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Simulation and Comparision of Back To Back System using Bidirectional Isolated DC-DC Converter with Active Energy Storage

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Abstract

This paper proposes simulation and comparison of BTB (back-to-back) system combining bidirectional isolated dc/dc converters and modular multilevel cascade PWM converters [1]. The system consists of multiple converter cells connected in cascade per phase at both front ends. Each converter cell consists of a bidirectional isolated medium-frequency dc/dc converter and two voltage-source H-bridge (single-phase full-bridge) PWM converters. Extremely low voltage steps bring a significant reduction in harmonics and EMI (electromagnetic interference) emissions to the BTB system. The proposed topology utilizes the active ripple energy storage method for rectifier capacitance design [2]. MatLab/Simulation has been done in this paper and proves that the proposed topology works well and the active energy storage method can significantly reduce the DC link capacitor.

Keywords: Back-to-back systems, bidirectional isolated dc/dc converters, Active ripple energy storage, multilevel converters.

Introduction

The simplified utility power distribution system consisting of two radial feeders is shown in fig.1 Feeder 1 has no distributed power generators whereas feeder 2 has many distributed power generators. As a result, the so-called "back feed" may occur through feeder 2, so that the terminal voltage at the load end of feeder 2 will increase while that of feeder 1 will decrease. This would make it difficult for both feeders to comply with the Japanese utility voltage code, in which the single-phase 100-V, 50/60-

Hz system must range from 95 to 107 V. The reason is that existing devices and techniques such as tap-changing of the primary distribution transformer are no longer useful. To solve the problem, the authors of [3] have discussed the possibility to install a 6.6-kV transformerless BTB (back to-back) system using three-phase two-level voltage-source PWM converters. Each arm consists of a string of eight 3.3-kV IGBTs connected in series. However, this transformerless system may have a zero-sequence current circulating between the feeders because the 6.6-kV utility distribution system in Japan is based on a three-phase ungrounded system. The zero-sequence current should be smaller than 0.2 A to avoid malfunction of grounding-detection relays [3].

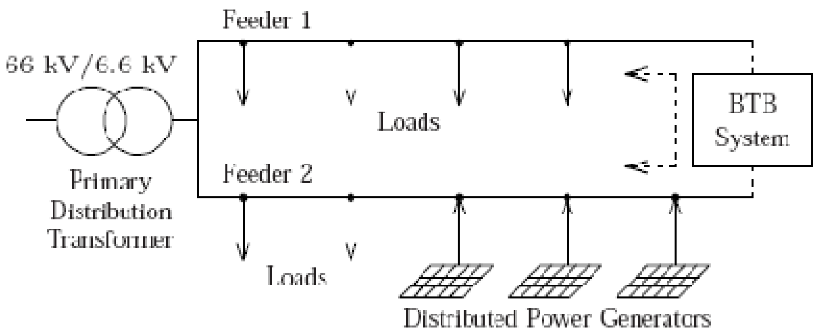


Figure 1: Example of a figure caption. (figure caption)

The authors of [4]-[6] describe a 6.6-kV modular multilevel cascade BTB (back-to-back) system characterized by the use of multiple bidirectional isolated dc/dc converters. Fig. 2 depicts the simplified circuit configuration of the BTB system. Two sets of modular multilevel cascade PWM converters with low voltage steps make a significant contribution to mitigating supply (line) harmonic currents and EMI (electromagnetic interference) emissions. Moreover, compact and light medium frequency transformers in the dc/dc converters perform galvanic isolation between the two feeders, thus resulting in no circulating zero-sequence current.

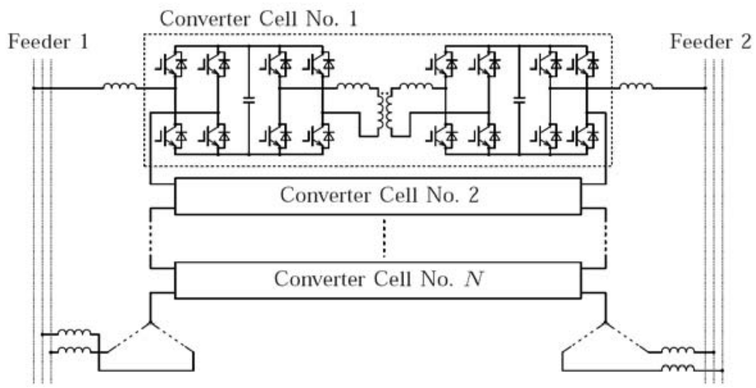


Figure 2: Modular Multilevel cascade BTB system

Overview of BTB System

The configuration of the 6.6-kV multilevel cascade BTB system [4]-[6] is shown in fig. 2. It consists of multiple converter cells per phase, which are connected in cascade at both front ends. Each converter cell consists of a bidirectional isolated dc/dc converter at the center and two identical voltage sources H-bridge converters at both front ends. Thus, the converter cell forms a symmetry circuit when it is seen from the medium-frequency transformer of the dc/dc converter to the two H-bridge converters. Extremely low voltage steps bring a significant harmonic and EMI reduction to the BTB system. Moreover, the medium-frequency transformer in each dc/dc converter achieves galvanic isolation between the two H-bridge PWM converters at both ends.

The detailed circuit configuration of the bidirectional isolated dc/dc converter sitting at the center of each converter cell as shown in fig. 3. It consists of two identical single-phase voltage-source converters, a medium-frequency transformer, and two external inductors. The two converters produce 180° conducting rectangular voltages V_A and V_B at their ac terminals. The delivered active power p is given by a phase difference ± [rad] as follows [7]:

$$p = \frac{V_{DCA}V_{DCB}}{\omega L}\partial(1-\frac{|\partial|}{\Pi}) \quad (1)$$

$$L = L_a + L_{trans} \quad (2)$$

Here, $\omega = 2\Pi f$ is the angular frequency of the medium frequency f, La is the total inductance of the two external inductors, and L_{trans} is the total leakage inductance of the primary and secondary of the transformer. A capacitor connected between the collector and emitter of each IGBT plays an important role in performing zero-voltage switching (ZVS), thus resulting in high conversion efficiency. The authors of [6] estimate that the efficiency from the dc input-to-output terminals reaches 99% when SiC devices are used.

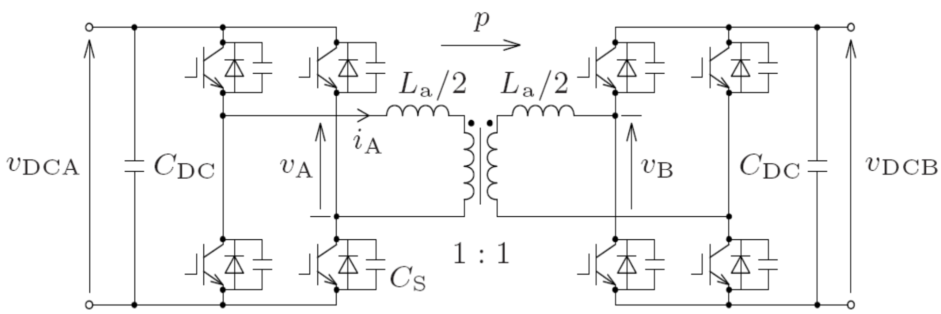


Figure 3: A bidirectional isolated dc-dc converter

Each converter cell consists of the bidirectional isolated dc/dc converter and two identical H-bridge PWM converters. As shown in Fig. 3, the cascade connection of N H bridge PWM converters per phase forms a cluster in a phase. Three star-connected clusters constitute the three-phase cascade PWM converter based on the so-called "phase-shifted unipolar sinusoidal PWM" at both front ends of Fig. 2. A phase shift of ∏/N [rad] is executed for N triangle-carrier signals [13] with each other. This results in bringing 2N + 1 levels to the line-to-neutral voltage, and 4N + 1 levels to the line-to-line voltage. Moreover, the equivalent carrier frequency of the cascade PWM converter is 2N times as high as each PWM carrier frequency.

It was verified by experiments using downscaled models that the multilevel cascade PWM converter with star configuration is applicable to a transformer less STATCOM [8] and a battery energy storage system [9]-[12]. Although the BTB system shown in Fig. 2 is intended for active-power control between the two radial feeders, it can act as a STATCOM for reactive power control at both front ends. Moreover, it can act as a battery energy storage system at both front ends when a battery module is installed at either or both dc link(s) in each converter cell.

Active Ripple Energy Storage

Because of the second-order harmonics embedded in the single-phase rectifier, there is an obvious low frequency harmonics in the DC-link voltage and requires big DC capacitor to absorb it, which is a big contributor to the overall system volume and weight. Reference [15] and [16] proposed the single-phase rectifier with active energy storage, shown in Fig.4.

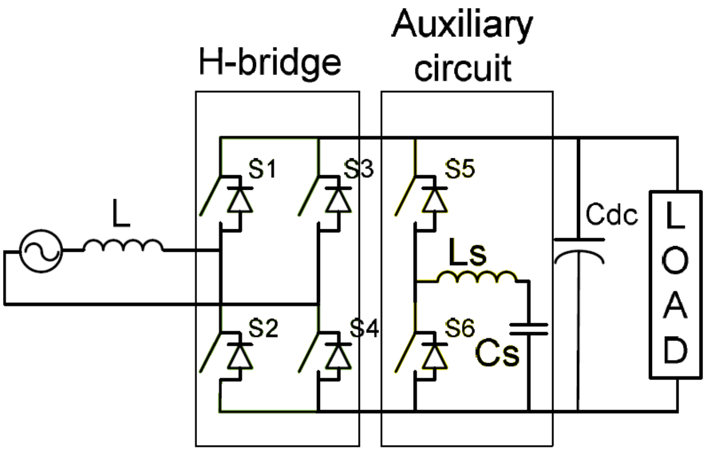


Figure 4: Single phase PWM Rectifier with AES

An auxiliary phase-leg is connected to Ls and Cs, by switching the auxiliary phase leg, the DC voltage ripple energy could be absorbed by Ls-Cs. Control of the auxiliary circuit is shown in Figure.5, the error of the DC-link voltage is controlled by two comparator and generated gate signals for the top switch G5 and bottom switch G6.

The DC bus capacitor has the biggest weight saving of 80% as shown in fig 6

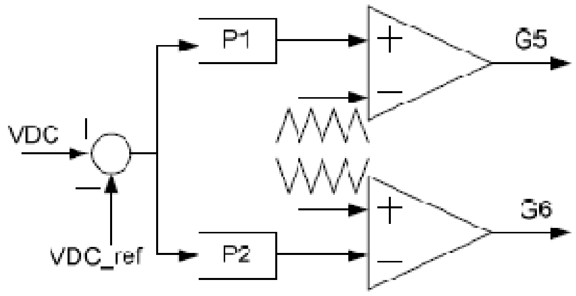


Figure 5: Voltage ripple control method for the auxillary bridge

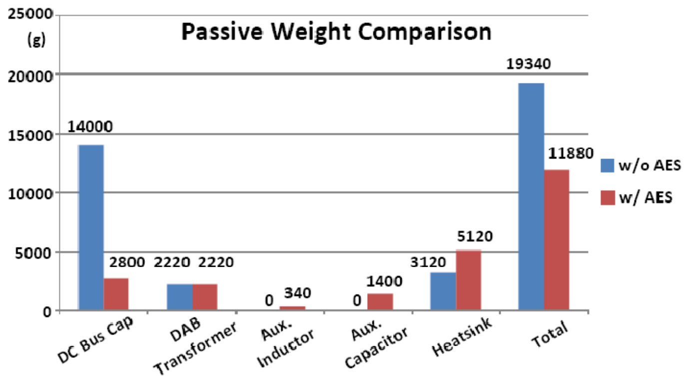


Figure 6: Passive weight comparission.

Simulation Analysis

Simulation in MATLAB/Simulink has been done for an example system to evaluate the feasibility and benefit of the proposed topology. Single-stage is used for simulation as shown in Fig.7. The parameters are shown in TABLE 1.The input side is a single-phase voltage source with 230V RMS voltage and controlled with unity power factor. The DC link voltage of the load side is 560V.

Table 1: Ratings and Specifications

System Voltage, Vs	230V
Nominal DC link Voltage, Vdc	560V
Source Inductance, Ls	1mH
DC Link Capacitor, Co	0.2mF
PWM Carrier frequency, fs	1kHz
Transformer turn	1:1
Transformer Leakage Inductance	0.08H
Auxiliary Inductor	1mH
Medium frequency	10kHz

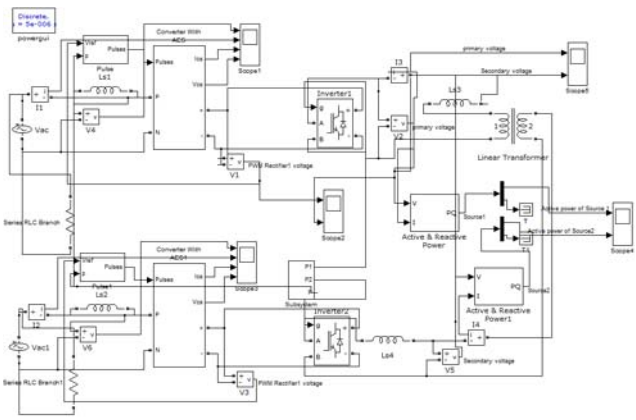
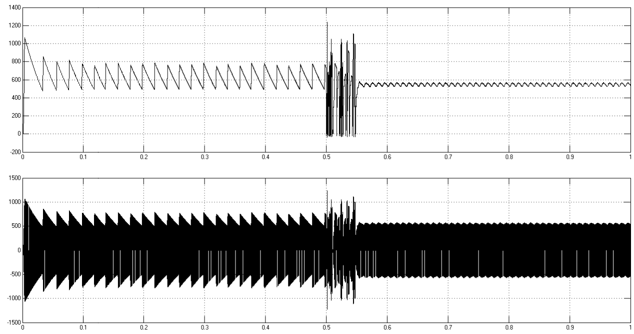


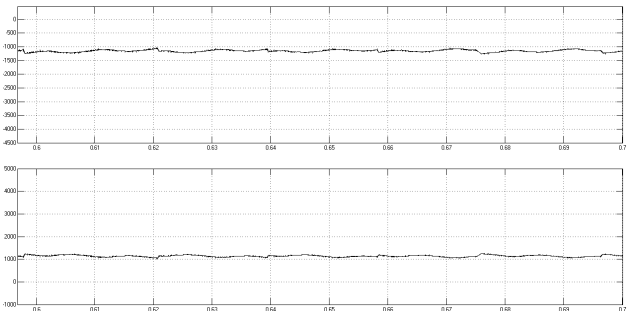
Figure 7: MatLab/ Simulink Model

In order to show the benefits of the active energy storage, upto 0.5s, the gate signals of the auxiliary phase leg are blocked both for input and output side. When performing PWM rectifier without AES , the Ripple voltage is 320V at 0.1s. At same time, the ripple voltage with AES is 55V



X axis 1unit =0.1s, Y_1axis 1unit =200V, Y_2 axis 1unit=500V

Figure 8: Former primary and secondary voltage



X axis 1unit=0.01s, Y_1axis 1unit=500W, Y_2 axis1unit=1000W

Figure 9: Active power control of 1200W ζ=30°

Conclusion

This MatLab/Simulink model of bidirectional isolated DC-DC converter with active energy storage system is described. It is intended for installation on the power distribution systems in which the BTB system. A single-phase downscaled BTB system with AES has exclusively been simulated to verify the effectiveness and viability. With the utilization of active ripple energy storage method for rectifier and inverter capacitance design, the proposed topology can largely increase the system power density by reducing the weight of passive components. Systematic simulation results prove that the proposed topology can achieve much smaller DC-link voltage ripple. Preliminary design of the passive components has been done in this project and proves that up to 38.6% of the passive weight [13].

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