A Multi-Band Hysteresis Controlled 5-Level SCHB-MLI based STATCOM with Power Quality Improvement

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Abstract- In this paper, a simple Static VAR compensating scheme with Multi-Band Hysteresis Controller (MHC) based symmetrical cascaded five-level inverter for STATCOM is proposed. In many high-power applications, VAR compensation is achieved using multilevel inverters. The proposed topology consists of two single cell inverters are connected in cascade to get five-level output on each phase. In this paper, the STATCOM is controlled to provide both reactive power (VAR) compensation and power quality improvement at the point of common coupling. Multi-Band Hysteresis current control scheme is used to drive the five-level cascaded H-bridge multilevel inverter based STATCOM. The performance of the proposed scheme is investigated using MATLAB/SIMULINK. The simulation study shows that the best performance of the proposed scheme and results are presented.

Key Words: Cascade H-bridge multilevel inverter, Power Quality (PQ), Static Compensator (STATCOM), Hysteresis Controller, Multi-Band Hysteresis Controller (MHC).

I. INTRODUCTION

Generally, reactive loads possess low Power Factor (PF), draw excessive reactive power (VAR) restricting the maximum active power transfer and also adding losses to the power transmission and distribution systems. Low power factor loads also cause voltage variations or disturbances such as voltage/swells, lighting, hard switching and sudden increase/decrease in the loading conditions. This will challenge the tolerance level of electrical equipment in terms of stability and reliability. Therefore, to improve the voltage stability of power system networks under both normal and abnormal operating conditions the development of flexible ac transmission system controllers are necessary. This led to use of FACTS controllers, such as static synchronous series compensator (STATCOM) and static synchronous series compensator (SSSC) in power systems.

The rapid development of the power electronics industry has opened-up opportunities for improving the operation and management of power system networks [1,2]. Generally, in high-power applications, VAR compensation is achieved using multilevel inverter [3]. Among these, the Symmetrical Cascaded H-Bridge Multi-Level Inverter (SCHB-MLI) has been an attractive topology for STATCOM due to their extensibility, control simplicity, high-quality output etc.[4]. This proposed topology connects several H-bridge inverter modules in series to produce the desired multilevel output waveform.

In this paper, a static Var compensation scheme is proposed with the Multi-Band Hysteresis Current Controlled Symmetrical Cascaded H-Bridge Multi-Level Inverter. This topology uses standard H-Bridge Cell inverters to achieve multilevel operation. To verify the efficiency of the proposed scheme, the simulation study is carried out for nonlinear loads using MATLAB/SIMULINK. The proposed scheme not only used for reactive power compensation and also used for power quality improvement.

II. MHC BASED SCHB-MLI FOR STATCOM

STATCOM is to suppress voltage variation and control of reactive power in phase with system voltage. It can compensate for inductive and capacitive current linearly and continuously. The terminal voltage $V_{bus}$ is equal to sum of inverter voltage $V_{STATCOM}$ and voltage across leakage reactance $V_L$ and resistance in inductive and capacitive mode. It means that if output voltage of STATCOM, $V_{STATCOM}$ is in phase with bus terminal voltage $V_{bus}$ and $V_{STATCOM}$ is greater than $V_{bus}$, STATCOM provide reactive power to the system. If $V_{STATCOM}$ is smaller than $V_{bus}$, STATCOM absorbs reactive power from power system. If $V_{STATCOM}$ and $V_{bus}$ is equal then no power will be exchange, at that time STATCOM will operate in floating mode. Figure 1 illustrates the basic block diagram of STATCOM.

Figure 1. Block Diagram of STATCOM

A. Mathematical Modelling of STATCOM

A typical AC System is used in this paper to show performance of STATCOM. The basic configuration of STATCOM is shown in Figure1. STATCOM consist of resistance, leakage inductance, and VSI and DC capacitor. Resistance and inductance acts as magnetic coupling to the system. They provide isolation to inverter circuit and grid circuit. DC capacitor provides constant voltage, it acts as source. IGBT with anti parallel diode is used. IGBT performs converter action
whereas Diode performs rectification action. Following equations are used to calculate resistance, leakage inductance and DC side capacitance First order differential equation for the ac-side circuit of the STATCOM is

\[ \frac{dI}{dt} = 1/\text{ls} (-Rs * Isa + Esa - Et) \] (1)

\[ \frac{dIb}{dt} = 1/\text{ls} (-Rs * Isb + Esb - Et) \] (2)

\[ \frac{dc}{dt} = 1/\text{ls} (-Rs * Isc + Esc - Et) \] (3)

STATCOM DC side equation is

\[ dV_{dc}/dt = 1/\text{Cs} (1_{dc} + V_d) \] (4)

Instantaneous powers at the ac and dc terminals of the converter are equal, giving the following power-balance equation:

\[ V_{dc} * I_{dc} = 3/2(EsR + Es\theta_s) \] (5)

Where the constant 3/2 is reference frame transformation constant. Based on the phasor diagram EsR and Esl is

\[ EsR = Es \cos\theta_s = Kcs * V_{dc} \cos \theta_s \] (6)

\[ Esl = Es \sin \theta_s = Kcs * V_{dc} \sin \theta_s \] (7)

B. Multi-Level Inverter

In recent years industrial applications require high power for their operation. Some industry appliances however require medium or low power for their operation. Using a high power source for all industrial loads may prove favorable to some motors requiring high power, while it may damage the other loads. Some medium voltage motor drives and utility applications require medium voltage. The multi level inverter has been introduced since 1975 as alternative in high power and medium voltage applications. The Multi level inverter is like an inverter and it is used for industrial applications as alternative in high power and medium voltage applications.

The cascaded H-bridge multi level inverter is to use capacitors and switches and require less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like 0, +Vdc and -Vdc voltages. Compared with diode clamped and flying capacitor inverters this type of multi level inverter requires less number of components. The price and weight of the inverter are less than those of the two inverters. Multilevel cascade inverters are used to eliminate the bulky transformer required in case of conventional multi phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply the each cell [5].

The traditional two or three levels inverter does not completely eliminate the unwanted harmonics in the output waveform. Therefore, using the multilevel inverter as an alternative to traditional PWM inverters is investigated. In this topology the number of phase voltage levels at the converter terminals is 2N+1, where N is the number of cells or dc link voltages. In this topology, each cell has separate dc link capacitor and the voltage across the capacitor might differ among the cells. So, each power circuit needs just one dc voltage source. Each H-bridge cell may have positive, negative or zero voltage. Final output voltage is the sum of all H-bridge cell voltages and is symmetric with respect to neutral point, so the number of voltage levels is odd. Cascaded H-bridge multilevel inverters typically use IGBT switches. These switches have low block voltage and high switching frequency. Figure 2 shows Cascade H-bridge 5-level multilevel inverter.

C. Modelling of SCHB-MLI with Hysteresis Controller

Figure 3 shows Basic Hysteresis Band Controller. Hysteresis band controller is a simple, effective and dynamic in nature and also applicable for any type of control systems. This controller will operate with a signal based on the band of controller, if it will be either in error or a command signal. The main advantages of the controller are having a square pulse outputs in the controller side. The goal is to keep the actual value of the Signals within their hysteresis bands all the time.

![Figure 2. Cascade H-bridge 5-level multilevel inverter](image)

![Figure 3. Basic Hysteresis Band Controller](image)
Figure 4. Basic Operation of Hysteresis Controller

In Figure 4 the basic operation of the hysteresis controller was clearly visualized. Generally hysteresis controllers [7] are having lower and upper band value, it may be symmetric of different form each other based on the working plant. In figure 4 the arrow gives the ON state when the hysteresis band controller was commanded like if the error signal is within the limits, otherwise it will be OFF, and it will be shown by the arrow.

D. Multiband Hysteresis Controller

Figure 5. Multi-Band Hysteresis Controller

Multiband Hysteresis Controller operation is same the basic controller but only the change is to comparison of error signal with the band of {0 to +A} and above +A as shown in figure 5, in same way negative side also. Here a digital or discrete code are generates for the different levels to identify the level of signal compared with the hysteresis bands.

Figure 6. Operation of the Multiband Hysteresis Controller

The digital codes based on the hysteresis band levels are indicated on right side of the figure 6, the error signal are compared with the reference of bands of hysteresis controller and with the basic strategy of hysteresis controller the generated digital code are indicated on the bottom of the figure 6. Based on these digital codes a particular operation is performed by the plant with the user commands and system parameters.

E. Implementation of Hysteresis/ Multiband Hysteresis Band Controller

Figure 7 shows the methodology of implementation of Hysteresis controller to multilevel inverter, here the multilevel inverters are operated based on the hysteresis current control strategy [6-10]. The strategy is explained in previous sections, so a simple block diagrams are presented for the variation of existing and proposed systems.

III. SIMULATION & RESULTS

The MATLAB/SIMULINK model of the proposed scheme is shown in figure 8. The proposed scheme consists of hysteresis current controlled cascade H-bridge five-level multilevel inverter based STATCOM. The pulses form the proposed control scheme is given to the gates of five-level multilevel inverter. STATCOM outputs for hysteresis current control based three-level multilevel inverter are shown with the help simulation. Figure 9 shows the cascade connection of three level H-bridge inverters to get the required five-level multilevel output. Three five-level cascades H-bridge multilevel inverter are implemented for three phase operation.
Figure 8. MATLAB/SIMULINK model of Cascaded Five-level H-bridge multilevel inverter based STATCOM

Figure 9. Five-level cascade H-bridge multilevel inverter

Figure 10 shows the Hysteresis control scheme of five-level cascade H-bridge multilevel inverter. Where $I_{abc}$ and $I_{Sref}$ are actual and reference source currents respectively. By comparing these two values error is generated and according to gate signal is generated and drive the five-level cascade H-bridge multilevel inverter.

Figure 11. Hysteresis current control based three-level multilevel inverter waveforms

Figure 12. Enlarged view of outputs for three-level multilevel inverter

Three-Phase outputs (Sequentially source current, load current, compensation current and induction machine current from top to bottom) are shown in Figure 13.

Figure 13. Three-phase outputs

Figure 11 and 12 shows hysteresis current control based three-level multilevel inverter outputs and enlarged view of outputs.
Figure 14. Compensator side voltage

Figure 14 shows compensator side voltage of the current control based three-level multilevel inverter. STATCOM outputs for Multiband hysteresis current control based five-level multilevel inverter are given below. Figure 15, 16 shows hysteresis current control based five-level multilevel inverter outputs and enlarged view of outputs.

Figure 15. Multiband hysteresis current control based five-level multilevel inverter waveforms

Figure 16. Enlarged view of outputs for five-level multilevel inverter

Three-Phase outputs (Sequentially source current, load current, compensation current and induction machine current from top to bottom) are shown in figure 17.

Figure 17. Three-phase outputs

Figure 18 shows compensator side voltage of the multiband hysteresis current control based five-level multilevel inverter

Figure 18. Compensator side voltage

IV. CONCLUSION

In this paper, a simple Static VAR compensating scheme with Multi-Band Hysteresis Controller (MHC) based Symmetrical Cascaded five-level inverter for STATCOM is proposed. The performance of the scheme is validated by simulation under non-linear load conditions. The proposed topology consists of two three-level inverters connected in cascade to get five-level output on each phase. In this paper, the STATCOM is controlled to provide both reactive power (VAR) compensation and power quality improvement at the point of common coupling. Multi-Band Hysteresis current control scheme is used to drive the five-level cascaded H-bridge multilevel inverter based STATCOM. The proposed system simulated using MATLAB/ SIMULINK software and results for 3-level and 5-level (both single-phase and three-phase) are presented.
REFERENCES


