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An Isolated Boost-Three Level Bi-directional DC-DC Converter with Phase Shift PWM

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Abstract. A novel bi-directional DC-DC converter applicable to micro-grid is proposed in this paper, which combines traditional boost-type converter and three-level converter. Excellent power transmission ability (including voltage step-up and step down) can be obtained by deploying phase-shift control strategy. The proposed converter with three-level topology is also capable to lower the voltage stress of the second stage switches to 50%. Operation modes have been analyzed in detailin the paper. A 3-kW laboratory prototype was designed and tested for performance evaluation. Experimental results indicate the effectiveness and stability of the system.

Keywords: Three-Level Converter, Bidirectional DC-DC Converter, Micro-Grid, High Voltage DC (HVDC) Bus.

1. INTRODUCTION

In numerous power related systems, including hybrid electric vehicle (HEV), renewable energy system, and micro-grid system, bidirectional DC–DC converter has been broadly used. In electric vehicle (EV) applications, bidirectional DC–DC converter manages energy and power flow between DC-bus and energy storage, and allows use of low-voltage battery as well as high-voltage inverter-motor drive. Bidirectional power flow enables energy capture of regenerative brake along with energy release during startup, accelerating, and hill climbing. In micro-grid applications, bi-directional DC–DC converter is used to transfer electric power to capacitive energy source when DC-bus voltage is high, while delivering energy to load when DC-bus voltage is low. Bidirectional DC–DC converters can be non-isolated or isolated, depending on the requirements of the system.

A novel bidirectional DC–DC converter with excellent power transmission ability is proposed in this paper, consisting of boost-three level topology and a control strategy based on DSP applicable to micro-grid system. The deployment of three-level circuit topology lower the voltage stress of the second stage switches to 50% in the meantime.

2. SYSTEM DESCRIPTIONS AND CONTROL STRATEGY

System Description

(Fig.1) shows the generalized circuit of the Isolated Boost-Three Level Bi-directional DC-DC Converter. The first stage is boost type inverter connected to a storage battery, second stage is a three-level inverter connected to the HVDC bus of micro-grid. There is a high-frequency transformer (HFT) in the middle of the two stages.

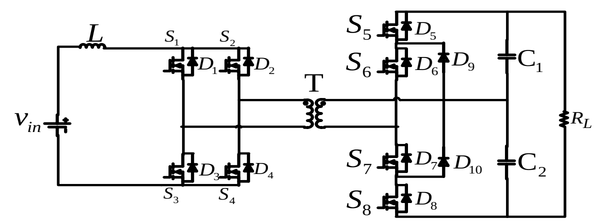

Fig. 1: Bi-directional DC-DC Converter

Control Strategy

Discharging process: The phase-shift PWM technique has been used for proposed bidirectional converter. The phase-shift PWM switching is shown in **(Fig. 2)** which is used as driving signals for the switches and is generated by TMS320F2407DSP. Switch signals of S1/S2 and S3/S4 are mutually complementary. Shoot-through duty cycle is determined by phase-shift angle between switches of the same phase-leg. The second stage work as an uncontrolled rectifier while discharging.

Charging process: Quasi phase-shift PWM technique is been deployed in this case as shown in **(Fig.3)**. Phase-shift angle between switches of the same phase-leg stay constant during buck process. Conduction dutycycle can be varied in order to control charging current. The first stage operates as an uncontrolled rectifier in the meantime.

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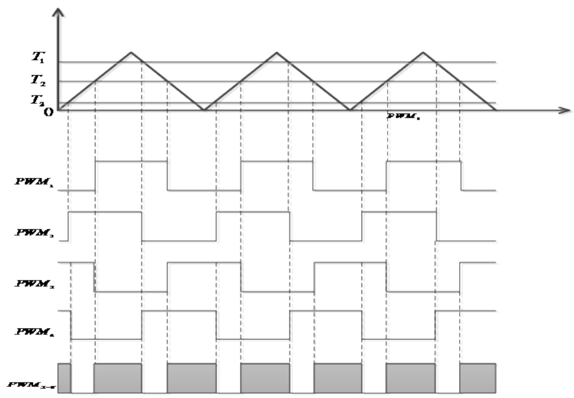

Fig. 2: Discharging Process PWM Switching

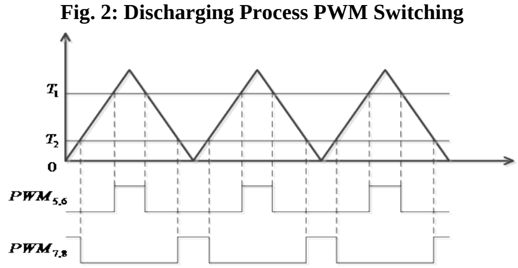

Fig. 3:Charging Process PWM Switching

3. OPERATION MODES ANALYSIS

(Fig. 4) shows operation modes of proposed bidirectional DC-DC converter over one switching period. Operation modes include twelve switching modes which can be explained as under:

Mode1: In this mode, S1 and S3 start to conduct, the first stage work under shoot-through state and thus charges inductor L, in the second stage, current flows through loop C1-C2-RL-C1.

Mode2: The gate pulse signal of S3 is removed for S4, the first stage work under conduction mode. Energy on L starts to release via transformer T to the second stage, V_{C1} decreases as C1 releases its energy via loop C1-R_L–D8–D7–C1, V_{C2} increases as current charges C2 via loop C2–D8–D7–C2.

Mode3: In this mode, the first stage work under shoot-through state and thus charges inductor L as S2 and S4 starts to conduct; the leakage current through L_r starts to decrease as it releases its energy through loop to zero.

Mode4: The leakage current through Lk2 decreases to zero, the first stage's still under shoot-through state. C1 and C2 work in series to supply HVDC bus.

Mode5: The gate pulse signal of S4 is removed for S3, the first stage works under conduction mode. Energy on L starts to release via transformer T to the second stage, V_{C1} increases as current charges C1 through loop C1–D6–D5–C1, V_{C2} decreases as C2 releases its energy via loop C2–D6–D5–R_L–C2.

Mode6: In this mode, the first stage works under shoot-through state and thus charges inductor L as S1 and S3 start to conduct, the leakage current through L_r starts to decrease as it releases its energy through loop to zero

Mode7:S5 and S6 starts to conduct, the second stage charges C2 with energy received from HVDC bus, V_{C1} decreases as C1 releases its energy via loop C1–D5–D6–C1, the first stage works as an uncontrolled rectifier and thus charges inductor L and storage battery through parasitic diodes of S2 and S3.

Mode8: The gate pulse signals were removed from S5 and S6, the leakage current through L_k starts to decrease as it charges C2 through loop L_k–C2–D8–D7–L_k, C1 releases its energy to HVDC bus. The inducted current charges storage battery through loop L–D2–D2–L.

Mode9: The leakage current through L_k soon decreases to zero; the current through L continues to charge storage battery of the first stage.

Mode10: S7 and S8 starts to conduct, the second stage charges C1 with energy received from HVDC bus, V_{C2} decreases as C2 releases its energy via loop C2–D7–D8–C2, the first stage works as an uncontrolled rectifier and thus charges storage battery through parasitic diodes of S1 and S4.

Mode11: The gate pulse signals were removed from S7 and S8, the leakage current through L_k starts to decrease as it charges C1 through loop L_k– D6– D5– C1– L_k, C2 releases its energy to HVDC bus. The inducted current charges storage battery through loop L–D4–D1–L.

Mode12: The leakage current through L_k soon decreases to zero; the current through L continues to charge storage battery of the first stage.

4. EXPERIMENTAL RESULTS

A 3-kW laboratory prototype has been built **(as shown in Fig.5)** to verify the control strategy and working modes of the proposed converter, and circuit parameters are in **(Table 1).** Set the switching frequency for all six MOSFETs at 20 kHz to decrease the volume of the input inductors and the high frequency transformer (HFT), with Texas Instruments' TMS320F2407DSP as the controller. MOSFETs with low drain to source resistance and extremely high capability are used. Schottky diodes with lower reverse recovery loss and forward voltage drop are used as voltage rectifiers. **(Fig. 6 and Fig. 7)** show the dynamic response, when increasing and decreasing the load. **(Fig. 8)** represents the voltage of storage battery and inductor currents at steady state condition.

Table 1: Specification for Experiment Parameters

	Value	Parameters	Value
Po	3 kW	L	500mH
Vo	250 V	C_1, C_2	470 µf
Vin	24 V	Fs	20 kHz

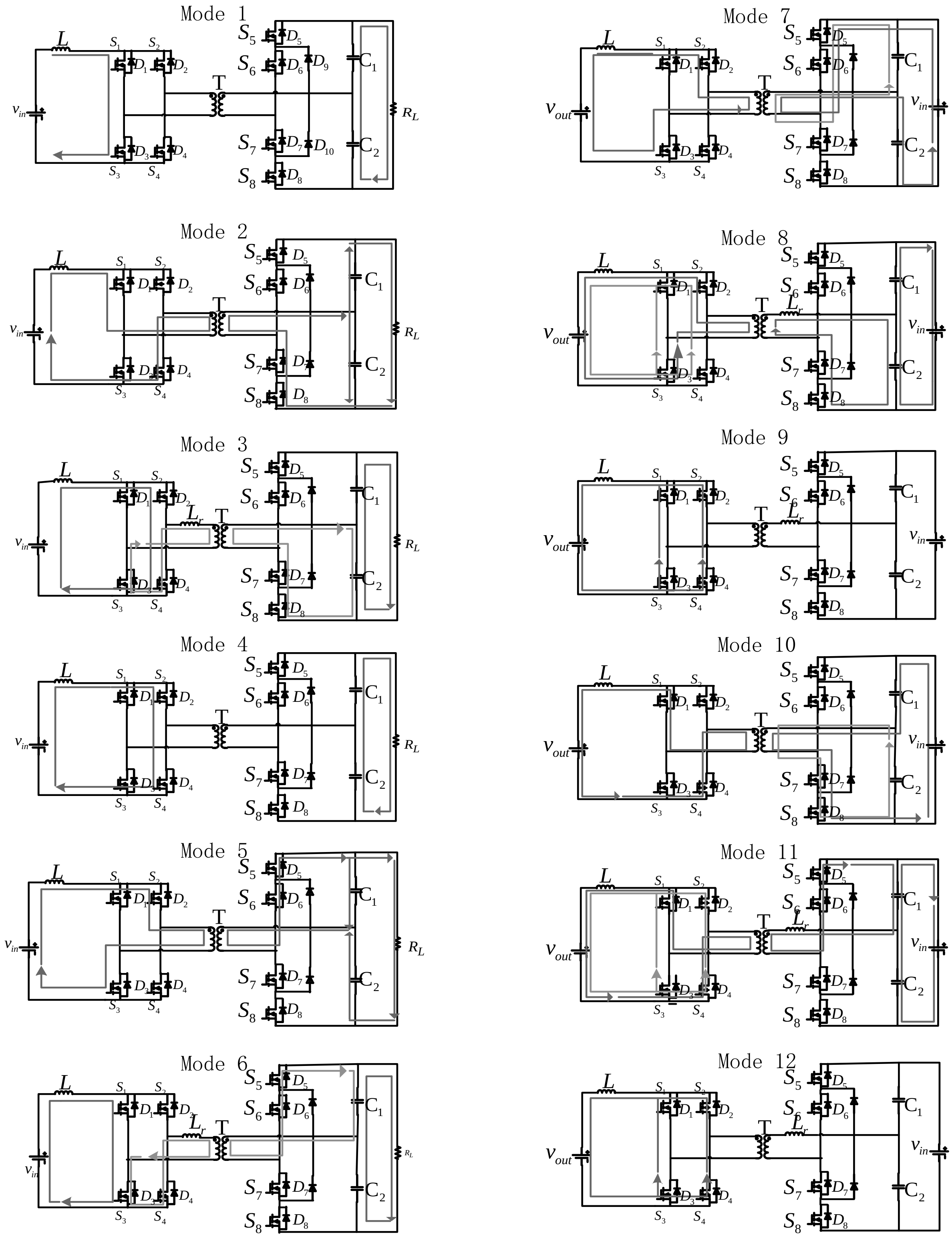

Fig. 4:Operation modes of the proposed topology

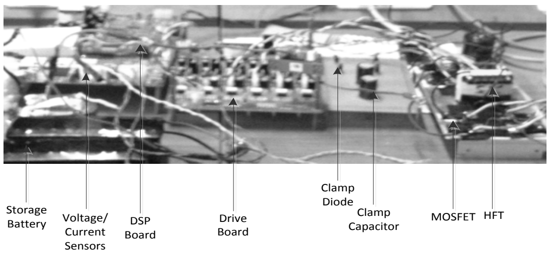

Fig. 5:Photographof proposed DC-DC converter

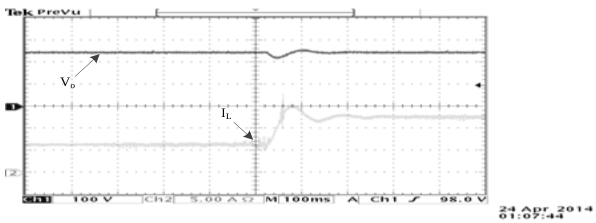

Fig. 6: Dynamic response for decreasing load

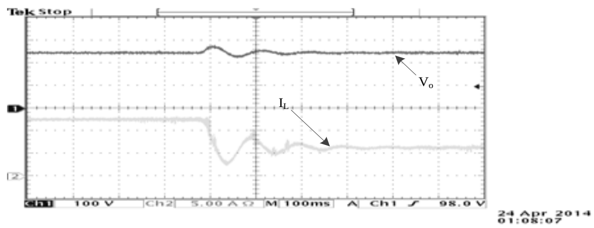

Fig. 7:Dynamic response for increasing load

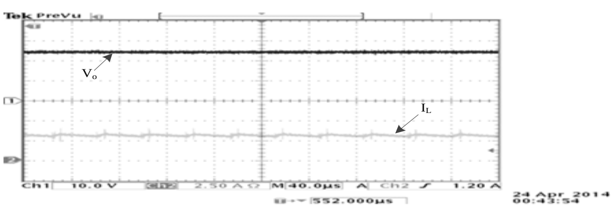

Fig. 8:Output voltage and inductor current at steady state condition

5. CONCLUSION

Isolated Boost-Three Level Bi-directional DC-DC Converter and a control strategy based on TMS320F2407DSP have been proposed in this paper. In the proposed Bi-directional Converter, phase-shift PWM technique has been applied. Based on experimental results it can be concluded that power transmission ability including voltage step-up and step-down ability can be obtained between input and output, Moreover, the Operation modes of proposed bidirectional converter are discussed in detail based on experimental results. The stability and effectiveness of the converter are found in the control strategy based on DSP with excellent dynamic response of the system.

REFERENCES:

Cha, H., J. Choi, and P. Enjeti, (2008) "A three-phase current-fedDC/DC converter with active clamp for low-DC renewable energy sources," IEEE Trans. Power Electron., vol. 23, no. 6, 2784–2793.

Das, P., B. Laan, S. A. Mousavi, and G. Moschopoulos, (2009). "A non-isolated bidirectional ZVS-PWM active clampedDC–DC converter," IEEE Trans. Power Electron., vol. 24, no. 2, 553–558.

Fathy, K., H. Lee, T. Mishima, and M. Nakaoka, (2006), "Boost-half bridge single power stage PWM DC-DC converter," in Proc. IEEE PECon 426–431.

Inoue S. (2007). "A bidirectional DC–DC converter for an energy storage system with galvanic isolation," IEEE Trans. Power Electron.vol. 22, no. 6, 2299–2306.

Lai J. S. and D. J. Nelson, (2007), "Energy Management Power Converters in Hybrid Electric and Fuel Cell Vehicles," Proceedings of the IEEE, vol. 95, 4, 766 - 777.

Lee, S. Y., A. G. Pfaelzer, and J. D. van Wyk, (2007) "Comparison of different designs of a 42-V/14-V DC/DC converter regarding losses and thermal aspects," IEEE Trans. Ind. Appl., vol. 43, no. 2, 520Pp,

Oliveira, Jr. D. S. and I. Barbi, (2005)."A three-phase ZVS PWM DC/DC converter with asymmetrical duty cycle associated with a three-phase version of the hybridge rectifier," IEEE Trans. Power Electron., vol. 20, no. 2, 354–360,

Oliveira, D. S., and C. E. A. Silva, (2006). "A three-phase ZVS PWM DC–DC converter associated with a double-wye connected rectifier, delta primary," IEEE Trans. Power Electron., vol. 21, no. 6, 1684–1690,

Peng, F. Z., H. Li, G. J. Su, and J. S. Lawler, (2004). "A new ZVS bidirectional DC–DC converter for fuel cell and battery application," IEEE Trans.Power Electron., vol. 19, no. 1, 54–65,

Peraca M. T. and I. Barbi, (2005), "The generation of dc–dc converters using new three-terminal multiple-state cells," in Proc. IEEE PESC, 16–19, 2657–2663.

Pinherio J. R, and I. Barbi (1992). Three-level ZVS PWM converter a newconcept in high-voltage dc/dc conversion[C]. in Proc. IEEE IECON,173-178.

Tao, H., A. Kotsopoulos, J. L. Duarte, and M. A. M. Hendrix, (2008). "Transformercoupled multiport ZVS bidirectional DC–DC converter with wide input range," IEEE Trans. Power Electron., vol. 23, no. 2, 771–781,

Urciuoli, D. P. and C. W. Tipton, (2006) "Development of a 90 kW bi-directional DC-DC converter for power dense applications," in Proc. IEEE APEC, 1375 - 378.

Xiao H. and S. Xie, (2008). "A ZVS bidirectional DC–DC converter with phaseshift plus PWM control scheme," IEEE Trans Power Electron. vol. 23, 2, 813–823.

Yu, W., H. Q. Jih-Sheng (Jason) Lai, (2010) "Design of High-Efficiency Bidirectional DC–DC Converter and High-Precision Efficiency Measurement," IEEE Trans. Power Electron, vol. 25, no. 3, 650–658.