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Fuel Cell Based Power Management Technique in Grid Connected Bidirectional DC-DC Converter

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Abstract:

In this research power management topology is developed in grid connected bidirectional dc-dc converter with fuel cell is acting as source and battery for storage purpose. In present time world is running for increased use of renewable energy resources like solar, wind and fuel cell etc. An efficient bidirectional dc-dc converter is necessary to couple the low DC-voltage (hybrid energy storage that is battery) source to high voltage DC-bus (DRER-distributed renewable energy resources) and vice versa. Power management is the major concern in smart micro-grids like in renewable power generation and hybrid electric vehicles.

But, the major limitation of the renewable energy is that they are intermittent in nature. In view of this, these sources need to be integrated with battery. This research proposes analysis and PIID based control of bidirectional DC-DC converter enables by battery and fuel based DC source. The proposed converter has the merits of less component count, reduction of leakage currents, high efficiency and smaller size. Power management technique is developed by bidirectional DC-DC convertor enables a battery module of low voltage to be interfaced with the high voltage dc bus, which is generated by fuel for subsequent utilization and is implemented in Simulink-environment.

Keywords:

Bidirectional converter; Fuel based DC Bus; Battery. Storage System;

I. INTRODUCTION:

Intelligent Microgrid system has been promoted quickly to fulfill increasing power demand and deal with global climate change. In addition to this it might solve the power shortage problem we face in recent times. In this research dc source and battery are acting simultaneously to provide continuous power, need to develop intelligent microgrid is combination of AC and DC microgrids acting together, In this research fuel cell generates dc voltage and is connected to battery by bidirectional DC-DC converter to supply the load continuously. In the conventional bidirectional DC-DC converter (BDC) represented as dual active bridge (DAB) shown in fig 1., HV side voltage is provided by mains supply by converting to DC with rectifier. In this BDC high frequency transformer is used to convert HVAC to LVAC finally the output of BDC is LVDC, which is connected to hybrid energy storage. But the problem with conventional BDC is that to connect to utility grid and to provide AC loads there should be one more transformer between inverter and utilitygrid according to IEEE1547 standards and other is by placing a high frequency transformer in high power applications more amount of leakage currents will be taking place. Proposed BDC converter with PIID controller is designed to overcome these problems.

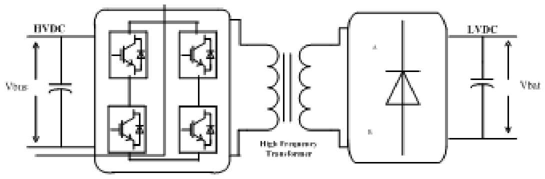

Fig 1. Dual Active Bridge

In most power electronic systems, input power, load demand or both simultaneously changing and are not exactly identical with each other at any given time instant. Hence, there is a need to provide a converter system that is capable of matching load demand as per the source capacities. Furthermore, due to the wide variation of the processed power, overall efficiency of the system is not high. Hence, additional energy storage devices like batteries or ultra-capacitors are required to assist the main source in fulfilling the load demand. If this is to be done then two converters i.e. buck and boost. In order to perform these two actions effectively and more efficiently BDC is designed. So that if fuel cell is insufficiently feed the load initially then grid also will come into action and both will fulfill the load demand, in second case if fuel cell is only sufficient to fulfill the load demand then it only will generates power to load, in third case if fuel is more sufficient to generate power to battery, load, if any more to grid also. If fuel is not even generates then battery and grid will fulfill the load demand. All these actions are possible only by BDC. Since the load voltage level and the energy storage device voltage levels need not be the same, the bidirectional converter should be operating as a buck converter in one direction and as a boost converter in the other direction.

Non-isolated BDC's offer benefits of single topology, simplicity of control, higher efficiency, higher power density and lower cost than an isolated one for the applications where isolation is not required, particularly more suitable in point of load applications. A proposed BDC can be derived by replacing the active and passive switches of a unidirectional DC-DC converter with bidirectional switches [1]. This paper mainly emphasizes on the improvement of proposed BDC topology. It includes four sections which are section-II discusses converter operation and design principles, section III provides modeling and design of PIID controller, section IV emphasizes on simulation results and analyses and section V discusses the concluding remarks.

II.CONVERTER OPERATION AND DESIGN PRINCIPLES:

The buck and boost converters are extensively used in industry as the unidirectional DC-DC converter stage for many high frequency inverter products and boost converter to step up the voltage which is from dc micro-grid to reach the load demand, but not yet in bi-directional manner. Proposed bi-directional DC-DC converter is not like a conventional because it is transformer less type so as to reduce size and weight to improve economy. It operates in two modes: One is discharge mode during which the BDC is used to boost the battery voltage to a suitable high level DC bus voltage . Second is the charging mode during which the BDC is used to buck the DC bus voltage to a suitable low level battery voltage. In this way it can supply to load, which is under variable conditions also. During forward discharging mode low voltage (LV) side switch (S1) operates and the converter acts as a boost converter; while during reverse charging mode, High Voltage (HV) side switch(S2) operates and the converter acts as a buck converter [2-4]. The BDC topology operates in two modes shown in Fig 3. The representation of symbols in the proposed topology are summarized as follows: V_{Bat} and V_{Bus}, respectively, denote the voltages at the low-voltage (LV) and high-voltage (HV), which is provided by dc microgrid.

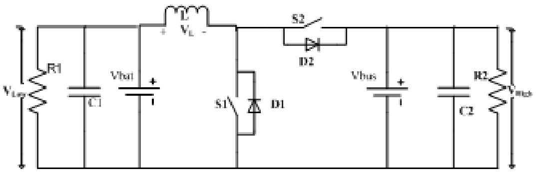

Fig 3.Bi-directional DC-DC Converter

A. Boost discharging mode of operation:

In this mode the bidirectional converter operates as a boost converter stepping up the battery voltage to the bus voltage to deliver load by discharging the battery. The switch S1 will be ON for the same duration and the switch S2 will be operating in complementary to S1. One cycle of operation is divided into two modes. In this case the converter will function as a boost converter.

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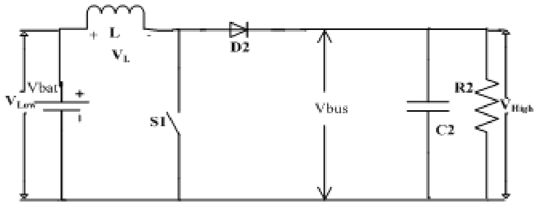

Fig 4. Boost discharging mode

Mode:1(S1-ON, S2-OFF):
In this mode the switch S1 is ON and the S2 is OFF. The capacitor C1 will be charged from the voltage sources Vb. This mode ends as the switch S1 is turned OFF and switch S2 is turned ON.

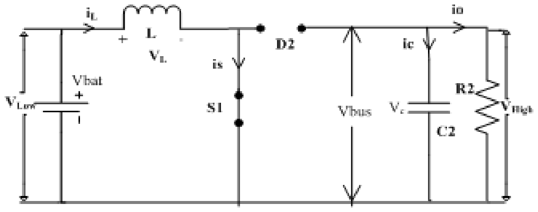

Fig.4(a). WhenS1-ON and D2-OFF (discharge mode)

From the above circuit diagram during mode 1 the inductor voltage and current can be written as

$$V_L = L\frac{di_L}{dt} = V_{Low} \qquad (1)$$

$$i_L(t) = \frac{v_L}{L}(t) + i_L(ini) = i_S \qquad (2)$$

Mode: 2 (S1-OFF, S2-ON):
In this mode the swit`ch S1 is OFF and S2 is ON. The capacitor C1 will be discharged. This mode ends as the switches S1 is turned ON and switch S2 is turned OFF.

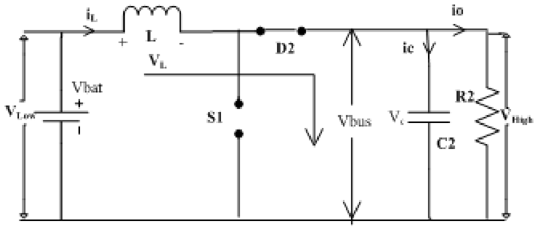

Fig 4(b). WhenS1-OFF and D2-ON (discharge mode)

In this mode of operation the inductor current freewheels through the diode. So that it satisfies the load demand. During mode 2 the inductor voltage and current can be written as

$$V_L = V_{Low} - V_{High} \qquad (3)$$

$$i_L(t) = \frac{v_L - v_H}{L}(t - DT) + i_L(DT) \qquad (4)$$

Average value of inductor voltage is

$$(V_L)_{avg} = \frac{1}{T}\int V_L(t)dt = 0 \qquad (5)$$

$$V_{High} = \frac{V_{Low}}{1-D} \qquad (6)$$

The boost converter operates in the continuous conduction mode (CCM) for $L_b < L$ where

$$L_b = \frac{(1-D)^2 DR}{2f} \qquad (7)$$

From the waveforms the current supplied to the output RC circuit is discontinuous. Thus, a larger filter capacitor is required in comparison to that in the buck deriver converters to limit the output voltage ripple. The filter capacitor must provide the output dc current to the load when the diode D is off. The minimum value of the filter capacitance that results in the voltage ripple V_r is given by

$$C_{\min} = \frac{DV_o}{V_r Rf} \qquad (8)$$

Expression for ΔI_L:

$$\Delta I_L = \frac{V_{dc}}{L}DT \qquad (9)$$

Expression for ΔV_O:

$$\Delta V_O = \frac{I_O DT}{C} \qquad (10)$$

Boundary condition for I_L:

$$L_{cr} = \frac{D(1-D)^2 RT}{2} \qquad (11)$$

B. Buck charging mode of operation:
In this mode the bidirectional converter operates as a buck converter stepping down the bus voltage to the battery voltage to charge the battery. The switch S2 will be ON for the same duration and the switch S1 will be operating in complementary to S2. One cycle of operation is divided into two modes.

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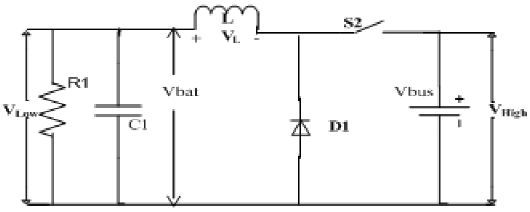


Fig 5. Buck charging mode

Mode- 1: (S2-ON and S1-OFF):

In this mode the switch S2 is ON and the S1 is OFF. The inductor L will be charged from the voltage source Vbus. This mode ends as the switches S2 is turned OFF and switch S1 is turned ON.

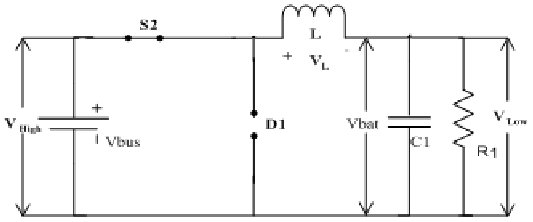


Fig 5(a). WhenS2-ON and D1-OFF (charge mode)

The voltage and current of buck converter during mode 1 operation is

$$V_L = V_{High} - V_{Low} \tag{12}$$

$$i_L(t) = \frac{V_{High} - V_{Low}}{L} \tag{13}$$

Mode- 2: (S2-OFF, S1-ON):

In this mode the switch S2 is OFF and S1 is ON. The inductor L will be discharged. This mode ends as the switch S2 is turned ON and switch S1 is turned OFF.

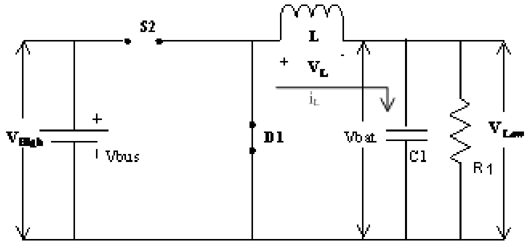


Fig 5(b). WhenS2-OFF and D1-ON (charge mode)

The voltage and current of buck converter during mode 1 operation is

$$V_L = -V_{Low} \tag{14}$$

$$i_L(t) = \frac{-V_L}{L}(t - DT) + i_L(DT) \tag{15}$$

Average value of inductor voltage

$$(V_L)_{avg} = \frac{1}{T}\int V_L(t)dt = 0 \tag{16}$$

$$V_{Low} = DV_{High} \tag{17}$$

Expression for $\Delta I_L(I_{L\max} - I_{L\min})$

$$\Delta I_L = \frac{V_{dc}}{L} D(1-D)T \tag{18}$$

Expression for ΔV_O:

$$\Delta V_{O\max} = \frac{V_{dc}}{32LCf^2} \tag{19}$$

Boundary condition for inductor current

$$L_{cr} = \frac{(1-D)RT}{2} \tag{20}$$

Boundary condition for V_O:

$$C_{cr} = \frac{(1-D)}{16Lf^2} \tag{21}$$

III.MODELING AND DESIGN OF PIID CONTROLLER

Proportional-double integral-derivative controller (PIID controller) has been the most popular control loop feedback mechanism and is extensively used in controlling industrial processes. In addition to its capabilities, PIID can be implemented easily in industrial control processes. And it tries to correct the error between the measured outputs and desired outputs of the process so that transient and steady state responses are improved as much as possible. Although it is used widely, PIID tuned by Ziegler and Nichols tuning method and is the first significant and most known one [14][15]. Among the methods used to control BDC, PIID controllers have been deployed extensively due to their less complexity, high performance and easy implementation. designing a multivariable PIID controller for the charge and discharge modes of operation. The design objective was to tune the PIID controller for minimizing integral absolute errors and to increase the band width. The complete closed loop system is stable as shown in Figure 6.

$$\frac{2.77e^5 s^2 + 3.454e^8 s + 1.077e^{11}}{s^3 + 3.167e^4 s^2 + 2.507e^8 s} \tag{22}$$

Equation 22, represent the controller transfer function. After designing of charge controller, bode plot has been drawn as shown in figure-11. From this bode plot, it is observed that the gain margin of the charge controller is 10.2dB at the phase crossover frequency 3140rad/sec. And Phase margin of the charge controller is 56 at the gain crossover frequency 9120rad/sec. From these frequency domain specifications i.e., PM and GM are observed that positive. Therefore, the designed closed loop DC-DC converter in conjunction with fuel cell system is fully stable.

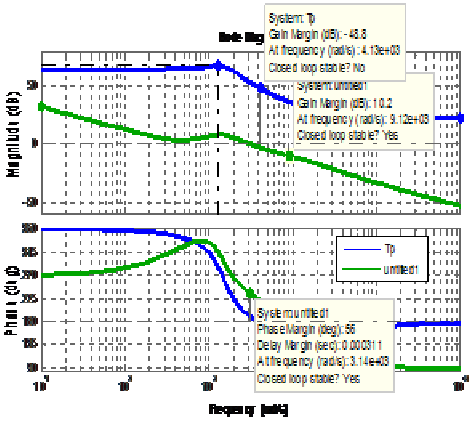
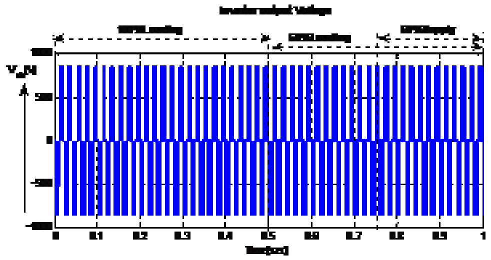


Fig 6: bode plot for the transfer function in s-domain of dc-dc converter

IV.SIMULATION RESULTS AND ANALYSES:

DC-DC Boost converter is designed for 250V to 900V with the following specifications-:

- Internal resistance Ron = 0.001Ω
- Inductor L = 7.225e-004H
- Inductor Internal resistance rL = 0.002Ω
- Capacitance C = 2.7682e-004F
- Capacitor ESR rC = 0.1110Ω
- Input Voltage Vi = 250V
- Output Voltage Vo = 900V DC
- Output Voltage of inverter V_{oinv}=900V AC
- Vgrid=11kV
- Output Power Po = 50kW
- Switching Frequency Fs = 5kHz
- Duty Ratio D=0.5
- Output Current Io = 50A
- Ts1.0000e-006Sec
- Ts-control=2.0000e-04Sec
- Ts-power=1.0000e-06Sec



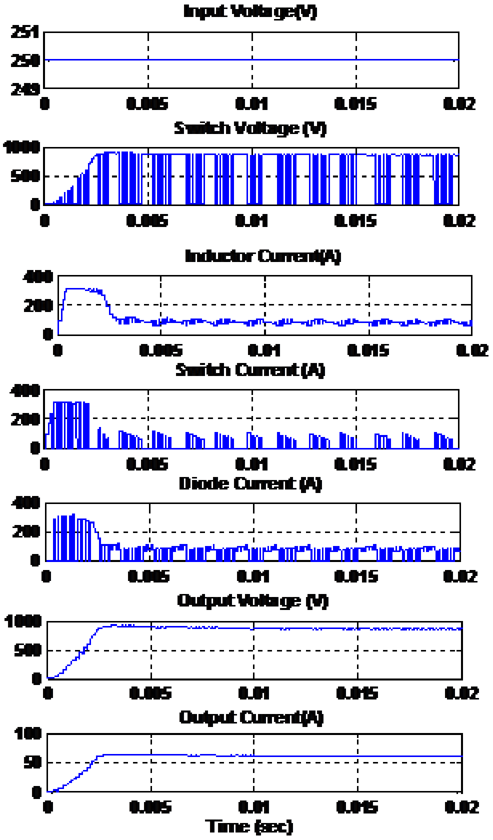


Fig 7: various parameters of the dc –dc boost converter

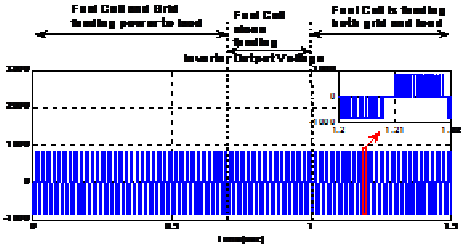


Fig 8(a), 8(b) : The output voltage of inverter under line and load variations

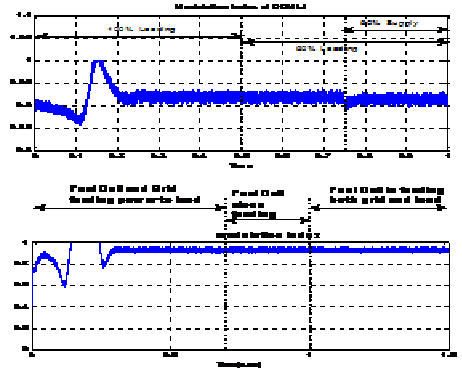


Fig 9(a), 9(b):modulation index under line and load variations

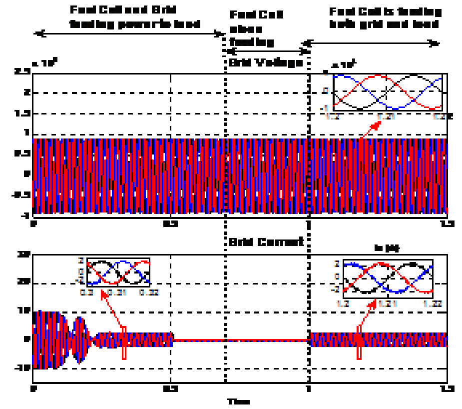


Fig 10: Grid voltage and current under line and load variations

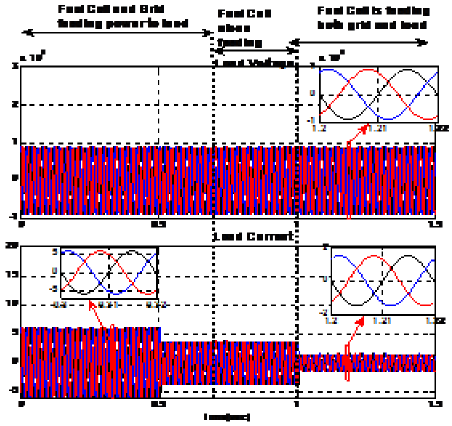


Fig 11: Load voltage and load current under line and load variations

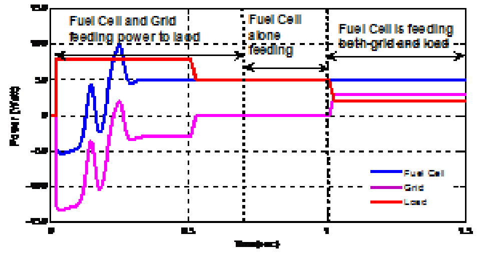


Fig 12: Load sharing by fuel cell under line and load variations

V.CONCLUSION:

In this study high efficient BDC converter is analyzed and developed in MATLAB/Simulink. As compared to conventional dual active bridge in this proposed model number of switches and transformers count reduces, which results reduces production costs, leakage currents and increase conversion efficiency. By enabling BDC to battery, DC bus(Fuel) and grid it is able to feed load under line and load variations. In order to perform the charging/discharging modes of operation PIID controller is designed. This is superior to the other control strategies because of fast transient response, minimum steady state error and good disturbance rejection under line and load variations. Hence, it achieves the most tightly output voltage regulation. Moreover, by knowing the dynamic behavior of proposed converter, stability analyses with respect to the PIID controller can be further studied using different modeling techniques.

REFERENCES:

[1] Hongfei Wu, Wei Shi, Yan Xin, Xudong Ma, “ A non-isolated bidirectional Buck-Boost converter with minimized reverse-recovery losses” IECON 2011-37th Annual Conference on IEEE Industrial Electronics Society , 2011, pp. 1085-1090.

[2] Chang Gyu Y, Woo-Cheol L, Kyu-Chan L and Bo H Cho, “Transient Current Suppression Scheme for Bidirectional DC-DC Converter in 42V Automotive Power systems, Conf. Rec. of IEEE 2005, pp.1600-1604.

[3] D. Diaz, and O. Garcia, et al., “Analyzes and Design considerations for the right half-plane zero cancellation on a boost derived dc/dc converter,” IEEE Transactions, pp. 3825-3828, 2008.

[4] S. Waffler and I.W. Kolar, “A Novel Low-Loss Modulation Strategy for High-Power Bi-directional Buck Boost Converters”, 7Th International Conf. on Power Electronics-07, PP.889-894, Oct 2007.

[5] Dogga Raveendhra, Saad Faruqui and Parvesh Saini, Transformer Less FPGA Controlled 2-Stage Isolated Grid Connected PV System,” Power and Energy Systems: Towards Sustainable Energy (PESTSE 2014).

[6] Jusoh, A. J. Forsyth and Z. Salam, “Analysis and Control of the Unloaded Bi-directional DC/DC Converter to Perform an Active Damping Function,” Jurnal Teknologi, 44(D) (JTjun44D[5]CRC.pmd), pp. 65-84, June 2006.

[7] J. Wai and R. Y. Duan, “High-efficiency dc/dc converter with high voltage gain,” Proc. Inst. Elect. Eng., vol. 152, pp. 793–802, 2005.

[8] J.Wei and B. Fahimi, “Active current sharing and source management in fuel cell-battery hybrid power system,” IEEE Trans. Ind. Electron., vol. 57, no. 2, pp. 752–761, 2010.

[9] Y. Zhang, Z. Jiang, and X. Yu,“Control strategies for battery/supercapacitor hybrid energy storage systems,” in Proc. IEEE Energy 2030 Conf., 2008, pp.1-6.

[10] J.Wei and B. Fahimi, “Active current sharing and source management in fuel cell-battery hybrid power system,” IEEE Trans. Ind. Electron., vol. 57, no. 2, pp. 752–761, 2010.

[11] Y. Zhang, Z. Jiang, and X. Yu, “Control strategies for battery/supercapacitor hybrid energy storage systems,” in Proc. IEEE Energy 2030 Conf., 2008, pp. 1–6.

[12] Z. Jiang and X. Yu, “Active power—Voltage control scheme for islanding operation of inverter-interfaced microgrids,” in Proc. 2009IEEE Power Energy Soc. General Meeting, pp. 1–7.

[13] W. Friede, S. Rael, and B. Davat, “Mathematical model and characterization of the transient behavior of a PEM fuel cell,” IEEE Trans.Power Electron., vol. 19, no. 5, pp. 1234–1241, 2004.

[15] Ziegler J. G. and Nichols N. B., (1942), "Optimum Settling for automatic Controllers", Trans. On ASME, vol 64, pp 759-768.