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CONTROL STRATEGY RESEARCH AND SIMULATION FOR MMC BASED ON PD-SPWM

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ABSTRACT
Modular multilevel converter was hot in the research field of high-voltage power converter, for its advantages of small switching loss, independent device tandem technology. Then, the principles of MMC for the PD-SPWM was briefly analyzed, and the balance control of the upper and lower arms voltage on the basic of the capacitor voltage sequencing method was proposed. The MMC three phase independent inverter based on PD-SPWM is simulated by Matlab/Simulink software. The results show that PD-SPWM method with good output characteristics.

KEYWORDS: modular multilevel converters, PD-SPWM, capacitor voltage, sorting, three phase independent inverter.

INTRODUCTION
Recently, modular multilevel converter (MMC) have become an important technology in high voltage direct current(HVDC) applications with its wide application range and low total harmonic distortion(THD)[1]. Modulation techniques is one of the key technologies to achieve MMC, including SHE-PWM,SVM,NLM,CPS-SPWM,CD-SPWM and so on. Selective harmonic elimination PWM (SHE-PWM) method is selecting N the angle of switches to eliminate the N-1 higher harmonic components. However, in this method difficulty persists in the identification of switching instants as it involves non-linear transcendental equations for obtaining the desired solution[2]. Space vector modulation (SVM) provides more flexibility to optimize the performance of the converters, but its implementation for four or higher level converters is challenging[3]. Nearest level modulation (NLM) is made the arm's output level to closest the reference level. [4] noted under the condition that sub-module(SM) number is small, its total harmonic distortion(THD) is relatively high. Carrier phase shift(CPS-SPWM) is compare modulation wave with the carrier waves. [5] pointed out its switching frequency is high, and the modulation algorithm is very complex for higher level converters .Carrier phase Disposition(CD-PWM) is compare modulation wave with the carrier waves which with the same amplitude and frequency. CD-PWM can be divided into PD-SPWM, APOD-SPWM and POD-SPWM. [6] pointed out (Phase Disposition)PD-SPWM with excellent output characteristics in low level.

This paper focuses on the MMC control strategy of PD-SPWM and its 3 phase inverter with passive load. Firstly study the principle of PD-SPWM. Next choose a single converter based on PD-SPWM to test. Then, simulate applications in 3 phase inverter with passive load based on PD-SPWM.

PD-SPWM
There is a principle for the normal operation of the MMC system. The total number of the cut-in SM is still n to get a constant DC voltage. For example, as is shown in Fig.1, to describe the process of PD-PWM modulation method with 4 SM of the upper arm. The width of carrier waves are both 1,and the frequency and phase are also same. Then,

compared with the same modulation wave respectively. The results of output is 1(modulation wave bigger than carrier wave) or 0(modulation wave smaller than carrier wave).The sub-module with output 1 should be switched.

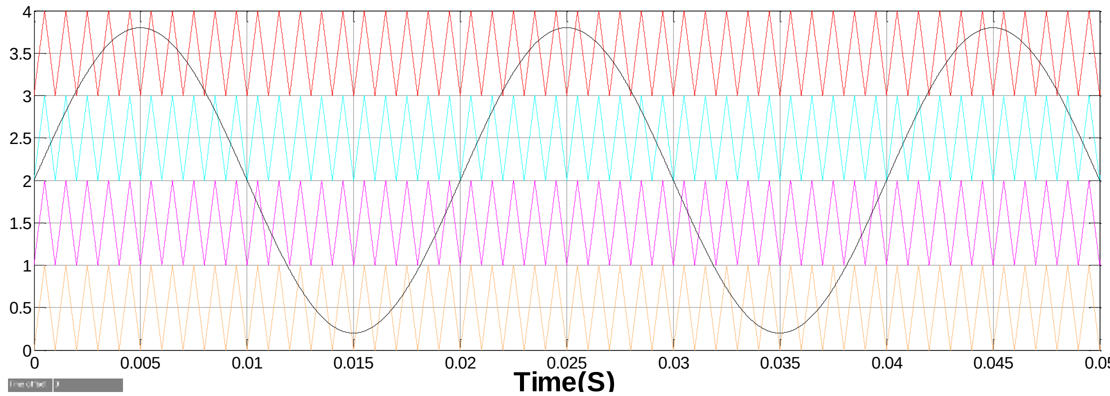

Fig.1 Modulation and carrier waves of PD-SPWM

Fig.2 is the number of the cut-in SM in the upper and lower arm. From Fig.2 we can see that the number of cut-in SM is changing, but the total number of the cut-in SM is always 4.

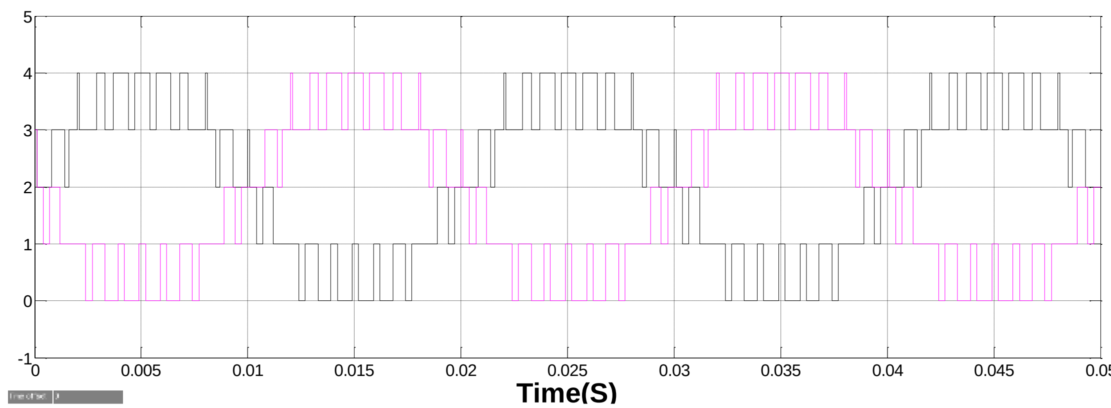

Fig.2 The number of the cut-in SM

CAPACITOR VOLTAGE BALANCE CONTROL BASED ON VOLTAGE SEQUENCE

PD-SPWM have no self-balance of SM capacitor voltage, without SM capacitor balance control, PD-SPWM can not work well to some degree. So it need capacitor balance control strategy. Capacitor voltage balance control based on voltage sequence can guarantee voltage balance of SM in upper arm (or lower arm) internally. As the picture 3 shows:
①Measure capacitor voltage of each SM in upper arm (or lower arm);
②Sort SM's capacitor voltage, as the picture 3(a) show;
③According to arm current's direction and capacitor voltage sequence, control pulse is distributed, as the picture 3(b) and (c) shows.

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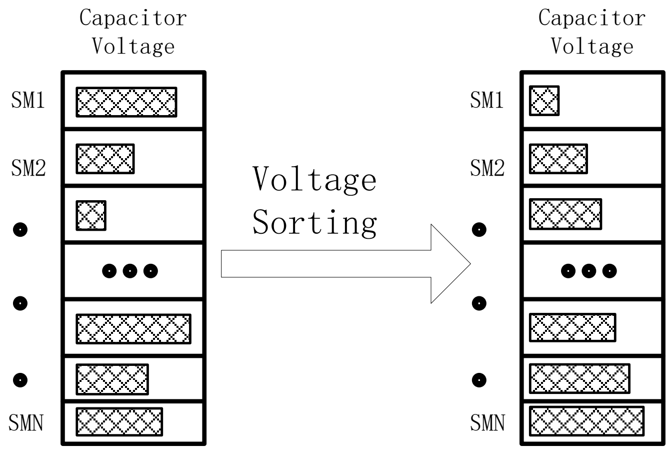
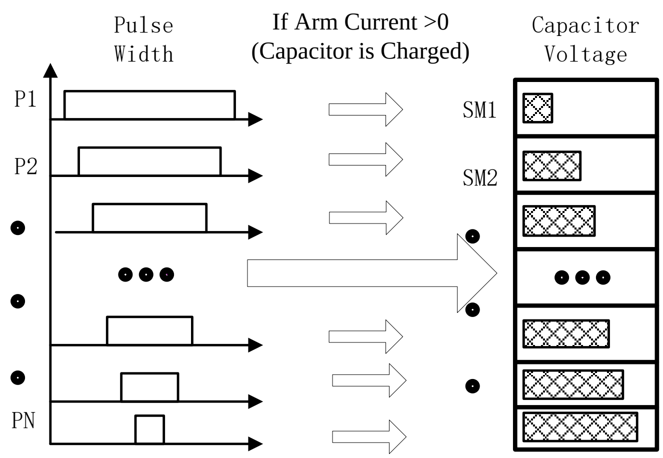
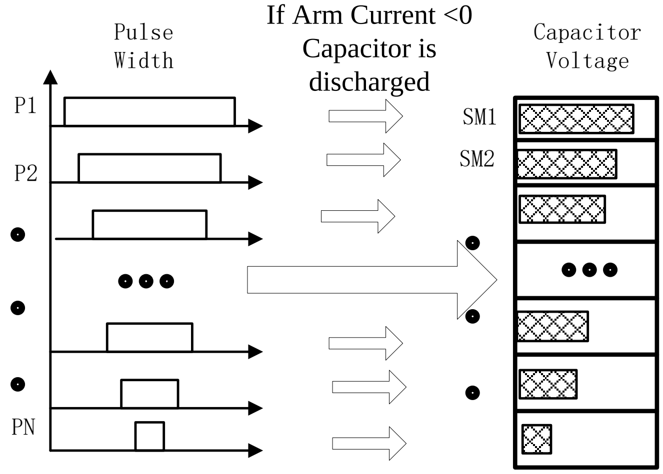


(a) Voltage Sorting



(b) Arm Current>0



(c) Arm Current<0

Fig.3 Capacitor Balance Control.

But it can not guarantee voltage balance of SMs in both arms. So, two PI regulators are adopted to control voltage balance of both arm's SM, which together with voltage sequence constitute comparatively complete MMC SM capacitor voltage balance control strategy. Control flow adopted is showed as the figure 4, in which each arm need only one PI regulator to balance SM capacitor voltage.

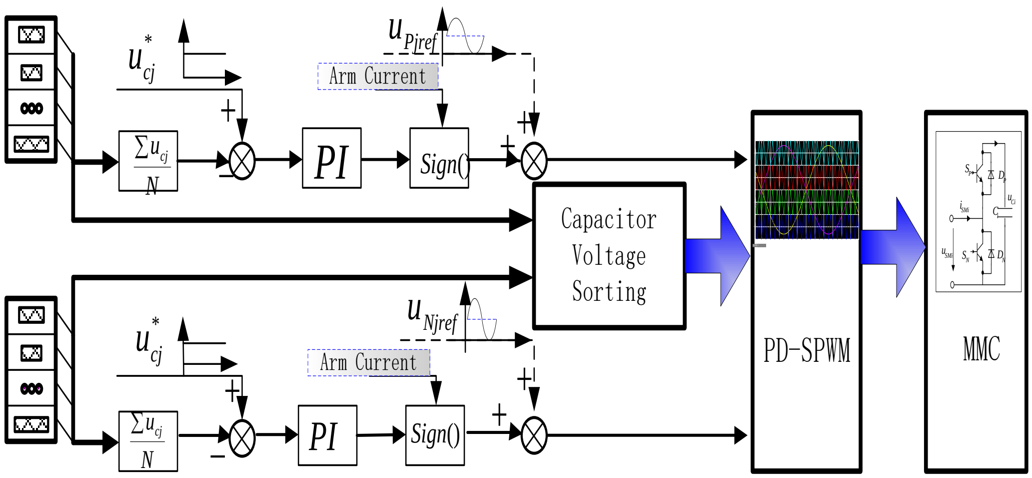


Fig.4 Voltage Balance of Both Arm's SM

PULSE MODULATION TEST IN INVERTER

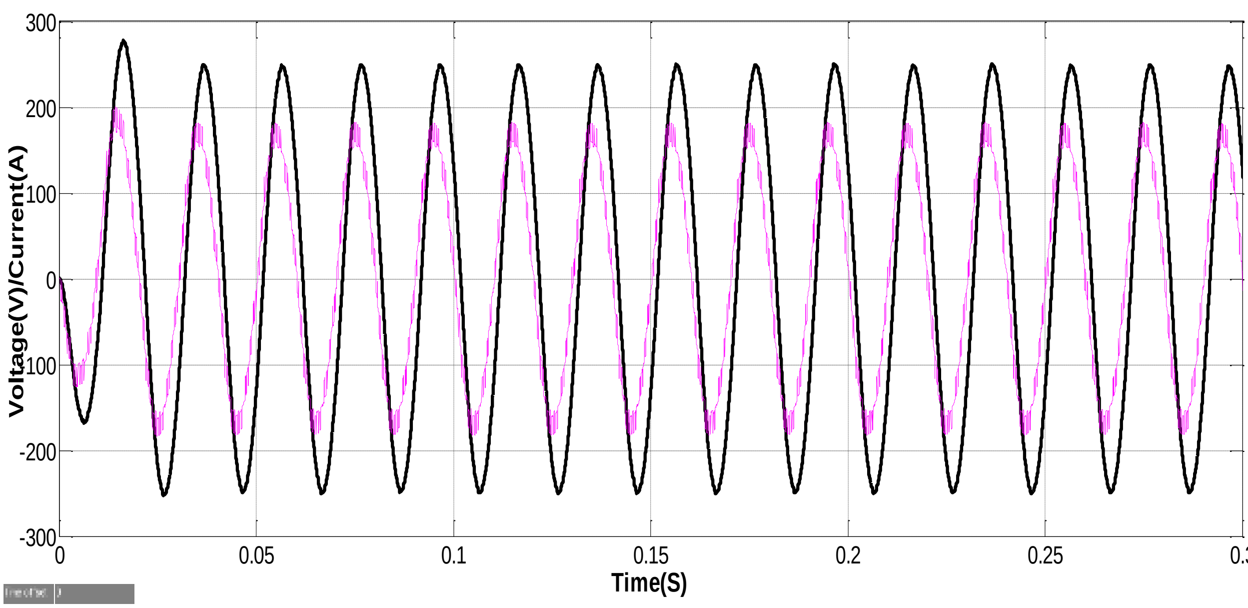
Test PD-SPWM modulation method in an independent inverter, test situation is:.

①Upper arm (lower arm is same) has 4 SMs.

②The voltage of DC source (bus) is 400V.

③The load comprises a 0.6 ohm resistor and a 1mH inductor.

The simulation results are shown in Fig.5.



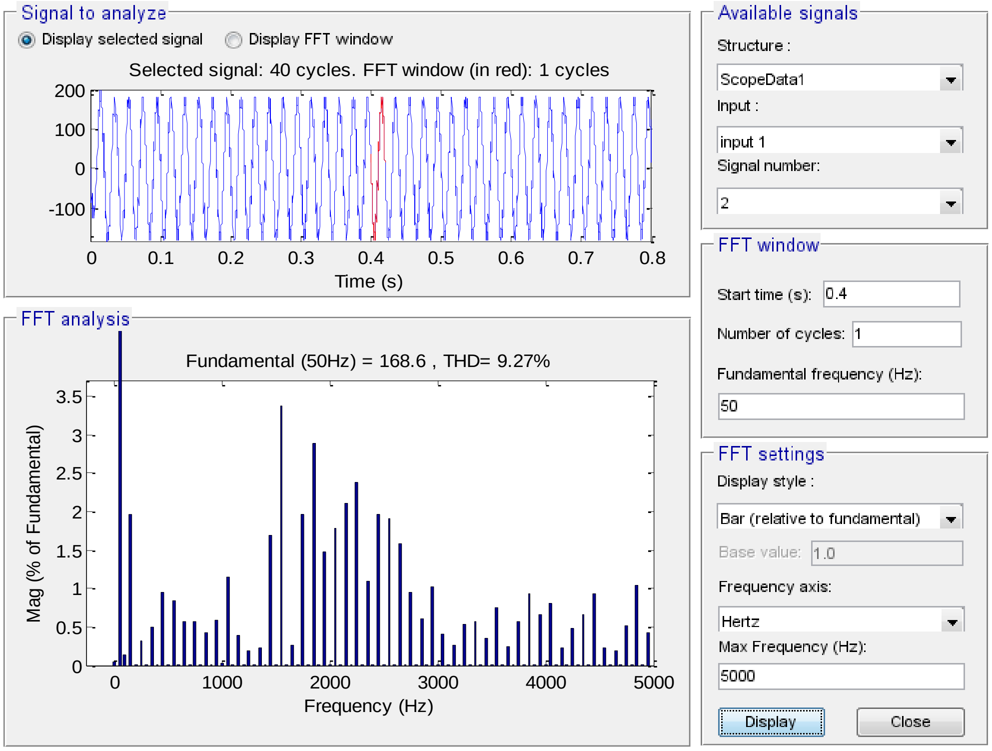


Fig.5 Voltage waveform of MMC and FFT analysis

Form fig.5 we can know that SM capacitor voltage balance control strategy based on capacitor voltage sequence together with arm voltage PI regulator can effectively keep SM capacitor voltage balance, and THD of PD-SPWM no more than 10%.

APPLICATION OF MMC

Simulate applications in 3 phase inverter with passive load, test situation is:

①Use PD-SPWM open loop control.

②Upper arm (lower arm is same) has 4 SMs.

③The amplitude of output voltage is 20kV (having boost transformer)

④The voltage of DC source (bus) is 8000V.

⑤Active power is 5MW, and inductive reactive power is 5MVar.

The principle of 3 phase inverter with passive load shows in fig.6.

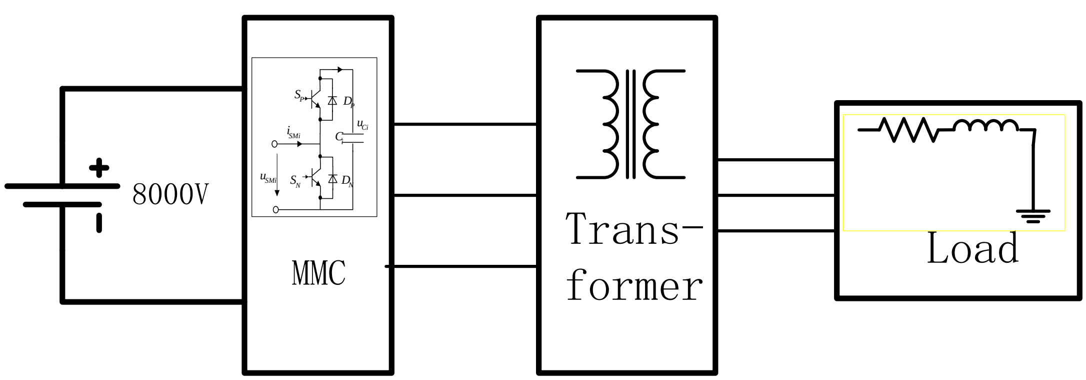


Fig.6 The principle of 3 phase inverter with passive load

The simulation results of output voltage and current are respectively shown in fig.7.

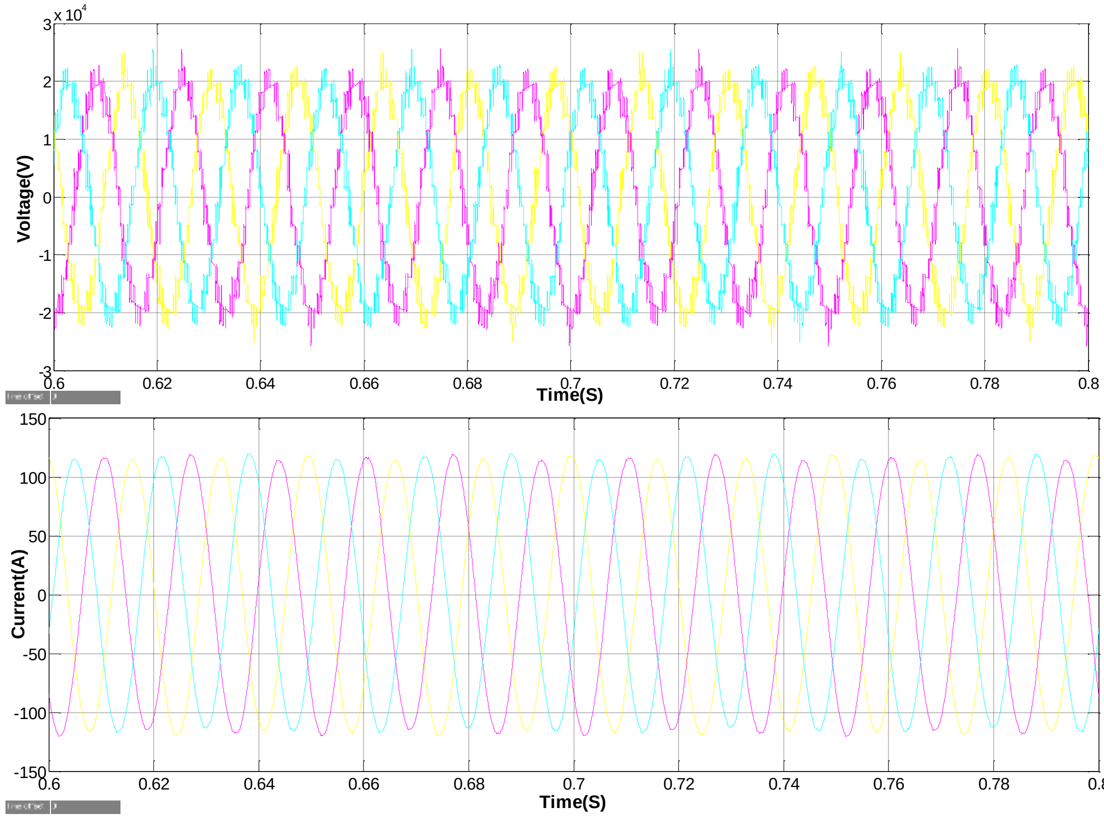


Fig.7 Output voltage and current

Form fig.7 we can know that the output voltage and current based on PD-SPWM are both in steady condition.

CONCLUSION

Through modulation strategy and application simulation analysis, the following conclusions are: SM capacitor voltage balance control strategy based on capacitor voltage sequence together with arm voltage PI regulator can effectively keep SM capacitor voltage balance. And PD-SPWM has the lower THD and it's easy to balance SM capacitor voltage. Moreover, MMC can be used in 3 phase inverter with passive load ,and the output voltage and current based on PD-SPWM are both in steady condition.

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