International Journal of Research
Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 05 Issue 12
April 2018

Power Balance Of Cascaded H-Bridge Multilevel Converters For Large-Scale Photovoltaic Integration

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ABSTRACT

The cascaded H-bridge (CHB) converter is becoming a promising candidate for use in next generation large-scale photovoltaic (PV) power plants. However, solar power generation in the three converter phase legs can be significantly unbalanced, especially in a large geographically-dispersed plant. The power imbalance between the three phases defines a limit for the injection of balanced three-phase currents to the grid.

This paper quantifies the performance of, and experimentally confirms, the recently proposed delta-connected CHB converter for PV applications as an alternative configuration for large scale PV power plants. The required voltage and current overrating for the converter is analytically developed and compared against the star-connected counterpart. It is shown that the delta-connected CHB converter extends the balancing capabilities of the star-connected CHB and can accommodate most imbalance cases with relatively small overrating.

INTRODUCTION

The cascaded H-Bridge (CHB) converter is considered one of the most suitable configurations to be used in next-generation large-scale photovoltaic (PV) power plants, attracting significant research interest both from the technical and financial perspective. With multilevel waveform synthesis, the switching frequency at the device level can be greatly reduced while the converter still achieves excellent harmonic performance. Multiple H-bridges cascaded in series also enable the converter to be directly connected to medium-voltage (MV) grids without the presence of a bulky and lossy line-frequency transformer. In addition, each H-bridge also operates at low voltage, which effectively reduces PV module mismatch loss. In applications where the CHB converter has achieved commercial success, such as Variable Speed Drives (VSDs) and Static Synchronous Compensators (STATCOMs), the active or reactive power processed by all of the H-bridges is more or less equal.

The situation is different for PV applications, as PV power generation levels in each bridge are unlikely to be equal, due to non-uniform solar irradiance, partial shading, unequal ambient temperatures, and inconsistent module degradation. The issue is referred to as power imbalance and can further divide into inter-phase and inter-bridge power imbalance. The current work on inter-phase power imbalance focuses predominantly on the star-connected topology, where the issue is addressed by injection of a zero-sequence voltage into the converter output voltages. Fundamental Frequency Zero-Sequence Injection (FFZSI) method is able to generate three-phase balanced grid currents in the case of inter-phase power imbalance.

However, zero-sequence voltage injection requires higher converter output voltages, which are constrained by the available dc-side capacitor voltages. As a result, the converter reference will saturate with only mild inter-phase power imbalance. Advanced zero sequence voltage injection methods were derived into minimize the required converter output voltages extending the range where balance can be achieved. However, even more advanced zero-sequence injection methods cannot cope with severe power imbalance scenarios. Simulations studies for the delta-connected CHB converter have demonstrated its potential to deal with severe inter-phase power imbalance in PV applications.

The contributions of this paper include the comprehensive description of the recently proposed delta-connected CHB converter for large scale PV applications, its control implementation and the analytical derivation of its power balancing capabilities also in comparison with the star-connected topology. Detailed experimental results under various power imbalance cases to demonstrate and verify the delta-CHB converter and its power balancing capabilities. Price reduction of PV cells and power conversion technology improvement in combination with government and market incentives have led to an increase in the uptake of PV systems to the grid.

In 2010 only, the installed capacity of solar PV was more than 120% of the cumulative capacity up to 2009. More than 99% of the installed capacity in 2010 was grid-connected PV application. This trend is expected to continue in the coming years. PV integration to the grid for domestic (up to 3 kW), commercial (100 kW), industrial (500 kW) and utility-scale (MW range) applications with power plants of more than 100 MW are currently under construction. One of the candidate topologies for PV applications is the cascaded H-bridge (CHB) converter.

The proposed system is illustrated in Fig. 1. Isolated DC-DC converters are applied at each H-bridge to ensure galvanic isolation between the PV panels and the CHB converter, eliminate the PV panel leakage currents and achieve individual MPPT. Two isolated DC-DC converters, namely the boost-half-bridge (BHB), and the fly-back, are evaluated through case studies. The paper is organized in the following way. Section II presents the modulation and control of the CHB converter.

EXISTING SYSTEM

The objective of this paper is to propose and experimentally verify three novels zero sequence injection methods to deal with the inter-phase power imbalance problem of CHB converters in large-scale PV power plants. Compared with the conventional solution (FFZSI), the proposed methods offer better utilization of the dc side voltages by modifying the harmonic components of the injected zero sequence.

The new methods are able to generate three-phase balanced grid currents under relatively severe power imbalance conditions, where the conventional solution fails. They allow direct connection to medium-voltage distribution networks without the presence of bulky line-frequency power transformers.

Owing to the stochastically-variable nature of irradiance level, ambient temperature and other factors, power levels in the three phases are expected to be unequal.

PROPOSED SYSTEM

The performance of, and experimentally confirms, the recently proposed delta-connected CHB converter for PV applications as an alternative configuration for large scale PV power plants. The required voltage and current overrating for the converter is analytically developed and compared against the star-connected counterpart. It is shown that the delta-connected CHB converter extends the balancing capabilities of the star-connected CHB and can accommodate most imbalance cases with relatively small overrating.

CONCLUSION

The delta-connected CHB converter provides an alternative configuration for large-scale PV applications. A major difference between the two configurations is that the delta-connected topology offers superior power balancing capabilities in order to address unbalanced power generation amongst the three phases without requiring significant voltage or current overrating. The capability has been demonstrated both analytically in terms of worst-case power imbalances and practically by comparing the Power Balance Space of the two configurations.

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