Control of Novel Indirect Matrix Converter with No Reactor in a Boost-up Chopper

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1. Introduction

Recently, many studies have done in power converters for hybrid electric vehicle (HEV) systems. A HEV has two sources of onboard power such as a generator and batteries. A power control strategy is needed to control the flow of power and to maintain adequate reserves of energy in battery system. To exploit the potential of HEV for emission reduction and performance improvement the energy storage system has to be considered as one of the key components in HEV [1]. One solution to reduce the energy storage in HEV design is to use an indirect matrix converter. It has no dc-link capacitor and more flexibility to modify compare to other type converter [2].

This paper proposes a novel three-phase AC/DC/AC indirect matrix converter with a control method based on a boost up DC/DC chopper. This circuit proposes a way of energy management between generator and battery. The control of zero vectors in indirect matrix converter with a DC chopper is the key factor in this proposal. The basic operation of the proposed control method is simulated and results are shown.

2. Circuit topology

Fig. 1 shows the proposed circuit diagram. In this circuit, a DC battery is connected within the neutral point of the motor load and the neutral point of the dc link in the circuit. A current-type PWM rectifier is designed in this circuit. Control is performed by generating a pulse in the current-type PWM rectifier using control of a virtual voltage-type PWM rectifier and the voltage and current duality [3]. Control on the rectifier will result a high DC voltage. For the inverter side, a lean controlled carrier modulation of the virtual inverter is designed. The leans of triangle carrier are controlled by the duty ratio of the rectifier side pulse. As a result, it reduces harmonic distortion of the input current by avoiding interference between rectifier control and the inverter control.

Fig. 2 shows the block diagram of the boost type DC/DC converter in an indirect matrix converter. PWM pulses for the indirect matrix converter are obtained by combining PWM pulses for rectifier side and inverter side. The input current and the output voltage are controlled individually. The inverter side converter operates as a four-phase voltage source inverter voltage as expressed as

$$\begin{bmatrix} v_u \\ v_v \\ v_w \\ v_c \end{bmatrix} = \begin{bmatrix} s_{up} & s_{un} \\ s_{vp} & s_{vn} \\ s_{wp} & s_{wn} \\ s_{cp} & s_{cn} \end{bmatrix} \begin{bmatrix} s_{rp} & s_{sp} & s_{tp} \\ s_{rn} & s_{sn} & s_{tn} \end{bmatrix} \begin{bmatrix} v_r \\ v_s \\ v_t \end{bmatrix}. \quad (1)$$

where S_{xy} stands for the switching function of the switches shown in Fig.1. When S_{xy} is turned on, s_{xy} =1 and when S_{xy} is turned off, s_{xy} =0. The rectifier side converter uses single-phase modulation [3]. Therefore, the DC link voltage contains ripple, which contains sixth order component of a power supply frequency. The inverter side converter must overcome the ripple. The proposed strategy is based on an indirect control method with the triangular carrier waveform. A DC/DC chopper command is included to compare with the carrier wave and the current.

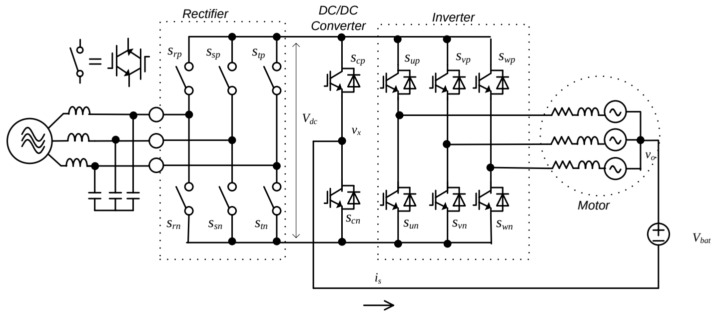

Fig.1. Proposed circuit diagram

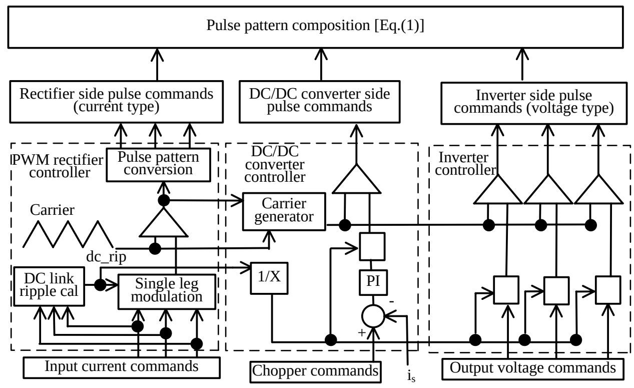

Fig.2. Control Block Diagram of proposed circuit.

3. Zero vectors control

In this circuit, the inverter legs combined with an additional DC/DC chopper leg are used to control the zero vectors of the inverter. It is possible to use zero vectors to control the battery current, (i_s). Three-phase inverter has two different switching states will generate zero vectors for the motor. Positive-phase sequence and zero-phase sequence occurs at per switching time. At positive-phase sequence, DC link voltage is supplied to the motor, inverter operates as normal and battery discharges. At zero-phase sequence, the motor is considered as a leakage inductance and the inverter with the dc chopper leg can be regarded as a single leg topology. It results a bidirectional battery current flows sequence which depends on the neutral point voltage of the load. In order to control zero vectors, a high dc link voltage is needed [4]. Equations below explain the relationship between dc link voltage (V_{dc}), inverter voltage (v_{inv}) and battery voltage (V_{bat}).

First, the inverter output voltage, v_u refers to the neutral point voltage of the dc link is expressed as

$$v_u = a\frac{V_{dc}}{2}Sin\ \omega t + v_o. \tag{2}$$

The inverter line voltage is given by

$$v_{uv} = a\frac{\sqrt{3}}{2}V_{dc}\,Sin\left(\omega t + \frac{\pi}{6}\right). \tag{3}$$

In order to obtain the maximum output line voltage V_{inv} (rms), V_{dc} is expressed as

$$V_{dc} = 2\frac{\sqrt{2}}{\sqrt{3}}V_{inv}. \tag{4}$$

Second, v_x is defined as the voltage between the neutral point of the chopper leg and the neutral point of the dc link. Since both v_u and v_x are referred to the neutral point of dc link voltage, it must be smaller than V_{dc}. The maximum line voltage between V_u and v_x can be expressed as

$$v_{ux} = \frac{\sqrt{2}}{\sqrt{3}}V_{inv} + V_{bat}. \tag{5}$$

Therefore, the dc link voltage of the proposed circuit must satisfy both requirements as shown below

$$V_{dc}\begin{cases} 2\frac{\sqrt{2}}{\sqrt{3}}V_{inv} & When\ \frac{Vinv}{\sqrt{3}} > V_{bat} \\ \frac{\sqrt{2}}{\sqrt{3}}V_{inv} + V_{bat} & When\ \frac{Vinv}{\sqrt{3}} < V_{bat} \end{cases}. \tag{6}$$

4. Simulation Results

Fig. 3 and Fig. 4 show the simulation results using the proposed control method. An ideal current source load (i_s) is used to check the proposed strategy. Table 1 is the simulation parameters.

Table 1 Simulation parameters

Input voltage	200V
Input frequency	50 Hz
Carrier frequency	10 kHz
Output frequency	50 Hz
DC source	100V

These two waveforms show the power supply R phase voltage (v_r), the input current (i_r, i_s, i_t), output line voltage ($v_{uv(LPF)}$) and three-phase output current (i_u, i_v, i_w). Low pass filter of 1.1 kHz and damping ratio of 0.7 is used to measure the inverter output voltage and input current.

Fig. 3 shows a good simulation result. i_s in positive and resulting the battery is being discharge. Notice at time 50ms, i_s step up, it results input currents magnitude increased. Fig. 4 represents the indirect matrix converter performance while the battery is being charge. i_s in negative direction and at 50ms i_s step down. A waveform show that i_s decreased results the generator current decreased. These two waveforms proved a good control by showing a form of generate and regenerate on the power grid side as well as charge and discharge of battery. Further, the transient behavior at time 50ms of i_s is controlled by PI controller.

5. Conclusion

This paper proposed a novel control strategy for the energy management of an AC and DC power supply direct interface converter. The idea of controlling battery current based on zero vectors is proven. Simulation shows a good result and an experimental is to be setup in next step.

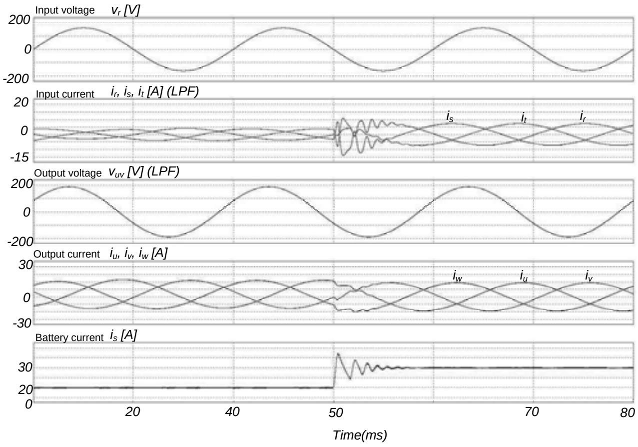

Fig.3. PSIM simulation results when battery is in discharge mode.

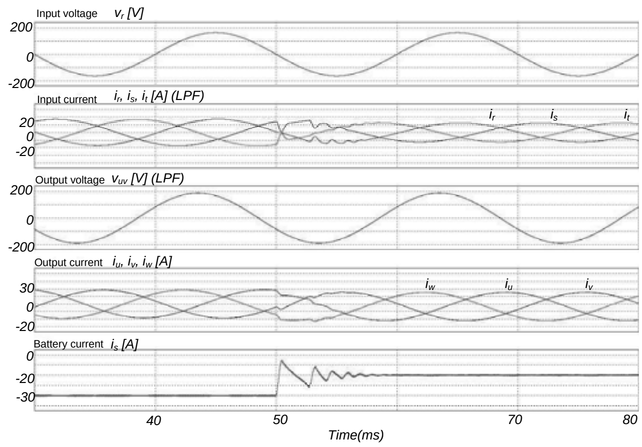

Fig.4. PSIM simulation results when battery is in charge mode.

References

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