A Novel Passivity-Based Control (PBC) Method for Transformer Less H-Bridge Cascaded STATCOM With Star Configuration

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Abstract - This work has analyzed the fundamentals of STATCOM based on multilevel H-bridge converter with star configuration, and then, the actual H-bridge cascaded STATCOM rated at 10 kV 2 MVA is constructed and the novel control methods are also proposed in detail. The proposed methods has the following characteristics. 1) A PBC theory-based nonlinear controller is first used in STATCOM with this cascaded structure for the current loop control, and the viability is verified by the experimental results. 2) The PR controller is designed for overall voltage control and the experimental result proves that it has better performance in terms of response time and damping profile compared with the PI controller. 3) The ADRC is first used in H-bridge cascaded STATCOM for clustered balancing control and the experimental results verify that it can realize excellent dynamic compensation for the outside disturbance. 4) The individual balancing control method which is realized by shifting the modulation wave vertically can be easily implemented in the FPGA. The experimental results have confirmed that the proposed methods are feasible and effective. In addition, the findings of this study can be extended to the control of any multilevel voltage source converter, especially those with H-bridge cascaded structure.

Keywords - STATCOM, PBC, Star Configuration, Transformer Less, H-Bridge.

I. INTRODUCTION

With the ever increasing need for energy, many power transmission networks are reaching their limits. Building new transmission lines could possibly alleviate this problem, but the associated cost is extremely high, and the level of urbanization in many regions often makes this impossible. One possible solution is to optimize existing networks.

Given that networks need a stability margin in order to cope with transient events, the power transmission capabilities cannot be increased up to the thermal limits of lines and transformers. However, if the size and severity of these tran- sient events can be reduced, the necessary margin can also be reduced, and more transmission capability can be obtained from the same network.

Several devices can be used in order to improve network transient stabiliy. One such device is the Static Synchronous Compensator or STATCOM as it will be referred to from here on. In addition to improving network transient stability, STATCOMs can also be used for voltage support and to improve power quality in many industrial processes. Utilities impose strict power quality requirements on industries, and the costs associated with the penalties for not fulfilling these requirements are quite high. Therefore, STATCOMs are often a worthwhile invest- ment for large industrial customers.

The flying-capacitor, diode-clamped and H-bridge cascade inverters are widely used multilevel topologies in STATCOM applications because of their advantages with low frequency switching, specific harmonic elimination and high voltage applications.

The STATCOM, is one member of the large family of Flexible AC Transmission Systems Controllers (FACTS Controllers). In simple terms, the STATCOM is a shunt device which acts as a voltage source by controlling the amount of reactive power it absorbs or generates. This work briefly explains what STATCOMs are used for, and how they operate from a system point of view.

Starting from a two bus network such as the one shown in figure 1.1, one can derive the following equations for active and reactive power flow. The derivation

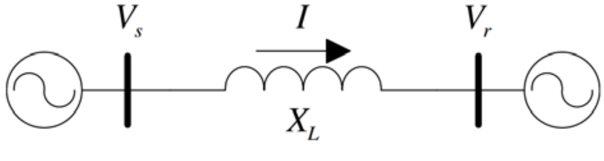

Figure 1.1 Two bus network with active/reactive power flow.

In the network of figure 1.1, the impedance X_L can be split into two parts. The first part can represent a Thevenin equivalent network together with the source Vs, and the second part can represent the combined transformer reactance and phase reactance of a STATCOM where the source Vr represents the converter. A schematic of a STATCOM is shown in figure 1.2.

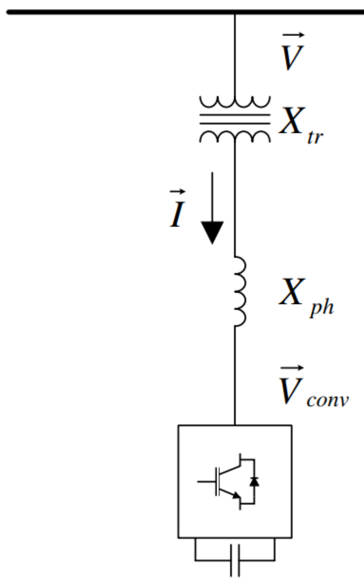

Figure 1.2 Typical STATCOM single - Line diagram.

II. SYSTEM MODEL

To model and design power systems, the first step is to study the power systems. According to the mechanical and electrical characters of power systems, the state space equations can be obtained. Different control methods which are applied to control the state space equations.

a. Passivity-Based Control

The passivity-based control (PBC) is a kind of energy-balancing control, it is a well-established technique that is very effective designing controller for systems that are also described by Euler-Lagrange equations of motion. To solve the regulation problem of mechanical systems, using passivity-based control design, only potential energy must be stabilized by "shaping". Passivity-based control also keeps system in the Euler-Lagrange form, to obtain a closed-loop energy function. This energy function equals the difference between the energy in the system and the energy supplied by the controller. Hence, stabilization of the system can be explained in terms of energy-balancing, which means that in a passivity-based controlled system, when the system runs toward equilibrium point, dissipation of the system becomes zero.

However, in some cases, shaping of total energy is required, and modification of the kinetic energy is necessary. Closed-loop system no longer satisfies the Euler-Lagrange structure, and energy function no longer represents the total energy. passivity-based control (PBC) is concerned. PBC is satisfied by energy-balancing, and it may be used to solve the problem of stabilization of under-actuated mechanical systems.

b. Cascaded H-Bridge (CHB) Converter

The cascaded H-Bridge (CHB) topology is based on the series connection of multiple electrically isolated standard H-bridge modules and is well reviewed [27, 31]. Each module is supplied by an isolated DC source (VDC/n), where "n" represents the number of cascaded H-bridges per phase.

Figure 2.1 shows one leg of a three-level CHB converter topology. With each module capable of generating (VDC/n, 0, -VDC/n), the final AC output is a cascade of the separate AC outputs on each level and proper modulation control of the converter ensures an output with low total harmonic distortion value and harmonic content. In the CHB topology the absence of clamping devices (capacitors, diodes) reduces the number of power components. In practice the CHB topology is modular and less complex to control, however the requirement of several isolated DC supplies results in an expensive converter arrangement.

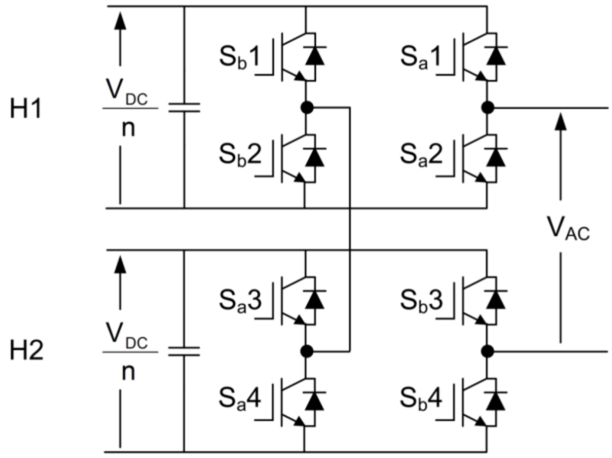

Figure 2.1 a single phase cascaded H-Bridge (CHB) Topology.

The arrangement shown in Figure 2.1 is one phase of a CHB converter topology formed from a cascade connection of two H-bridge modules.

III. PROPOSED SYSTEM MODEL

The modelling of proposed system based on PBC has completed on Matlab Simulink. Figure 3.1Shows a block diagram of the control algorithm for H-bridge cascaded STATCOM. The entire proposed design algorithm fundamentally divided in four components, such as, PBC, Compensator block, controller circuit consists of balancing control, and individual balancing control. The first three parts are achieved in DSP, while the last part is achieved in the FPGA.

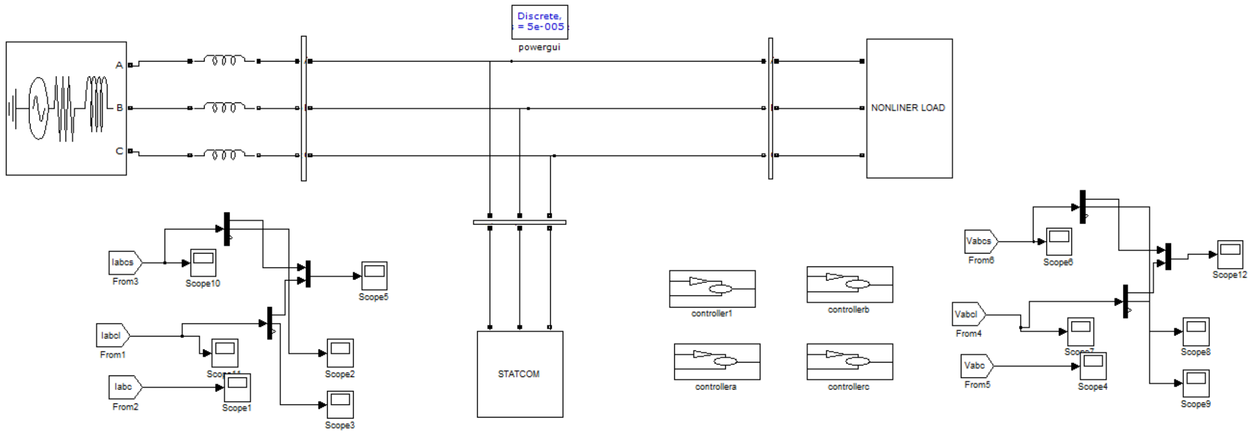

Fig. 3.1 Proposed System Model with PBC.

A Compensator block has been shown in figure 3.2. A compensator is an electrical circuitry utilized to produces a sinusoidal output waveform having the phase lag when a sinusoidal input is applied. In order to produce the phase lead at the output of this compensator, the phase angle of the transfer function should be positive. The simulink model of control circuitry has been shown in figure 3.3. Passivity-Based Control (PBC) Circuit used to in proposed work has been shown in figure 3.4. Star-configured STATCOM cascading H-bridge converters in each phase and it can be expanded easily according to the requirement. By controlling the current of STATCOM directly, it can absorb or provide the required reactive current to achieve the purpose of dynamic reactive current compensation. Finally, the power quality of the grid is improved and the grid offers the active current only. PBC is a kind of energy-balancing- based control used to design the ideal control for proposed system.

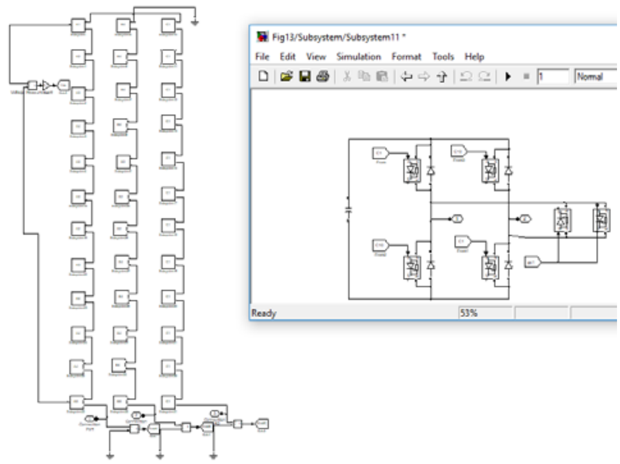

Figure 3.2 Compensator Block.

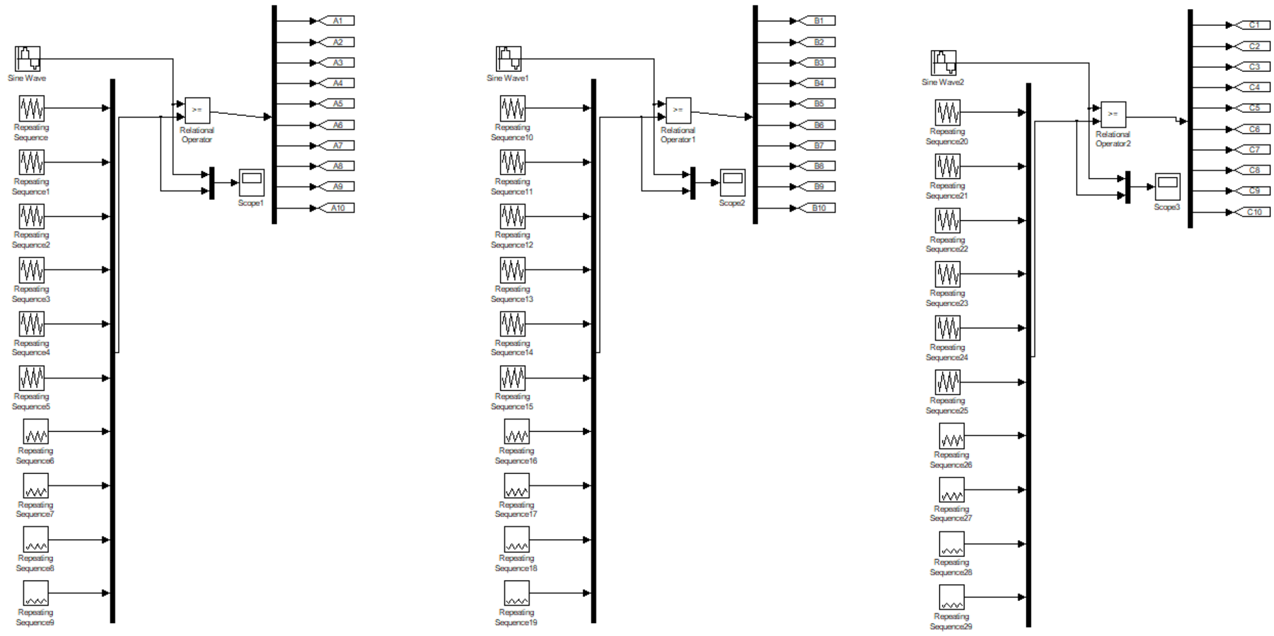

Figure 3.3 Controller Circuit Simulink Model.

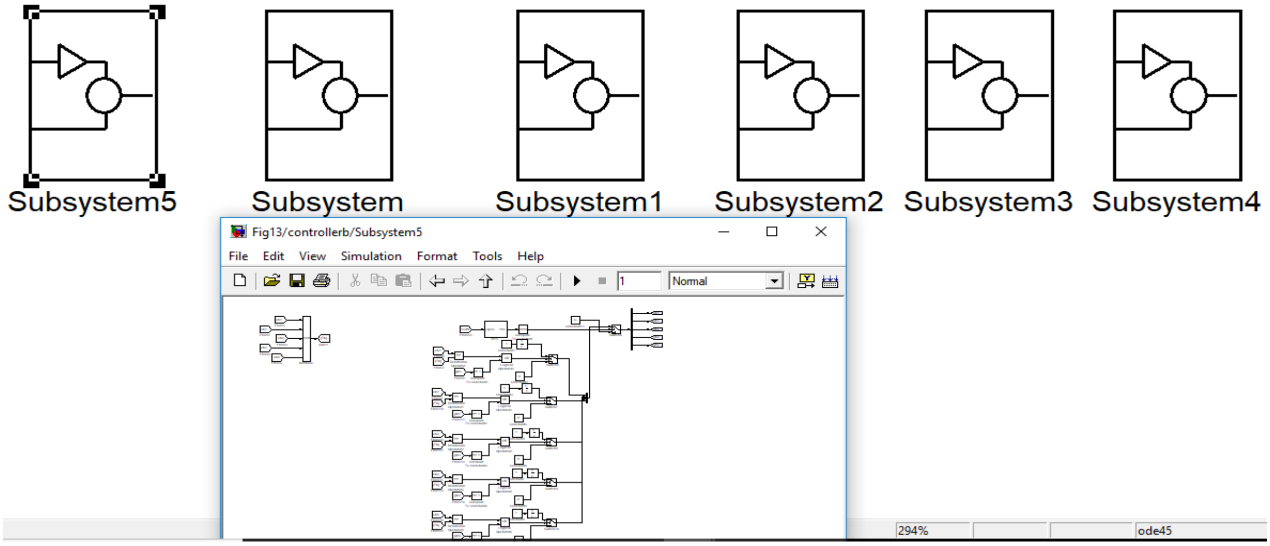

Figure 3.4 Passivity-Based Control (PBC) Circuit.

IV. SIMULATION RESULTS

To verify the performance of the proposed passivity-based control (PBC) system for transformer less H-bridge cascaded STATCOM with Star Configuration, the simulation platform is performed on MATLAB SImulink. The simulation waveform of proposed work has obtained and compared with the existing based work. It is found that the proposed work has better performance as compared to existing work. From the simulation results shown in Fig. 4.1 and Fig.4.2, Fig.4.3, Fig. 4.4, Fig. 4.5 Fig. 4.6 and Fig. 4.7 it can be concluded that the precise calculation of the feed- forwarding term by the proposed method enhances the reliability and stability of the STATCOM conspicuously.

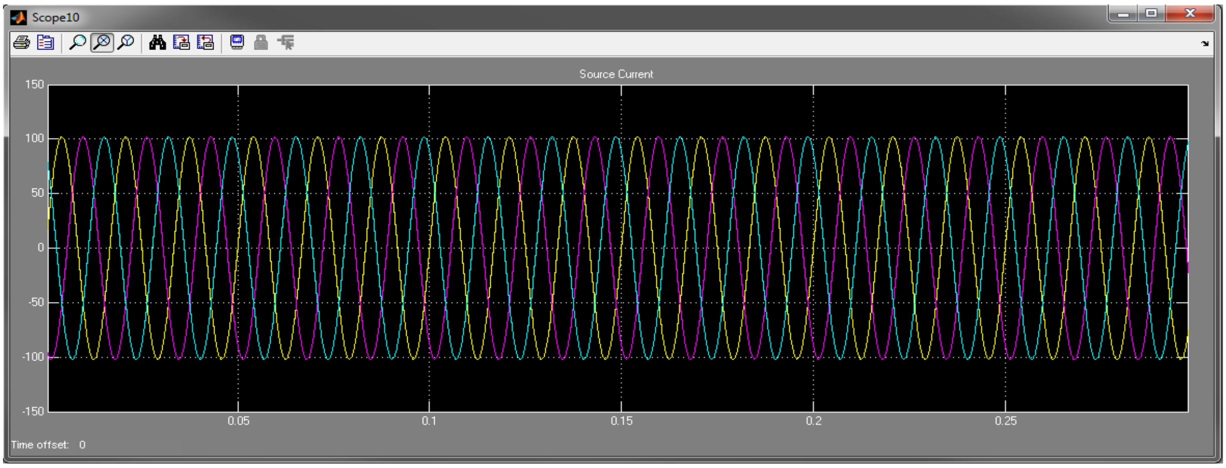

Figure 4.1 Three Phase Source Current Waveforms.

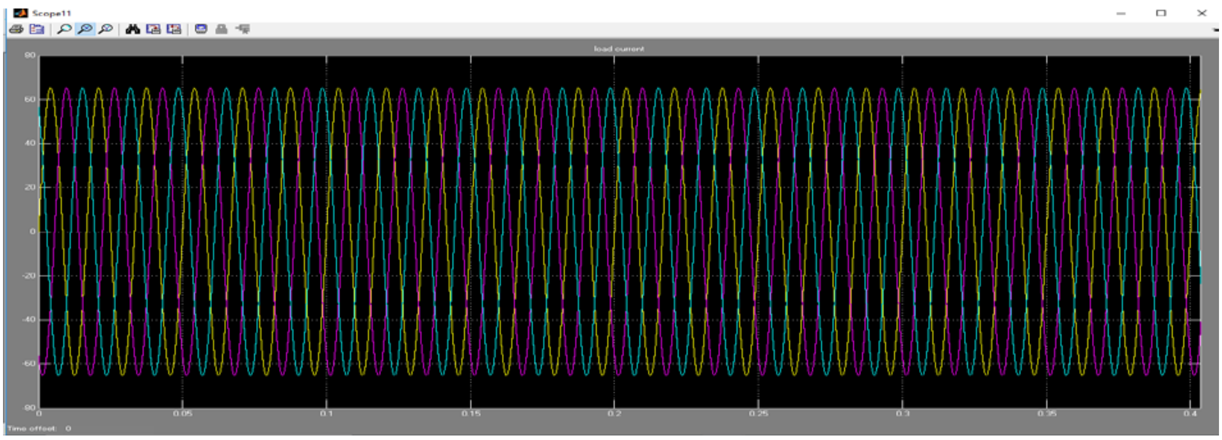

Figure 4.2 Three Phase Load Current Waveforms.

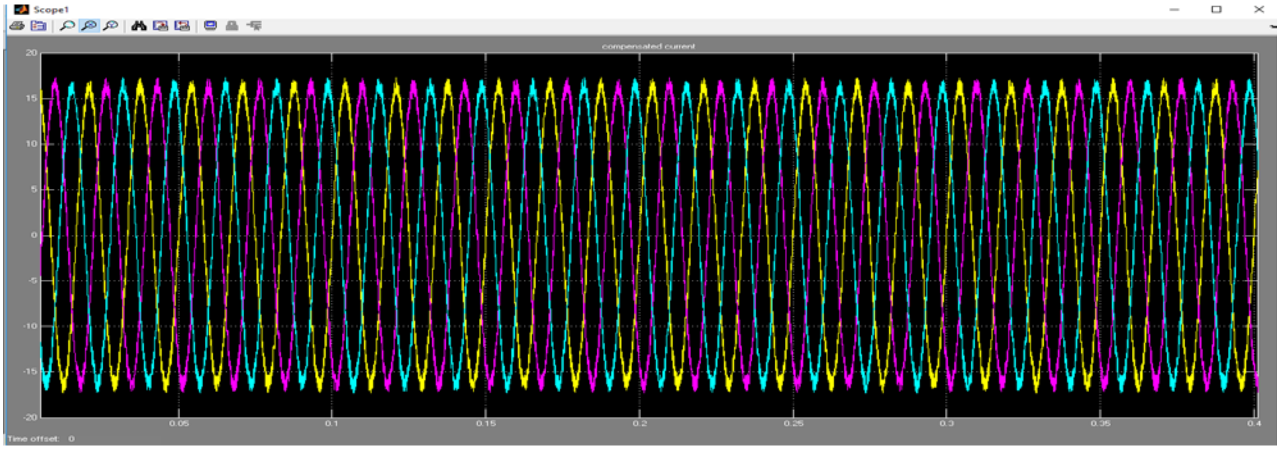

Figure 4.3 Three Phase Compensated Current Waveforms.

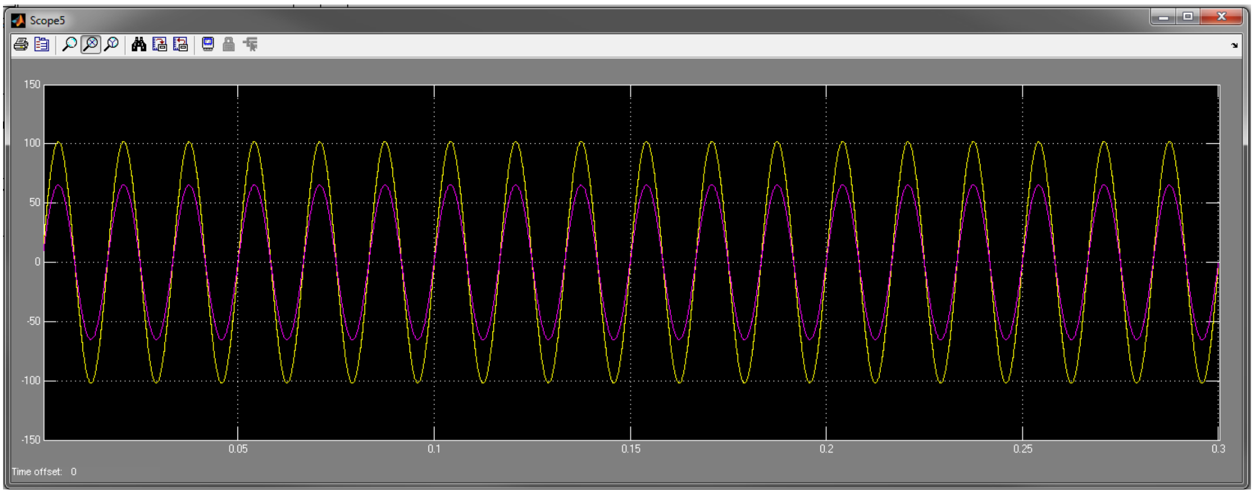

Figure 4.4 Single Phase Source and Load Current Waveforms.

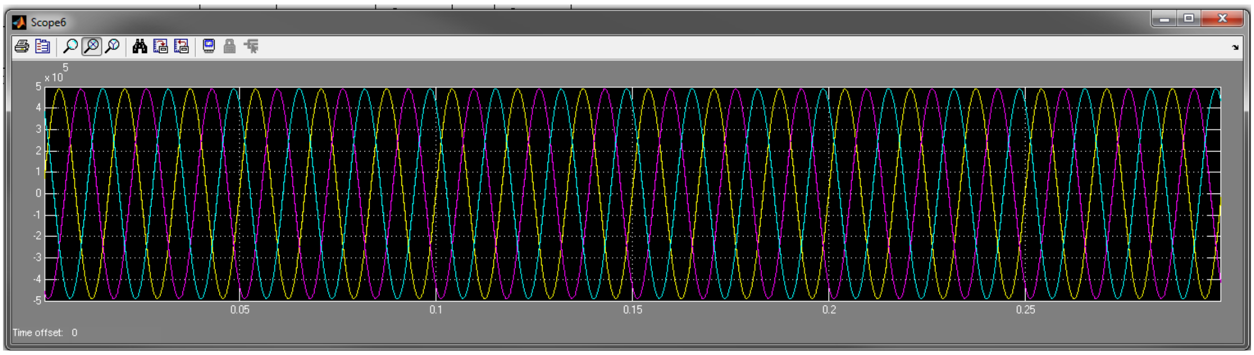

Figure 4.5 Three Phase Load Voltage Waveforms.

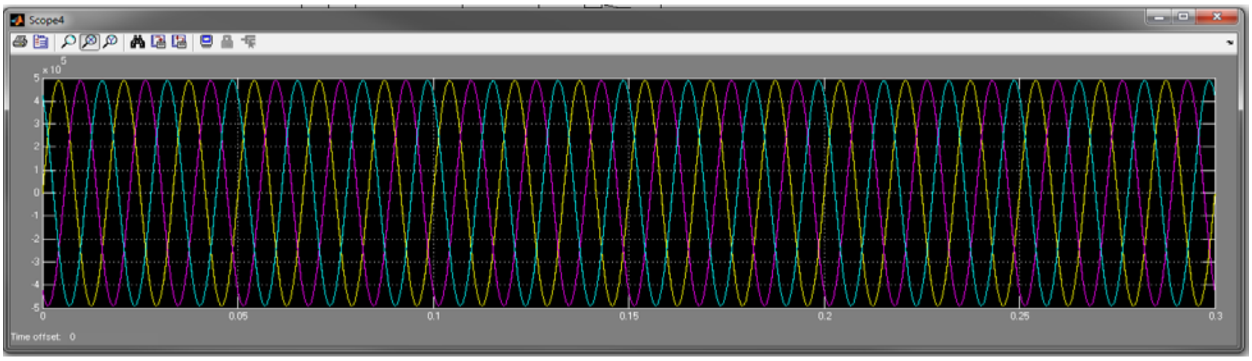

Figure 4.6 Single Phase Source and Load Current Waveforms.

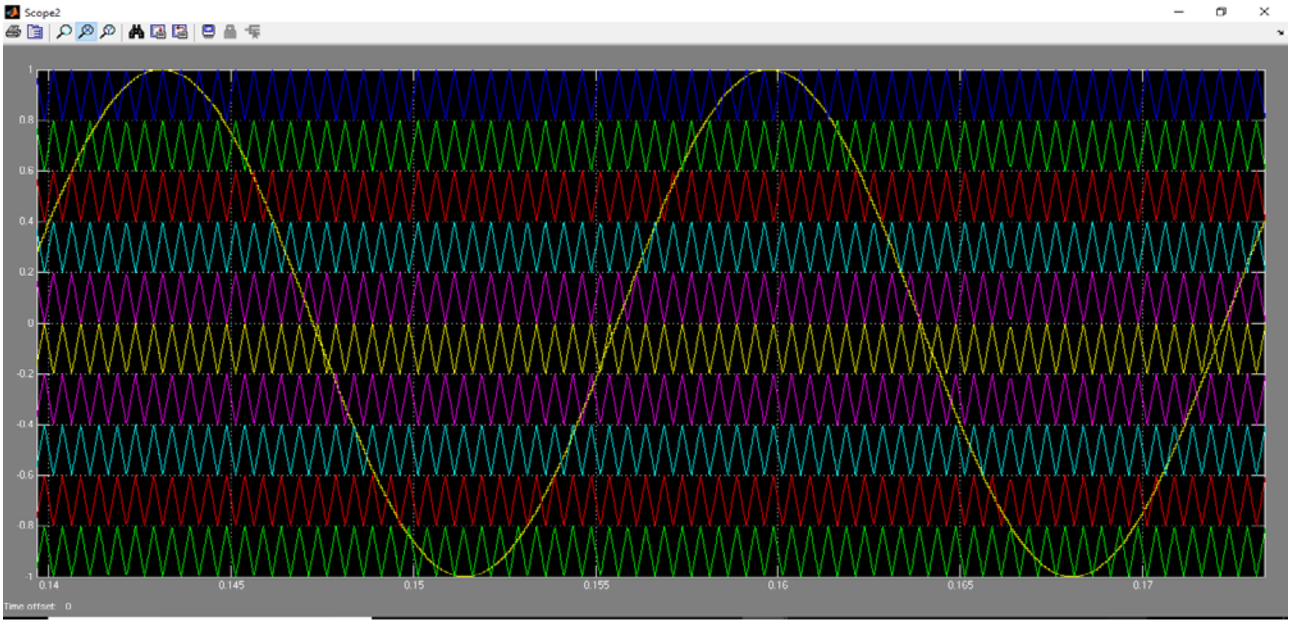

Figure 4.7 Compensating Signals of STATCOM Block.

V. CONCLUSION

In this work a novel passivity-based control (PBC) method for transformer less h-bridge cascaded STATCOM with star configuration was intended to investigate the feasibility of implementing a topology. The performance of the Cascaded Multi Level Inverter (MLI) topology based STATCOM with cascaded H-Bridge CHB is investigated for reactive power compensation. The proposed system design is implemented and simulated on MATLAB Simulink. The results obtained are verified and the performance is compared with existing work. The H-bridge Multi Level Inverter (HMLI) with single dc source is investigated for reactive power compensation. A PBC algorithm based nonlinear controller is initially utilized as a part of STATCOM for control, and the performance is verified by the test results.

Several scopes are available for further work. Future studies may include the application of STACOM for unbalanced grid conditions to the converter at system level. To achieve this, the transformer less CHB configuration may need to be adjusted to match the requirements of different scenarios

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