SIMULATION ON MODIFIED HYSTERESIS CURRENT CONTROL IN HALF-BRIDGE BIDIRECTIONAL DC-DC CONVERTER

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ABSTRACT

This paper proposes a modified hysteresis current control method for half bridge bidirectional DC-DC converter (HBDC). Hysteresis current controller is modified by adding logic circuit at input signal $S1$ and $S2$ to change performance of inductor current, I_L. According to current direction transition, I_L stays at zero in a moment. It is happens when I_{refp} is crossing zero and continues bouncing when I_{refm} is crossing zero. This method is applied to reduce loss in HBDC performance, which as a result will achieve reduction in switching losses and conduction losses. The conduction losses and switching losses has been analyzed which conduction losses has slight changes in losses reduction and switching losses is reduce from 6.31 J to 4.53 J. The proposed hysteresis current controller was simulated using PSIM and the losses is verify on each switching changes. The result validated proposed hysteresis current control capability in losses reduction.

Keywords: half-bridge, non-isolated bidirectional DC-DC converter, hysteresis current controller.

INTRODUCTION

Since renewable energy is rapidly being introduced at global, research and development of bidirectional DC-DC converters are broadly carried out for various applications such as battery charger, electric vehicles and UPS systems [1]. For example, bidirectional DC-DC converter is used to transfer energy between a DC machine and a battery as shown in Figure-1. With bidirectional power flow, the energy is transferred between the two devices, back and forth in motoring mode and generating mode.

Bidirectional DC-DC converters can be classified as isolated type and non-isolated type. Isolated type usually use transformer as galvanic isolation purposes, which is necessary for some applications [2,3]. On the other hand, non-isolated type operates of no isolation transformer [2,4-5]. Non-isolated bidirectional DC-DC converter type is preferred to reduce additional size, weight and cost. It is used in applications where low weight and size is required [2]. Non-isolated bidirectional DC-DC converter is an arrangement of step-up (boost mode) and step-down (buck mode) stages with anti-parallel connected rectifier and inverter circuits.

Over the past few years, a lot of topologies and control strategies have been developed in bidirectional DC-DC converter field. Several types of DC-DC converter topologies are cascade buck-boost, half-bridge, Cuk, Luo and full-bridge [6]. Half-bridge topology is chosen for this study due to its minimum number of switching devices. As for switching strategies, current controller is used in this study to simulate the bidirectional current flow.

Current controller types can be categorized as linear, predictive and hysteresis [7]. For this study, hysteresis current control is used because of its robustness, simplicity and good transient response [7-9]. Although hysteresis current control has been applied in many application [10], very little information available on its application in bidirectional half-bridge DC-DC converter. Therefore, this paper presents a simulation test on half-bridge topology for non-isolated bidirectional DC-DC converter with current control technique based on fixed hysteresis band.

Losses in DC-DC converter can be categorized into two main groups: conduction losses and switching losses [11]. Conduction losses are the losses that occur while the power device is the on-state. Switching losses is the power dissipation during turn-on and turn off switching transitions [12]. To reduce the losses, a modified hysteresis current controller is proposed; furthermore, this design also addresses the issue of zero value while crossing zero intersection.

Section II describes the operation of HBDC. Section III is proposed hysteresis current controller in HBDC Section IV discusses the results and discussion regarding proposed method.
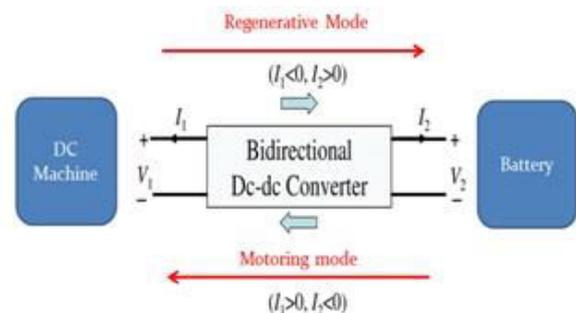
Figure-1. Bidirectional power flow in machine application.

HALF BRIDGE NON ISOLATED BIDIRECTIONAL DC-DC CONVERTER OPERATION PRINCIPLES

The circuit topology of HBDC is shown in Figure-2. Commonly, half bridge topology used two switches; buck switch, $S1$ and the boost switch, $S2$. The HBDC with non-isolated structure employs the buck and boost mode to operates bidirectional power flow. Throughout the research, DC machine is founded applicable to supply or (absorb) energy from bidirectional

DC-DC converter for investigate the performance of bidirectional power flow whether its function on both direction.

The half-bridge non-isolated bidirectional DC-DC converter shown in Figure-2, is operated in buck and boost mode. In real world application, one of the popular usages for bidirectional DC-DC converter is to forward motoring and regenerative braking of the motor. The application in the research, during motoring mode, energy is transferred from the DC machine to the Battery. To prove the bidirectional capability, the energy stored at the Battery then is transferred back to DC machine by regenerative mode. The current is shaped by the switching actions of switch *S1* and *S2*, controlled by current controller.
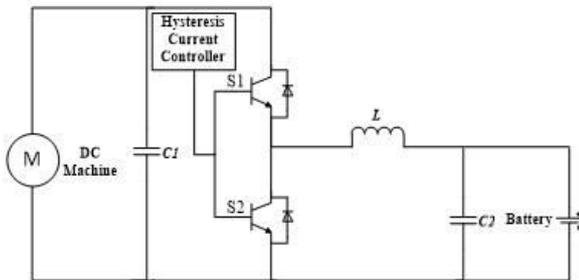
Figure- 2. Half-bridge non-isolated bidirectional DC-DC (HBDC) converter topology.

In order to accomplish bidirectional energy flow, the arrangement of buck mode condition and boost mode condition during operation is shown in Figure-3. According to Figure-3, the operation of bidirectional power flow involved four sub intervals. Initially the performance is started with input voltage, V_{in} as supply and the operation is in buck mode which is involving interval I and II. As shown in Interval I, switch *S1* is activate and *S2* is in inactive mode. The circuit currently transfers energy from V_{in} to the output voltage, V_{out} in buck mode condition. During this mode, V_{out} value is reducing regarding to buck principle operation. Then *S1* from the HBDC circuit is in OFF state. At this condition, the current flows depicted in Figure-3 (b) in Interval II. Switch is open thus the current

flow still available with the existed freewheeling diode, *D2* which is parallel with *S2*.

On the other hand, boost mode operated at interval III and IV where the operation is exactly similar with buck mode. The main difference is power flow of the circuit is change from V_{out} to V_{in}. These situations prove that bidirectional power flow is happens in HBDC. According Figure-3 (c), the Interval III shows the power flow while *S1* is inactive and *S2* is activated. Cooperated with controller, V_{out} started to supply energy through *S2* then absorbed by V_{in}. While both *S1* and *S2* is deactivate, the operation is similar to buck mode but the direction of energy flows is change to opposite direction.

Half bridge topology is used in HBDC because voltage and current stress is less than full-bridge. Moreover, half-bridge topology gives higher power[13] where appropriate to be used in DC machine generation and regeneration. Therefore, to examine the capability of bidirectional power flows from DC machine to battery and vice versa hysteresis current control used as controller.

PROPOSED HYSTERESIS CURRENT CONTROL WITH ADDITIONAL LOGIC GATE

The proposed HBDC circuit as shown in Figure-2 is verified by simulation on buck and boost mode accordance to Table-2 parameters. The current control technique of HBDC is simulated using hysteresis current controller. Step change is performed to analyze the performance of hysteresis current controller simulation as shown in Figure-4 [14]. The step change is applied to the current reference, I_{ref}. During buck mode, I_{ref} is in positive side to perform as generator thus after change the direction of the converter I_{ref} receive negative signal from the step change. According to Figure-4, the operating circuit is test with both supply V_{in} and V_{out}. By using buck and boost mode, the performance of bidirectional energy flow can be analyzed. Step change is applied at reference signal I_{ref} where negative values and positive values are involved. During I_{ref} in negative value the circuit is in regenerative condition and during I_{ref} in positive value the circuit is in generating condition.
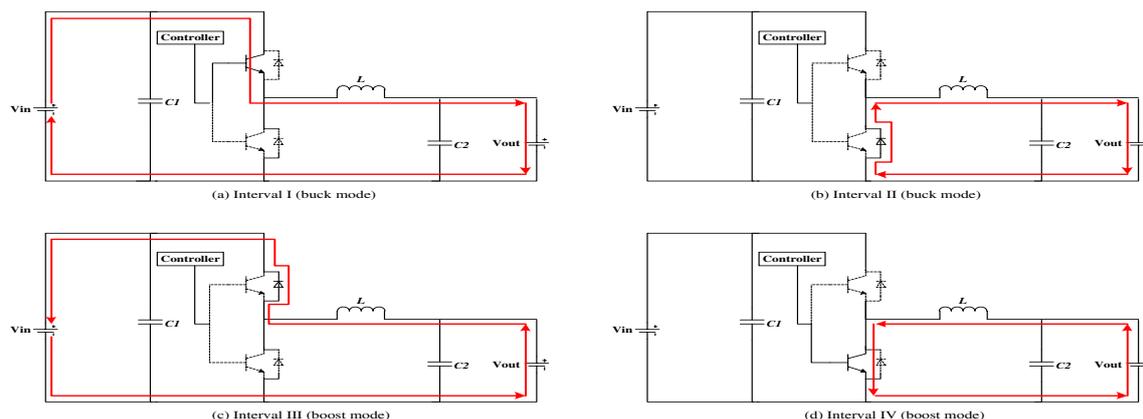
Figure-3. Operation mode of half bridge bidirectional DC-DC converter (buck and boost).
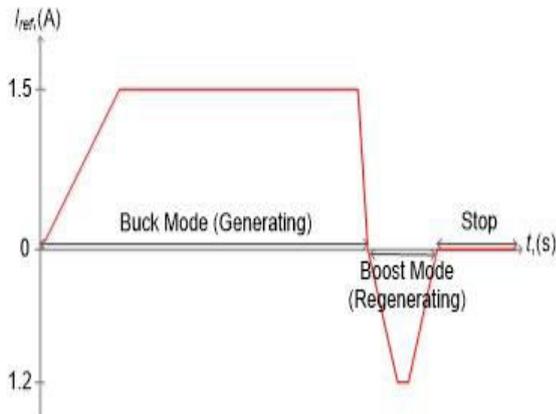
Figure-4. Step change applied at the current reference, I_{ref} signal.

Figure-5 and Figure-6 shows logic circuit of hysteresis current control using comparator. Both logic circuit shows bidirectional power flow but Figure-6 show a modified from the conventional control method. Comparator is using as hysteresis block where the negative terminal is connected with I_{ref} to construct a hysteresis band. Hysteresis band is introduced as positive band, I_{refp} and negative band, I_{refm} band. Positive terminal is connected with I_L where I_{ref} band at the negative terminal. As shows in Figure-5, the I_L as the feedback is currents of $L1$ from HBDC circuit and $S1$ and $S2$ are the switching signal to activate IGBT 1 and IGBT 2 respectively [15]. In order to test performance of hysteresis current controller switching devices IGBT is conducted in two switching mode. Generating mode during I_{ref} is in positive value and regenerative mode during I_{ref} is in negative value.
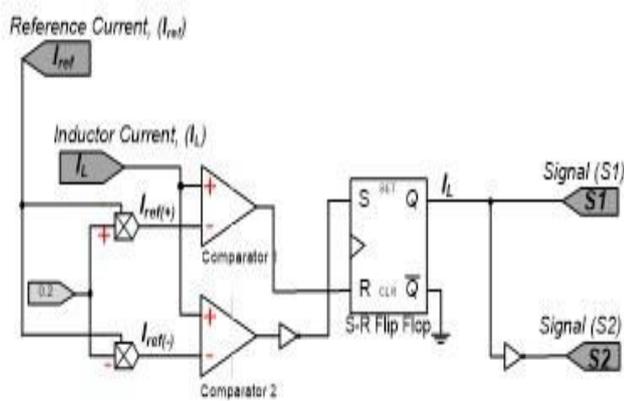
Figure-5. Conventional logic control of hysteresis current controller in HBDC.

The output from comparator 1 and 2 then is transfer to S-R flip flop to be translate again with AND gate and NOR gate. Regarding both gate, the signal $S1$ and $S2$ is generated to switching signal of HBDC circuit operation. The proposed method is modified actual circuit with additional logic AND and NOR. Both logics are

added to adjust the performance results of I_L. The transition between buck mode and boost mode is become 0. This situation can be advantage to hysteresis current controller to reduce losses during switching.

Therefore, when I_{ref} is greater than zero HBDC circuit in generating mode and when I_{ref} is less than zero HBDC circuit in regenerative mode. According to Figure-7 (a) and (b) hysteresis current control is translated on simulation results. Beginning with generating mode, I_L is less than I_{ref} ($I_L < I_{ref}$) then switching signal $S1$ is ON while $S2$ is OFF. Regarding ($I_L < I_{ref}$), I_L is increase until it reach I_{refp} then I_L is decrease. On the other hand, I_L is greater than I_{ref} ($I_L > I_{ref}$) so the I_L is started to decrease thus effected to switching signal where both $S1$ and $S2$ is OFF.
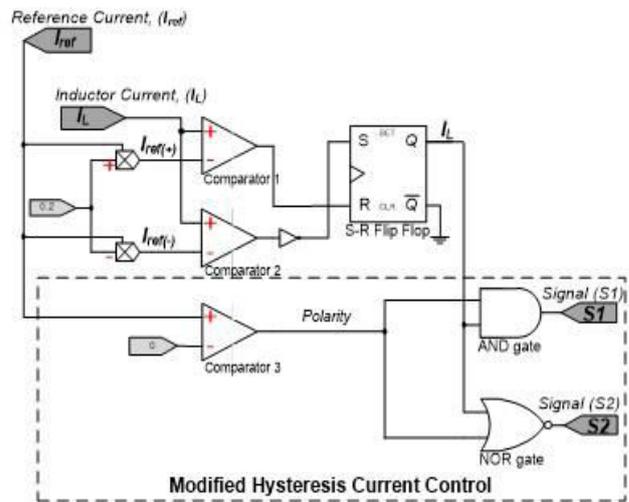
Figure-6. Proposed logic control of hysteresis current controller in HBDC.

Furthermore, hysteresis current control during regenerative mode is similar to generating mode but the switching signal performance is difference. From Figure-7 (a) at negative value side, while I_L is less than I_{ref} ($I_L < I_{ref}$) both switch $S1$ and $S2$ is OFF. The difference is I_L increasing during both switch is in OFF condition. Next, I_L is greater than I_{ref} ($I_L > I_{ref}$) switching signal $S2$ is ON to decrease I_L and $S1$ is in OFF state.

However, from Figure-7 (b), I_L is in zero states while bidirectional transition occurs. I_L started to become zero when I_{refp} is crossing zero. I_L is continuously at zero state until I_{ref} is crossing zero and I_L is increasing nearly to I_L then when reach to I_{refp}, I_L is decrease unfortunately while reach to zero, I_L continue on zero state. During I_{refm} crossing at zero, I_L start to increase to perform controller.

Summarize of hysteresis current control is translated as shown in Table-1 analyzing from hysteresis current control. Although the advantages offered by half-bridge, further research is needed to improve performance and overall control and management of the hysteresis current control. In addition, to improve hysteresis current control, study on various technique of hysteresis band needed for bidirectional circuit.

Table-1. Switching signal rules.

Mode	Switch (S1)	Switch (S2)	Inductor Current (I_L)
Buck Mode	ON	OFF	Increasing
Buck Mode	OFF	OFF	Decreasing
Boost Mode	OFF	ON	Decreasing
Boost Mode	OFF	OFF	Increasing

Table-2. HBDC system parameter.

Parameter	Value
Input Voltage, (V_{in})	96V
Output Voltage, (V_{out})	30V
Capacitor, ($C1$ & $C2$)	470µF
Inductor, (L)	1367mH

RESULTS AND DISCUSSION

Figure-7 shows the complete results of the simulation:

(a) and (b) are the inductor current, IL of HBDC
(c) and (d) are conduction losses of HBDC
(e) and (f) are switching losses of HBDC

Figure-7 (a) and (b), shows the inductor current, IL being wave shaped to follow the reference current, Iref by two control techniques; the conventional hysteresis current control and the proposed hysteresis current control. For both control techniques, the conduction and switching losses for IGBT S1 and S2 are depicted. The main difference between conventional hysteresis and proposed hysteresis can be best observed during the transition from (to) buck mode to (from) boost mode. As shown in Figure-7 (a) and (b), conventional hysteresis current controlled IL keep on bouncing inside the hysteresis band. Whereas, proposed hysteresis let IL stays zero during the transition. The conduction loss of conventional hysteresis and proposed hysteresis are shown in Figure-7 (c) and (d). It is noted that throughout transition interval, the conduction loss from both control technique are slightly different. Referred to (b), IL stops bouncing and stay zero at transition interval. This absence of switching during zero transition, dramatically reduce the conduction losses. Consequently, reduce overall losses on HBDC performance.

The switching loss behaves differently in Figure-7 (e) and (f). A loss shape happens in the range of 2 W – 4 W sequentially. According conventional hysteresis, the loss at OFF state is rapidly increasing to 7 W before through transition interval. Thus, switching losses during transition interval is keep delivers a loss signal in the range of 3 W. It is clear that during IL keep bouncing in transition interval results increases of losses.

Figure-8 shows calculated losses of conventional hysteresis and proposed hysteresis. The total losses are calculated from power in watts times with time in seconds then performs as Joule, J. The total loss calculated from conventional hysteresis has largest value in switching

losses. According the bar chart, total switching losses for the proposed hysteresis is 4.5 J when conventional hysteresis is 6.3 J. The reduction value of total losses is contributed from modified logic circuit.
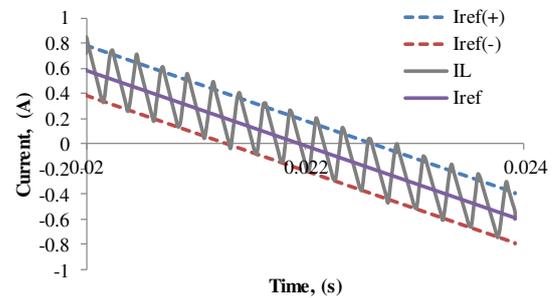
(a) Conventional hysteresis current control with constant inductor current, I_L.
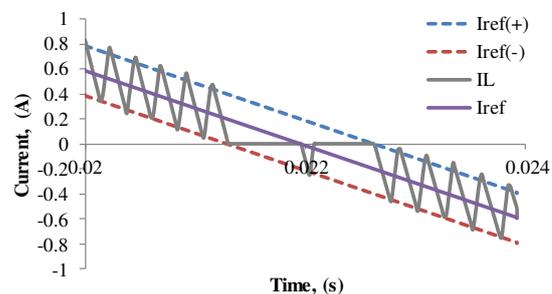
(b) Proposed hysteresis current control with modified inductor current, I_L.
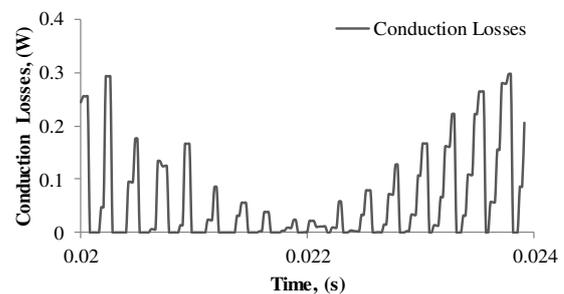
(c) Conduction losses of HBDC topology with conventional hysteresis current control.
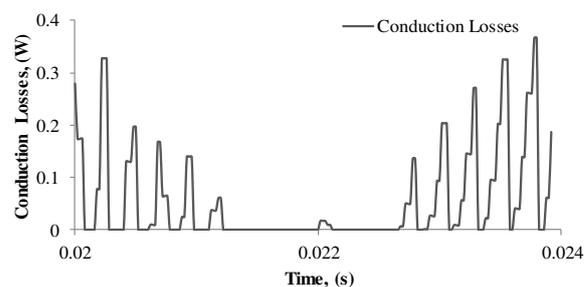
(d) Conduction losses of HBDC topology with proposed hysteresis current control.

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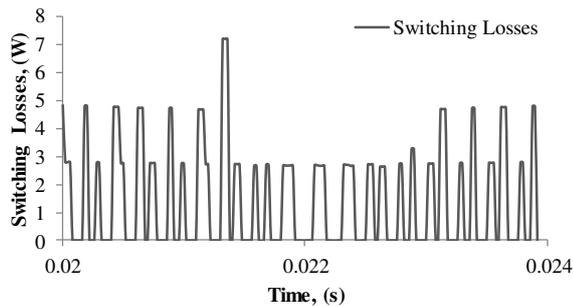
(e) Switching losses of HBDC topology with conventional hysteresis current control.
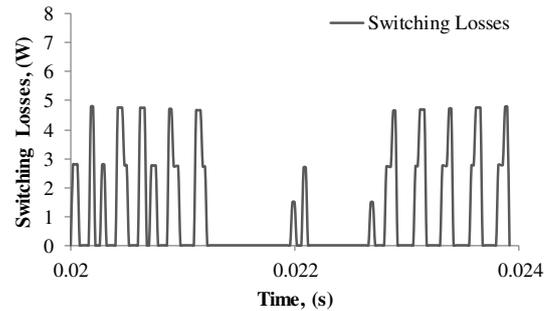
(f) Switching losses of HBDC topology with proposed hysteresis current control.

Figure-7. Comparison conventional hysteresis current control and proposed hysteresis current control.
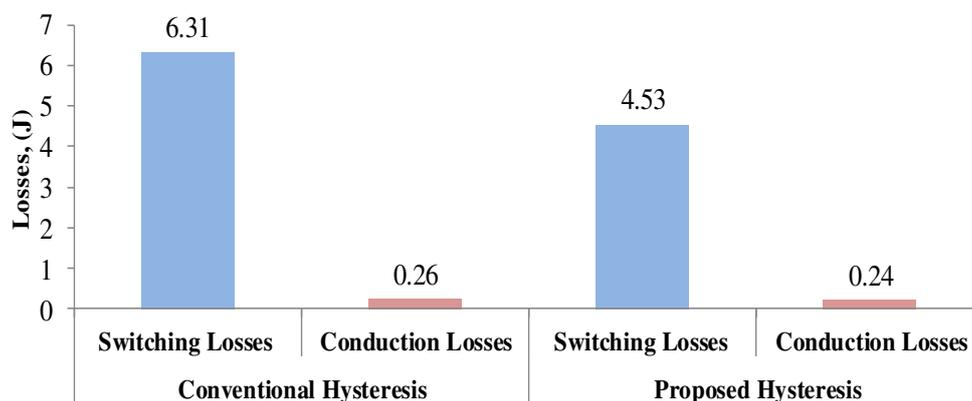
Figure-8. Switch loss comparison the conventional hysteresis and proposed hysteresis.

CONCLUSIONS

The main contribution of the paper is the advantages using hysteresis current as controller for HBDC. The hysteresis current is compared with conventional and modified method for reduce switching losses. The modified method is practical to be used to reduce switching losses. Meanwhile conduction losses have slight changes compare from conventional method. This paper also has simulated half-bridge topology for non-isolated bidirectional DC-DC converter. In the study, the result obtained has showed that the new current control is able to shape the current as demanded by the reference, in both current directions.

ACKNOWLEDGEMENTS

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