Closed Loop Reactive Power Control by A SPWM STATCOM Based On Modular Multilevel Cascade Converter for Electric Welding Machine

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Abstract

This paper presents the application based on single delta bridge cells (SDBCs) to a STATic synchronous COMpensator (STATCOM) for closed loop reactive power control both positive sequence and negative sequence. The SDBC is characterised by cascade connection of H-bridge (or full bridge) converter cells per leg. The SDBC based sinusoidal pulse width modulation (SPWM) technique based STATCOM to control reactive power in closed loop with reduced harmonics and switching losses for the application of welding machine. In this proposed method to circulate the circulating current among the delta connected cluster and to stable the dc mean voltage in the each capacitor in the cluster arm for control the reactive power. In this method minimum number of power electronics switches are used and simultaneously to minimize the total harmonic distortion (THD). The performance of the proposed method is developed using MATLAB/Simulink software.

Keywords - Single delta bridge cells (SDBC), Sinusoidal pulse width modulation(SPWM), STATic synchronous COMpensator (STATCOM), Total Harmonic Distortion(THD)

1. INTRODUCTION

In recent years FACTS devices are used for reactive power compensation in electrical power system network. One of the many devices is a STATCOM which can be used to regulate the flow of reactive power in the system independent of other system parameters. The Modular Multilevel Cascade Converters (MMCCs) is expected as next generation power converters suitable for high voltage or medium voltage applications without line frequency transformers. The MMCC has various converter cell configurations: a) Single Star Bridge Cell (SSBC), b) Single Delta Bridge Cell (SDBC), c) Double Star Chopper Cell (DSCC) and d) Double Star Bridge Cell (DSBC) among above four configurations the SDBC, DSCC, and DSBC have the capability to control reactive power but the SDBC is better choice than others because it has the count ratio of 1.7 [1]. Flicker compensation of welding machine requires the control of reactive power. The SDBC has the capability of controlling reactive power mainly on negative sequence because it allows a current to circulate among their each cluster arms.

The SDBC based STATCOM with stair case modulation and pulse width modulation are used for operation of each H – bridge connected in each arm of the clusters. In stair case modulation no feedback loop is formed to control the circulating current among delta connected clusters.

The aim of this paper is to provide simulation results of a SDBC based sinusoidal pulse width modulation (SPWM) STATCOM for closed loop reactive power control (both positive and negative sequence) [5] for welding machine. In this control method that is characterised by forming feedback loop of the circulating current among the delta connected clusters. In this method five level cascade multilevel converter is used, to implement the hall effect voltage sensor on each H – bridge side to sense the voltage level of the each capacitor and feedback to the processor to control the amplitude of the carrier signal and also for balancing the capacitor voltage in each arm. As a result the STATCOM output voltage can be controlled by the modulation index. It improves the resultant STATCOM output voltage appears only as sidebands centered around the frequency of 2Nfs [2], this is provided that the voltage across the dc capacitor of each inverter is the same. It is followed by simulation results for downscaled model rated at 440V and 2kVA SDBC based STATCOM.

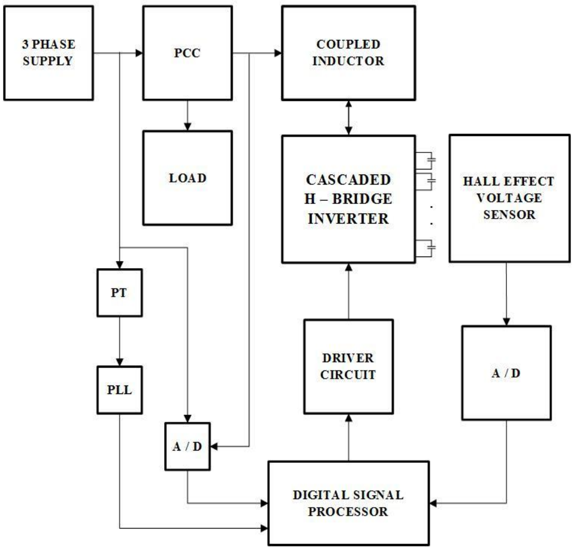

Figure 1. Block Diagram

The block diagram of closed loop reactive power control scheme is shown in Figure 1. 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 takes in the digital signals and produces the voltage commands after completing the digital processing to the gate driver circuit for 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) block is used to synchronize internal control signals with the line phase for d – q transformation and inverse d−q transformations [6].

2. CIRCUIT CONFIGURATION OF THE SDBC

The Figure 2 shows the detailed circuit configuration of the 440V, 2kVA STATCOM used in this simulation. Each cluster of the SDBC consists of cascade connection of three bridge cells. Three clusters are connected in delta configuration via a single coupled inductor L. The SDBC is connected to a three phase ac mains of 440V (line to line rms).

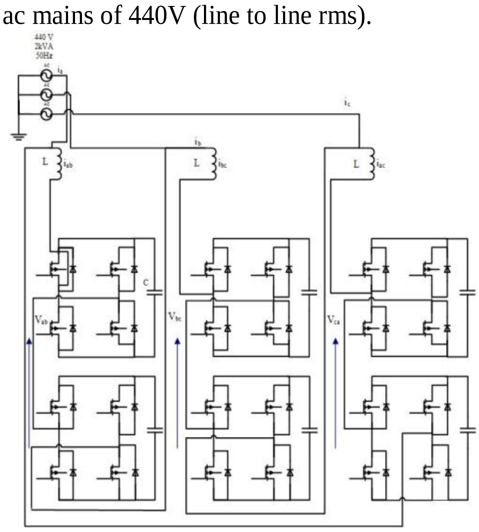

Figure 2. SDBC Circuit configuration

Here V_{ab}, V_{bc} and V_{ca} are the cluster voltages and i_{ab}, i_{bc} and i_{ca} are the cluster currents and p and q are the instantaneous active and reactive powers at the PCC. The following relations exist between the compensating currents and the cluster currents :

$$i_a = i_{ab} - i_{ca} \ ; \ i_b = i_{bc} - i_{ab} \ ; \ i_c = i_{ca} - i_{bc} \qquad (1)$$

Let the circulating current flowing inside the delta connected clusters be i_Z. It is defined as

$$i_Z = \frac{1}{3}(i_{ab} + i_{bc} + i_{ca}) \qquad (2)$$

Each carrier frequency of sinusoidal PWM for bridge cells was set as f_c = 2.5 kHz. The dc capacitor was set as V_c= 100μF. AC source inductance and coupled inductor were set as L_s = 0.5μH and L =10nH. Welding machine load was designed to set as input voltage of 20V and output load current of 100A.

3. DESIGN OF THE 2kVA STATCOM

The Figure 2 shows the circuit configuration of the 2 kVA delta configured STATCOM cascading two H-bridge PWM converters in each phase. All the GTOs have the same voltage rating and current rating as 4.5 kV and 1.7 kA. Each H – bridge has floating dc capacitors with maximal dc mean voltage capability of 1000V. The "sinusoidal PWM" with a carrier frequency of 2.5 kHz is applied to a cluster of six cascaded H-bridge converters in each phase. The ac voltage of each cluster becomes a 5 level line to neutral PWM waveform with the lowest harmonic sideband center 10kHz.

4. CHOICE OF WELDING MACHINE

In this paper an arc welding machine is chosen for a load because the arc process needs a large amount of current, up to 650A but at a relatively low arc voltage 10 to 40V with a typical high voltage main power supply and 230 to 400V. This type of equipment produces very high disturbances in the low voltage network and also in high voltage network, where they are mostly connected. The arc welding machines input currents have low frequency oscillations which can give rise to flicker. The group of devices in the range of above 5MVA connected to the high voltage grid for industrial manufacturing purposes like Shielded Metal Arc Welding (SMAW), Tungsten Arc Welding, Gas (GTAW) also known as TIG, Metal Arc Welding (GMAW) popularly known as Metal Inert Gas (MIG). These devices draw reactive power from supply so it causes low power factor, it heats the welding transformer, etc.., these drawbacks are overcome by using single delta bridge cell. In this paper 20V, 100A welding machine model is designed to represent as an arc welding model [8].

5. CONTROL METHOD OF THE SDBC

The main theme of this paper is to control reactive power and 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.

5.1 CLUSTER BALANCING CONTROL

The figure 3.1 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:

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

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

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

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

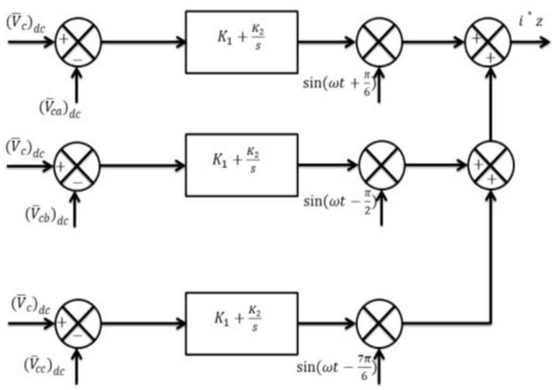

Figure 3.1. Cluster balancing control

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 $(\bar{V}_{ca})_{dc}$, $(\bar{V}_{cb})_{dc}$, $(\bar{V}_{cc})_{dc}$). The low pass filter is used to extract the dc component.

5.2 CIRCULATING CURRENT CONTROL

The Figure 3.2 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.

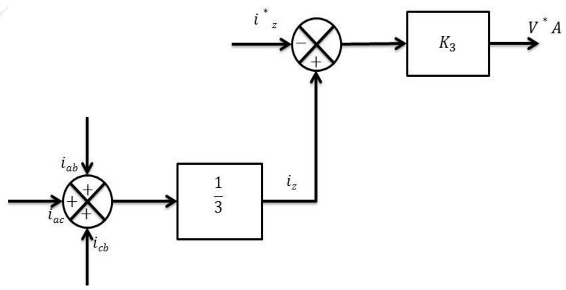

Figure 3.2. Circulating current control

5.3 INDIVIDUAL BALANCING CONTROL

The Figure 3.3 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 [3] and [4]. The voltage commands V^*B_{ja} , V^*B_{jb} , V^*B_{jc} are given by

$$V^*B_{ja} = K_4(\bar{V}_{C_a} - V_{C_{ja}})i_{ab}$$

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

$$V^*B_{jc} = K_4(\bar{V}_{C_c} - V_{C_{jc}})i_{ca} \qquad (4)$$

The following equation is obtained from (1) and (2)

$$\sum_{j=1}^{3} V^*B_{ja} + \sum_{j=1}^{3} V^*B_{jb} + \sum_{j=1}^{3} V^*B_{jc} = 0 \qquad (5)$$

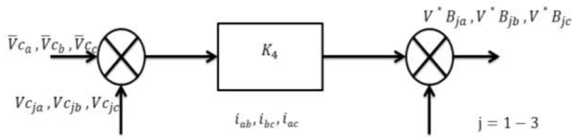

Figure 3.3 Individual balancing control

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.

6. REACTIVE POWER AND OVER ALL VOLTAGE CONTROL

The Figure 4 shows the block diagram of the active and reactive power and overall voltage control [7] 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. 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 reactive power particularly on negative sequence. The line to line voltage commands V^*_{ab}, V^*_{bc}, and V^*_{ca} are determined by decoupled current control of the compensating currents.

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 8ms using a moving average method with a frequency of 100 Hz.

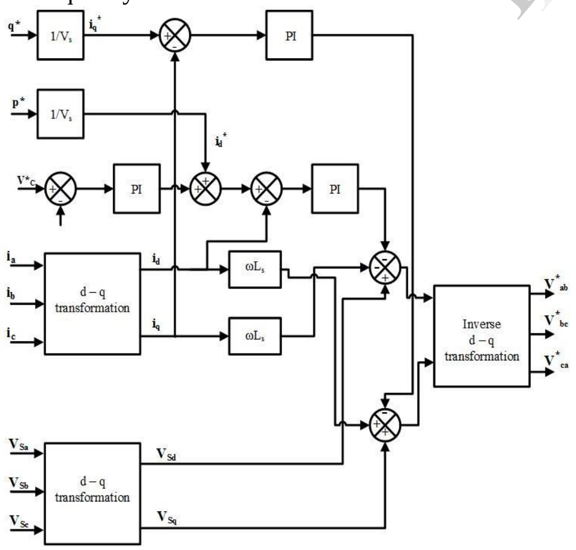

Figure 4. Reactive power control and overall voltage control

7. MATLAB SIMULINK MODEL

7.1 REACTIVE POWER CONTROL USING SDBC BASED STATCOM

SDBC based STATCOM for closed loop reactive power control for welding machine block diagram is

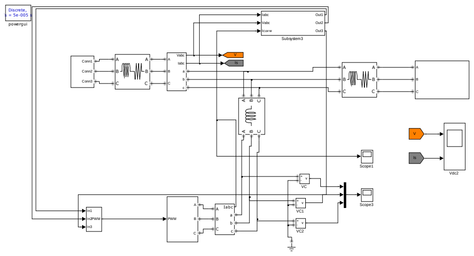

Figure 5.1 SDBC based STATCOM

shown in figure 5.1. In this method the SDBC bridge is used to control reactive power with feedback loop control. The output voltage of the bridge can be control by changing the modulation by closed loop. Circulating current is injected in the delta connected cluster for the control of reactive power due to load disturbances. The reactive power can be control by adjust the circulating current among delta connected clusters.

7.2 REACTIVE POWER CONTROL AND OVER ALL VOLTAGE

The figure 5.2 shows the reactive power control and overall voltage control block. The above mention control strategies are implemented in this block for control reactive power in closed loop manner. The modulation index can be varied by parameters obtained from the various control method implemented in the system.

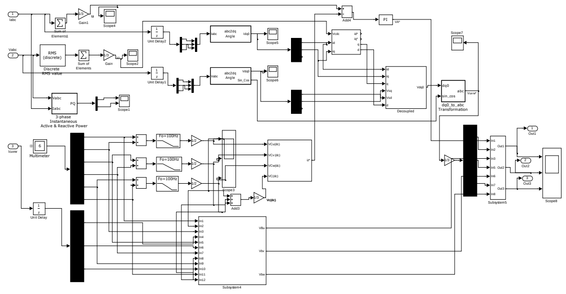

Figure 5.2. Reactive power control and over all voltage control

7.3 SINGLE DELTA BRIDGE CELL CONFIGURATION

The Figure 5.3 shows the delta connected H – Bridge in SDBC. Each cell has floating dc capacitor , the initial value of each capacitors has maintain by the system manner. The switches (GTOs) in the SDBC has 4.5kV capability so it can withstand higher level of input voltage. The clusters are connected in delta configuration manner.

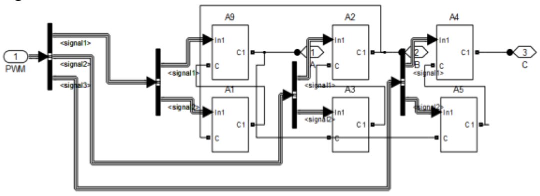

Figure 5.3. Single delta bridge cell configuration

7.4 WELDING MACHINE MODEL

The figure 5.4 shows welding machine model. Welding machine model is representing as a welding transformer. The values of the primary and secondary resistances and inductances are chosen form arc welding transformer. The rating of the machine is designed to provide 20V, 100A rating. The welding transformer output is given to bridge rectifier circuit to produce arc.

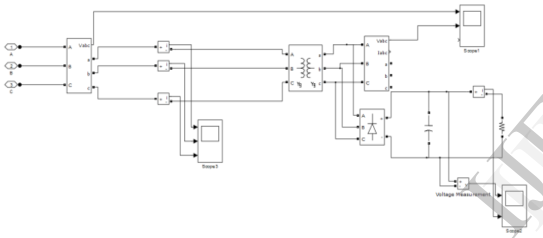

Figure 5.4. Welding machine

7.5 SIMULATION RESULTS

The following figure shows the output waveforms of SDBC based STATCOM for closed loop reactive power control in welding machine.

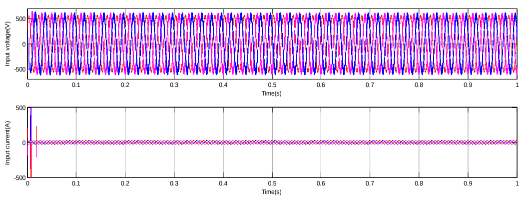

Figure 5.4. Input voltage and current

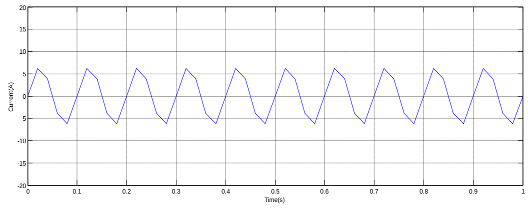

Figure 5.5. Circulating current in delta cluster

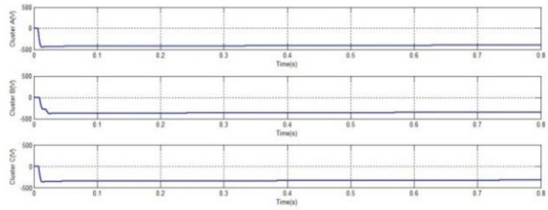

Figure 5.6. Capacitor voltage in each cluster

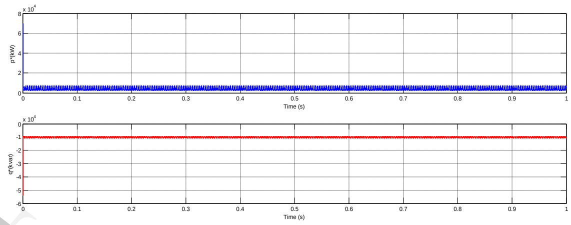

Figure 5.7. Active and reactive power

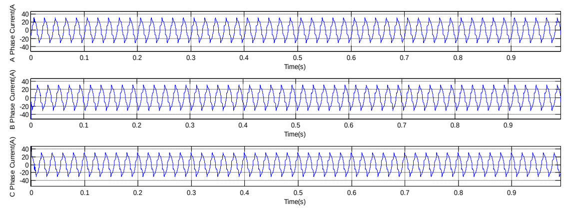

Figure 5.8. Input current to welding transformer

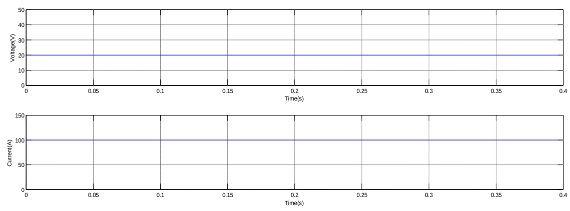

Figure 5.9. Output voltage and current

The single delta bridge cell is connected to the point of common coupling it inject circulating current in SDBC bridge to the supply for controlling reactive power the results are shown in figure 5.4. The capacitor voltage control is shown in figure 5.6 Capacitor voltage remains same up to 8ms after its decreased to lower level and maintain constant level. Figure 5.7 shows the active and reactive power control. Figure 5.8 shows the input current obtained in welding machine. Figure 5.9 shows the output voltage and current waveforms obtained from the welding transformer.

7.6 CONCULSION

In this paper the simulation of an arc welding machine reactive power is controlled by using single delta bridge cell and it acts as a STATCOM to control reactive power by injecting circulating current among delta connected arms in SDBC. The closed loop which helps to control the circulating current by change the modulation index of the carrier signal used in sinusoidal pulse width modulation for control the output voltage of STATCOM. The low voltage steps at the terminal of each cluster to make closely correlated to reducing the THD values. THD value of i_a in phase A is 0.54%. Active power and reactive power both are controlled on concurrent execution. In this single delta bridge cell topology can be applicable to control reactive power in adjustable speed drives, induction furnaces, grid connected transformer, transmission line, etc…,

8. REFERENCES

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