An Extensive Review on DC Capacitor Voltage Balancing Control for Cascaded H-Bridge STATCOM

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Abstract- 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 development in many regions often makes this impossible. One possible solution is to optimize existing networks. The need for high power apparatus in industry has increased in recent years. Multilevel converters have developed as easy alternatives for such power requirements. Mostly used in medium voltage applications, multilevel converters have gained prominence since it is not feasible to connect a single power semiconductor switch directly to the grid. There are other advantages of multilevel converters such as their capability to be easily interfaced with the renewable energy sources such as solar power, wind power, and fuel cells. Load compensation, voltage balancing and voltage regulation are some of the major problems being faced by electric power utilities across the globe. If not addressed, these issues can cause power losses in lines, mal-operation of critical loads, damage to customer equipment, and potentially power system instability. This work presents an extensive review on dc capacitor voltage balancing control for delta-connected cascaded h-bridge STATCOM considering unbalanced grid and load conditions on the basis of brief survey of literature.

Keywords- DC Capacitor, Unbalanced Grid, Voltage Balancing, Cascaded H-Bridge, STATCOM.

I. INTRODUCTION

Several devices can be used in order to improve network transient stability. 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 investment for large industrial customers.

Depends on using this series of switches and sources to synthesize a stepped or staircase output voltage waveform. Therefore, to reduce the voltage stress on each device or component used. Multilevel converters play a significant role in enhancing the quality of high power distribution networks, power conditioning systems, variable speed drive systems etc because of the availability of higher number of voltage levels at the output. This helps in reducing the size of switching components which can be operated at lower switching frequencies [8].

However, multilevel converters have their own disadvantages. Voltage sharing may not be as desired under all conditions because of the series connection of the switching devices.

Cascaded H-bridge Cell multilevel inverter topology is a series connection of two or more individual full- bridge inverters. Figure 1.1 shows a single-phase, five-level cascaded H-bridge cell inverter realized by connecting two three level conventional full bridge inverters in series.

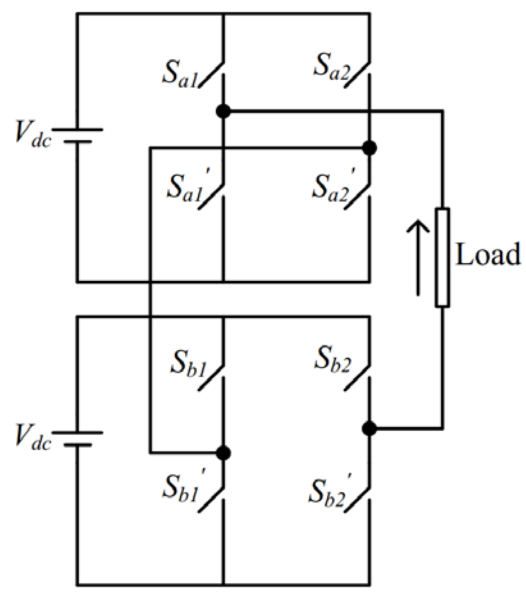

Figure 1.1 Five Level cascaded H bridge cell - Inverter.

Cascaded H-bridge cell inverters use the least number of power electronic devices when compared to any other topology. However, it requires isolated power sources in each cell which in turn requires a large isolating transformer.

In recent years, power system has been undergoing too many changes. The voltage control, stability, reactive power compensation and mitigation of harmonics are the essential requirements of the power system. To enhance the power system stability, minimum line losses, better energy transfer efficiency, and maximum utilization of line capacity and for future extension of power systems. Hence, all these factors should be tactically handled in order to maintain the stability and security of power system. Now days, the growth of power electronics based equipments in industries, commercial and domestic appliances has been increased.

The Power Quality (PQ) is one of the important requirements in the modern power system. Various issues such as low power factor, low energy efficiency, low power transfer capacity, voltage disturbance and harmful effects to appliances are also arising in power system due to the usage of power electronic based equipment.

The Multi Level Inverter (MLI) solves this problem, because it generates high voltage at high power. Due to the implementation of fundamental switching frequency, the switching losses are reduced and also less Electro Magnetic Interference (EMI) happens.

This MLI is used to compensate the reactive power and it minimizes the voltage disturbance in the power system. It is called as STATCOM (STATIC COMPENSATOR). Thus, the PQ is improved with the installation of STATCOM at PCC. The reactive current component to be compensated is calculated from the reactive load current, for which the compensation is to be done and is given as reference to the inverter control block. The inverter will act as a current source and supplies the required reactive current to the power system in a controlled manner. For this, the inverter voltage magnitude with respect to system voltage magnitude is a key control. Hence, the load draws only real power from the source.

II. STATIC SYNCHRONOUS COMPENSATOR

Static Synchronous Compensator (STATCOM): A Static synchronous generator operates as a shunt-connected static var compensator whose capacitive or inductive output current can be controlled independent of the ac system voltage.

The STATCOM is the static counterpart of the rotating synchronous condenser but it generates/absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the same voltage regulation functions as the SVC but in robust manner because unlike the SVC, its operation is not impaired by the presence of low voltage. The STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant. (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit of capacitive susceptance). It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload.

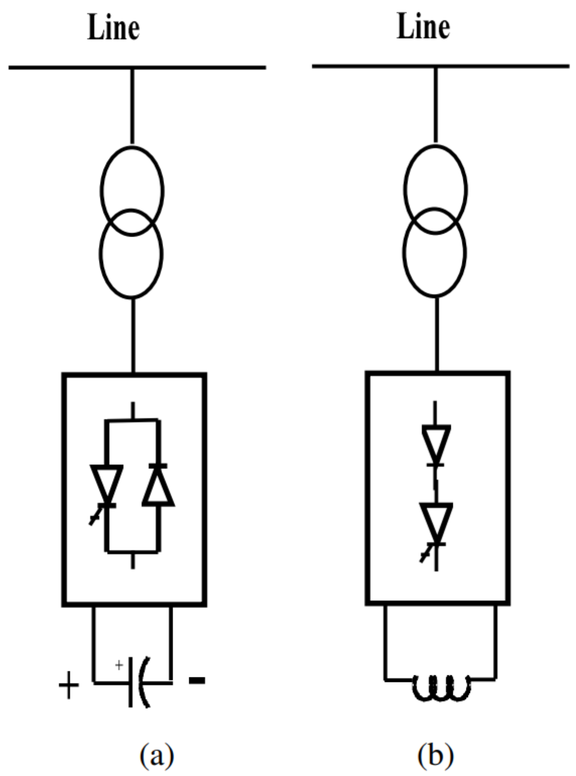

Figure 2.1 Static Synchronous Compensator (STATCOM) based on (a) voltage- sourced and (b) current-sourced converter

The possibility of generating controllable reactive power directly, without the use of ac capacitors or reactors by various switching power converters was disclosed by Gyugi in 1976. Functionality, from the standpoint of reactive power generation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control. Like the mechanically powered machine these converters can also exchange real power with the ac system if supplied from an appropriate, usually dc energy source. Because of these similarities with a rotating synchronous generator, it is termed as a Static Synchronous Generator (SSG). When SSG is operated without an energy source and with appropriate controls to function as shunt-connected reactive compensator, it is termed, analogously to the rotating synchronous compensator (condenser) a Static Synchronous Compensator (STATCOM) or Static Synchronous Condenser (STATCON).

III. LITERATURE REVIEW

J. J. Jung, J. H. Lee, S. K. Sul, G. T. Son and Y. H. Chung, [1] In this work, a comprehensive control scheme for a delta-connected cascaded h-bridge (CHB) converter based static synchronous compensator(STATCOM) is presented, especially focusing on improving dynamic performance by novel feedforward control method. The method can conspicuously improve the dynamics of circulating current regulation of delta connected CHB STATCOM especially under grid fault condition as well as load unbalance without excessive DC cell capacitor voltage fluctuation. The full scaled simulation results and the down scaled experimental results verify that stable operation is guaranteed for both emulated grid and load unbalance conditions.

P. Sochor and H. Akagi,[2] This work provides a theoretical discussion and comparison in energy balancing between a modular multilevel cascade inverter based on single-star bridge cells (SSBC) and that on single-delta bridge cells (SDBC). Attention is paid to applications involving asymmetric active-power generation in utility-scale grid-tied photovoltaic systems. Both qualitative and quantitative evaluation metrics to assess the energy-balancing capability are introduced and applied to both SSBC and SDBC inverters. As for the SSBC inverter, six zero-sequence voltage waveforms with different harmonic content enabling enhanced energy-balancing capability are analyzed and compared regarding their effectiveness. This work also emphasizes on the SDBC as an alternative to the SSBC and highlights its superior operating characteristics under asymmetric active-power generation.

D. Lu, H. Hu, Y. Xing, X. He, K. Sun and J. Yao [3] To study the clustered voltage balancing mechanism for cascaded H-bridge STATCOM, the active power from the grid is decomposed of by using positive and negative sequences in dq frame. Based on the detailed analysis, portion of clustered active power generated by negative-sequence voltages and currents, referred as negative-sequence clustered active power (NCAP), can redistribute the active power among three clusters, which implies it can be utilized to balance the three clustered voltages. Then, the relationship between NCAP and control variables-duty cycle is built. The relationship reveals that three clustered voltages are capable of converging to stable voltages without any clustered balancing control, indicating the cascaded H-bridge STATCOM having the clustered voltage self-balancing feature. Finally a balancing control method is reported to regulate NCAP. The effectiveness of the reported control method is verified by the experiments.

J. I. Y. Ota, Y. Shibano and H. Akagi,[4] This work provides an experimental discussion on zero-voltage-ride-through (ZVRT) capability of a phase-shifted pulsewidth-modulation distribution static synchronous compensator (D-STATCOM) using the modular multilevel cascade converter based on single-star bridge cells (SSBC). The cluster-balancing control producing a significant effect on the ZVRT capability is modeled and analyzed with focus on either a low-pass filter (LPF) or a moving-average filter (MAF) to attenuate the 100-Hz (double the line frequency) component inherent in each dc capacitor voltage. The cluster-balancing control using the MAF is better in transient performance than that using the LPF. A three-phase downscaled SSBC-based D-STATCOM rated at 150 V and 10 kVA is designed, constructed, and tested to verify the ZVRT capability under the severest single-, two-, and three-phase voltage sags with a voltage depth of 100%. Experimental waveforms show that the STATCOM continues operating stably as if no voltage sag occurred.

H. C. Chen, P. H. Wu, C. T. Lee, C. W. Wang, C. H. Yang and P. T. Cheng, [5] This work presents a dc capacitor voltage balancing control method for the star-connected cascaded H-bridge pulsewidth modulation converter in the static synchronous compensator applications. With the zero-sequence voltage injection as a basis for dc capacitors voltage balancing, this work investigates the detailed power flow of the converter as a whole and within individual modules under unbalanced grid voltages and then proposes a method to control the reactive power output and the dc capacitors voltage by precisely managing the power flow. This approach enhances the low-voltage ride-through capability, which is very critical as the penetration of distributed energy resources grows rapidly. The reported control method is verified by a scaled-down prototype in the laboratory.

C. T. Lee, H. C. Chen, C. W. Wang, P. H. Wu, C. H. Yang and P. T. Cheng, [6] This work presents a dc capacitor voltage balancing convtrol method for the star-connected cascaded H-bridge PWM converter in the static synchronous compensator (STATCOM) applications. The reported control utilizes the zero-sequence voltage injection to accomplish the dc capacitor voltage balancing, and the this operation of zero-sequence voltage does not affect the original reactive power control. The reported control method also works for the low-voltage ride-through operation. The control algorithm is verified with a 220-V 1kVA STATCOM based on star-connected cascaded PWM converter, and the test results verify that all the dc capacitor voltages are still regulated at the commanded value even as the grid voltage sag occurs.

Y. Gang, Z. Lidan, Y. Gang, F. Ruifeng and L. Dongdong, [7] Based on active power voltage vector addition, a new simple and clear algorithm is presented in this article to solve the existed phenomenon of the imbalance problem of the DC capacitor voltage of cascaded static synchronous compensator. The strategy has clear physical meaning and simple algorithm and it's easy to implement. Both simulation and experimental results prove its correctness.

Lin Wang, Ping Wang, Zixin Li and Yaohua Li,[8] Recently modular multilevel converters are highly attractive for medium, high-voltage power transition and electrical machine drive. Capacitor voltage sorting is very important for capacitor voltage-balancing control. This work describes a novel sorting algorithm for capacitor voltage of modular multilevel converters (MMC).

IV. PROBLEM STATEMENT

Several different topologies can be acheived by connecting the VSCs in different ways. For example, two of the simplest and more intuitive topologies are the converters, where each phase of the STATCOM is connected phase-to-ground, and the delta-coupled converters, where each phase of the STATCOM is connected phase-to-phase. Variants of these topologies as well as other topologies also exist. However, all of them suffer from the same problem which is DC capacitor voltage unbalance. The purpose of this work is therefore to define the problem of DC capacitor voltage balancing in cascaded H-bridge converter based STATCOMs, and to solve this problem for four different STATCOM topologies. A comparison of the advantages and disadvantages of each converter topology is then reviewed. For various reasons, loads may be unbalanced as well. Often, this is caused by the presence of single phase loads. Single phase loads are sometimes preferred at the distribution level because of fed by fewer conductors than three-phase loads.

V. CONCLUSION

In this work an extensive survey of literature has been reported on DC Capacitor Voltage Balancing Control for Delta-Connected Cascaded H-Bridge STATCOM Considering Unbalanced Grid and Load Conditions. The power system today is complicated networks with hundreds of generating stations and load centers being interconnected through power transmission lines. An electric power system can be subdivided into four stages: i) generation, ii) transmission iii) distribution and iv) utilization (load). The power system is a highly nonlinear system that operates in a constantly changing environment; loads, generator outputs, topology, and key operating parameters change continually. Now-a-days it is becoming very difficult to fully utilize the existing transmission system assets due to various reasons, such as environmental legislation, capital investment, rights of ways issues, construction cost of new lines, deregulation policies, etc. The fundamental principle of a STATCOM installed in a power system is the generation ac voltage source. The STATCOM can also increase transmission capacity, damping low frequency oscillation, and improving transient stability. The voltage of the source is in phase with the ac system voltage at the point of connection, and the magnitude of the voltage is controllable.

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