Loss Analysis of an Indirect Matrix Converter with Neutral Point of the Motor Connected

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1. Introduction

The developments of HEV and EV tend to reduce the CO_2 that produced by vehicles which also one solution to the recent global warming issue are studied intensively. In addition to the CO_2 reduction, it also aims to meet the requirements of HEV's electric propulsion,

a) A reasonable building cost.
b) A high efficiency power control unit (power converter).
c) A high reliability and robustness system for various vehicle operating conditions.

This paper analyzed performance of a new application method of a power converter for HEV. The unit is constructed based on an indirect matrix converter (IMC) with connected to the neutral point of the motor [1].

2. Proposed circuit topology

The conventional BTB (Back to Back) converter has several drawbacks such as the need of keeping the switch-frequent ripple in the DC link at an acceptable level. This is usually governed by applying a capacitor in the DC link. Another way to resolve this issue is by transferring such fluctuations to the power grid, but this will raise another problem which already dealing with in the PWM rectifier is the line current harmonics. Capacitor is one simple solution but suffers from several limitations such as life time and cost. Respite to the disadvantages of the capacitor, DC voltage can be optimized by applying a boost up chopper connected to the DC link section as shown in Fig.1[2]. This application can maintain the DC voltage at the dc bus and allow the VSI to transfer the total voltage.

Fig.2 shows a new application of a boost up chopper in the DC link with no reactor. One advantage of the indirect matrix converter is to having DC link included in the circuit. However, the DC link section does not require a capacitor to achieve a steady DC voltage. Further, this DC link section can be utilized by adding a boost up chopper as a supplement circuit to improve the circuit performance. Two IGBTs are added in the DC link to perform as a boost up chopper. Then, the neutral point of motor is connected to the battery.

3. Zero phase vector switching

Secondary side needs to switch at zero phase vectors in order for boost up chopper functions. These two rates (S_{up},S_{vp},S_{wp}= 000 and 111) generate a line voltage of zero and hence called as zero phase vectors. Secondary side inverter can be considered as a single leg topology during the zero phase sequence. The inverter current will flow into neutral line and go through the battery. A boost up chopper ACR (Automatic Current Regulator) is implemented to control the neutral line current (battery current). A relationship between the inverter current and battery current can be formed as the following equation,

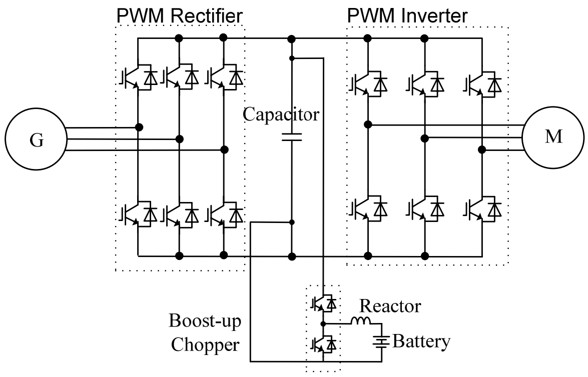

Fig.1 BTB PWM converter with a boost-up chopper.

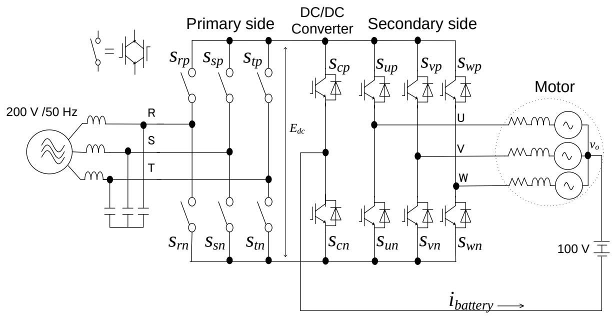

Fig. 2 Proposed circuit diagram

$$i_u = i_a + \frac{i_{bat}}{3} \quad (1).$$
$$i_v = i_b + \frac{i_{bat}}{3}$$
$$i_w = i_c + \frac{i_{bat}}{3}$$

Where i_a, i_b, i_c = inverter current;
i_{bat} = battery current;

Nevertheless, leakage inductance of the motor can be considered as a reactor to replace a regular reactor in a boost up chopper.

4. Converter loss analysis

This section will discuss about the switching loss analysis of the proposed circuit. Loss analysis method is by using circuit simulator (PSIM, Powersim Technologies Inc.) and DLL file (Dynamic Link Library) [3]. Fig. 3 represents a 1kVA system with battery power at 100W in both charging mode and discharging mode of the proposed system. Primary side of the IMC which is formed by 12 unidirectional switches is a current source type converter. Zero current switching is applied to reduce the switching losses [4]. As there is no current flow thru during the switching, primary side is to have conduction loss only at about 15W. Since $P_{in}=P_G+P_{bat}$, where P_G= Generator power, P_{bat} = Battery power, the increment or decrement of the battery power will affect the primary side. When battery is discharging, the loss of the primary side will reduce as the current had decreased.

Secondary side is having a total loss at about 44W at both modes. Additionally, the inverter losses vary in respect to the battery current which can be explained in equation 1. Note that the inverter switching frequency is double of the input frequency in the simulation system. The switching frequency of 10 kHz can be applied into the inverter to reduce the switching losses. DC chopper loss is about 2W at both modes. Simulation achieves an efficiency of 95% for a 1kVA system. Efficiency for a conventional system as shown in fig.1 is almost 92%. The proposed system reduced the power loss at about 3%.

Fig.4 shows the loss comparison between the proposed circuit and the conventional IMC with changes in the input power ratio, as given 10:0 to 1:9, where it represents the ratio of generator power to battery power. The increment of chopper power results the total loss of the proposed circuit increased.

5. Motor loss analysis

In an induction motor, only the stator is connected to the AC source and rotor current and voltage are generally produced by induction. However, with the connection of neutral point of the motor and zero phase vectors switching, stator did not generate any current or voltage. Further, no flux is produced too. The parameter is from the Fuji induction motor MLH6085M which also is used in experimental and shown in Table 1.

There are two losses in motor known as copper loss and iron loss. Since the zero-phase current does not produce flux in the motor, the iron loss under zero-phase current can be neglected. The copper loss in zero phase motor equivalent circuit is expressed as

$$P_n = \left(I_n^{2} + \frac{1}{9} i_{bat}^{2} \right) R_1 \qquad (2).$$

Where

P_n is the per-phase motor power loss,

I_{bat} is the battery current,

and I_n is the positive-phase motor current (RMS).

Fig.5 shows the graph of copper loss against battery output under zero-phase current. The increasing loss under zero-phase current condition is calculated from equation 2. 5% of motor efficiency is reduced by the used of zero phase current with an input power at 500W.

6. Conclusion

This paper demonstrates the important of DC link with conjunction with a DC boost up chopper. Zero phase vectors switching explains the uses of motor leakage inductance results that a common boost-up reactor can be replaced. This paper analyzed the losses of the proposed circuit. The losses are classified into main circuit loss (IGBTs) and motor loss. An overall efficiency of 95% is obtained in simulation.

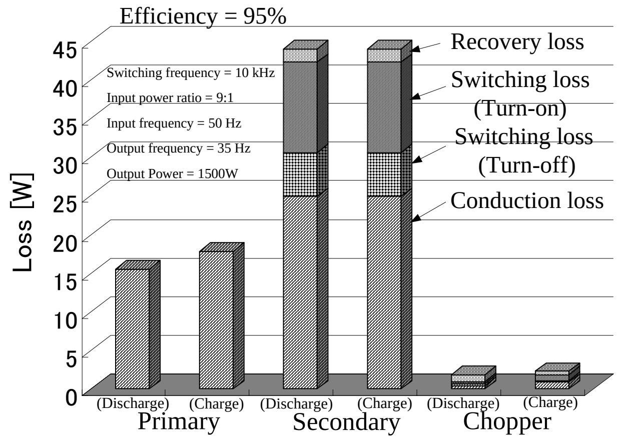

Fig. 3 Loss analysis for charge mode and discharge mode.

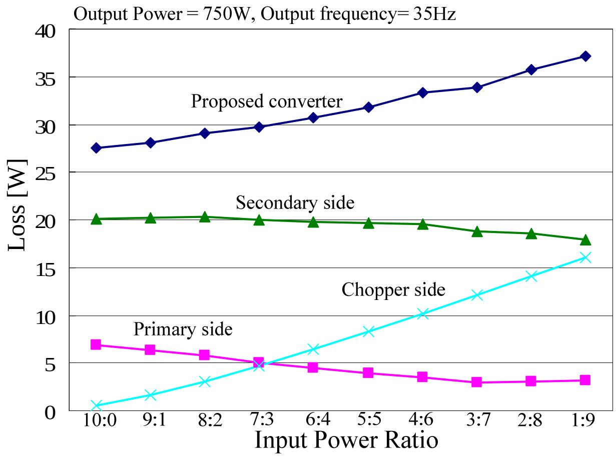

Fig. 4 Loss comparison between proposed converter and IMC.

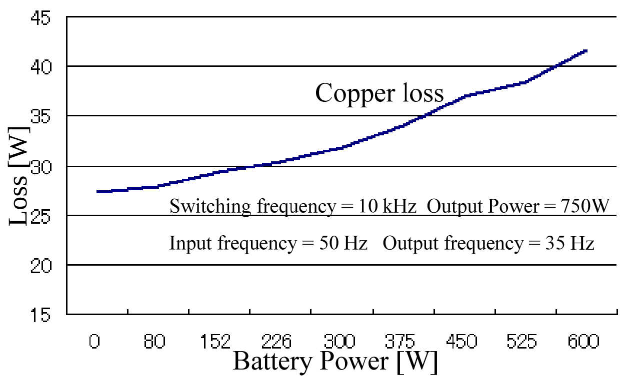

Fig.5 Copper Loss under zero phase current vs Battery Power.

Table 1: Motor Parameters (MLH6085M)

Motor Power	750W	Rated current	3.6A
Poles	4/ 50Hz	Rated voltage	200V
RPM	1420	Leakage inductance	4.42mH

References

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