor and harmonic content at user interface. These factors are taken into consideration and the welding supplies are designed such that power factor is improved and harmonics are reduced. The welding supply consists of a modular PFC converter which is connected to a PWM DC-DC converter switched at higher frequency. Full bridge modular converter provides attractive features such as inherent power factor correction, simple DC-DC switching control, high frequency transformer isolation and single stage power conversion. Welding power supplies are made to operate at both DCM and CCM modes for different power ratings. FFT analysis is done under both modes of operation and are compared and find out which supply gives the improved performance with THD value well below IEEE standards. MATLAB R 2008b version software is used to simulate he model.

**KEYWORDS**: Gas metal arc welding power, PFC converter, PWM DC-DC converter, DCM mode, CCM mode, Total harmonic distortion.

## 1. INTRODUCTION

Welding is the process of joining similar or dissimilar metals by the application of heat, with or without the application of pressure and addition of filler material. It is an economical method and highly corrosion resistant compared to bolt and reverting. There are different types of welding like gas welding, arc welding etc. The most widely used fusion process for joining metal and alloy is gas metal arc welding..A metal is allowed to touch the joint faces of the metal parts to be joined and is quickly removed to create a gap of 2 mm to 4 mm such that current continuous to flow through a path of ionized particles. Thus, an electric arc is produced and generates a temperature rise up to 6000-7000$^0$C at the centre of the arc. Intense heat so produced melts the faces of the prepared joint forming a pool of molten metal. The arc is maintained by uniformly moving the electrode towards the work piece and hence keeping a constant gap between the electrode and work piece. At the same time the electrode is moved along the desired line of welding. Generally, electrodes are coated with fluxing materials. This provides a gas shield around the arc to prevent a direct contact of oxygen and nitrogen in the air with the deposited metal. Also it prevents the oxidation of welding metal while cooling [7].

The welding power supply can be high frequency ac or dc. Input to the circuit is ac; the circuit has a high frequency isolation transformer, filter etc. Inside the welding set, we have a rectifier, DC-DC buck converter and is then connected to a welding torch. Efforts to reduce power harmonics have led to the development of various power factor corrections (PFC) circuits that draw almost sinusoidal current with nearly unity power factor as per IEC 61000-3-2 and IEEE 519-1992 standards. For higher power rating ( > 3 kW) welding power supplies, three phase converters are generally employed. However, three phase AC-DC converters with sinusoidal input AC mains currents add to the complexity in the system. This requires the extension of existing and well proven single-phase technology to the development of the high rating systems.

## II. WELDING POWER SUPPLIES, CONTROL SCHEMES & DESIGN CONSIDERATIONS

### 2.1 WELDING POWER SUPPLIES

### 2.1.1 Three phase three wire welding power supply

Circuit description and working:

A modular full-bridge isolated dc-dc converter configuration for a three phase arc welding power supply is shown in Figure 2.1. Three single phase converter modules are connected in series to form a three phase system. The series connection provides balanced three phase currents and galvanic isolation using high frequency transformer. Inputs are star connected so that third harmonics and its multiples are eliminated automatically. Each module consists of AC supply with line-to-line voltage being connected to each bridge rectifier, a PWM full-bridge buck converter with a high frequency transformer and the welding load. High-frequency transformer isolation is preferred to reduce the size, cost, weight, and volume of transformer used for isolation.

A small value of input filter capacitance $C_f$ is selected. Three converter modules are switched in the same manner. The switching pairs of $S_1$-$S_4$ and $S_2$-$S_3$ are switched on alternately during each half cycle of a switching period. The rectifier diodes $D_1$ and $D_2$ act as freewheeling diodes when both the switching pairs are switched off. A small size L-C filter provides a ripple-free output DC voltage.

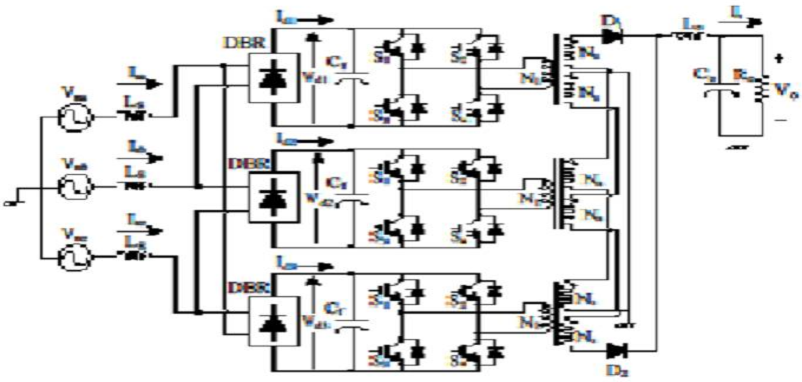



Figure 2.1: Circuit configuration of modular full-bridge isolated dc-dc converter

### .2.1.2 Three phase single wire system

Circuit description and working:

An isolated three phase full bridge converter is shown in figure 2.2. The three phase system is connected to a three phase bridge rectifier. The pulsating output of bridge rectifier is filtered using capacitor. The filtered output is fed to the full bridge converter. Here S1 and S3 are ON while S2 and S4 are switched OFF and vice versa. A high frequency transformer with centre tapped winding provide isolation between input and output mains. The advantage of this circuit is that the number of switches and voltage harmonics get reduced but the current harmonics is higher compared to that of voltage harmonics which is the main disadvantage.

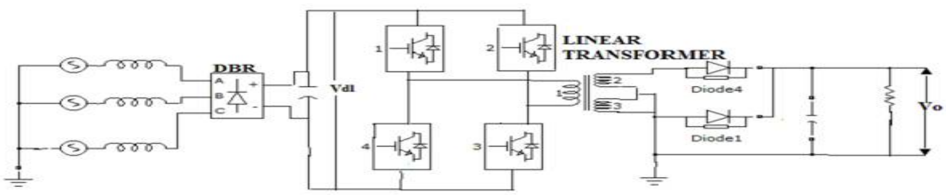



Figure 2.2: Circuit configuration of three phase full-bridge isolated dc-dc converter

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

*An ISO 3297: 2007 Certified Organization* *Vol. 5, Special Issue 3, March 2016*

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

### 2.1.3 Single phase welding power supply

Circuit description and working:

An isolated full bridge single phase welding power supply is shown in figure 2.3. Here a single phase supply is connected to two leg diode bridge rectifier and after filtration fed to full bridge converter where high frequency switching is done. A high frequency transformer with center-tapped winding is connected to the output of the dc-dc converter to provide input-output isolation. The diagonal switches are gated and are complementary to each other. It combines both the advantages of three phase welding power supplies.

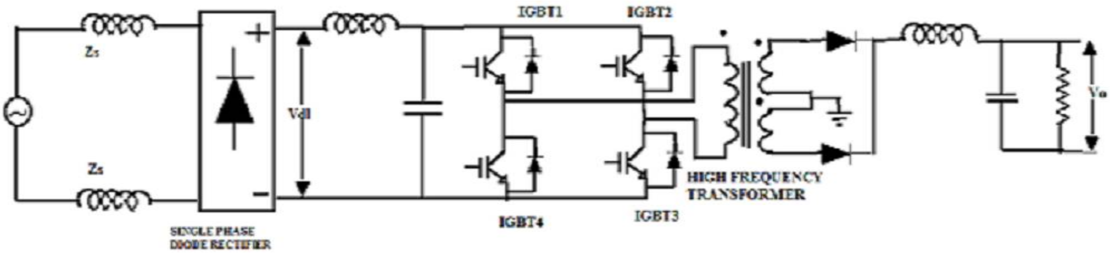



Figure 2.3: Circuit configuration of single phase full-bridge isolated dc-dc converter

## 2.2 CONTROL SCHEMES

### 2.2.1 DCM mode of control

The control technique is as shown in figure 2.4. The voltage error between output voltage, $V_0$ and a reference voltage, $V_{ref}$ is amplified and is compared with a sawtooth wave to produce gating pulse at converter switching frequency.

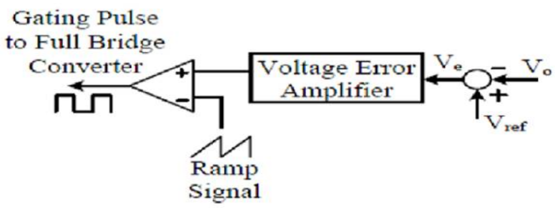



Figure 2.4: Control circuit for DCM mode

### 2.2.2 CCM mode of control

The voltage error between output voltage, $V_0$ and a reference voltage, $V_{ref}$ is multiplied by a full wave rectified dc voltage, $V_{dl}$ such that a current reference signal is produced and this reference current signal is compared with $I_{dl}$ which is the current from the diode bridge rectifier. The output current signal is amplified and compared with a sawtooth signal such that gating signals are produced at converter switching frequency.

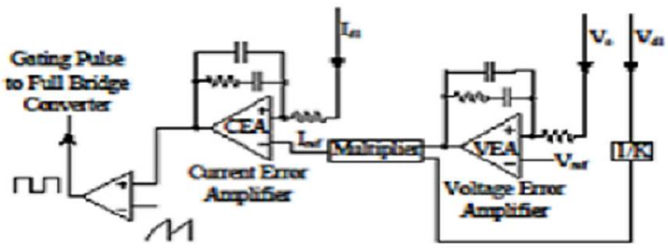



Figure 2.5: Control circuit for CCM mode

## 2.3 DESIGN CONSIDERATIONS

Design of the welding power supplies under two different modes (DCM and CCM) using PWM technique is discussed here.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization | Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

### 2.3.1 Design for DCM converter

DCM converter is designed for 8.75 KW which is an assumption with constant output voltage to be of 35 V and output current of 250 A at a frequency of 60 KHz. For an isolated full bridge buck converter operating under DCM mode, the voltage-second balance equation [1] is given by:

$$(V_d(N_2/N_1)- V_o)DT_s(V_o)D_1T_s = 0 \qquad \text{………(2.3.1.1)}$$

Value of output inductor at the boundary of CCM and DCM operation is as:

$$L_o = (V_o(1\text{-}D)^2 /2f_sI_o)(N_1/N_2)^2 \qquad \text{………(2.3.1.2)}$$

Considering $N_1 = N_2 = 6.731$, D = 0.2,value of output inductor is: $L_0$= 33.8 microH. But selected value is 10 microH for proper DCM operation. From the voltage ripple equation, output capacitor as,

$$C_o = Vo(1\text{-}2D)/32f_s^2\ Lo(V\ o) \qquad \text{………(2.3.1.3)}$$

Considering $V_o$ = 2 % of $V_o$ , $f_s$ = 60 kHz, $V_o$ = 35 V, D =0.2, Lo= microH, value of output capacitor is obtained as: $C_o$ = 7.69 microF , and selected value is 9 microF for proper filtration.

### 2.3.2 Design for CCM converter

CCM converter section is designed for 17.6 KW power supply with an output voltage of 44 V and output current of 400 A with converter frequency of 50 KHz. The voltage-second relationship [1] on output inductor is as:

$$(V_d(N_2/N_1)\text{-}V_o)(t_{on} /T_s)(V_o)(t_{off}/T_s) = 0 \qquad \text{………..(2.3.2.1)}$$

The value of output inductor is obtained as:

$$L_o = V_o(0{:}5\text{-}D)/(f_si_{Lo}) \qquad \text{………..(2.3.2.2)}$$

Considering $i_{Lo}$ = 1% , $f_s$ = 50 kHz, $V_o$= 44 V, D = 0.45,$I_o$= 400 A, then $L_o$ = 11 microH and selected value is 15 microH. The value of output capacitor can be obtained from the voltage ripple equation of output capacitor as:

$$C_o = V_o(1\text{-}2D)/32f^2_s\ L_o(V\ _o) \qquad \text{………..(2.3.2.3)}$$

Considering $V_o$ = 1% of $V_o$ , $f_s$ = 50 kHz, $V_o$ = 44 V, D = 0.45, $L_o$=15 microH, value of output capacitor is obtained as: $C_o$ = 5.625 microF and selected value is 7 microF to reduce output voltage ripple. The above calculated values of capacitors and inductances are tuned for improved performance of welding power supplies.

## III. SIMULINK MODEL AND RESULTS

In this chapter we can see the simulation and results of above discussed welding power supplies at both CCM and DCM modes of operation. DCM operation is used for power supply system rated as 8.75 KW while CCM is applied to an 17.6 KW power supply system. The gating pulses produced by this control technique is shown in figure 3.2.

### 3.1. Simulation Results of DCM Mode of Operation

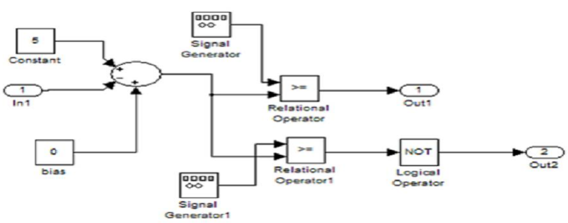


Figure 3.1: Simulink model of DCM controller

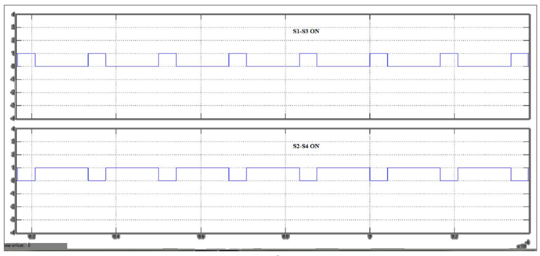


Figure 3.2: Switching Waveform under DCM mode at 60 KHz

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization | Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

### 3.1.1. Simulink model of Three Phase Three Wire welding power supply

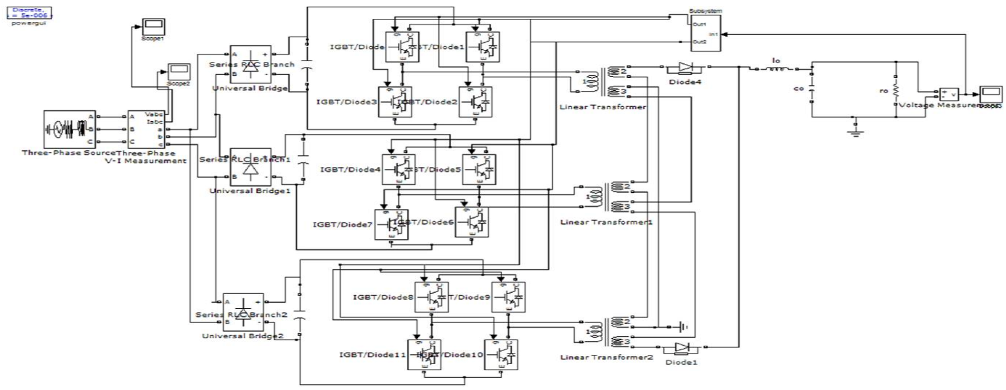
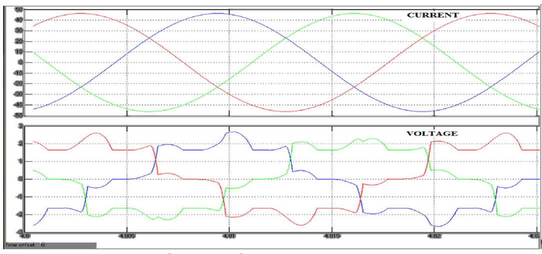


Figure 3.3: Simulink model of Three Phase Three Wire welding Power supply

Figure 3.3 shows the simulink model and Figure 3.4 shows the input current and voltage waveform. From the graph it is clear that although the voltage waveform is distorted maximum value of voltage and current occurs at same angle and thus power factor is almost unity. And also Figure 3.5 shows the output voltage and current and a voltage of 35 V and current of 250 A is achieved.



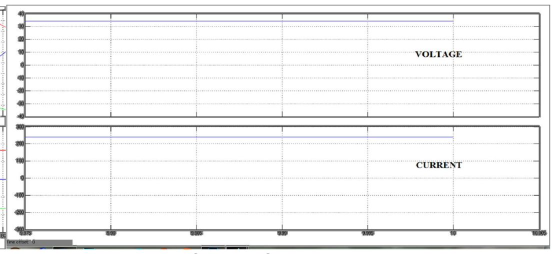
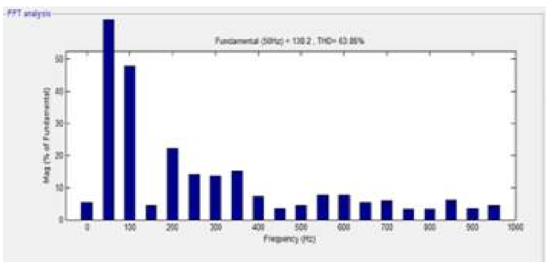


Figure 3.4: Waveform of input current and voltage   Figure 3.5: Waveform of output voltage and current

Now, the FFT analysis was done for a single phase A, and the analysis shows that the circuit configuration reduce current harmonics. Figure 3.6 and Figure 3.7 shows the FFT analysis done for a single phase A input voltage and current.



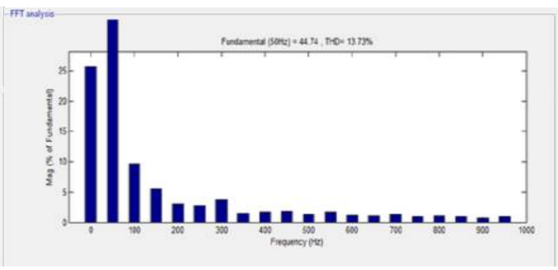


Figure 3.6: FFT analysis of input voltage, THD = 63.86%   Figure 3.7: FFT analysis of input current, THD = 13.73%

### 3.1.2. Simulink model of Three Phase Single Wire System

Figure 3.8 shows the simulink model. Design is same as three phase system. The difference is that the single phase modules are replaced by a three phase system. But the main disadvantage of Three Phase system is that current harmonics will be higher. And therefore it is better to use single phase modules.

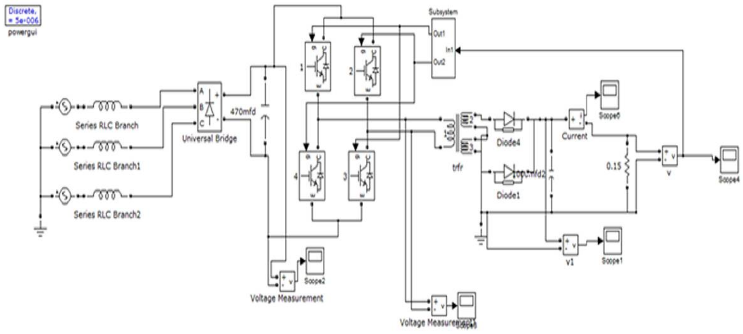



Figure 3.8: Simulink model of Three Phase Single Wire System

Although switches are reduced, requirement of high voltage devices increase and the current harmonics are increased compared to use of single phase modules for three phase system. An output voltage of 35 V and output current of 250 A is achieved. FFT analysis was done for input voltage and current. FFT analysis of input voltage with THD = 5.77% and FFT analysis of input current with THD = 47.40% is achieved.

### 3.1.3. Simulink Model of Single Phase Welding Power Supply

Single phase welding power supply under DCM mode is shown in figure 3.9. The input voltage is 220 V.

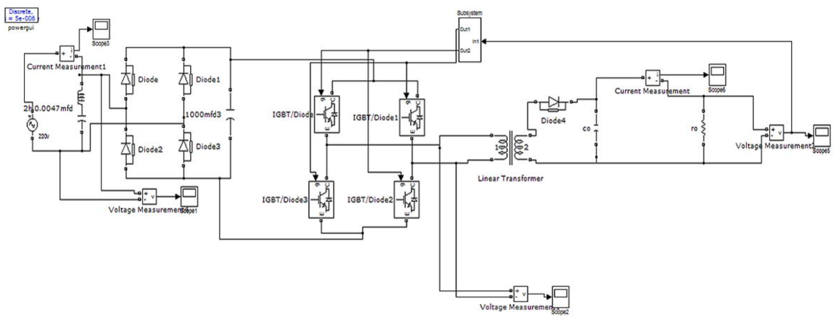



Figure 3.9: Simulink model of modular single phase welding power supply

An output voltage of 35 V and output current of 250 A was able to obtain for the single phase welding power supply. Here the main disadvantage of using single phase system is that the power factor obtained is less compared to three phase. FFT analysis of input voltage with THD = 0.00% and FFT analysis of input current with THD = 3.76% is achieved.

### 3.2. Simulation Results of CCM Mode of Operation

The only difference in simulink model is the control unit i.e here we use CCM control instead of DCM control technique. Simulink model of CCM control technique is shown in figure . It has been designed at converter switching frequency of 50 KHz.

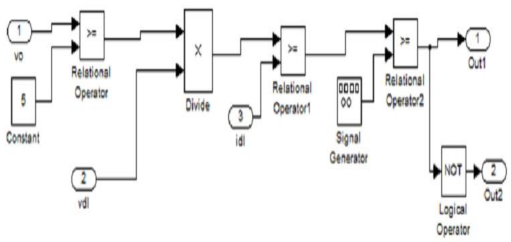



Figure 3.10: Simulink model of CCM control

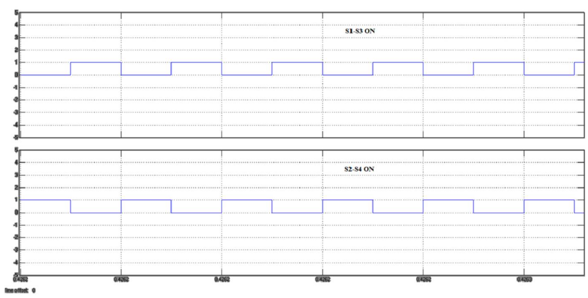



Figure 3.11: Switching waveform under CCM mode

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

An ISO 3297: 2007 Certified Organization Vol. 5, Special Issue 3, March 2016

National Conference on Recent Advances in Electrical & Electronics Engineering (NCREEE'16)

Organized by

Dept. of EEE, Mar Baselios Institute of Technology & Science (MBITS), Kothamangalam, Kerala-686693, India

On 17th & 18th March 2016

The gating pulses which are produced by this control technique is shown in figure 3.11.
The discussed welding power supplies in above section is repeated for CCM mode and the control circuit for DCM was replaced with CCM mode of control. It has been designed for a load of 17.6 KW and the results of THD analysis for these welding power supply is used to compare the effectiveness of circuits in both modes. The table shown below gives the obtained values for the simulation done.

Table 3.1: Comparison of Welding Power Supplies

| POWER SUPPLY | MODES | THD OF CURRENT(%) | THD OF VOLTAGE(%) |
|---|---|---|---|
| Ordinary DC-DC Buck converter based welding power supply | | 270 | 20 |
| 3-Phase modular welding power supply | DCM | 13.73 | 63.86 |
| | CCM | 13.73 | 57.08 |
| Single phase modular welding power supply | DCM | 3.76 | 0.00 |
| | CCM | 1.73 | 0.00 |
| 3 –phase modular welding power supply using 3-phase full bridge rectifier | DCM | 47.40 | 5.77 |
| | CCM | 46.89 | 6.14 |

## IV. CONCLUSION

An ordinary dc-dc buck converter based welding power supply has high current harmonics (>200%) compared to the welding power supplies that we have discussed. Welding power supply incorporating three single phase modules reduce current harmonics at input side than three phase single wire system. Now comparing to single phase welding power supply, it offers better performance than the three phase systems in which the THD value of input voltage and current is achieved to be zero which is well below IEEE standards. But the main disadvantage of using single phase welding power supply is that, power factor correction is not achieved as per requirement. So, by use of Power factor equipments we can improve the performance of the Single Phase welding power supply with harmonics free voltage and current.

## REFERENCES

[1] Bhim Singh , Swati Narula , G.Bhuvaneswari, "Power Quality Improvement Using Three Phase Modular Converter for Welding Power Supply", IEEE trans- actions on Power India Conference, Pp.1- 6, December 2012.
[2] Khairy Sayed, Keiki Morimoto, Soon-Kurl Kwon, Katsumi Nishida and Mutsuo Nakaoka, "DC-DC converter with three-phase power factor correction for arc welder", IEEE transactions on 8th international conference on power electronics, pp. 1273-1279, June 3, 2011.
[3] R. kalpana, B Singh, G.Bhuwaneshwari, "Direct single stage power converter with power factor improvement for switched mode power supply", Journal of Electrical Engineering and Technology, Vol.5, pp.468-476, 2010.
[4] S.Y.R Hui, H. Chung, "Modular single stage three phase full bridge converter with inherent power factor correction and isolated output", IEEE transactions on Power applications , vol. 146, No. 4, July, 1999.
[5] Bhim Singh, Sanjeev Singh, "Comprehensive study of Single-Phase AC-DC Power Factor Corrected Converters With High Frequcy Isolation", IEEE trans- actions on Industrial Informatics, Vol.7, No.4, November 2011.
[6] Dr.PS Bimbhra, "Power Electronics", KHANNA publishers, fifth edition,2012
[7] http://en.m.wikipedia.org/wiki/welding-power-supply
[8] http://en.m.wikipedia.org/wiki/pulse-width-modulation