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Ripple Voltage Mitigation for Delta-Connected Cascaded H- Bridge STATCOM

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Abstract— Performance of multilevel single-star bridge-cell (SSBC) STATCOM is affected by the low-frequency oscillation in the dc capacitors' voltages which is originated due to the double line frequency component on the absorbed active power. To avoid using big capacitors to limit this oscillation. In this project, zero sequence voltage injection is utilized to mitigate the oscillation and consequently improve harmonics performance in the ac side of the system. This project is implemented in Matlab simulation.

Index Terms—**STATCOM, CHB, H Bridge, PWM**

I. INTRODUCTION

Static compensator (STATCOM) provides instantaneous and continuous reactive power in response to voltage fluctuation; it is also used for active harmonics filtering and flicker mitigation. Usually, STATCOM operates according to the voltage source inverter principle in which high operation speed of power semiconductors leads to unequaled performance. Effective research directions for STATCOM are: low capacitor value STATCOMs distributed energy resources (DER) based STATCOM multiple STATCOM operation and stability; structure-wise MMC based STATCOM. issue for stable and efficient performance of the system. Many works have addressed capacitor imbalance among the units in each phase and between the phases. A relevant problem that affects the harmonics performance of STATCOM is the low switching frequency oscillations that appear across capacitor voltage. These oscillations produce third harmonic component in the output voltage of STATCOM which deteriorate overall performance. Recently, some works propose reduction of capacitor size in STATCOM which indicates higher ripple if not properly controlled

In the work presented in, the star-connected CHB is considered as the most suitable configuration for positive-sequence reactive power control, typically for voltage regulation purpose and, more in general, for utility applications; on the other hand, delta configuration is considered to be the best solution for applications where negative-sequence is required, as it is the case for industrial applications (for example, flicker mitigation). However, requirements from Transmission System Operators (TSOs) are changing and start to demand negative-sequence injection capability for the converters connected to their grid. Furthermore, the delta configuration can present limitations in injecting negative-sequence current in case of weak grids, where both load current and voltage are unbalanced, or under unbalanced fault conditions. For this reason, it is of high importance to investigate the limits in terms of negative-sequence compensation for this kind of configurations.

II. OBJECTIVES

Objectives of this project are to find and create solutions to the statement of the problem arising from the effects of harmonic disturbances in industrial. Objectives identified are as follows:-

- To mitigate third harmonics component in the output voltage of the bridge-cell (SSBC) STATCOM
- To validates the performance of balancing control of the SSBC-STATCOM in both modes of operation (i.e. capacitive and inductive).

III. PROPOSED SYSTEM

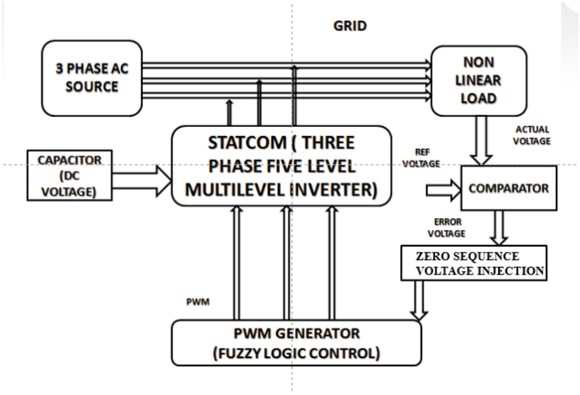

Fig 1 Block Diagram of Proposed System

In this thesis, the modular multilevel converters that are based on the use of H-bridge converters will be denoted as Cascaded H-Bridge (CHB) converters, while the converter based on half-bridge cells will be simply denoted as Modular Multilevel Converters (MMCs). Therefore, the star and delta configurations will be CHB converters, while the double start can be either CHB or MMC depending of the adopted cell topology.

The main modular configurations: star, delta and double star configurations

Each phase consists of several H-bridge converters connected in series. Double star configuration with H-bridge cells is superior to the one with half-bridge cells since it has additional buck and boost functions of the DC-link voltage. Having H-bridge cells enables this configuration to tolerate a broad range of variation in the DC-link voltage. This feature makes it suitable for renewable resources such as wind and solar power since the DC-link voltage varies with weather variations. Moreover, this configuration has the ability to suppress fault currents arising from DC-side short circuit events

The proposed system explore the control and modulation schemes for the H-STATCOM, both under balanced and unbalanced conditions of the grid, highlighting the advantages but also the challenges and possible pitfalls that this kind of topology presents for this specific application. Based on the described purpose, the following specific contributions can be identified:

- Control of H-STATCOMs at zero-current mode: It is shown that although existing approaches for individual DC-link voltage control are able to provide an appropriate voltage control, they are not able to provide a proper DC-link voltage control when the converter is operated at zero-current mode. Two methods for individual DC-link voltage balancing at zero-current mode are proposed and analyzed. The first method is based on a modified sorting algorithm and the second method is based on DC-link voltage modulation. Using the proposed methods, proper individual DC-link voltage balancing is achieved at zero-current mode.
- Investigation of Phase-Shifted PWM: It is shown that poor cancellation of harmonics of Phase-Shifted PWM (PS-PWM) leads to non-uniform power distribution among cells. Theoretical analysis shows that by proper selection of the frequency modulation ratio, a more even power distribution among the different cells of the same phase leg can be achieved, which alleviates the roll of the individual DC-link voltage control.
- Control in case of unbalanced conditions: Zero-sequence voltage/current injection is utilized for the control of H-STATCOMs under unbalanced condition. It is shown that a singularity in the solution of the zero-sequence component exists, which in turn limits the operational range of these converters under unbalanced conditions. The singularity in the delta configuration occurs when the positive- and negative-sequence components of the voltage at the converter terminals are equal, while for the star it is governed by the equality between the positive- and the negative-sequence component of the injected current. In addition to the amplitudes, the phase angles of currents in star and voltage in delta will highly impact the sensitivity of the converter. For the star configuration, the highest demand on the zero-sequence voltage occurs when the three-phase positive-sequence currents are aligned with the negative-sequence tern; on the contrary, the lowest demand on the zero-sequence component occurs when the two terns are in phase opposition. Analogue results hold for the delta case.

IV. RESULT AND DISCUSSION

The CHB-STATCOMs with system parameters of are simulated in PSCAD including the individual DC-link voltage controller. In order to avoid the interaction between the cluster and individual DC-link voltage controller, the individual controller is intentionally designed to be slower than the cluster control loop. The closed loop bandwidth of the individual DC-link. Figure 2 shows the filtered DC-link voltages and the output of the individual DC-link voltage controller of each cell in phase a for both star and delta when integer carrier frequency of 1 kHz is used.

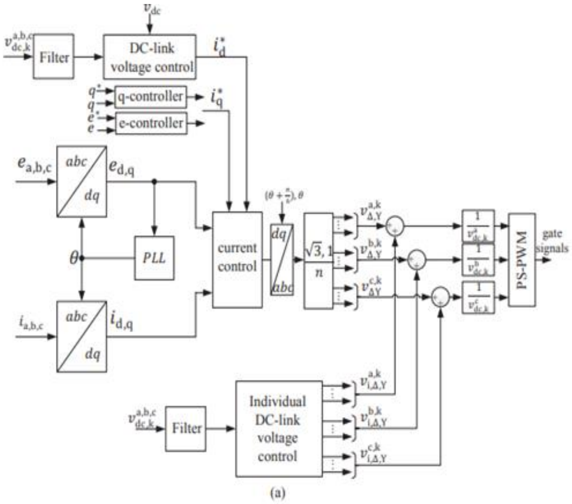

Fig 2

The reference reactive current is set to 0.3 pu. The individual DC-link voltage controller is not activated in the beginning of the simulation and activated at t = 3 S. Figure (top) shows the ability of the individual DC-link voltage controller to control the DC-link voltages. Figure shows the obtained simulation results when non-integer carrier frequency

It can be observed from Figure that by using non-integer frequency modulation ratio, the individual DC-link voltage controller puts much less effort in controlling the DC-link voltages. This shows the advantage of using non-integer frequency modulation ratio instead of the integer one.

Although sorting algorithm is an effective solution for voltage balancing when the converter is exchanging current with the grid, less attention has been paid for zero-current operating mode (STATCOM in standby mode) in the literature. Sorting algorithm needs current sign information to provide a correct sorting pattern. As a consequence, when the exchanging current that flows in the cells is zero, the sorting algorithm is unable to take the correct insertion decision for proper balancing of the DC-link voltages. In practical applications, this is even more problematic when noise is also added in the measured current signal. The problem of system operation at zerocurrent mode also exists when using individual DC-link voltage control loop,. Here, two methods for capacitor voltage balancing at zero-current mode are proposed. The first method is based on a modified sorting algorithm, while the second method is based on DC-link voltage modulation. It is of importance to stress that the investigated methods are for zerocurrent mode only, since when a current circulates in the phase leg the classical or advanced sorting techniques can be adopted. The proposed methods are meant for the star configuration. Although the same methods can be used for the delta configuration, it is of importance to consider that in this case, it is possible to force a current that circulates inside the delta and thereby allow a uniform distribution of the active power among the different cells. This solution cannot be implemented in practice in the star case. For this reason, capacitor cells balancing is more challenging in star configuration, especially in case of zero (or more in general, very small) current exchange between the compensator and the grid.

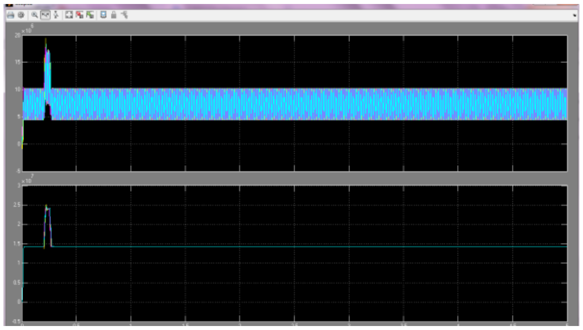

Fig 3 DC-link line current in phase a without the proposed methods

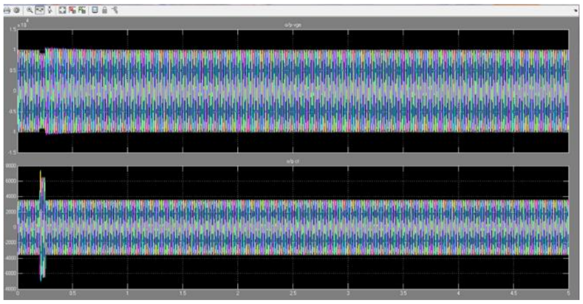

Fig 4 DC-link voltage current in phase a without the proposed methods

Figure 3 shows the simulation results when using the conventional sorting algorithm. Top plot shows the line current in phase a while the lower figure shows the DC-link voltages in phase a. Similar behavior can be observed for the other phases. All figures are showing the measured quantities in pu. At t=0.9 s, the reactive current is changed from 0.35 pu to zero.

Figure. 4 shows that conventional sorting algorithm is not able to provide proper individual cell balancing at zero-current mode. Figure 4 shows a detail of a cell output voltage, line current between two sampling points together with the interrupt signal. It can be observed from this figure that the sign of the current is negative in the first half of the control period and changes to positive after almost half of the period, as anticipated earlier in this section. Theoretically, at zero-current operating mode, the current sign changes exactly in the middle of the control period. This provides equal positive and negative areas, leading to equal charging and discharging. Consequently, the DC-link voltage should remain constant. However in practical applications this symmetry will not be achieved, leading to slightly more charging or discharging area (as in this specific example). Therefore the DC-link voltages will not remain constant and diverge from their reference values

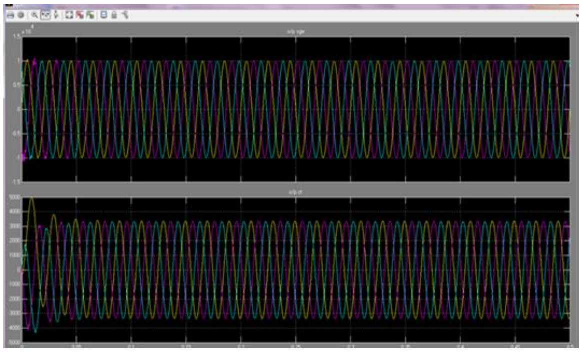

Fig. 5 DC-link voltages result with the DC-link voltage modulation method

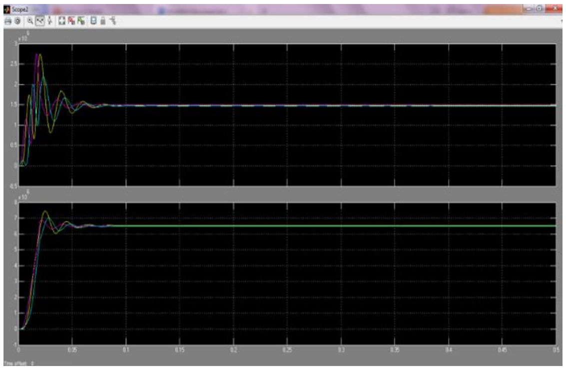

Fig. 6 Result with the DC-link Current modulation metho

In this the ability of CHB-STATCOMs to exchange negative-sequence current with the grid is investigated. A general solution for the required zero-sequence voltage and current under any unbalanced condition will be derived. It will be shown that both configurations exhibit a singularity in the solution of the zero-sequence component, which in turn limits the operational range of the compensator under unbalanced conditions. It can be observed from that each phase of the converter is characterized by a different active power, due to the interaction between the sequence components. Similar result is also valid for delta structure. In order to show the effect of an unbalanced condition on the phase active powers, the CHB STATCOMs are here simulated when injecting a negative-sequence current in the grid. For this simulation, the DC-link capacitors are replaced by fixed DC sources. Figure 6 shows the active power flowing in each phase of the star and delta configurations. For clarity of the illustration, the powers are low-pass filtered in order to remove the double-frequency component. The grid is balanced and the STATCOM is injecting 0.9 pu positive-sequence current in the grid. At t = 0.5 s the negative-sequence current is stepped from 0 pu to 0.4 pu. It is clearly possible to observe from the figure that under this condition, different active powers will flow in each phase leg; this would lead to diverging DC-capacitor voltages in the phase legs.

V. CONCLUSION

The effect of unbalanced voltage and current on CHB-STATCOM has been investigated, both in case of star and delta configuration of the converter phase legs. Zero-sequence voltage (for the star configuration) or current (delta) allows to maintain the DC-link voltage of the different cells balanced in case of unbalanced operation. However, it has been shown that there are special operating conditions for both the star and the delta configuration where the zero-sequence component is unable to control the active power in each phase to zero. This is due to a singularity that exists in the solution for the calculation of the zero-sequence components. The singularity in the delta configuration occurs when the positive- and negative-sequence components of the voltage at the converter terminals are equal, while for the star case it is governed by the equality between the positive- and the negative-sequence component of the injected current. In addition to the amplitudes, the phase angles of currents in star and voltage in delta will highly impact the sensitivity of the converter. For the star configuration, the highest demand on the zero-sequence voltage occurs when the three-phase positive-sequence currents are aligned with the negative-sequence tern; on the contrary, the lowest demand on the zero-sequence component occurs when the two terns are in phase opposition. Analogue results hold for the delta case. In utility applications, where the priority is on voltage regulation, the converter aims to prioritize positive-sequence current injection to boost the voltage at the connection point and at the same time improve the degree of unbalance. Therefore, the star configuration can be utilized for this purpose. In industrial application, such as arc furnaces, the converter aims to exchange both positive- and negative-sequence current; being this kind of loads typically connected to relatively strong grids, the delta configuration appears the most preferable choice for this kind of applications.

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