A Fault-Tolerant Strategy for Indirect Matrix Converter

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Abstract

This paper proposes a fault-tolerant strategy for indirect matrix converter (IMC) based on the concept of four-leg matrix converter in case of an open-circuit fault in the inverter stage. The proposed strategy can maintain the same output performance as the healthy condition during the faulty condition. Some simulated results are provided to verify the effectiveness of the proposed strategy.

Keywords - Matrix converter (MC); Indirect MC; Fault-tolerant; Space vector pulse width modulation (SV-PWM).

1. Introduction

In recent years, there are many researches which have focused on modulation techniques, commutation problems and improvement of output performance for the MC. However, the field of the remedial reliability for the MC is relatively challenging and has just a several researches. In [1] and [2], the authors proposed a fault-tolerant approach for three-phase MC drives in case of open-circuit faults. During the faulty operation, the MC structure is modified by using additional devices to connect the neutral point of load to the neutral point of power supply. The fault-tolerant strategies for MC are described in [3] and [4] based on the concept of four-leg MC. But, most approaches need to connect the neutral point of the power supply and they are only suitable for star connected loads. Besides, these researches are established for direct MC, and the fault-tolerant for IMC is not considered sufficiently until now.

In this paper, we introduce a fault-tolerant strategy for the IMC in case of an open-circuit fault happens in the inverter stage. In order to improve the reliability, the paper proposes a fault-tolerant topology by using additional devices to reconstruct the normal topology based on a four-leg IMC. Also, the space vector modulation strategy is developed to control the IMC. The proposed fault-tolerant strategy can maintain the continuous operation of the IMC as well as keep the almost same performance compared to the healthy operation regardless of an open-circuit fault.

2. Fault Tolerant Strategy to Control Indirect Matrix Converter

Fig. 1 shows the proposed fault-tolerant topology for the IMC. In this topology, the rectifier stage has the same structure as the conventional one, whereas the inverter stage consists of the four-leg inverter which incorporates three additional devices [5]. The additional devices, which are called connecting devices, are used to connect three phases of the inverter stage to the additional phase by using bidirectional switches such as TRIAC or back-to-back SCRs. During the normal operation, three connecting devices and all switches of the fourth phase are inactive, so that the fourth phase does not affect to the IMC operation. When an open-circuit fault occurs in the inverter stage, all switching signals related to

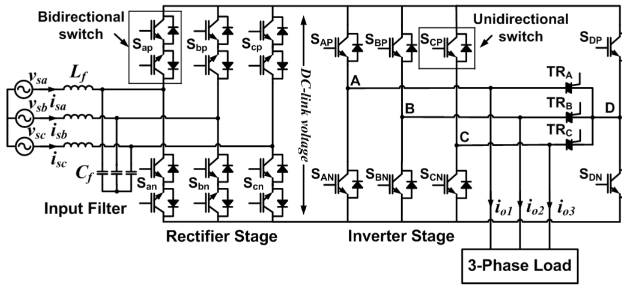

Fig. 1. The proposed IMC topology in faulty condition.

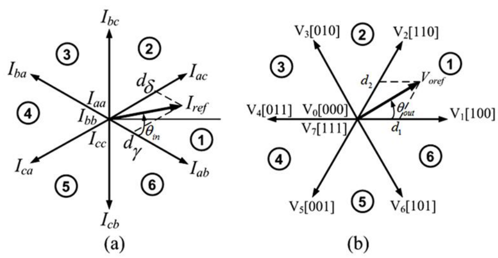

Fig. 2. Space vector diagram of (a) rectifier stage and (b) inverter stage.

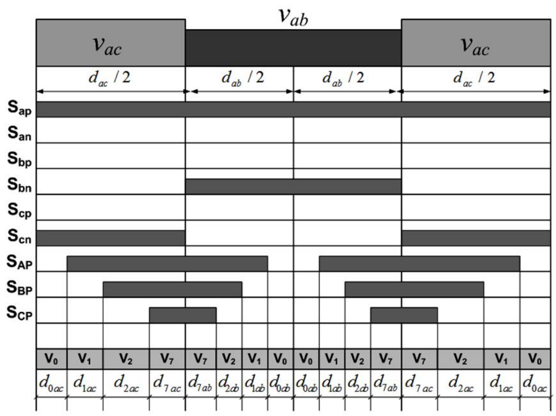

Fig. 3. Switching patterns of the IMC.

the faulty phase are disabled and the connecting device corresponding to faulty phase is rapidly triggered on to connect the back-up phase to the converter. Then, the IMC continuously operates in spite of the fault by replacing the faulty phase with the fourth back-up phase.

2.1 Modulation Strategy for Normal Condition

According The indirect SV-PWM technique, which was introduced in [6], is often used to control the IMC. Firstly, the space vector of the rectifier stage is composed of six active vectors and three zero vectors as shown in Fig. 2(a). The duty cycles of two active vectors are calculated as following:

$$\begin{aligned} d_\gamma &= m_i \sin(\pi/3 - \theta_{in}) \\ d_\delta &= m_i \sin(\theta_{in}) \end{aligned} \tag{1}$$

where m_i is the rectifier stage modulation index and θ_{in} is the angle between the reference current vector and the right nearest active current vector. Normally, in the rectifier stage, the zero vectors are not considered and the modulation index is unity.

Secondly, the traditional space vector PWM for three-phase two-level PWM inverter can be applied to control the inverter stage. The output voltages are generated by using six active vectors and two zero vectors as shown in Fig. 2(b). Assuming the reference output voltage vector is located in sector 1, the duty cycles are calculated as following:

$$\begin{aligned} d_1 &= \sqrt{3}\frac{V_{oref}}{V_{dc}}\sin(\pi/3-\theta_{out}) \\ d_2 &= \sqrt{3}\frac{V_{oref}}{V_{dc}}\sin(\theta_{out}) \\ d_0 &= d_7 = 0.5(1-d_1-d_2) \end{aligned} \tag{2}$$

where θ_{out} is the angle of reference output voltage vector V_{oref} and d_1, d_2, d_0 and d_7 are duty cycles of output voltage space vectors V_1, V_2, V_0 and V_7, respectively.

The switching pattern of IMC shown in Fig. 3 is based on the combination of the switching states of the rectifier stage and the inverter stage. The duty cycles are calculated by:

$$\begin{aligned} d_{0ac} &= d_0.d_{ac} & d_{7ab} &= d_7.d_{ab} \\ d_{1ac} &= d_1.d_{ac} & d_{2ab} &= d_2.d_{ab} \\ d_{2ac} &= d_2.d_{ac} & d_{1ab} &= d_1.d_{ab} \\ d_{7ac} &= d_7.d_{ac} & d_{0ab} &= d_0.d_{ab} \end{aligned} \tag{3}$$

2.2 Fault-Tolerant Strategy

Under the open-circuit fault condition, the modulation strategy has been modified to keep the continuous operation of the IMC. When an open-circuit fault is detected, the modulation scheme must rapidly isolate the faulty phase and reconstruct the inverter stage. For example, in case that an open-switch fault occurs in the switch S_{AP}, the control scheme immediately isolates the phase A by removing the switching signals for switches S_{AP} and S_{AN}. Simultaneously, the connecting device TR_A is turned on, and the switching signal of the phase A is assigned to the phase D. Now, the switching pattern of the IMC is represented as phase D, phase B and phase C instead of phase A, phase B and phase C in the healthy condition.

3. Simulation results

In order to evaluate the proposed fault-tolerant strategy, simulations are carried out with a three-phase *RL* load using PSIM software. In the simulation, we assumed that an open-switch fault occurs in the switch S_{AP}, and the fault-tolerant strategy is applied after *0.01s.* Fig. 4 shows the waveforms of line-to-line output voltage which related to the faulty phase under different operating conditions. The three-phase output currents and input currents are shown in Fig. 5 and Fig. 6, respectively. It is seen that the output current corresponding to the faulty phase is dropped to zero during the faulty condition without fault-tolerant control. From these figures, we can see that the proposed strategy can generate the balanced and sinusoidal output currents to the load in spite of the fault condition.

4. Conclusion

In this paper, the fault-tolerant topology along with the modulation strategy is proposed to keep the continuous operation for the IMC. Based on the connecting devices and the back-up phase, the reconfigurable IMC can deal with the open-circuit fault in the inverter stage. The proposed topology does not need to connect to the neutral point of load or power supply, so it is suitable for the system of three-phase load in both star and delta connection.

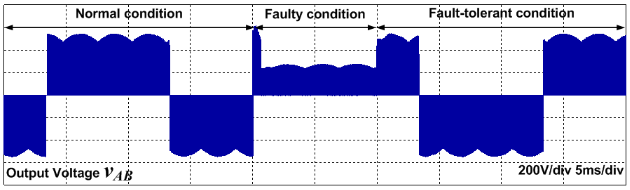

Fig. 4. Line-to-line output voltage under different operating conditions.

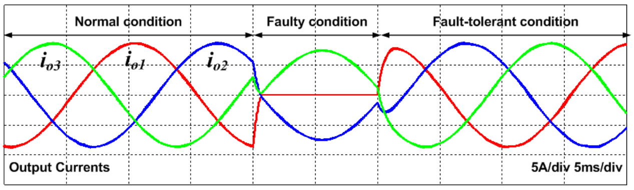

Fig. 5. Three-phase output currents.

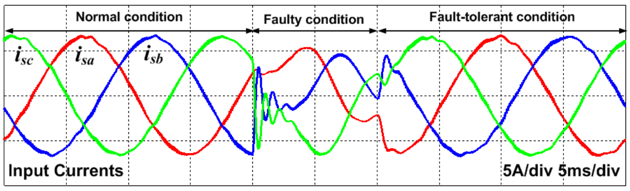

Fig. 6. Three-phase input currents.

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