Research on Hysteresis-band Current Tracking Strategy for Modular Multilevel Converter in DG System

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***Abstract*—Modular multilevel converter(MMC) can be used in DG system. The double closed-loop control strategy including dc bus voltage outer loop and current inner loop is adopted in the control system, which makes dc bus voltage stable even when active power changes. The current inner loop has a new control strategy which is hysteresis-band current tracking control. By real-time monitoring the voltage of the grid and the deviation between the output current and the given current, the input submodules' number of upper/lower arm is determined. Monitoring the direction of current in one arm and comparing the voltage of submodules, then changing the working states of real submodules, the voltages of the upper/lower arm's capacitors can be well balanced. The validity of the proposed method is verified by simulation and experimental results of five-level prototype of MMC.**

Keywords- Modular multilevel converter(MMC); DG system; Dc bus voltage; Hysteresis-band current tracking control; Voltage balancing control.

I. INTRODUCTION

In recent years, besides the conventional energy sources, the small scale distributed generation of power from renewable energy sources has drawn plenty of attention. Distributed Energy Resources need additional infrastructure and inverter to connect them to the grid. Modular multilevel converter (MMC) which was proposed by Marquardt and Lesnicar in Germany has attracted many researchers recently. MMC is composed of several submodules and has a common dc bus which has advantage in HVDC system and distributed generation. The output power of distributed generation is not very stable because of the fluctuation and intermittent output. The double closed-loop control strategy is based on dc bus voltage outer loop and currents inner loop. Dc bus voltage is stable when the active power changes. The currents inner loop has a new control strategy which is hysteresis-band current tracking control. The proposed control strategy is simple and reliable. The validity of the proposed method is verified by the simulation results and experimental results of five-level prototype of MMC.

II. SYSTEM STRUCTURE

Fig. 1 shows the structure of DG system. Photovoltaic/fuel power system and wind power system can operate in parallel where the converter must be MMC.

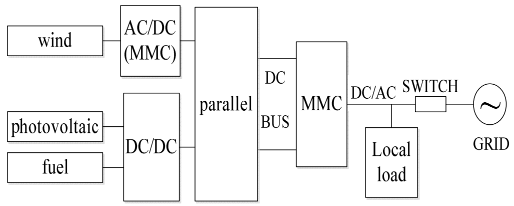


Figure 1. Structure of DG system

Fig.2 shows the three-phase equivalent circuit of the MMC, which has two arms including the upper arm and the lower arm, with each arm having n submodules (SM), one equivalent resistor R and buffer inductor L. L_s is the ac-link inductor which connect MMC to grid/load. The SM is composed of one capacitance and two switches.

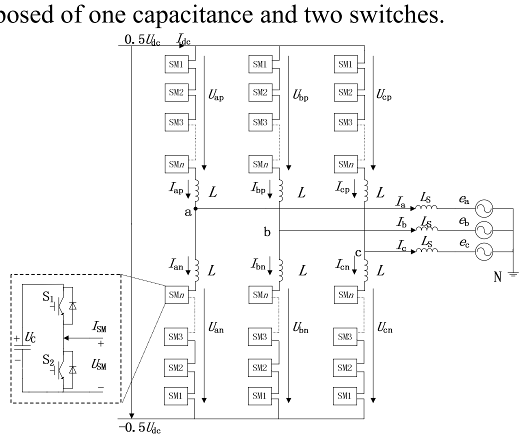


Figure 2. Three-phase equivalent circuit of MMC

The working states of SM are shown in Table I. The output voltage of SM is "U_C" or "0" according to the current I_{SM} direction and the status of two switches. The capacitance of SM has three status. For example, if I_{SM} >0, the capacitor would be charged, and if I_{SM} <0, the capacitor would be discharged. The capacitor voltage will be kept while the SM is "OFF."

TABLE I. HALF-BRIDGE SUBMODULE WORKING STATES

mode	S_1	S_2	I_{SM}	U_{SM}	capacitor
1	1	0	>0	U_C	charging
2	1	0	<0	U_C	discharging
3	0	1	>0	0	bypass
4	0	1	<0	0	bypass

III. BASIC STRUCTURE AND CONTROL

From Fig.2, output current i_j and output power P_j can be expressed as following (i=a,b,c):

$$\begin{cases} P_a = i_a \cdot e_a \\ P_b = i_b \cdot e_b \\ P_c = i_c \cdot e_c \end{cases} \tag{1}$$

I_j represents the current of j phase, e_j represents the voltage of j phase, P_j represents the power of j phase.

Using Park transformation to (1), we obtain:

$$\begin{cases} P = e_d I_d = U_{dc} I_{dc} \\ Q = -e_d I_q \end{cases} \tag{2}$$

P represents the total active power, while Q represents the total reactive power. So, we obtain the double closed-loop control strategy based on dc bus voltage outer loop and currents inner loop which is seen in Fig.3. In comparison with the traditional PI control strategy, the new strategy is simple and reliable.

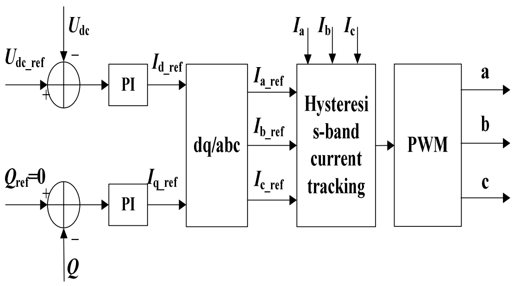


Figure 3. The grid-connected Strategy of hysteresis-band current tracking control

IV. N+1 HYSTERESIS-BAND CURRENT TRACKING LEVEL STRATEGY

The system is symmetrical. Just taking a phase as an example, the upper and lower arm's voltage can be expressed as followings:

$$\frac{U_{dc}}{2} - U_{ao} = U_{ap} + L\frac{dI_{ap}}{dt} \tag{3}$$

$$\frac{U_{dc}}{2} + U_{ao} = U_{an} + L\frac{dI_{an}}{dt} \tag{4}$$

$$I_{ap} = I_{an} + I_a \tag{5}$$

$$U_{ao} = L_s\frac{dI_a}{dt} + e_a \tag{6}$$

From (3)-(6), we obtain:

$$\begin{cases} L_a = L_s + \dfrac{L}{2} \\ U_{dao} = \dfrac{1}{2}(U_{an} - U_{ap}) \\ L_a\dfrac{dI_a}{dt} = U_{dao} - e_a \\ U_{AO} = U_{dao} - e_a \end{cases} \tag{7}$$

L_a is equivalent inductance, U_{dao} is equivalent output voltage, e_a is the voltage of grid/load. U_{AO} is the deviation between e_a and U_{dao}.

If $U_{AO}<0$,the output current I_a decreases. If $U_{AO}>0$, I_a increases. Fig.4 shows the principle drawing of hysteresis-band current tracking control.

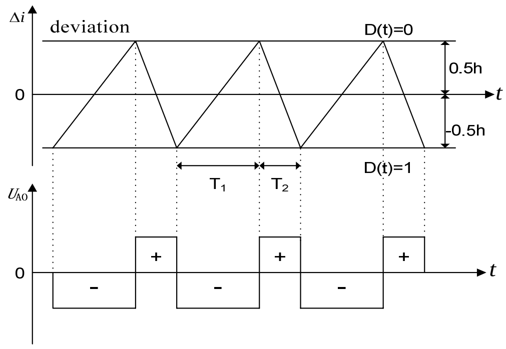


Figure 4. Principle drawing of hysteresis-band current tracking control

The intervals of the load/grid voltage is seen in Fig.5

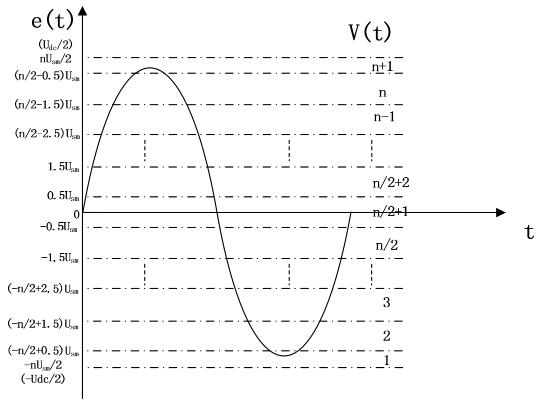


Figure 5. The intervals of load voltage

From Fig5, we can see that there is n+1 intervals of load voltage. In order to suppress circulating-current, we adopt n+1 level strategy, then U_{dao} and SM voltage U_{sm} can be expressed as followings:

$$\begin{cases} U_{sm} = \dfrac{U_{dc}}{n} \\ U_{dao}(t) = \left[N_n(t) - 0.5n\right] \cdot U_{sm} \end{cases} \tag{8}$$

$N_n(t)$ is the sum of the input lower SM. From Fig4 and Fig5, we ensure that if D(t)=1, $U_{dao}(t)>e_a(t)$.If D(t)=0, $U_{dao}(t)<e_a(t)$. So, we can obtain the $N_n(t)$ and the sum of the input upper SM $N_p(t)$:

$$\begin{cases} N_n(t) = \begin{cases} 0 & 2D(t)+V(t)-2=-1 \\ 2D(t)+V(t)-2 & 0\le 2D(t)+V(t)-2\le n \\ n & 2D(t)+V(t)-2=n+1 \end{cases} \\ N_p(t) = n - N_n(t) \end{cases} \tag{9}$$

In summary, The current inner loop has a new control strategy which is hysteresis-band current tracking control. By real-time monitoring the voltage of the grid and the deviation between the output current and the given current , the input SM number of upper/lower arm is determined, then the output current can track the given current quickly and stably.

V. CAPACITOR VOLTAGE BALANCE CONTROL

From Tab.1, there are three modes of submodule capacitor working states:" charging", "discharging" and "bypass", which is due to the arm current direction and the status of the two switches. Capacitor voltage balance is very important in MMC. We can obtain the strategy of voltage balance control: Monitoring the direction of current in one arm and comparing the voltages of submodules, then changing the working states of real submodules, the voltages of the upper/lower arm's capacitors can be well balanced.

Assume that n is equal to 4,we can see there are 4 submodules in the upper/lower arm. If we find $U_1>U_2>U_3>U_4$, the mapping relationships must be changed.

TABLE II. THE WORKING STATES OF SUBMODULE

mode	$I_p(t)/ I_n(t)\geq0$		$I_p(t)/ I_n(t)<0$	
$N_p(t)/ N_n(t)$	charging	bypass	discharging	bypass
0	none	1,2,3,4	none	1,2,3,4
1	4	1,2,3	1	2,3,4
2	3,4	1,2	1,2	3,4
3	2,3,4	1	1,2,3	4
4	1,2,3,4	none	1,2,3,4	none

Tab.2 shows the working states of submodule, we can obtain that: SM1 is the easiest discharging submodule and the hardest charging submodule while SM4 is the hardest discharging submodule and the easiest charging submodule. Therefore, the voltage of SM1 will decrease while the voltage of SM4 will increase. After several cycles, capacitor voltage balance will come true.

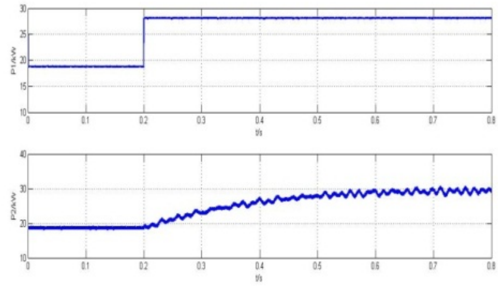
VI. SIMULATION AND EXPERIMENT

A. Simulation

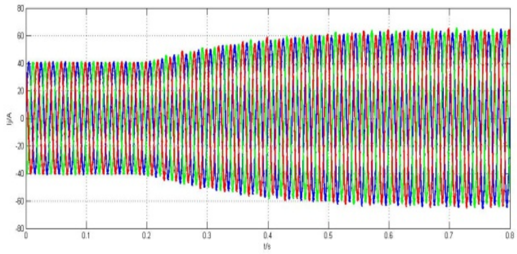
In order to verify the validity of the analyses, we build simulation model in matlab/simulink. The simulation parameters are seen inTab.3.The simulation waveforms are seen in Fig.6.

TABLE III. THE SIMULATION PARAMETERS

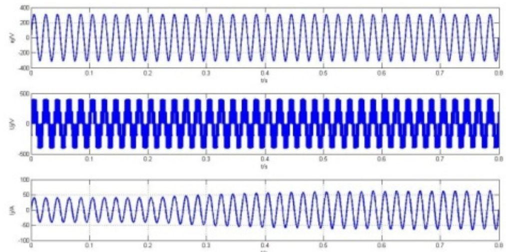
Parameters	Values
No.of Submodules in each arm	4
Submodule Capacitor C	4700uF
Arm Equivalent Resistance	0.1Ω
Arm Inductor L	1.2mH
AC Link Inductor L_s	8mH
DC Bus Voltage U_{dc}	800V
h	0.04A
AC system voltage U_s(rms)	220V
Active power	18kW~27kW
Power frequency	50Hz



(a)



(b)



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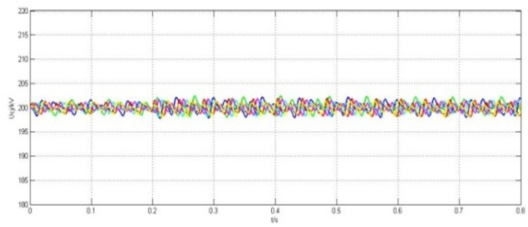


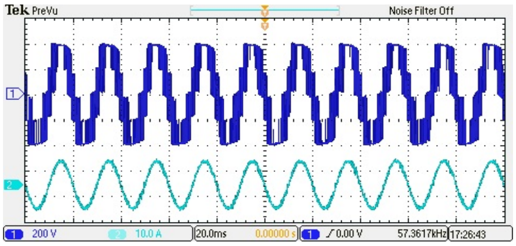
(d)

Figure 6. The simulation waveforms of hysteresis-band current tracking control

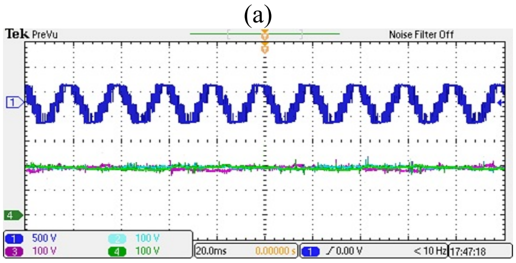
From Fig6(a), We can see the change of absorbing and producing active power. The absorbing active power increases from 18kW to 27kW, then the producing active power will increase accordingly. Fig6(b) shows the output current of three-phases. The current increases quickly after 0.2s which is symmetrical. Fig6(c) shows the grid voltage, output voltage and output current of a single phase. We can find that the output current can track the given current smoothly. Fig6(d) shows the voltages of SMs, the voltages of the upper/lower arm's capacitors can be well balanced.

B. Experiment

The experimental parameters are the same as Tab.3 , waveforms are shown in Fig.7.



(a)



(b)

Figure 7. Experimental waveforms

Fig7(a) shows the output current and output voltage, we can see that they have the same phase, the voltage of the dc bus is 800V which is stable. Fig7(b) shows the voltages of SMs, the voltages of the upper/lower arm's capacitors can be well balanced.

VII. CONCLUSIONS

In this paper, Hysteresis-band Current Tracking Strategy for modular multilevel converter in distributed generation is introduced. The output current can track the given current smoothly and the voltages of the upper/lower arm's capacitors can be well balanced. The proposed strategy is simple and reliable for control which has great promise.

REFERENCES

[1] B.N.Alajmi, KH Ahmed, GP Adam, S.J.Finney, and B.W.Williams. *Modular multilevel inverter with maximum power point tracking for grid connected photovoltaic application[J]*.IEEE International Symposium on Industrial Electronics,2011,22(6):2057-2062

[2] S.Rajasekar and R.Gupta. *Solar photovoltaic power conversion using modular multilevel converter[J]*. Students Conference on Engineering and Systems, 2012,1(1): 1–6

[3] Gu Herong,Yang Zilong, Wu Weiyang. *Research on Hysteresis-band Current tracking Control of Grid-connected Inverter[J]*. Proceedings of the CSEE,2006,26(9):108-112

[4] Hong Feng,Shan Renzhong,Wang Huizhen,Yan Yangguang.*A Varied Hysteresis-Band Current Controller With Fixed Switching Frequency [J]*.Transactions of China Electrotechnical Society,2009,24(1):115-119

[5] Zou Chao,Wang Ben,Li Tai.*Control strategy of VSC—HVDC system supplying power for passive networks[J]*.Power System Technology, 2009,33(2):84-88

[6] M. Guan and Z. Xu. *Modeling and control of a modular multilevel converter-based HVDC system under unbalanced grid conditions[J]*.IEEE Transactions on Power Electronics,2012,27(12): 4858–4867