Research on A Novel two-step Commutation Strategy for Matrix Converter Based on the Value of Input Voltage

Xinghe Ma, Hongling Dong, Junying Zhao

School of Electrical Engineering & Automation, Henan Polytechnic University, Jiaozuo 454000, Henan, China

Email：ma_cumt@126.com

Abstract: Matrix converter has a very good application prospect for its ability to solve the low power factor and serious harmonic pollution problem in Ac-Ac power transformation. But the commutation security and complexity is the main reason to restrain its promote application. The paper presents an improved two-steps safe commutation strategy on the basis of analyzing the characteristics of the existing traditional converter through the direction of output current and input voltage amplitude controlled. In order to reduce the number of switch and solve the influence of current direction with effective combination of two-way switch tube conduction state by dividing sector in the input voltage; Introduced the transitional interval and zero vector modulation to avoid the short circuit when voltage amplitude are close to, which can improve waveform quality. Executed experiment in the prototype controlled by the DSP+FPGA, experimental data verified the feasibility of the new commutation strategy.

Keywords: matrix converter ; voltage controlled ; two-steps commutation; transitional interval

1 Introduction

Matrix Converter[1], as a complementary and alternative technology for existing AC-DC-AC PWM inverter and traditional AC-AC frequency conversion circuit, has been paid more and more attention in the field of variable frequency speed control with its superior characteristics such as bidirectional energy flow, which can realize in four quadrants; sinusoidal input or output current; unity input power factor for any load; energy storage element without DC and so on. That endows the converter with a bright future to solve traditional problems of low power factor and seriously harmonic pollution exiting in the AC-AC power conversion devices.

Commutation control method is one of the key techniques for matrix converter. to realize its advantages depend on whether or not choice proper commutation strategy. The complexity and the safety reliability of the converter process is the main factor of restricting its use in high-power promotion.

To simplify the converter steps, improve the reliability of the converter, MC commutation strategy [2-7] based on output current direction detection strategy and the input line voltage polarity amplitude detection method of voltage type converter have been proposed by the domestic and foreign scholars. Literature [2] presented a security four-step commutation strategy for two-way switch, at the output current zero point easy to cause the failure of converter. Literature [3] proposed a method of voltage type two-step commutation which increase the state loss, worse more the short circuit on the line voltage zero point affect the output waveform. Literature [4] put forward force converter by one step under the condition of detecting output current direction and the size of the input voltage concurrently, but that was only completed in a three-phase - single-phase matrix converter , not universal. Literature [5] proposed the prevention and replace type method which does not need accurate measurement device, in turn increased the commutation sequence, input current also deviates from the ideal value at the same time. Literature [6] analyzed in detail how two step converter save in time, summed that change in the input phase voltage polarity will cause the interphase short circuit, and the four step is put forward to the combination of conversion. Literature [7] improved the safety of two step voltage source converter with fixed

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three switch state in transition zone, but transient flow caused a certain voltage loss.

After analyzing four-step commutation strategy and two-step commutation strategy, this paper provides a safe commutation strategy based on voltage aimed at decrease the number of times, reduce the switching loss. At the same time introduce the zero vector switch state in intermediate sector, combined with the space vector modulation, enhances reliability of commutation, and improves the quality of the output waveform.

2 The Traditional Commutation Strategy Analysis

Due to the properties of the matrix converter input voltage source and output current source, there is a rule must be followed that any three-phase of input cannot be short circuited (voltage source short-circuit will produce over current) and any phase of output cannot be a circuited breaker (inductive load circuit breaker will produce over voltage).

Find out a safe and reliable commutation method in single output phase, analogy to the other two phase can be achieved a converter control strategy for MC ,the three-phase to single-phase matrix converter simplified circuit topology structure is shown in figure 1.According to certain switching order to realize the safety switch conversion between input phase and load current.

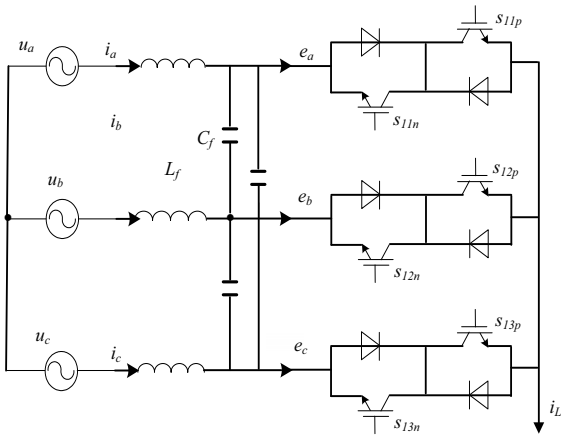


fig.1 Switching circuit of three phase to single phase

Take the e_a phase to e_b phase converter switch as an example analysis of two-way switch 4 steps in commutate process, according to the safety inversion principle, get 8 kinds of effective two-way switch composite state as shown in table 1. State 1,2, represent the S_{11}, S_{12} input side and output side switches have been triggered conduction respectively, Conversion process from S_{11} to S_{12} will be implemented after 3, 7, 5 state transformation when the current flows from MC to load side considered as positive; through 4, 6, 8 state transformation perform the same task when the current is negative. This is the four steps traditional commutation strategy based on direction of output current. which has weaknesses of long current change time and breaking down easily for direction determined inaccuracy when the output current passing zero point.

Table.1 Switch status combination of bidirectional switch

Switch state	S_{11p}	S_{11n}	S_{12p}	S_{12n}	i_L detection
1	1	1	0	0	+、-
2	0	0	1	1	+、-
3	1	0	0	0	+
4	0	1	0	0	-
5	0	0	1	0	+
6	0	0	0	1	-
7	1	0	1	0	+
8	0	1	0	1	-

The four-steps communication strategy which based on magnitude of the input phase voltage can effectively solve the converter problem of bidirectional switch theoretically and avoid the combination of switch state which may lead to short circuit at the input side. But in practical application there are still the following problems which can fall into two aspects: one is the reliability of commutation, and the other is the input and output waveform distortion due to the delayed commutation time.

In order to solve the input and output waveform distortion caused by long commutation time, Literature [8] presented a two-step commutation method based on input voltage value and the direction of load current. The method is that according to input voltage value and direction of load current at the communication time, the real time of communication can be judged in the second step or the third one. After real communication there is some time which can be interval to ensure the completion of commutation, while the interval time of the other is reduced to zero so as to decrease the commutation time.

The above two-step commutation strategy can realize safe commutation in the case of accurate measurement of input voltage value and the direction of

load current direction. But in the practical application when load current changes from positive to negative or changed from negative to positive, a logical error of load current will occur because of the current sensor error detection which will directly lead to two-step commutation based on voltage failure and generate short circuit fault.

Through above analysis, it is necessary to adjust the strategy to make the commutation independent to the accurate measurement of the input voltage and output current. this paper proposes a two-step commutation strategy based on voltage: divided the input voltage into six non-critically regions where three differential phase-voltages are obviously and six transitional intervals where phase-voltages are close to. improved commutation strategy, took reasonable arrangement of switch conduction sequence to realize the conversion.

3 Analysis of Improved Two-step Communication Strategy

The improved 6 range voltage two-step communication is based on input voltage value, according to the relationship between the size of the input voltage to divide it into Ⅰ, Ⅱ, Ⅲ, Ⅳ, Ⅴ, Ⅵ altogether six non-critical safety ranges in each voltage cycle, in each interval, we can see the biggest input voltage is always positive, minimum phase always negative, mesophase from positive to negative or from negative to positive change, and then introduced in six transitional intervals which near the two safety intervals border. The 12 divided intervals are shown in Figure 2.

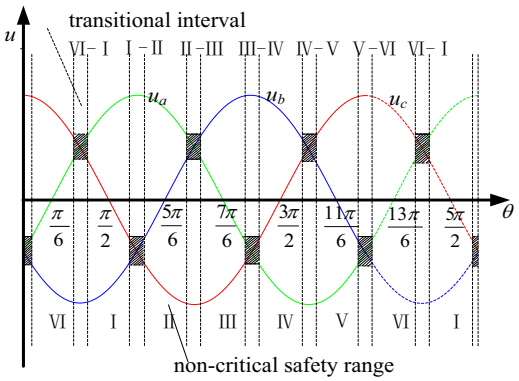


Fig.2 Input voltage divided sections

Combining with the non-critical safety range and the transitional intervals, we take effective measures to improve the two-steps voltage commutation strategy in the two kinds zoning.

(1) In the safety ranges, modified the conventional two-steps voltage-commutation strategy, employ the novel switch states and commutation steps;

(2) In the transitional intervals, the new zero switch states and differ commutation steps is utilized. Allow the converter commutate between phases with high differential voltage, and avoid the direct commutation between phases whose voltage value is approximately equal.

3.1 The modified two-steps commutation strategy in non-critical range

In the non-critical range, we can detect there is a significant difference between the input voltage, then divide it into minimum phase, intermediate phase and maximum phase according to the size of the instantaneous value, and remember as $U_P > U_M > U_N$. In order to reduce commutation time the maximum phase reverse switch tube and minimum phase positive switch tube will be provided conduction drive pulse in advance. Through the combination switch state between the three input phase loop converter complete the commutation. According to figure 1 three-phase to single-phase switch simplified topology to analyze the simplify process of converter.

Assume that the voltage is in the Ⅰ non-critical interval $u_a > u_c > u_b$, Before communication the S_{11p} and S_{11n}, which consist of bi-directional switch connected to u_a, will be offered conduction drive pulse. In addition, S_{12p} will be provided conduction drive pulse which will not result in a short-circuit for u_b is the minimum phase voltage.

Current converter process from S_{11} transfer to S_{13} can be described as follow. The first step is to shut down the S_{11p}. If the load current flows from converter to load, then current will be transferred from S_{11n} to S_{12p}, otherwise, the load current will still flow through S_{11n}, after this step in the a - c auxiliary state, duration should be a little more than switch on-off time. The second step, provide the conduction drive pulse to S_{13p} and S_{13n} at the same time. If the load current direction flows from MC to load, then the load current will transfer from S_{12p} to S_{13p}, otherwise the load current will transfer from S_{11n} to S_{13n}. The current transfers from phase-a to phase-c after the above two

steps successfully.

In the same way deduce the commutation process transfer from S_{13} to S_{12}: first step is to shut down S_{13n}. If the load current transfers from load side to MC, then the current will transform from S_{13n} to S_{11n}, otherwise the path of load current will be not be changed through S_{13p} . The second step, shut down S_{13p} and open S_{12n}. If the current flows from MC to load, current will transfer from S_{13p} to S_{12p}. otherwise current will transfer from S_{11n} to S_{12n}.

Similarly through shut down S_{12n}; open S_{11p} and shut down complete the conversion from phase-b to phase-a. The Figure 3 shows the state transition diagram of two step communication. The six numbers in the diagram represent in turn the switch state of S_{11p}, S_{11n}, S_{12p}, S_{12n}, S_{13p}, S_{13n}. The number 1 represents corresponding turn-on and the number 0 represents corresponding turn-off. P, M, N represent for the three main steady switch state, PM, MN, NP replace the transient state.

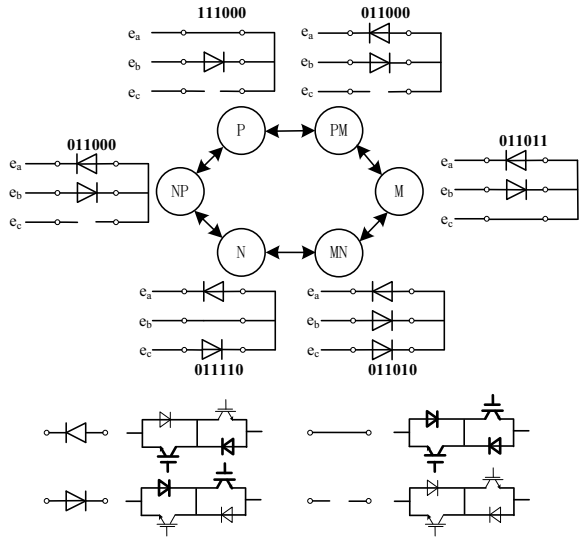


Fig.3 State transition diagram of two-step commutation

By analyzing we know the improved converter strategy can get rid of the influence of output current direction. and MC general with only two switch tube as auxiliary converter in the most transient process which can reduce conduction losses on the premise of reduce commutation time. But this method need to accurately detect the input voltage relative size relations, there exist potential safety hazard when two phases input voltage amplitude are closed that may lead to interphase short circuit because of inaccurate judgment for detection device.

3.2 The zero switch vector commutation strategy in transitional intervals

Because there are the influence of the bandwidth detection device and response time , It will be unable to accurately detect the voltage information when the input phase voltage are near two intersection points, the critical range of commutation method will fail, measures must be taken to prevent similar two converter, avoid the input side short circuit as the commutation method in non-critical range failed, so introduce in zero vector switch state, adjust switch conduction sequence to implement the current security transition when voltage across borders.

As shown in figure 2 , the area where two input phases voltage are close to is defined as the transitional interval. in Ⅱ-Ⅲ, Ⅳ-Ⅴ, Ⅵ-Ⅰ three intervals U_P close to U_M and in Ⅰ-Ⅱ, Ⅲ-Ⅳ, Ⅴ-Ⅵ three intervals U_N close to U_M. Take rearrangement of switching states to keep a phase all opened and another shut off completely when the communicate change occurs between U_M and another approximate phase to avoid short circuit.

Take the interval Ⅰ - Ⅱ for example, $U_N \approx U_M$, $u_a > u_c \approx u_b$,design the conversion among three phases safely as follows:

(1) Input phase-a is always input the maximum phase, keep S_{1n} offer driving signal as a converter auxiliary switch, assuming that switch at the steady state with the S_{11p}, S_{12p} are offered conduction driving signal before entering Ⅰ - Ⅱ interval. To realize conversion from phase-a to phase-c: shut off S_{11p} and shut off S_{12p} followed; then conduct S_{13p}, S_{13n}. which can avoid the input line-to-line fault effectively and does not affect the load transmission power converter.

(2) Blocking-up the commutation directly between phase-c and phase-b in this interval by using switch zero vector, shut off S_{13p}, conduct S_{12n} switch to accomplish transit to zero vector; Shut off S_{13n}, opened S_{12p}, switch state will be converted to input phase-b from the state of zero vector. Realized the current flow transition from S_{13} to zero switching vector and in a further step convert to S_{12} road.

(3) Shut off S_{12n}, conduct S_{11p}, the current flow path transit from S_{11} to S_{12} . The switch state transition as shown in figure 4.

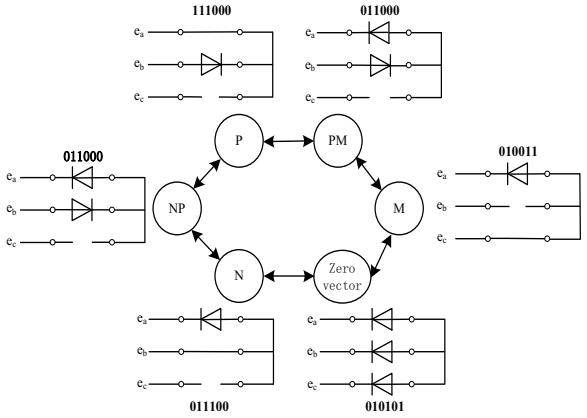


Fig.4 State transition diagram of commutation in intermediate sector

In transitional interval Ⅱ - Ⅲ, $U_N \approx U_p$ the commutation process can be analyzed in the same way. With the introduction of zero vector switch state, avoid short circuit between the input phases when their relative relationship happen change , and can also improve the input current waveform.

Compared with other communication Strategies in transitional intervals: The ban commutation method [8]that prohibit converting between the related two phase in the interval, which will greatly influenced the input current waveform; Alternative commutation method take measure to change the sequence of converter making current flow through the third phase. such as if b, c phases voltage are close to , a new sequence b-a-c-a-b is obtained, which increases the switch loss, double converter time and input output waveform is deviating from the ideal value.

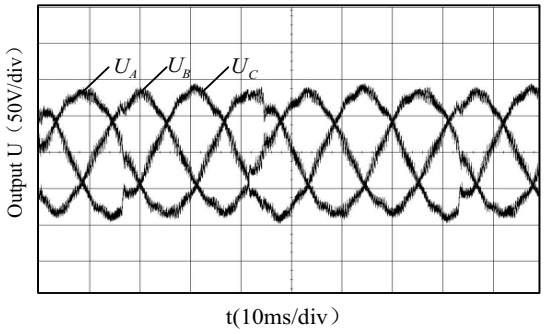
While the control is more complex, it can reduce the switching loss, improve the input and output waveform effectively when combination switch in the transitional intervals, introduce with zero vector modulation to achieve communication safely.

4 Communication Test

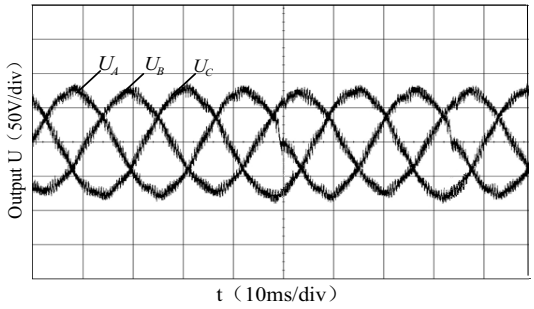
To verify the feasibility of the proposed converter method, a MC prototype has been constructed based on DSP + FPGA [9-10] experiment platform. performed experiment to test the improving two-step commutation strategy, using indirect space vector modulation, DSP is responsible for switch conduction time calculations and switch state judgment, the FPGA for timing and producing converter drive pulse.

The MC input is connected with supply through a regulating transformer with value and frequency are 120V and 50Hz respectively through a LC filter (the parameters are L=0.1mH and C=10μF). the MC sample frequency is 10 KHz; and the output is connected to the three-phase symmetry passive R-L load（L=0.1mH and R=12Ω）. expected output voltage value is 65V and frequency 30Hz. the power factor is 1.

Compare and analysis the results with traditional converter strategy in the same conditions. figure 5 shows the output voltage experimental waves of traditional four-step converter strategy and improved two-steps communication strategy. figure 6 shows the experimental wave of input current and voltage under the two strategy.

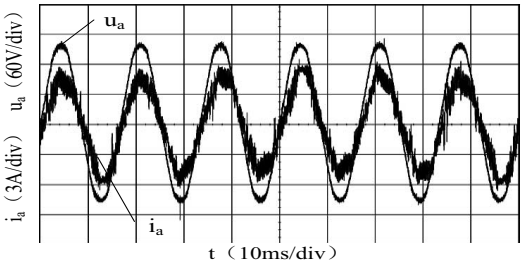


（a）Experiment output voltage waveform of traditional four-step commutation

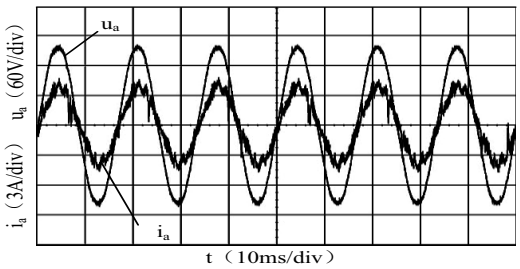


（b）Voltage waveform of improved two-step commutation

Fig.5 Experiment output voltage waveform



（a）Input voltage-current waveform of traditional four-step commutation



（b）Input voltage-current waveform of improved two-step commutation

Fig.6 Input waveform contrast of Grid-side

Comparing the output voltage experimental wave of two strategies in fig5, We can conclude that it will avoid the commutation failure due to the relative size of input voltage detection inaccuracy and avoid the possibility failure caused by the wrong load current direction detection after improvement of commutation strategy. Dealing with output experimental wave data in matlab can be calculated that the THD of output current adopting four-step commutation is 3.97 percent, while the THD of improved two step commutation is 2.54 percent.

Figure 6 demonstrate that in the transitional interval introduced zero vector switch state can improve the input current waveform effectively .

5 Conclusions

This article proposes an improved two-steps voltage commutation strategy, aiming to solve the short circuit problem when the input voltage detection is not accurate in transitional intervals and to shorten the switch time in non- critical range. through the experiment optimize the combination of switch states and use zero switch state modulation can achieve the desired effect. From the waveform of DSP + FPGA platform can be concluded that the proposed converter strategy solve the problem in crossover interval under the condition of the voltage judgment is not accurate. and reduce the distortion rate of output voltage and input current waveform.

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