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Power Quality Improvement with D-STATCOM using PI & HC Regulator

K. Nagesh[1], Dr.Srinu Naik[1], Nekkanti S. S. S. Chandra[1], S. Naveena[2]

[1]PG Scholar, Dept of Electrical Engineering, Andhra University, Andhra Pradesh, India
[2] Associate Professor,Dept of Electrical Engineering, Andhra University, Andhra Pradesh, India

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ABSTRACT

In this paper a new method four-leg topology is suggested for shunt compensation, the H-bridge multilevel converters based on the half-bridge converters, to achieve higher performance as a STATCOM in a distorted and unbalanced medium-voltage large-current system. Further, an extended PI based STATCOM is proposed in order to manage more accurate compensation for high-power applications. Both proposals can be controlled for various purposes such as reactive power and unbalance compensation, voltage regulation, and harmonic cancellation. One interesting application for the PI based STATCOM could be the improvement in power quality and performance of the electrified railway traction power supply system. Both the STATCOM along with their proposed control strategies were simulated.

Key words: Harmonics, medium-voltage large-current modular multilevel converters, unbalanced compensation.

1. INTRODUCTION:

MODERN medium-voltage distribution systems supply nonlinear loads such as single-phase ac traction systems. These loads make the network to operate under undesired conditions, i.e., distorted, uncontrolled reactive power and significant unbalance enforcement [1], [2]. Therefore, these associated in-evitable issues ought to be simultaneously resolved to achieve acceptable power quality level. Meanwhile, mitigation of all these power quality problems by means of a single compensator is a challenging task in a medium-voltage network [3],[4]. A full-bridge cascaded converter (FBCC) could be directly connected to a medium-voltage network [5], [6]. However, the FBCC has been established as the most preferred solution for managing reactive power in distribution systems, improving the power quality in the medium-voltage high-power industries. Un-like diode-clamped multilevel converters (DCMC) and flying-capacitor-clamped multilevel converters (FCMC), the FBCC introduces lower total losses along with higher reliability [7]. Meanwhile, they have their restrictions when operating under distorted unbalance situations in a medium-voltage network compared to those of the DCMC and the FCMC [3]–[8]. In the mean time, a three-phase FBCC, connected in delta or star type, is unable to fully compensate the source currents when the un-balanced loads containing harmonics. A delta-connected FBCC cannot generate zero sequence components flowing through the fourth neutral-wire. Also, balancing an unbalanced load using a star-connected FBCC is faced with some complications. Assume that a star-connected FBCC-based STATCOM is balancing three different active powers supplied by the source. Then, a certain average real power has to either flowing into or out of individual series connected full-bridge converters (leg). This results in either dc-link build-up or discharge of capacitors in that leg. In other words, the unbalanced currents of the star connected FBCC imposes unequal active power exchange by the FBCC legs. This makes the dc voltage balancing for the storage capacitors in all three legs much complicated [9].

The idea of modular multilevel converters (H-BRIDGE) was first introduced by Marquardt for medium-voltage applications [10].These converters consist of two similar parallel half-bridge cascaded converters (HBCC) per phase (three-phase in star-connected configuration). Due to the modularity of these converters, they are very attractive for high voltage dc transmission (HVDC), flexible ac transmission systems (FACTS), and medium-voltage drives [11], [12]. The main advantage of ap-plying the H-BRIDGE as a STATCOM [13] is that they could operate under unbalanced and distorted voltages and currents properly, while voltages of the dc-link capacitors remains balanced [9].

Hence, this paper proposes a new type of the H-BRIDGE topology as a STATCOM in order to achieve full compensation of MV-LC loads, i.e., harmonic elimination, reactive power optimization and in particular balancing the three or four-wire systems. The full compensation using the proposed STATCOM is achieved without any coupling transformer for MV-LC applications (high-power). Nevertheless, available power semiconductor technology may impose limitations due to the voltage and current ratings, losses, and switching frequency. Hence, here the H-BRIDGE is proposed that is composed of parallel connection of multiple H-BRIDGE per phase in order to deal with large-current requirements. There are two main differences between the H-BRIDGE and just parallel connection of H-BRIDGE: 1) two or more H-BRIDGE share the common dc-link (positive and negative common points); and 2), the presence of the coupling inductors that lowers down considerably the circulating current between them. The H-BRIDGE produces higher quality waveforms for the network compared to the H-BRIDGE, reducing the conductive electromagnetic interference concerns in large-current applications. Also, paralleling multiple H-BRIDGE improves reliability, performance, and efficiency of the overall system, making it more flexible. This paper is initially focusing on description of the H-BRIDGE-based STATCOM, both the proposed power circuit and control algorithms.

2. STATCOM PROPOSITION

The STATCOM is composed of two parallel connected complementary HBCC as shown in Fig. 1. Each star-connected HBCC has either three or four similar legs (cascaded HBM). While one HBCC has a negative common point (NCP), the other one has a positive common point (PCP). Both the NCP and PCP are float. To compensate a three-wire distorted load, the converter can be composed of two three-leg complementary HBCC. The number of levels, in a general (n+1)-level H-BRIDGE, is defined by the available n identical HBM cascaded in each leg. Then, all (n+1)-level legs are connected to the network using an inductive filter (LF).

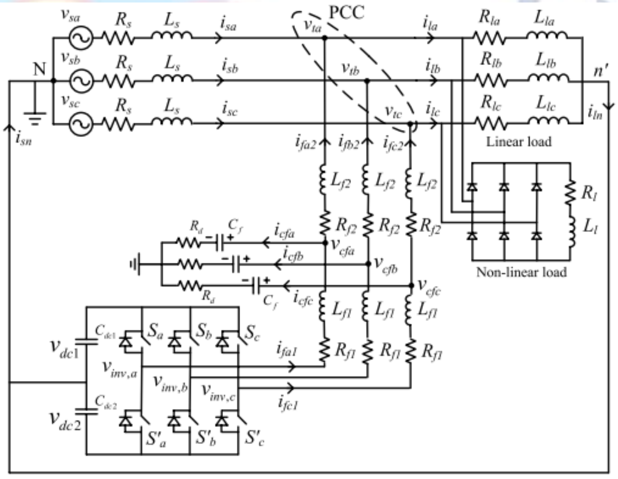

Figure 1: Proposed STATCOM circuit

The VSI structure is designed to make use of a three-level pole structure, also called neutral point clamped (NPC), instead of a standard two-level six-pulse inverter structure This three-level inverter topology generates a more sinusoidal output voltage waveform than conventional structures without increasing the switching frequency. The additional flexibility of a level in the output voltage is used to assist in the output waveform construction. In this way, the harmonic performance of the inverter is improved, also obtaining better efficiency and reliability respect to the conventional two-level inverter. A drawback of the NPC inverters is that the split dc capacitor banks must maintain a constant voltage level of half the dc bus voltage. Otherwise, additional distortion will be contributed to the output voltage of the DSTATCOM/BESS. In this work, the use of battery energy storage in an arrangement with neutral point (NP) permits to independently contributing to the charge of the capacitors C1 and C2, and thus to maintain the voltage balance of the dc capacitors without using additional control techniques. The connection to the utility grid is made by using low pass sine wave filters in order to reduce the perturbation on the distribution system from high-frequency switching harmonics generated by PWM control. The total harmonic distortion (THD) of the output voltage of the inverter combined with a sine wave filter is less than 5 % at full rated unity power factor load. Typically, leakage inductances of the step-up transformer windings are high enough as to build the sine wave filter simply by adding a bank of capacitors in the PCC. In this way, an effective filter is obtained at low costs, permitting to improve the quality of the voltage waveforms introduced by the PWM control to the power utility and thus meeting the requirements of IEEE Standard 519-1992 relative to power quality.

STATCOM Controller:

The proposed multi-level control scheme for the integrated DSTATCOM/BESS device, consisting of an external, middle and internal level, is based on concepts of instantaneous power on the synchronous-rotating dq reference frame [4] as depicted in figure 2. Rotating reference frame is used because it offers higher accuracy than stationary frame-based techniques [5]. All blocks make use of control variables that are feasible to be locally measured.

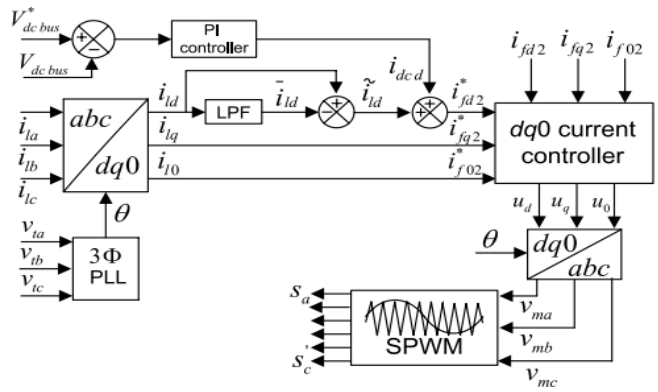

Figure 2: Block diagram of the proposed DSTATCOM controller

Here the STATCOM is proposed for full compensation of the MV-LC loads such as electric traction systems. The suggested high power STATCOM comprises of two or more identical all connected in parallel. A simple model of the STATCOM, having two H-BRIDGE, is shown in Fig. 6. While all H-BRIDGE have the same electrical specification, all NCP legs connected together, and the same is done for all PCP legs to achieve a better voltage regulation for the capacitors. Hence, voltage regulation for the HBM capacitors is managed without any additional connections or energy transfer circuits

3. SIMULATION DIAGRAM AND RESULTS

The simulation is done based on the figure 1. The simulation diagram for the proposed grid interfaced wind energy system with STATCOM is shown in figure 4.

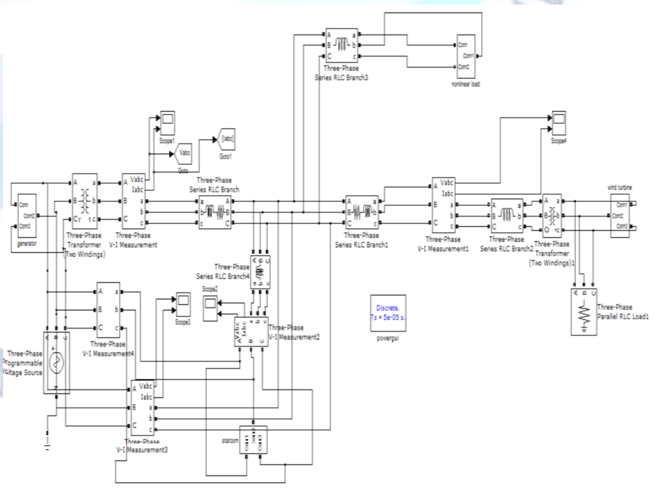

Figure 4: Simulation Diagram for STATCOM

Simulations were carried out using PSIM, while the control algorithm was managed with MATLAB; then, they were linked together using SIMCOUPLER of the PSIM. Assume that a 25-kV network is supplying a distorted unbalanced load in an electrical railway application. The load is coupled across two phases of the PCC. Spectral of the load current, shown in Fig. 4, introduces a total harmonic distortion (THD) of 18.27%. Sep-arate simulations were arranged for both the H-BRIDGE and the H-BRIDGE-based STATCOM for a power rating of±15 MVA. Each leg of the two compensators has 22 cascaded HBM. All HBM have a dc-link capacitor with a nominal dc voltage of 3.3 kV.

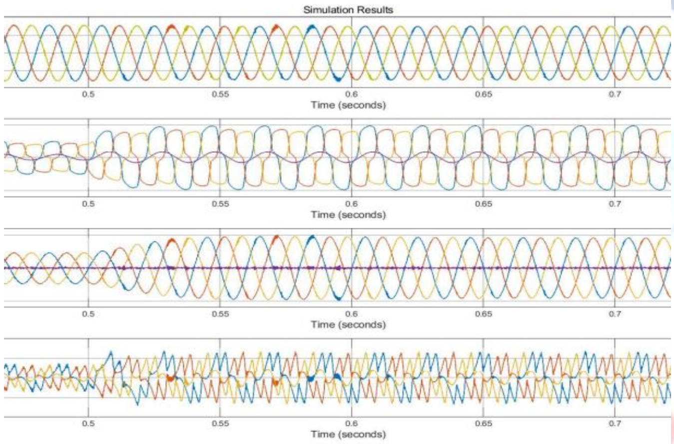

Figure 5: Simulation Waveform for Grid Current, Load Current, Inverter current and Injected currents

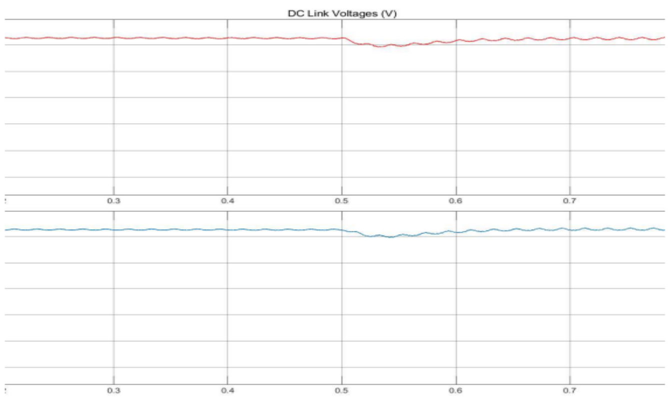

Figure 6: Simulation Waveform for DC-Link Voltages

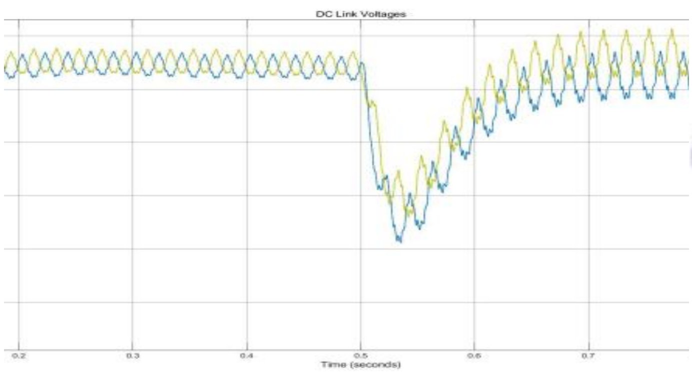

Figure 7: Simulation Waveform for STATCOM DC Voltages

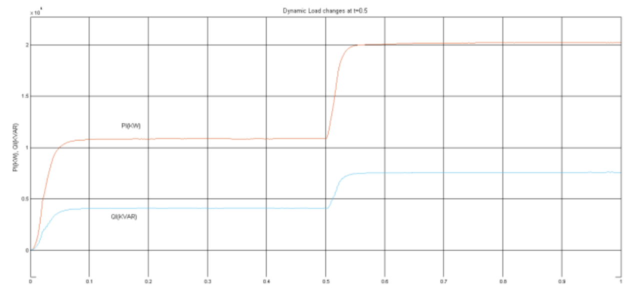

Figure 8: Simulation Waveform for Active and Reactive Powers under Dynamic Load Changes

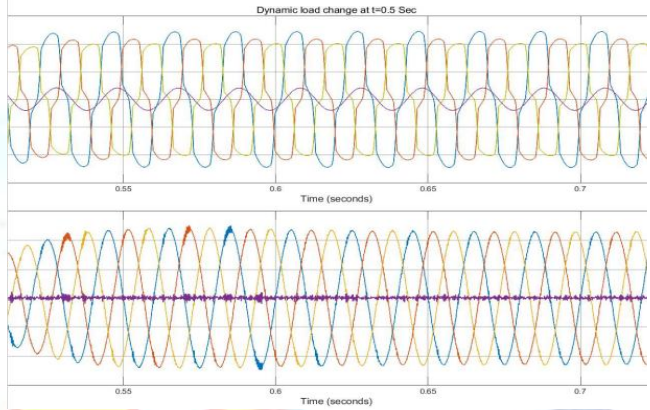

Figure 9: Simulation Waveform for Load Voltage and Current under Dynamic Load Changes

4. CONCLUSION

Compensation of unbalanced nonlinear load is carried out satisfactorily by LCL filter DSTATCOM with dq0 current controller and SPWM switching. UPF operation of source currents is achieved and THDs are maintained at 3%, though the load current THDs are around 15%. Compensation with two types of current regulators, PI and PI plus HC regulators is studied and it is observed that less tracking error (between reference and injected filter currents) is achieved with PI plus HC regulator compared to PI regulator. Better switching ripple attenuation in terminal voltages and source currents is obtained with LCL filter compared to the L filter. Moreover, the inductance and size of LCL filter are also reduced.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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