Optimization of a Boost Converter with the connection of Neutral Point of a Motor In an Indirect Matrix Converter

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This paper proposes a new control strategy for a boost converter that is using the neutral point of a motor in a three-phase converter. In the proposed converter, the leakage inductance of the motor is used for a boost up reactor. However, the large ripple current is found in the boost converter due to the insufficient amount of the leakage inductance of a motor. A new inverter carrier proposed in this paper is to reduce the current ripple without an additional hardware requirement. Further, the THD of the output currents are improved by applying this method.

(Keywords: Indirect Matrix Converter, Boost converter, Zero Vectors, Battery current)

1. Introduction

The development of green energy technologies in automobile industry has shown a good interest to communities. A three-phase converter with two input power sources, which consists of an AC power source such as a generator and DC power source such as a battery, is one particular important subject in the automobile application, the renewable energy interface and the hybrid power source system. Especially, the studies of a boost converter to provide power to the motor in a way that is more sufficiently and efficiently.

In conventional system, a back-to-back converter with a DC chopper is used for this application. However an electrolytic capacitor in DC link part and a boost up reactor in the boost converter are bulky. Thus, an indirect matrix converter with DC chopper has been proposed to achieve downsizing and high efficiency [1-3]. However, there is a known problem in this circuit, where the battery current contains of high current ripple. A high ripple current increases the temperature of a battery and the temperature will reduce the life cycle of the battery [4]

This paper proposes a control method that can optimize a boost converter performance which is connected to the neutral point of a motor in a three-phase converter. One simple method to reduce the ripple is to apply a high switching frequency. However, there are a lot of considerations on applying high frequency such as system efficiency, switching devices and more. Therefore, a simple method with no additional hardware cost is proposed. This paper uses a variable frequency carrier in the secondary side to reduce the ripple in the battery current and obtain high performance circuit characteristic. The validity of the proposed method has evaluated by the simulation results.

2. Circuit Configuration

Fig.1 shows the circuit topology. A boost converter is connected to the DC-link voltage of an indirect matrix converter (IMC). The secondary power source, a battery, is connected to the boost converter and the neutral point of a motor. Fig.2 shows the equivalent circuit of the boost converter. A conventional boost converter that used a boost-reactor is controlled by two switching legs. However, in the proposed method, the boost converter is controlled by four switching legs, S_{cp}, S_{cn}, S_{invp} and S_{invn}, where S_{cp} and S_{cn} are the switching units for the boost converter and S_{invp} and S_{invn} are the switching units for the inverter. In this case, S_{invp} and S_{invn} are referred to the zero vector switching pattern of the inverter.

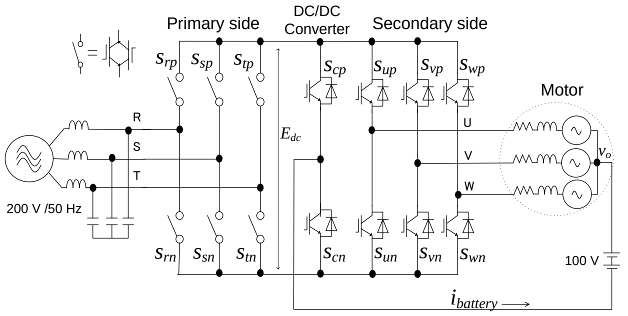


Fig.1. Circuit configuration of the proposed system.

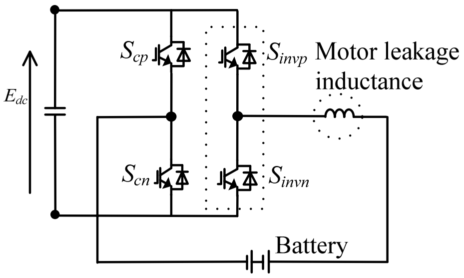
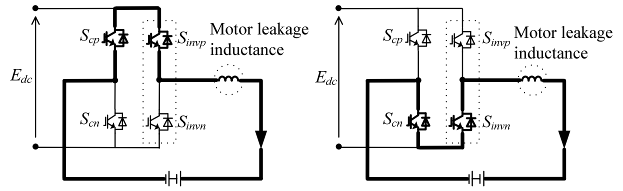


Fig.2 Zero phase equivalent circuit of the proposed converter.

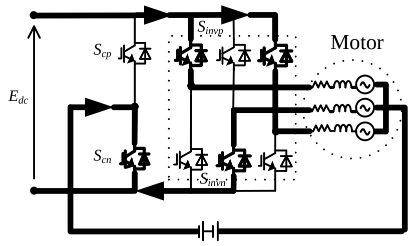
3. Operating principle of a Boost Converter

Fig.3 illustrates the operating principle for the boost converter that corresponds to the inverter switching pattern. The zero vector periods of an inverter determines the function of a boost converter. The basic principle of a boost converter consists in two states, On-state and Off-state. There are two On-state periods which represent in Fig.3(a) and Fig.3(b) respectively. Fig.3(a) shows the upper arm On-state switching pattern; S_{cp} is turned on and S_{invp} is turned on. Likewise, Fig.3(b) shows the lower arm On-state switching pattern; S_{cn} is turned on and S_{invn} is turned on. These two On-state periods are resulting an increase in the battery current via the motor leakage inductance.

Fig.3(c) shows the Off-state period of a boost converter. When inverter is not in the zero vector periods, the upper arm of the chopper leg is always switched off. The accumulated energy during the On-state will be transferring into the DC-link current. It should be noted that in Fig.3(c), the switching pattern in inverter is one of the many patterns. The motor behavior will not be disturbed because inverter is still able to control the motor speed and torque during the positive phase sequence.



(a). Upper arm On-state circuit. (b). Lower arm On-state circuit.



(c). Boost converter Off-state circuit diagram.

Fig 3. Basic principle of the proposed converter.

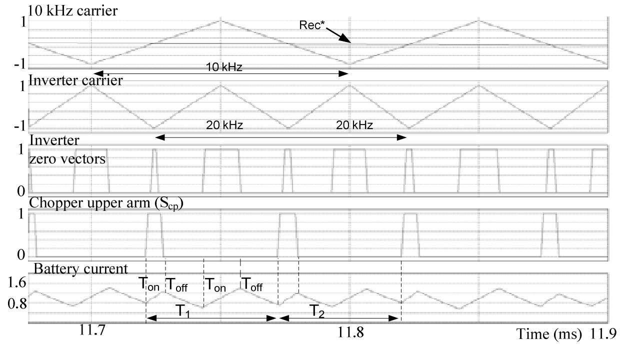
4. Relation between the ripple current and the chopper frequency

The previous section clearly shows that the relation between the inverter and chopper. Since the boost converter operating principle depends on the inverter stage, they must apply the same type of a carrier and same frequency. One known limitation in this method, is the value of the inductance cannot be selected because the leakage inductance follows the structure of a motor. When a leakage inductance is too small, it causes the high ripple in the battery current. In order to overcome the high ripple current, a higher switching frequency must be applied.

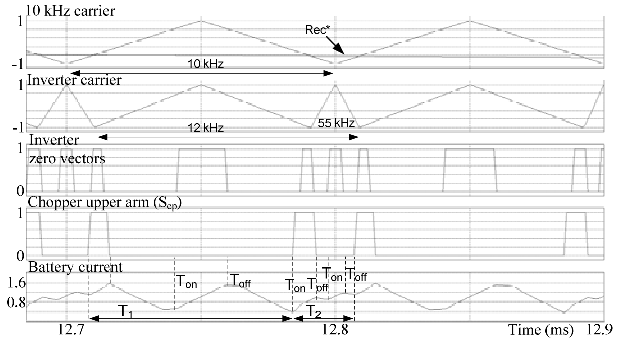
In addition, the application of this boost converter in an indirect matrix converter (IMC) results an inconstant switching duty ratio to the boost converter. The secondary side (inverter stage) of the IMC uses a new carrier that has a frequency which is two times higher than the original carrier. This new carrier is generated based on the duty of the rectifier side [5]. In the subject to this, the switching periods for the zero vectors are varying from one point to one point.

Fig.4(a) and Fig.4(b) show the found ripple error in subjected to the inverter carrier. In Fig.4(a), the rectifier command is located at the middle range of the original carrier. The new inverter carrier can be formed with the same duty per cycle at about 20 kHz. The zero vector periods can be considered as constant at this range. From the graph, the time T_1 is equal to T_2. The chopper upper leg is switched on at every 20 kHz at the same time of the upper arm zero vector periods. During the On-state (T_{on}), the battery current increases and it decreases during Off-state (T_{off}).

In Fig.4(b) the rectifier command is at the minimum range (or the maximum range) of the original carrier. (Rec* =0.0→0.2 or 0.8→1.0). During this range, the new inverter carrier does not have a same frequency at per cycle. Hence, the zero vector periods are inconstant as shown between T_1 and T_2 of Fig.4(b). It can be told that T_1 is not equal to T_2. The battery current increased sharply during the time T_1. And until the time T_2, the battery current cannot be released because the On-state and Off-state are happened too rapidly. The large current ripple is happening during this range.



(a) Rectifier command Rec*=0.5



(b)Rectifier command Rec*=0.2

Fig.4. Relation between chopper leg and zero vectors.

One extra point needs to be mentioned is that an individual switching frequency, which is differ from the inverter carrier, is not possible to apply for the chopper. If the switching pattern of the chopper fails to synchronize with the zero vectors, the ripple will generated greatly. This is because the chopper fails to accumulate and release the battery current in the correct timing. There is also a possibility that the motor loss will increase.

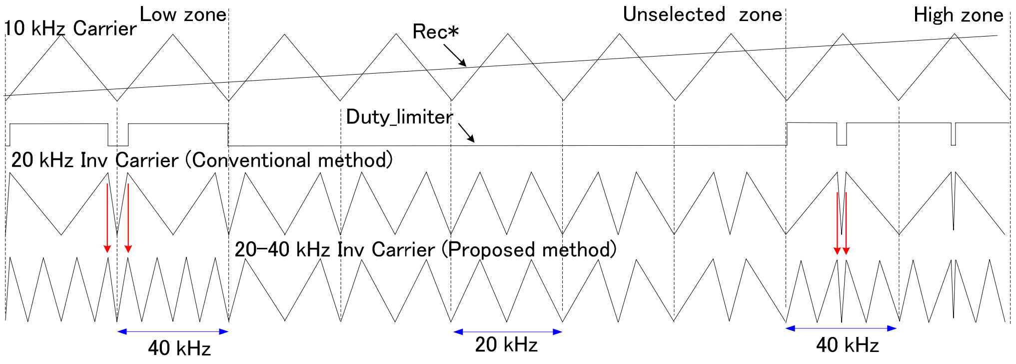


Fig.6. Diagram explanation for the proposed control method.

5. Proposed control block diagram

Fig.5 shows the control block diagram of the proposed method. In order to eliminate the ripple in battery current, if we merely increase inverter frequency only, the switching loss will increase. Therefore, a new inverter carrier that includes a limiter is introduced to eliminate the current ripple in the selected zone only. The unselected zone remained in the same as the conventional carrier.

The controller is divided into four sections; a primary side controller, a boost converter controller, a secondary side controller and an enhanced carrier controller. Compared with the conventional controller, all parts except the carrier controller are the same [5].

The inverter carrier is combined by a carrier generator 1 and a carrier generator 2 to output a new inverter carrier. The carrier generator 1 is the carrier that carries two times frequency of the original carrier, which is the inverter carrier from the conventional method. The carrier generator 2 is a carrier that will double the frequency of the carrier generator 1. The carrier generator 2 uses a fixed point duty command so that at every cycle an approximate two times higher frequency will be generated. Then, these two carriers will be sent to a block that is controlled by the limiter signal. The limiter decides when carrier 1 or carrier 2 is sending to the boost converter controller and secondary side controller.

Fig.6 explains the characteristic of the new inverter carrier. Start from the top, it is the original 10 kHz carrier and the rectifier command. Second is the duty limiter signal. Third is the inverter carrier from the conventional method (20 kHz). The last is the proposed inverter carrier.

First of all, there are two zones in one cycle of the rectifier command, separated as the selected zone and the unselected zone. The low zone is within 0.0-0.25 and high zone is within 0.75-1.00. The duty limiter is a command to execute the carrier multiplier during the selected zone. When the duty limiter is turned on, a new carrier which will have a double frequency of the inverter frequency is produced (40 kHz). When the duty limiter is turned off during the selected zone, the same frequency of the original carrier will copy into the new carrier. This is because those areas are too narrow to create a new carrier.

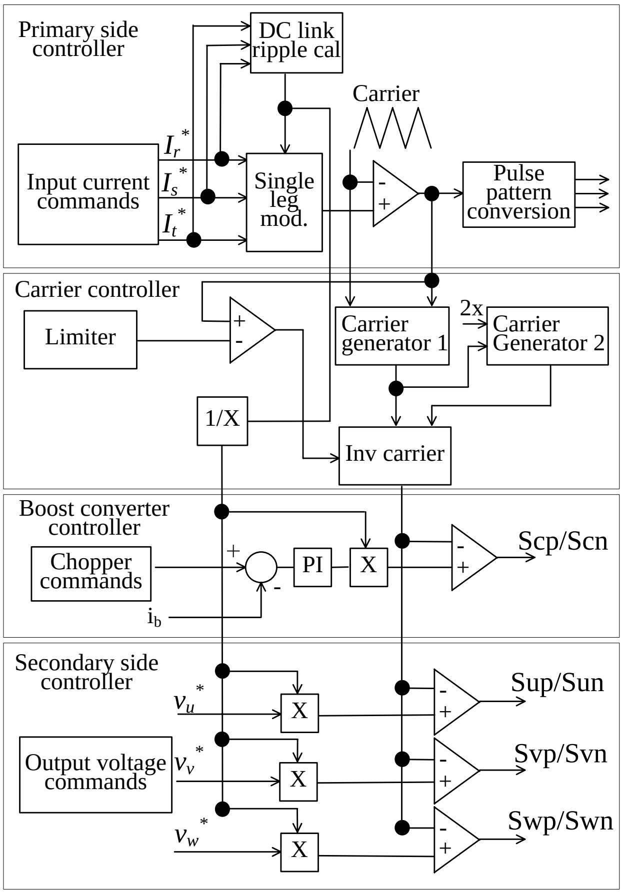


Fig.5 Proposed control block diagram.

The limiter does not apply in the unselected zone; the same frequency will be brought into the new carrier. As a result, a new inverter carrier that contains 20 kHz and 40 kHz frequency will be formed. When the inverter carrier reaches the inconstant zone, a 40 kHz constant carrier will take place. This method can ensure that there is a constant switching of the zero vectors for those selected zone.

Fig.7 shows the switching pattern for the selected zone. This figure is under the same period and condition as Fig.4(b). It can be seen that the time T_1=T_2, the battery current is well under control.

6. Simulation results

Two operating conditions have taken into consideration to examine the proposed method. Table 1 shows the simulation parameters. Fig.8 is the simulation results that are using a 10 kHz inverter carrier [6]. The battery current contains large ripple and also affected the inverter currents. Knowing from [3], the inverter current contains 1/3 of the battery current. The total harmonics distortion (THD) value of the output currents is influenced by the battery ripple.

Fig.9 shows the simulation results that is using the proposed method. Note that the battery current is greatly reduced. The limiter ranges for this simulation are 0.0-0.25 and 0.75-1.00. The zone declaration can be clearly seen from the inverter carrier. The darker side represents the 40 kHz carrier and the lighter side represents the 20 kHz carrier. The new inverter did not affect the performance of the system and yet further reduce the THD value of the output currents.

Fig.10 shows the harmonics analysis for the output current (i_u). The top is using the conventional method and the below is using the proposed method. At 10 kHz, the 2nd harmonic component of the proposed method is lesser than the conventional method. It indicates an improved in the THD of the output current.

7. Conclusion

This paper proposed a control method to optimize the performance of a boost converter. This boost converter is a secondary input power source of a three-phase power converter system. Further it reduces the size of the circuit by utilizing the neutral point of a motor. This new proposed method is able to reduce the ripple in battery current and obtain a better THD value of output currents. The next task is to examine this method in an experimental setup.

References

(1) Jun-ichi, Itoh, “Novel Unity Power Factor Circuits Using Zero-Vector Control for Single-Phase Input Systems”, IEEE 2000

(2) TC Goh, “ Evaluation of a Three-port Indirect Matrix Converter connected to the Neutral Point of a Motor”, SPC Korea 2008

(3) TC Goh, “Loss analysis of an Indirect Matrix Converter with Neutral Point of the Motor Connected”, IEEJ 全国大会 2009

(4) Dan Lambert, “ The case for automated battery management”, American Power Conversion Corp.

(5) Jun-ichi Itoh, “ A Control Method for the Matrix Converter based on Virtual AC/DC/AC Conversion Using Carrier Comparison Method”, IEEJ 2005

(6) 加藤康司, “スイッチング回数を低減するインダイレクトマトリックスコンバータの一制御法”, 産業応用 2008

Table 1 Simulation parameters

Input voltage	200 V
Input frequency	50 Hz
Carrier frequency	10 KHz
Output frequency	35 Hz
DC source	100 V
Leakage Inductance	5 mH

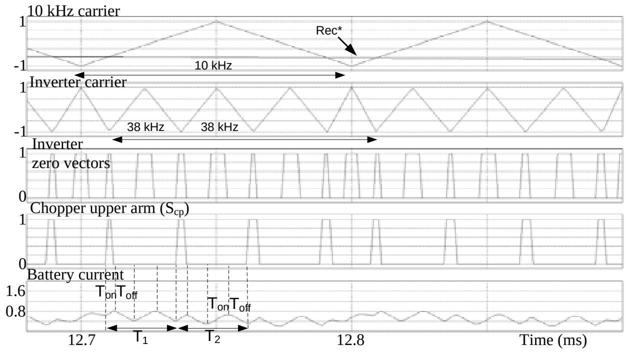


Fig.7 Relation between chopper leg and zero vectors. (Rec*=0.2)

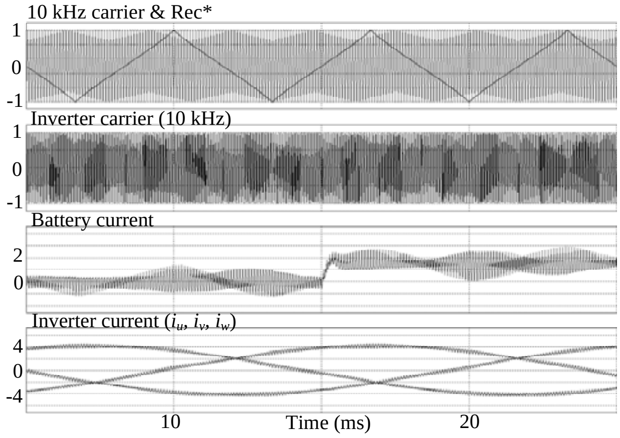


Fig.8 Simulating using conventional method.

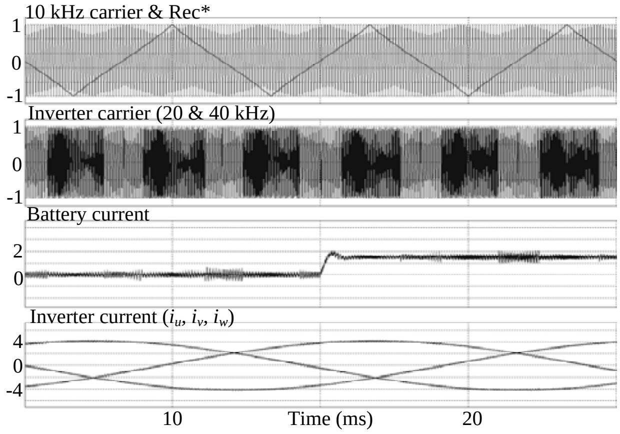


Fig.9 Simulating using proposed method.

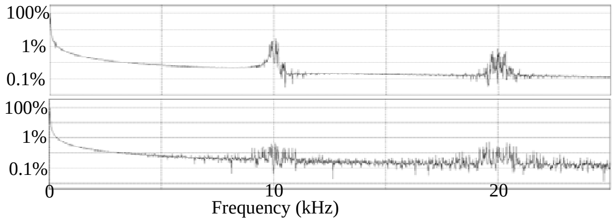


Fig.10 Output current (i_u) FFT analysis.