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# Modelling of Cascaded Multilevel STATCOM for Square Wave-Controlled and Circulating current Compensasion

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**ABSTRACT**: The proposed system implemented a FACTS device like STATCOM based cascaded multilevel converter is an effective solution to compensate the circulating current and to control the square shaped waveform. Simultaneously in order to maintain the voltage stability by compensating the circulating current in transmission line. Cascaded multilevel based STATCOM can be placed at near the point of common coupling for improving the power quality. This paper develops the mathematical model of cascaded multilevel based STATCOM system in which voltage and current waveforms are simulated with the help of MATLAB / SIMULINK. The good agreement between theoretical analysis and simulation results verify that the proposed theoretical analysis method is valid and feasible, which can be extended to the analysis of similar power electronic circuits. The analytical and simulation results show at the same condition, the voltage and current harmonic contents of the dual three-level STATCOM can be effectively decreased compared with the three-level STATCOM, and the capacity of the dual three-level STATCOM can be increased. Finally, the analytical results obtained in this paper.

**KEYWORDS:** H-Bridge stack cell, Cascaded multilevel Static Synchronous Compensator (STATCOM), circulating current, square waveform.

## I.INTRODUCTION

Power Quality (PQ) related concern is one of the most apprehensions now a days. The extensive use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting etc. led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems. Due to the non-linear loads, mostly disturbances are occurred in power system as well as circulating current also flowing from non linear load to source through transmission line. The circulating currents are created by the mutual fluxes between the primary and secondary windings of the transformer as well as some electromagnetic machines and which causes large amount of heating in conductor [1]. The circulating current compulsorily depends upon the load. Generally there are three main regions in a power system and they are generation, transmission and distribution. Out of them our focus is on the transmission system. Transmission line interconnects one region to another region through conductor. Due to bilateral situation in the transmission system i.e. same impedance of both systems from source to load or vice versa. Transmission conductors act like an RLC parameters. Because of the bilateral condition of transmission conductor, reverse (circulating) current enter into the transmission conductor. We can't change the bilateral characteristics of the transmission line and we can't change the conductor also. So to change this effect we have to implement one of the techniques. The proposed technique cascaded multilevel H-Bridge STATCM is shown in fig.1. As an industry customer of electric power, an electrical arc furnace (EAF) is a major flicker source that causes major power quality problems. For a 40-MVA EAF in Tennessee, USA, a cascade-multilevel converter (CMC)-based Static Synchronous Compensator (STATCOM) with high bandwidth is proposed for EAF flicker mitigation[2]. A modular and decoupled approach to achieve harmonic cancellation in a multilevel Static Compensator (STATCOM) is presented in [3].

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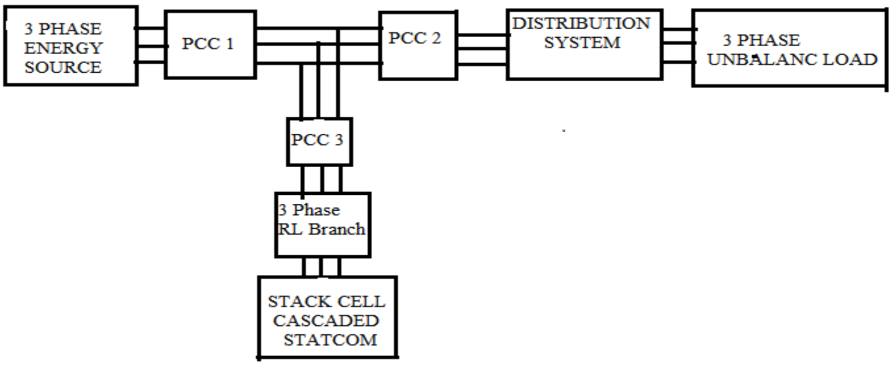


Figure 1Basic block diagram of proposed system

## II. OPERATING PRINCIPLE OF THE CASCADED MULTILEVEL CONVERTER BASED STATCOM

The STATCOM is connected to the problematic bus of a power network at a PCC. To make the entire system work efficiently and accurately, the controller requirements to be strong. All necessary voltages and currents are measured and then fed into the controller to be compared with the commands. The controller then performs feedback control, and outputs a set of switching signals to drive the main valves of the power converter accordingly. The feedback controller regulates the output currents and DC-link voltages. The single-line diagram of the STATCOM system is illustrated in Figure 2. In general, the CMC is represented by an ideal VSC, which is associated with internal loss, that is connected to the AC power by means of coupling impedances. Generally, the internal losses are accumulated from semiconductor switching and conduction losses, stray resistance losses in interconnections and passive components, snubber circuit losses, etc.

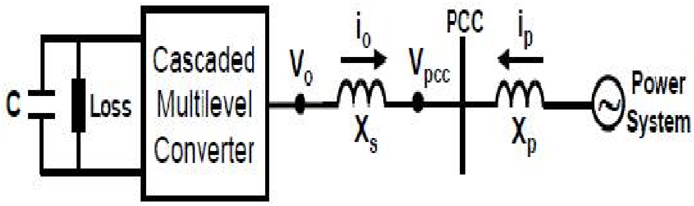


Figure 2 Single-line diagram of the cascaded-multilevel converter-based STATCOM.

The exchange of real power and reactive power between the cascaded converter and the power system can be controlled by adjusting the amplitude and displacement angle of the converter output voltages with respect to the voltage at the PCC. In the case of a lossless converter, the output voltage of the converter is controlled to be in phase with that of the power system. In the capacitive mode, the STATCOM generates a given amount of reactive power to the connected network, while, in the inductive mode, the STATCOM absorbs a given amount of reactive power from the connected network. To operate the STATCOM in capacitive mode, +Q, the magnitude of the converter output voltage is controlled to be greater than that of the power system. On the other hand, the output-voltage magnitude of the converter is controlled to be less than that of the power system in order to operate the STATCOM in inductive mode, -Q. However, in practice, a converter is associated with internal losses. As a result, without any control, the capacitor voltage will decrease and will eventually collapse. To regulate the capacitor voltage, a small phase shift δ is introduced between the converter voltage and the power system voltage.

A schematic of a CMC-based STATCOM is shown in Figure 3. Basically, the STATCOM system is composed of three main parts: a multilevel-cascaded VSC with separated DC capacitors, the coupling inductors, and a controller. A coupling inductor in each phase serves as both a converter output-current filter and a reactive power coupler. The main purpose of the coupling inductors is to filter out current harmonic components that are mainly caused by the

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modulation techniques used in the converters. In a very-high-voltage system, above 13.8 kV, the leakage inductances of coupling step-up power transformers can function as coupling reactors. A multilevel-cascaded converter consists of a number of identical H-bridge converters, whose output terminals are connected in series. The output voltage is thus the summation of those H-bridge converters, i.e.,

$$V_{kn} = V_{k1} + V_{k2} + \ + V_{kN}$$

where $k$ is the phase notation, i.e., a, b or c, and $N$ is the number of H-bridge converters per phase.

Since three output voltage levels can be synthesized by an H-bridge converter, the total number of output-phase voltage levels, as shown in Figure 4, equals $2N+1$. The maximum number of line-to-line voltage levels is $4N+1$. By increasing the number of H-bridge converters, the output-voltage THD is significantly improved. The output-voltage waveform approaches sinusoidal when the number of H-bridge converters reaches infinity. Moreover, the power capacity of the system is increased, and the dynamic response is improved. The number of H-bridge converters is, however, limited by numerous practical concerns. The most important one is the complexity of the control system. A greater number of voltage levels introduces the DC-link-imbalance problems, and of course increases the system cost.

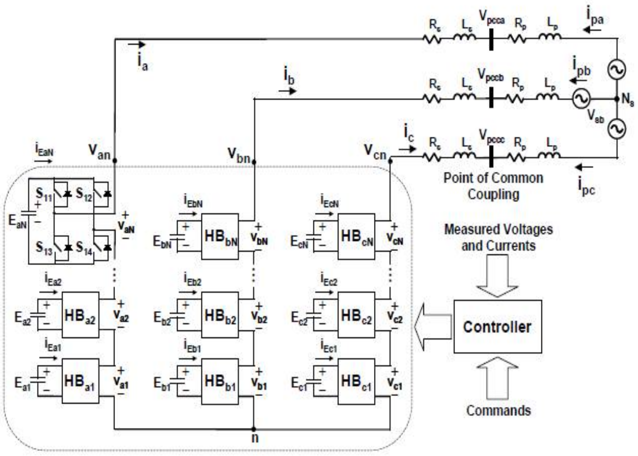


Figure 3 Schematic of a cascaded-multilevel converter-based STATCOM system

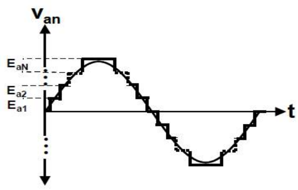

Figure 4 Phase-voltage waveform of the cascaded-multilevel converter.

## III. INTRODUCTION OF PROPOSED STATCOM

The selected test STATCOM, which contains a cascaded (chain-circuit) multilevel converter and its connection to the ac system, is shown in Figure 5. The multilevel STATCOM system includes a three-phase transformer and three strings of single cells that are connected in series. A single cell here is a full-bridge, single-phase inverter with a capacitor as the dc source. Note that only chain circuit. A with its insulated- gate bipolar transistors (IGBTs), diodes, and capacitors is shown, but similar groups of single cells are also connected in branches B and C.

The STATCOM parameters that determine the main circuit are the number of cells per phase X dc capacitances $C_{DC1}$ to $C_{DCX}$, buffer inductance $L_{DC}$ transformer leakage inductance and transformer ratio . The relationship between the number of single cells per string and the number of levels for a cascaded multilevel converter is given by X=(N-1)/2. It is assumed that all capacitances are equal and that the steady-state voltages across these capacitors are also identical (with the help of a suitable controller). To ensure low converter losses and dc voltage ripple, the STATCOM system parameters are optimized. The ratio between $X_{AC}$ (w* $L_{AC}$) and $R_{AC}$ is assumed to be constant $X_{AC}$ / $R_{AC}$ = 10. The

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converter switching losses are reduced by the use of "square wave control" where each device has only one turn-on and turn-off per cycle. The harmonic distortion is reduced by calculating the firing angle at each cell to cancel one harmonic. In view of the fact that triplen harmonics are cancelled in the converter delta connection, the firing angles for the individual cells are calculated for cancellation of the lowest odd, non triple harmonics, and their values are shown for selected test systems. These calculated firing angles can cancel only steady-state harmonics but as loading changes, harmonics increase.

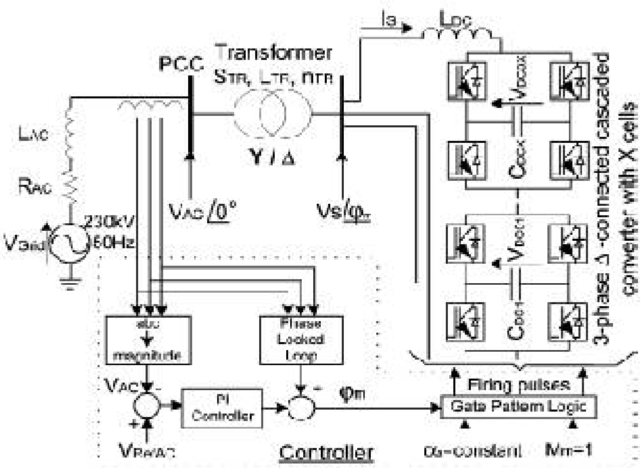


Figure 5 Multilevel STATCOM test system with indirect control**.**

The ideal stepped output voltage of a 13-level converter is shown in Figure 6. The STATCOM uses indirect control, as shown in Figure5. This control has, as a benefit, a constant modulation ratio, resulting in constant control angles and, therefore, in low harmonics even at low converter voltages. The dc voltage is affected by controlling the angle (i.e., the active power transfer). The phaser diagram of the STATCOM system is shown in Figure 7. It is assumed that the system is balanced and all variables are represented with a fundamental frequency phaser. All ac voltages are shown as line-neutral magnitudes. The STATCOM parameters that determine the main circuit are the number of cells per phase X dc capacitances $C_{DC1}$ to $C_{DCX}$, buffer inductance $L_{DC}$ transformer leakage inductance and transformer ratio . The relationship between the number of single cells per string and the number of levels for a cascaded multilevel converter is given by X=(N-1)/2. It is assumed that all capacitances are equal and that the steady-state voltages across these capacitors are also identical (with the help of a suitable controller). To ensure low converter losses and dc voltage ripple, the STATCOM system parameters are optimized. The ratio between $X_{AC}$ (w* $L_{AC}$) and $R_{AC}$ is assumed to be constant $X_{AC} / R_{AC} = 10$.

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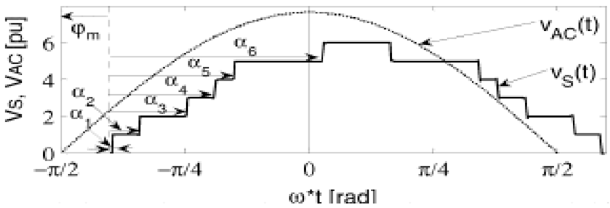


Figure 6 Ideal stepped output voltage of the 13-level converter

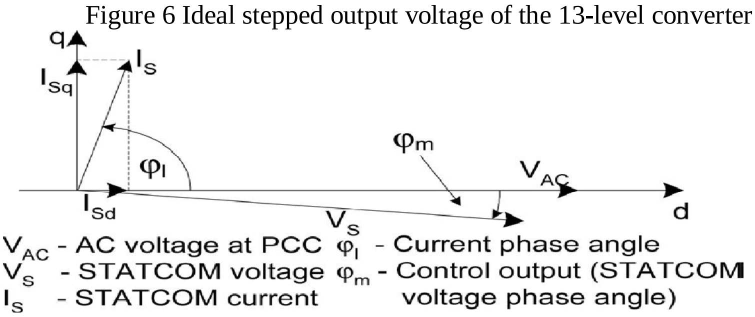


Figure 7 STATCOM phaser diagram where the general reference frame is linked with $V_{AC}$ .

## IV. CONTROL STRATEGY

This section proposes a development procedure for the model and feedback control of a CMC-based STATCOM. Figure 8 illustrates the block diagram, showing the relationship between the modelling and feedback-control design. Although this methodology focuses on STATCOM applications, it can be employed elsewhere. The process begins with model development. The results of this step are key transfer functions of the control parameters to state variables such as STATCOM currents and DC capacitor voltages. As will be proposed in Chapter 5, the feedback control is designed and evaluated based on the derived transfer functions. Because of the proposed modelling method, the stability of the feedback loops can be systematically evaluated. The loop gains are then modified to achieve as much stability as possible, while the dynamic response is not sacrificed. The proposed control technique is validated by both computer simulation and experiments.

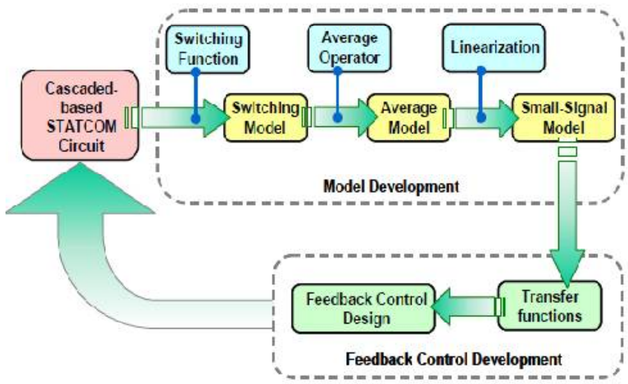


Figure 8 Control development for the cascaded-multilevel converter-based STATCOM

## V. SIMULATION RESULTS

The performances of MMC based STATCOM are evaluated by computer simulation using MATLAB/SIMULINK. The simulated system is shown in following figures.

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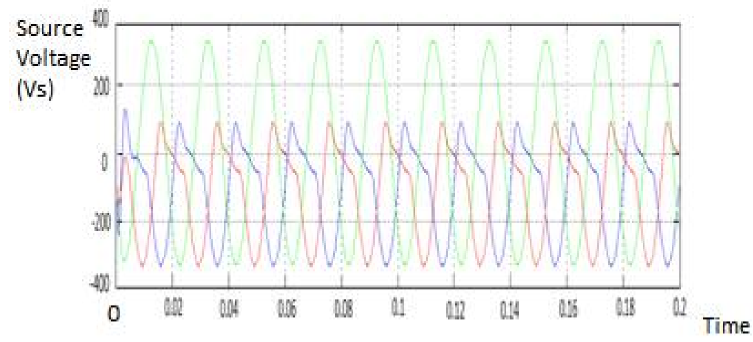


Figure 9 Source Voltage waveform

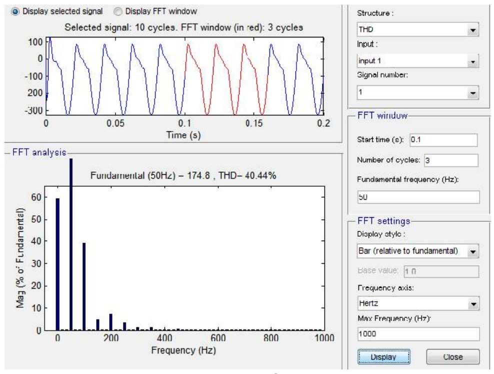


Figure 10 THD of source side

Figure 9 shows the input waveform for source voltage versus time in which there is no positive amplitude present in phase Y & B due to circulating current. Some voltage sag occurs in it. The respective Total Harmonic Distortion present in source side is 40.44 % without injecting the current. This is shown in figure10.

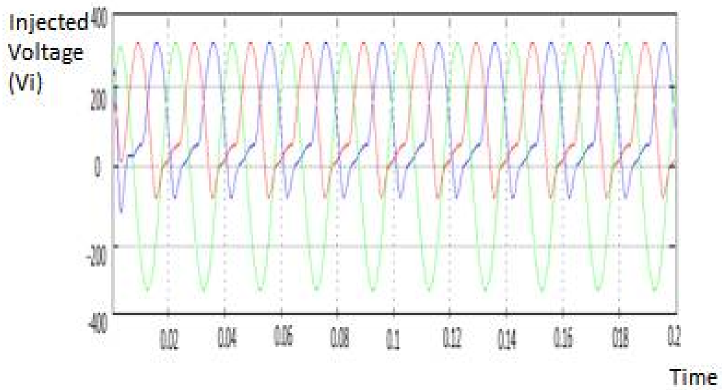


Figure 11 Injected voltage waveform

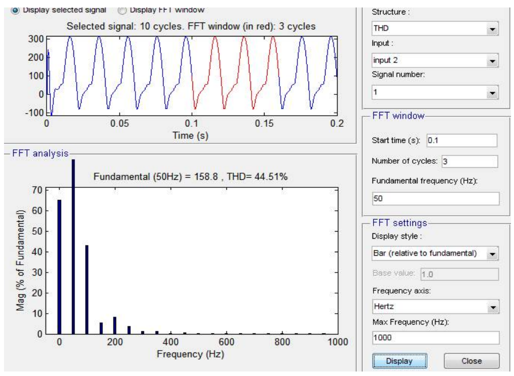


Figure 12 THD of injected side

To overcome this problem we have inject the current into the system by Cascaded Multi level Converter Based STATCOM i.e. Stack Cell. Figure 11 shows the injected waveform for injected voltage versus time such that there is no negative amplitude in phase Y & B. The respective Total Harmonic Distortion present in injected side is 44.51 % without injecting the current. This is shown in figure12.

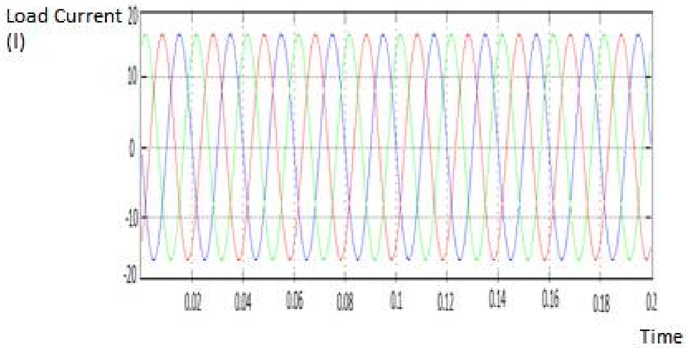


Figure 13 Load current waveform

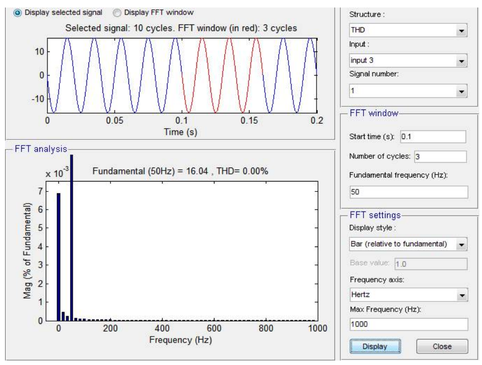


Figure 14 THD of load side

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Figure 13 shows the output waveform for load current versus time in which pure sinusoidal waveform is obtained. The respective Total Harmonic Distortion for load side is 0 % as shown in figure 14.

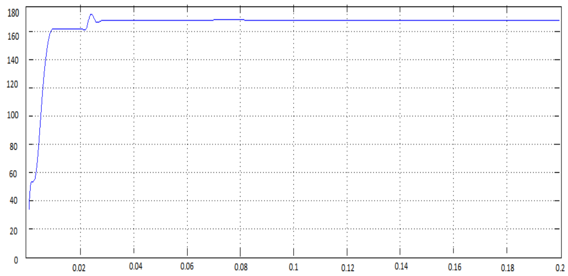

Figure 15 Magnitude of Single phase Voltage.

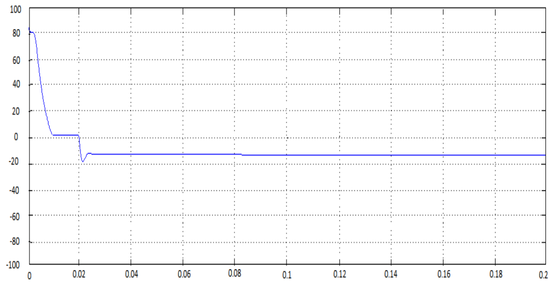

Figure 16 Phase angle of the Stack cell output.

Figure 15 shows the magnitude of 1 phase output voltage of Stack Cell which are $180^0$ electrical apart. Some of the problems occurred in transmission line. So to undergo that problem, we are developing additional voltage i.e. above $120^0$ phase angle. So the phase angle is $-20^0$ which is shown in figure 16.So the magnitude & phase angle of injected voltage will be working together to maintain the power quality.

## VI.CONCLUSION

A suitable and accurate analytical model of an indirectly controlled cascaded multilevel STATCOM with square-wave control is presented in this paper. The converter voltage Components are analyzed in detail for a single-cell and the results are then generalized for a multilevel cascaded converter. The converter ac voltage waveform is of a nonlinear, discrete, and dynamic nature, which is described mathematically by appropriate averaged expressions.The dynamic, analytical state-space model is built of subsystems to enable model application to a wide range of system configurations and various dynamic studies. The developed STATCOM model is linearized and implemented in MATLAB. Eigenvalue studies are conducted for each particular test system in order to select optimum open-loop controller gains.

## VII. FUTURE SCOPE

Although this paper has covered most of the interesting issues and challenges of the CMC-based STATCOM, additional work has been left for future research. The first part is the coordination between the proposed internal and external controls. From the standpoint of external control design, the internal control, which is the combination of the decoupling power control technique and the cascaded PWM, can be modeled as a black box in which high-quality output voltage-current waveforms and relatively fast dynamic responses are embedded. With aneffective external control design, a high-performance, stable, reliable CMC-based STATCOM system can be completely achieved. The second part is the fault-protection study for the CMC-based STATCOM. Due to the excessive number of semiconductor devices and passive components, how to design a fault protection scheme to enhance the ride-though capability in various fault scenarios remains as an important challenge. Finally, the last part is the redundancy of the CMC-based STATCOM system. Due to the identical HBBBs used in the CMC, the N+1 rule may be applied, where N is the number of HBBBs per phase.

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