International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

PWM STATCOM Based Reactive Power Control by Using a Modular Multilevel Cascade Converter

Krishna Kumar .R[1], Bhavithira .V[2]

[1]PG Scholar, Department of.EEE, Karpagam University, Coimbatore, Tamilnadu, India

[2]Assistant Professor, Department of.EEE, Karpagam University, Coimbatore, Tamilnadu, India

Abstract: ***The closed loop reactive power control by a Sinusoidal Pulse Width Modulation (SPWM) technique based static synchronous compensator (STATCOM) is used in modular multilevel cascade converter for reactive power control for welding machine. In these method five level cascade multilevel converters is used to implement the Hall Effect voltages on each H – bridge side. And sense the voltage level of the each capacitor and controls the amplitude of the carrier signal and also balance the capacitor voltages the digital signal processor is used. As a result the STATCOM output voltage can be controlled by the modulating index. It improves the harmonics of the resultant STATCOM output voltage only appear as sidebands centered around the frequency of 2Nf$_{s.}$ Its multiples provided that the voltage across the dc capacitor of each inverter is the same. Here N is the number of H-bridge inverters and f$_s$ is the frequency of triangle carrier signals.***

Keywords: MATLAB, DSP, STATCOM, MOSFET, PT

1. Introduction

In recent years FACTS devices are used for reactive power compensation in electrical power system network. One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. The new family of Modular Multilevel Cascade Converters (MMCCs) is expected as one of the next-generation power converters suitable for high-voltage or medium-voltage applications without line-frequency transformers. The MMCC has various converter cell configurations, the Single Delta Bridge Cell (SDBC) has the capability of controlling reactive power mainly on negative-sequence reactive power because it allow a current to circulate among three clusters for the SDBC and a current to circulate through the positive and negative arms in each leg.

The SDBC is used as a STATCOM; the amplitude of the circulating line-frequency current is proportional to the amount of negative-sequence reactive power, whereas it is independent of the amount of positive-sequence reactive power and it also to compensate the flickering on welding machine side. The most of the electrical machine like arc furnaces, arc welding, spot welding, induction furnaces, etc.., these devices. Consuming more amount of reactive power from the electrical source for their operation so it causes the flickering, low power factor and to reduce the life time of the machine. The reactive power control is a major drawback in electrical system so in this project SPWM STATCOM based on modular multilevel cascade converter for reactive power control in closed loop manner for welding machine.

2. Proposed System

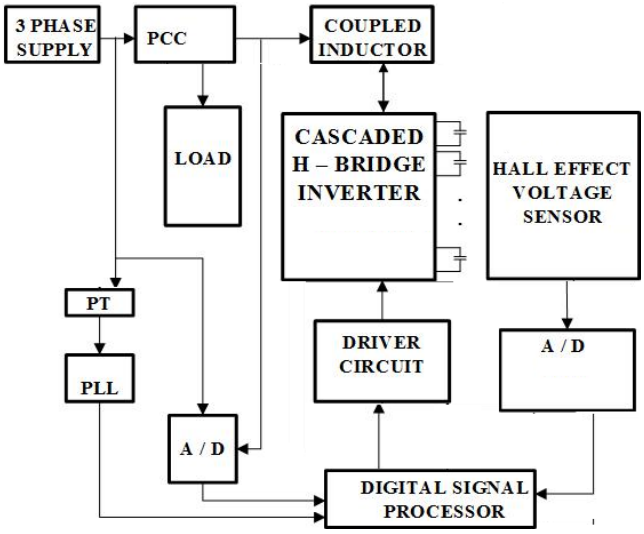

Figure 1: Block Diagram f Proposed System

The Figure 1 shows block diagram of proposed system. The system detects each dc-capacitor voltage V_C both active (p^*) and reactive (q^*) powers and a dc supply voltage V_c as input signals to the A/D unit. The A/D unit consisting of seven A/D converters takes in the analog signals, and then it converts them into digital signals. A digital signal processor (DSP) unit using a 16-bit DSP (ADSP 2105) takes in the digital signals, and produces the voltage commands after completing the digital processing to the gate driver circuit to produce pulses to GTO's. The welding machine is connected to the point of common coupling. The point of common coupling is introduced between source and cascaded H – bridge inverter. The phase-locked loop (PLL) in block is used to synchronize internal control signals with the line phase for d –q transformation and inverse d−q transformations.

2.1 Cascaded H-Bridge Inverter

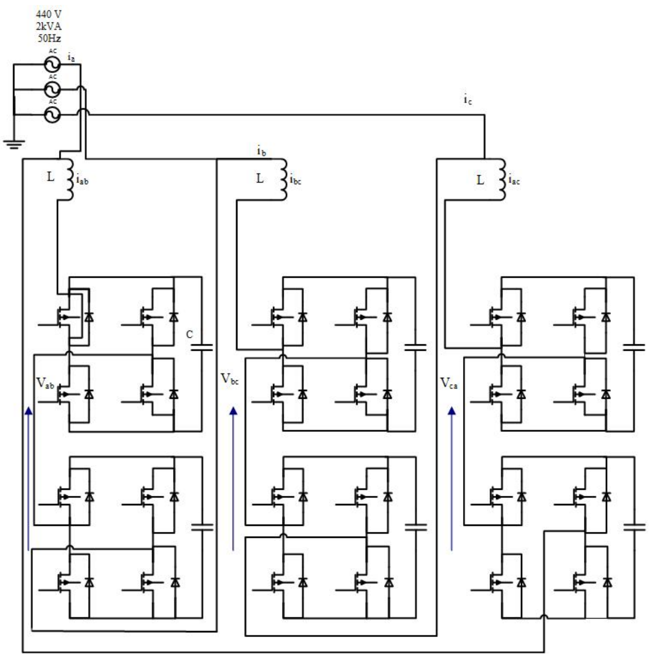

Figure 2: Cascaded H-Bridge Inverter

Multilevel inverter is based on cascade connection of the ac output terminals of modular single-phase full-bridge or "H-bridge" inverter cells, cascade multilevel inverter a series-connected H-bridge multilevel inverter. The Family of modular multilevel cascade converters (MMCCs) is expected as one of the next-generation power converters suitable for high voltage or medium voltage applications without line-frequency transformers. The SDBC seems to be a better choice than the DSCC from a practical point of view because the converter-cell count required for the SDBC is only 1.7 times of that for theSSBC.The SDBC based STATCOM can draw any negative- sequence reactive power with circulating current capability. Flicker compensation of welding machine requires the control of reactive (both positive and negative sequence) power and low frequency active power at the same time. The SDBC, DSCC, and DSBC have the capability to control negative-sequence reactive power because they have the circulating current(s) that flow inside.

The SDBC based STATCOM is used in this project for welding machine applications. The welding machine consumes more amount of reactive power for its operation so its reduces the power factor and introduces the voltage flicker. These distortions enter into the utility system and affect the interconnected customers so the above drawbacks are rectified by using single delta bridge cell connected between supply and load. It absorbs the reactive power from the supply and also compensated for voltage flickering.The cascade H – bridge consist of GTO power electronics switches in each arms.GTO gives faster response makes STATCOM suitable for continuous power flow control and power system stability improvement. The selection of GTO is based on the ratings of the inverter module. A readily available GTO has a typical peak voltage rating of 4.5 kV and peak turn-off current capability of 1 kA .GTOs are connected in series to make up the rated DC link voltage to satisfy the redundancy requirement. The redundancy requirement is that if any singleGTO fails (as short circuit) in one inverter arm, the remaining functional GTOs can sustain continuous operation until the next planned maintenance outage.

Table 1: Circuit Parameters

Rated Capacity	-	2 kVA
Rated line to line rms voltage	V_S	440
Rated line frequency	$\omega / 2\pi$	50 Hz
Rated line current	I	25 A
Rated cluster current	$2I / \sqrt{3}$	29 A
DC capacitor of Bridge cell	C	100 µF
DC capacitor voltage reference	V^*_C	60V
Carrier frequency	f_C	2.5
Equivalent switching frequency	$2 f_C$	5 kHz
Coupled inductor	L	10 nH

2.2 Control Method of the SDBC

The main theme of this project is to reduce the level of the multilevel inverter and to maintain dc-capacitor voltage control in each cluster to be same. Voltage control of the six floating dc capacitors can be divided into the following:
1)Cluster-balancing control.
2)Circulating-current control.
3)Individual-balancing control.

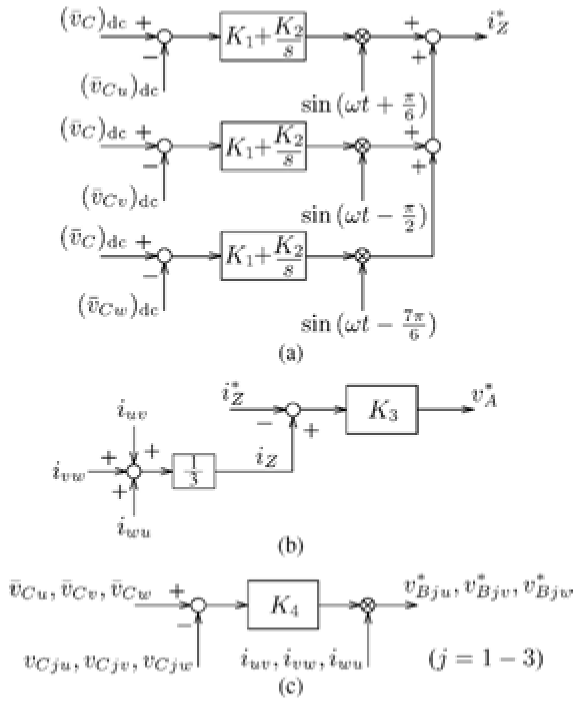

Figure 3: Block Diagram of (A) Cluster Balancing Control (B) Circulating Current Control (C) Individual Balancing Control

2.2.1Cluster-Balancing Control

The Figure 3 (a) shows the block diagram of the cluster-balancing control. The voltage major loop forces the average voltage of each cluster namely, $\bar{V}_{Ca}$, $\bar{V}_{Cb}$, and $\bar{V}_{Cc}$, to follow the average voltage of the three clusters $\bar{V}_C$ where they are defined as:

$$\bar{V}c_a = \frac{1}{3}\sum_{j=0}^{3} Vc_{ja}$$

$$\bar{V}c_b = \frac{1}{3}\sum_{j=0}^{3} Vc_{jb}$$

$$\bar{V}c_c = \frac{1}{3}\sum_{j=0}^{3} Vc_{jc}$$

$$\bar{V}_c = \frac{\bar{V}c_a + \bar{V}c_b + \bar{V}c_c}{3}$$

Here $\bar{V}c_a$, $\bar{V}c_b$, $\bar{V}c_c$ and $\bar{V}_c$ are instantaneous values containing both ac and dc components. It is desirable to extract only the dc components (i.e. $(\bar{V}_{ca})_{dc}$, $(\bar{V}_{cb})_{dc}$, $(\bar{V}_{cc})_{dc}$) because the existence of the ac components deteriorates the controllability. The following methods can be utilized to extract the dc components:

1) The method using a low-pass filter.
2) The method using a feed forward control.
3) The method using a moving-average filter of 100 Hz.

The first method is adopted in this project. Note that $\sin(\omega t + \frac{\pi}{6})$ in fig 3 (a) is in phase with V_{ab}. $(\bar{V}_c)_{dc} > (\bar{V}_{ca})_{dc}$, the product if $\bar{V}_{ab}$ and $i_z(=z^*)$ forms positive active power because i_z contains the same component V_{ab}. As a result an amount of active power flows into the a phase cluster, thus leading to increasing $(\bar{V}_{ca})_{dc}$.

2.2.2 Circulating-Current Control

The Figure 3 (b) shows the block diagram of the circulating-current control. The current minor loop forces i_Z to follow its command i^*_Z, producing the voltage command V^*_A that is common to the three clusters.

2.2.3 Individual-Balancing Control

The Figure 3 (c) shows the block diagram of the individual balancing control. It forms an active power between the ac voltage of each bridge cell and the corresponding cluster current. The voltage commands V^*B_{ja}, V^*B_{jb}, V^*B_{jc} are given by

$$V^*B_{ja} = K_4(\bar{V}_{c_u} - V_{c_{ju}})i_{ab}$$

$$V^*B_{jb} = K_4(\bar{V}_{c_b} - V_{c_{jb}})i_{bc}$$

$$V^*B_{jc} = K_4(\bar{V}_{c_c} - V_{c_{jc}})i_{ca}$$

The following equation is obtained by

$$\sum_{j=1}^{3} V^*B_{ja} + \sum_{j=1}^{3} V^*B_{jb} + \sum_{j=1}^{3} V^*B_{jc} = 0$$

Hence the sum of the voltage commands is equal to zero. This means that no interference occurs between the individual balancing control and the circulating current control.

2.3 Active-Power, Reactive-Power, and Overall Voltage Controls

The Figure 4 shows the block diagram of the active-power, reactive- power, and overall voltage controls in which p^* and q^* represent the power commands of p and q at the PCC. The dc component of q^* is adjusted to control positive-sequence reactive power keeping the relation of $p^*=0$. On the other hand, a couple of second-order components (100 Hz) with the same amplitude but a phase difference of 90° are superimposed on p^* and q^*, respectively, to control negative-sequence reactive power. A low-frequency component is superimposed on p* to control active power, keeping the relation of $q^*=0$. The line- to-line voltage commands V^*_{ab}, V^*_{bc}, and V^*_{ca} are determined by decoupled current control of the compensating currents. A voltage major loop intended for compensating the converter loss is formed as shown in Figure. 2.6, which forces $(V_C)_{dc}$ to follow its command V_C.

The clustered balancing control is characterized by including the circulating-current control constituting a current minor loop in it. Note that the voltage-balancing control is not to regulate the "instantaneous" voltages of the dc capacitors at their voltage reference, but to regulate the "mean" voltages over a time of 5 ms, using a moving average method with a window frequency of 100 Hz.

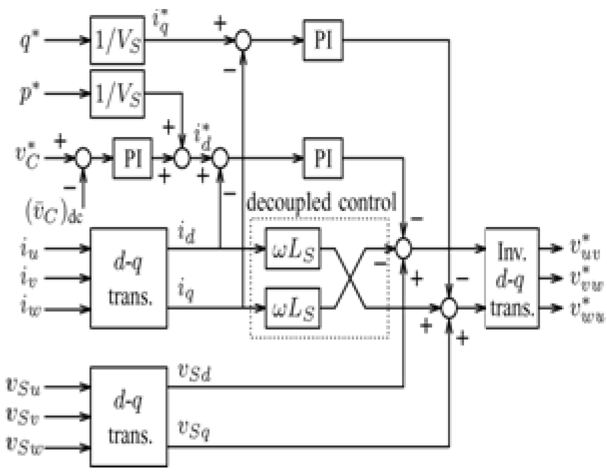

Figure 4: Instantaneous Active and Reactive Power Controls and Overall Voltage Control

3. Simulation Diagrams of Proposed System

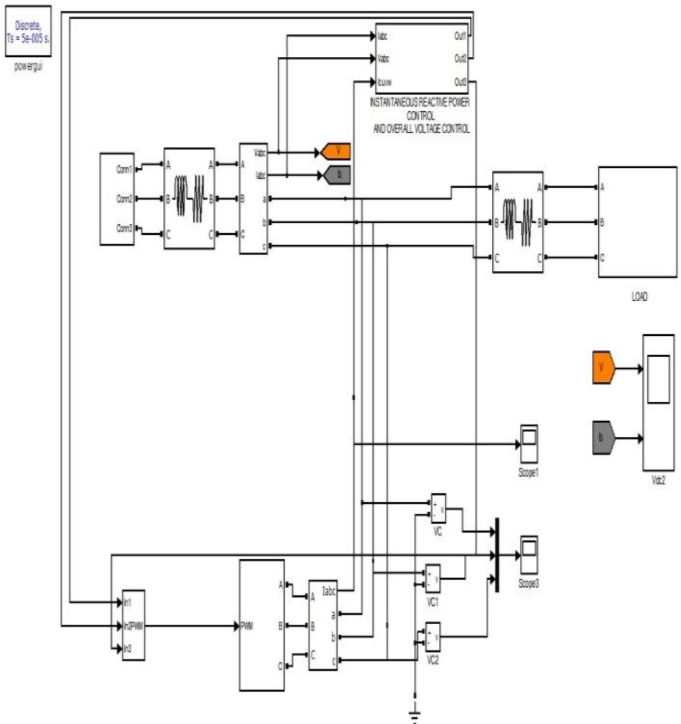

Figure 5: Simulink Model of the Proposed SDBC Based STATCOM

The Figure 5 shows the proposed method , SDBC based STATCOM for closed loop reactive power control for welding machine block diagram. In this method the SDBC Bridge can be control by changing the modulation index of the PWM pulse. The reactive power control block is connected with supply and also SDBC as shown in figure below. The SDBC can absorb or inject reactive power to the supply.

3.1 Single Delta Bridge Cell Block Diagram

The Figure 6 shows the delta connected H – Bridge in SDBC. Each cell has floating dc capacitor; the initial value of each capacitors has equal voltage level. The switches (GTOs) in the SDBC has 4.5kV capability. The clusters are connected in delta configuration manner to circulate the current between each arm.

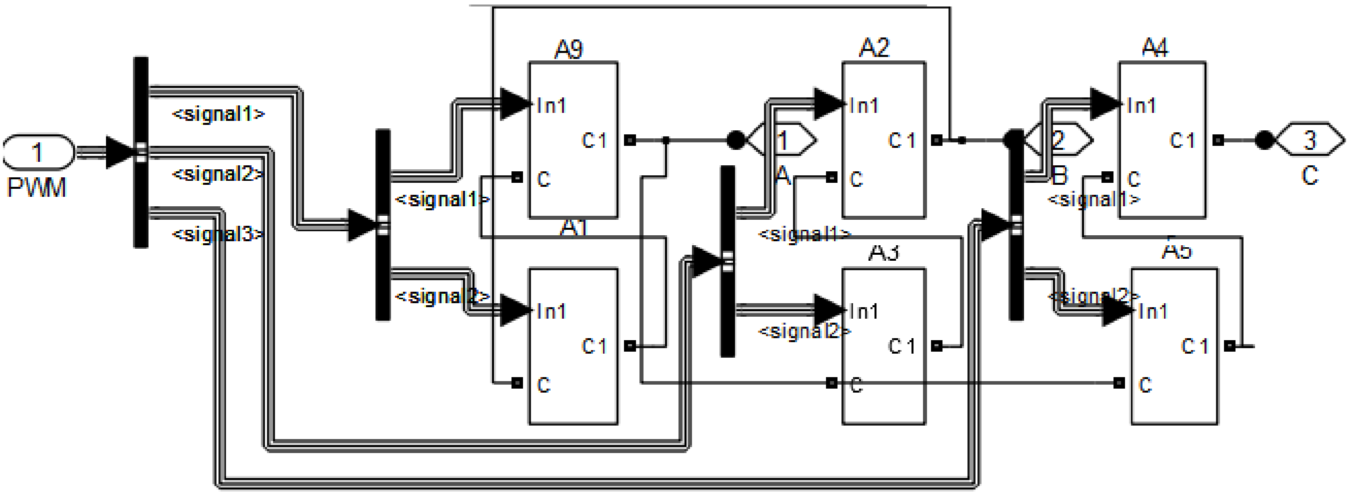

Figure 6: SDBC Configurations

3.2 Simulink Block Diagram For Instantaneous Reactive Power And Overall Voltage Control

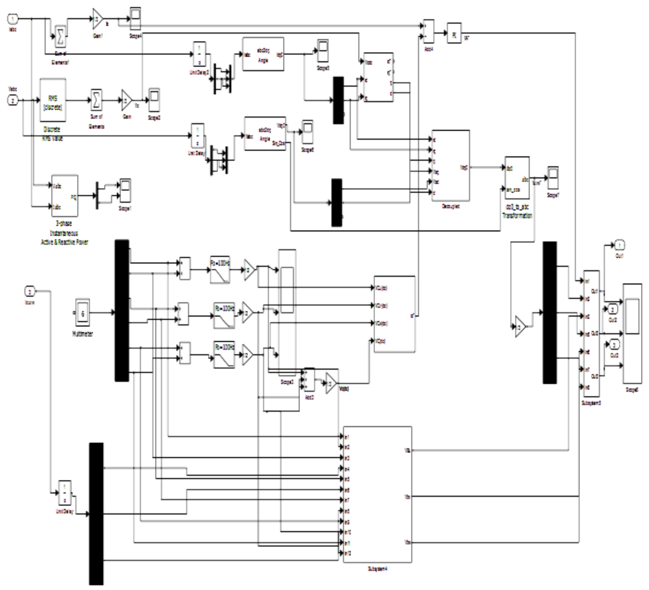

Figure 7: Instantaneous Reactive Power and Overall Voltage Control

The Figure 7 shows instantaneous reactive power control and overall voltage control block diagram. In this block consist the control method of single delta bridge cell and reactive power Control. The three controlling methods are explained in the chapter 2.2 is implemented in the control block.

4. Simulation Results

The Figure 8 shows the Single Delta Bridge Cell voltage waveform (line to neutral value). The SDBC is controlled by SPWM method to generate output voltage at the time of starting it produces some deviations in the output voltage.

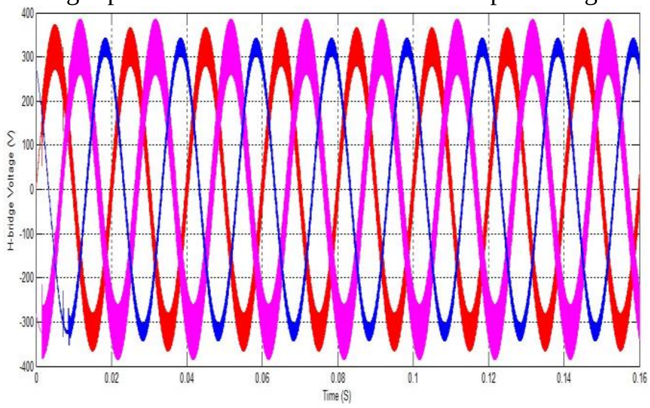

Figure 8: Single Delta Bridge Cell Voltage Waveform

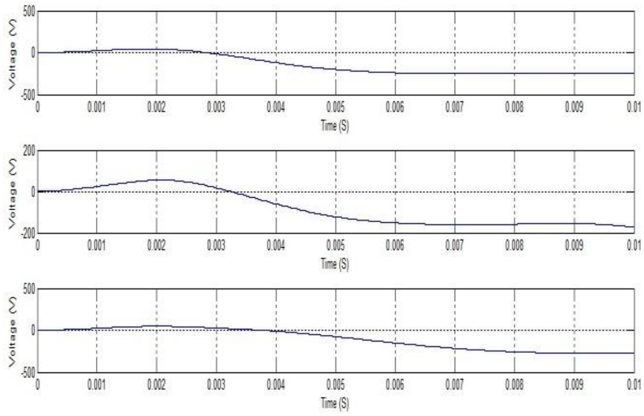

Figure 9: Capacitor Voltage(X – AXIS 1 DIV = 0.001 S; Y – AXIS 1 DIV = 20V)

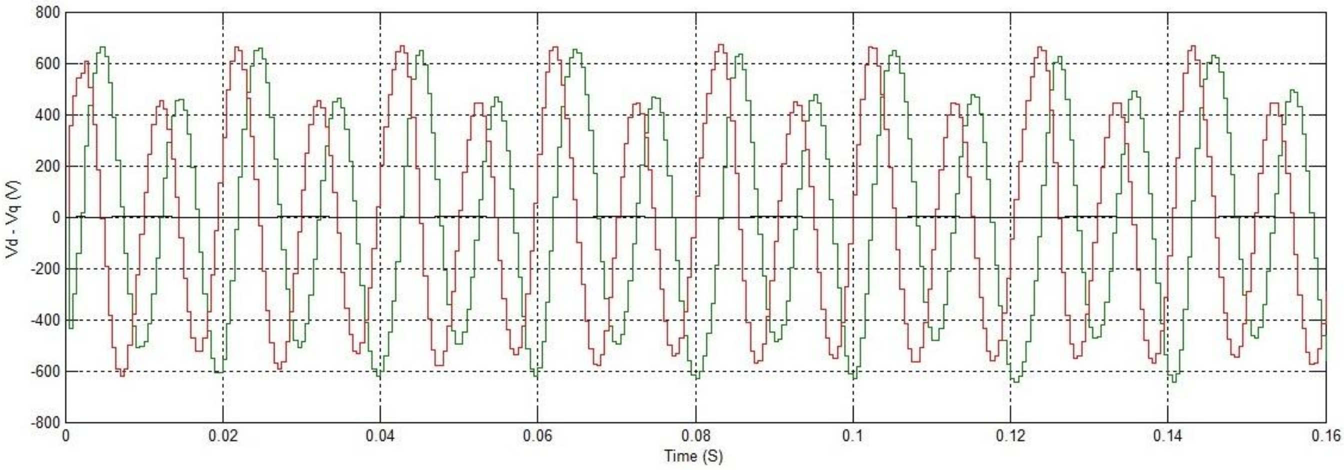

Figure 10: D – Q Transformation(X – AXIS 1 DIV = 0.02 S; Y – AXIS 1 DIV = 200V)

The Figure 9 and figure 10, the waveform shows the capacitor voltage and three phase voltages into to d-q transformation. The capacitor voltage is to be maintain for 3.5 msec at the time of operation after it's settled down at constant value, the below figure 9 shows the capacitor waveform. Figure 10 shows the abc to d – q transformation for overall voltage control. The three phase quantity to be converted into two phase quantity to simplying the operation. The Figure 11 shows the active and reactive power values for welding machine in the proposed method. The reactive power to be controlled as much as minimum to achieve active power for machine operation, it improves the power factor in the input side.

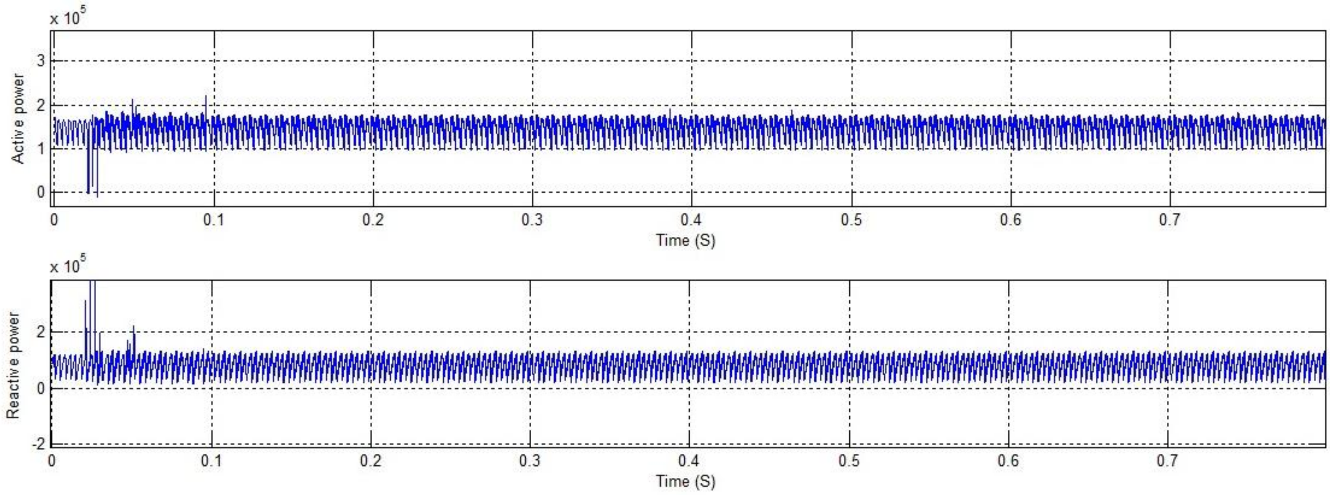

Figure 11: ACTIVE AND REACTIVE POWER VALUES
(X – AXIS 1 DIV = 0.1 S; Y – AXIS 1 DIV =1000 W)

The Figure 11 shows the output voltage and current waveforms of the welding machine. The machine output current is 100A is shown in the waveform, the welding transformer increases the current rating for machine operation at same time the voltage level is to be reduced from 440V to 12V.

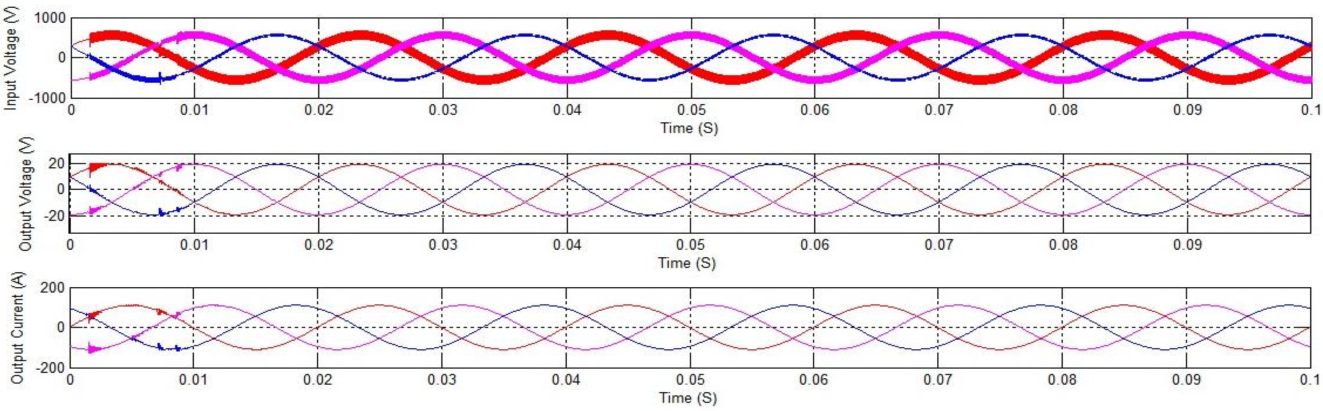

Figure 12: Output Voltage And Current Waveforms Of The Welding Machine Model (X – AXIS 1 DIV = 0.01 S; Y – AXIS = 20 V; Y – 200 A)

5. Results and Discussion

Discussion

The result shown in the figure 12 shows the input voltage and output voltage and current waveforms are in phase with each other and the THD obtained is 1.79% , for the welding machine. The single delta bridge cell configuration control the reactive power and increases the active power for its machine operation is shown in graph, it improves the system performance better.

Figure 8 to figure 12 shows the various waveform the of proposed method, after eight seconds the output voltage of the capacitor becomes constant. The output voltage is 12V and the output current is around 100A.

Future Scope

In this modular multilevel cascade converter topology can be applicable to control reactive power in induction furnaces, grid connected transformer, transmission line, etc.., And also SDBC bridge can be used for adjustable speed drives, Battery energy storage systems, multilevel inverter, etc..,

Conclusion

This project has discussed a SPWM STATCOM using an MMCC-SDBC, with focus on operating principle and performance. The experimental results obtained from the440-V 2kVA model have led to the following conclusions.

1) Low-voltage steps at the ac terminals of each cluster make a significant contribution to reducing the THD values of the compensating currents.
2) The SDBC has a capability to control reactive power with the help of the circulating current among the delta-connected clusters.
3) Positive and negative reactive power and low-frequency active power can be controlled simultaneously, realized in MATLAB environment.

References

[1] Akagi.H, ‘Classification, terminology, and application of the modularmultilevel cascade converter (MMCC)’, IEEE Trans. Power Electron., vol. 26, no. 11, pp. 3119–3130, Nov. 2011.
[2] Akagi. H , Inoue S, and Yoshii. T, ‘Control and performance of a transformerless cascade PWM STATCOM with star configuration’, IEEE Trans. Ind. Appl., vol. 43, no. 4, pp. 1041–1049, Jul./Aug. 2007.
[3] Akagi. H, Ryo Maeda and Makoto Hagiwara, ‘Negative-Sequence Reactive-Power Control by a PWM STATCOM Based on a Modular Multilevel Cascade Converter (MMCC-SDBC)’, IEEE Trans. Ind. Appl., vol. 48, no. 2, pp. 720–729, Mar./Apr. 2012.
[4] Barrena. J. A, Marroyo. L, Rodriguez. M. A, and Torrealday. J. R, ‘Individual voltage balancing strategy for PWM cascaded H-Bridge converterbased STATCOM’, IEEE Trans. Ind. Electron., vol. 55, no. 1, pp. 21–29, Jan. 2008.
[5] Cary, Howard.B, Helzer, Scott C. (2005), Modern Welding Technology, Upper Saddle River, New Jersey: Pearson Education, ISBN 0-13-113029-3.
[6] Hagiwara. M and Akagi. H, ‘Control and experiment of pulse width modulated modular multilevel converters’, IEEE Trans. Power Electron., vol. 24, no. 7, pp. 1737–1746, Jul. 2009.
[7] Han. C, Yang. Z, Chen .B, Huang. A. Q, Zhang. B, Ingram. M. R, and Edris. A, ‘Evaluation of cascade-multilevel-converter-based STATCOM for arc furnace flicker mitigation’, IEEE Trans. Ind. Appl., vol. 43, no. 2, pp. 748–755, Mar./Apr. 2007.
[8] Kalpakjian, Serope, Schmid, Steven R. (2001), Manufacturing Engineering and Technology, Prentice-Hall, ISBN 0-201-36131-0.
[9] Lee. C. K, Leung. J. S. K, Hui. S. Y. R and Chung. H. S. H, ‘Circuit-level comparison of STATCOM technologies’, IEEE Trans. Power Electron., vol. 18, no. 4, pp. 1084–1092, Jul. 2003.
[10] Liang. Y and Nwankpa. C. O, ‘A new type of STATCOM based on cascading voltage-source inverters with phase-shifted unipolar SPWM’, IEEE Trans. Ind. Appl., vol. 35, no. 5, pp. 1118–1123, Sep./Oct. 1999.
[11] Lincoln Electric (1994), The Procedure Handbook of Arc Welding, Cleveland, Ohio: Lincoln Electric, ISBN 99949-25-82-2.
[12] Sawicki. A, Switon. Ł and Sosinski. R, ‘Process Simulation in the AC Welding Arc Circuit Using a Cassie-Mayr Hybrid Model’, American Welding Society and the Welding Research Council, Mar 2011.
[13] J.S.Lai and F.Z.Peng, “Multilevel converters-A new breed of power converters” IEEE Trans.Ind.Appl., vol. 32, no. 3, pp. 509-517, May/Jun.1996.
[14] F.Z.Peng and J.S. Lai, “Dynamic performance and control of a static var generator using multilevel inverters” IEEE Trans.Ind. Appl.,vol.33,no.3,pp.748-755,May/Jun.1988.
[15] Weman, Klas (2003), Welding processes handbook, New York: CRC Press, ISBN 0-8493-1773-8.
[16] L.Maharjan, S.Inoue, and H.Akagi, “A transformer less energy storage system based on a cascade multilevel PWM converter with star configuration” IEEE Trans.Ind.Appl., vol. 44, no.5, pp. 1621-1630,Sep/Oct.2008.