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Multi Band Hysteresis Current Controlled Flying Capacitor Multi Level Inverter Based Shunt Active Power Filter for Distribution Systems

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Abstract -This paper presents application of flying capacitor multi level inverter in high voltage shunt active power filter. The proposed strategy uses three independent multi band hysteresis current regulators to generate gating signal for multi level inverter. Flying capacitor multi level inverter is used for high voltage and high power application with low distortion of source current waveforms at low switching frequency. A new flying capacitor voltage balancing technique is proposed which maintain constant capacitor voltage with desired current wave shape. Five level flying capacitor multi level inverter topology has been considered for active filtering of 11 kV distribution systems. The fast dynamic response of active power filter with low total harmonic distortion of source current has been achieved with the proposed strategy.

Key Words:multi level inverter, hysteresis current control, active power filter.

1.INTRODUCTION

Extensive use of power electronics equipments like rectifiers, variable speed drives have caused an increase of harmonic disturbances in power systems. Harmonic causes many problems like low power factor, excessive neutral current, transformer overheating, capacitor blowing, motor vibration etc. To enhance power quality, harmonics need to be eliminated. The active power filter can solve problem of harmonic elimination and satisfies the reactive power demand of non linear load.

For low voltage level most compensator for APF use a standard two level voltage source inverter. For high voltage and high power application, multi level inverters have been introduced. Multi level inverters are now becoming popular topology for high power application. For a given switching frequency there is a less distortion in the output voltage and less di/dt and dv/dt stresses across the switching devices. When MLI is used for shunt compensation, it works in current control mode. It can improve power quality by harmonic elimination and raising load power factor.

Three different multi level inverter topologies are popular now a day. (1) Diode clamp MLI (2) Flying capacitor MLI (3) cascade H bridge inverter. FCMLI has many advantages over DCMLI structures like, no DC link unbalancing problem, does not require clamping diodes etc. cascade inverter needs a complex dc voltage regulation techniques and complexity increase with increase in level of inverter. Also in UPFC and UPQC application, there is a problem of short circuit between back to back converters. Voltage regulation of FCMLI is simpler compared to other structures and does not require a number of power supplies as required in cascade MLI.

2. FCMLI CONFIGURATION

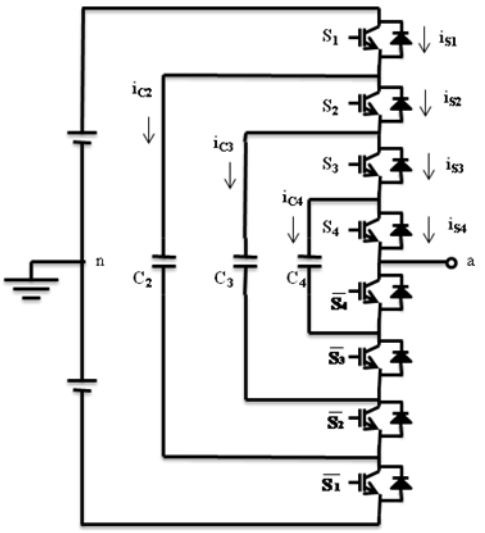

Fig-1: Five level Capacitor clamped inverter circuit topology

Fig. 1 illustrates the basic structure of a phase leg capacitor clamped five level inverter. The circuit has been called the flying capacitor MLI with independent capacitors clamping the device voltage to one capacitor voltage. Fig. 1 shows schematic diagram of one leg of a three phase five level FCMLI. C_2, C_3 and C_4 are flying capacitors which are regulated using control scheme at $3V_{dc}/4$, $V_{dc}/2$ and $V_{dc}/4$ respectively. Capacitors clamp voltage across switches at $V_{dc}/4$ in five level inverters. In fig. 1, S_1 through S_4 are binary variables, which are 1 for on state and 0 for off state of the switch. The expression for current through and voltage across the switches are as under,

$$
\begin{aligned}
i_{S1} &= S_1 * i_a & \qquad V_{S1} &= \overline{S_1}(V_{C1} - V_{C2}) \\
i_{S2} &= S_2 * i_a & \qquad V_{S2} &= \overline{S_2}(V_{C2} - V_{C3}) \\
i_{S3} &= S_3 * i_a & \qquad V_{S3} &= \overline{S_3}(V_{C3} - V_{C4}) \\
i_{S4} &= S_4 * i_a & \qquad V_{S4} &= \overline{S_4}\, V_{C4}
\end{aligned}
$$

3. INSTANTANEOUS POWER THEORY

Three phase instantaneous reference compensating current can be calculated with the instantaneous power theory. Three phase instantaneous source voltage and current can be converted into α-β coordinates as following equations.

$$
\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1)
$$

$$
\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (2)
$$

The instantaneous real power p and instantaneous imaginary power q are defined from the instantaneous phase voltages and line currents from the α-β axes as

$$
\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (3)
$$

$$
\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \qquad (4)
$$

These two powers have constant values and a superposition of oscillating components as follows

$$
\begin{aligned}
p &= \bar{p} + \tilde{p} \\
q &= \bar{q} + \tilde{q}
\end{aligned} \qquad (5)
$$

Where $\bar{p}$ and $\tilde{p}$ represents the average and oscillating parts of p, whereas $\bar{q}$ and $\tilde{q}$ represents the average and oscillating parts of q. The average value $\bar{p}$ represents the energy flowing per time unity in one direction only. The oscillating part $\tilde{p}$ represents amount of additional power flow in the system without effective contribution to energy transfer from source to load or load to source. The average value of $\bar{q}$ represents conventional three phase reactive power and does not contribute to energy transfer. The oscillating component of the imaginary power $\tilde{q}$ is the power that is exchanged between three phases, but does not contribute in power transfer between source and load. Compensation of $\tilde{p}$ and $\tilde{q}$ results in elimination of harmonics from source current and compensation of $\bar{q}$ results in unity power factor.

$$
\begin{bmatrix} I_{c\alpha} \\ I_{c\beta} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} -\tilde{p} \\ -q \end{bmatrix} \qquad (6)
$$

$$
\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \qquad (7)
$$

4. HYSTERESIS CURRENT CONTROL

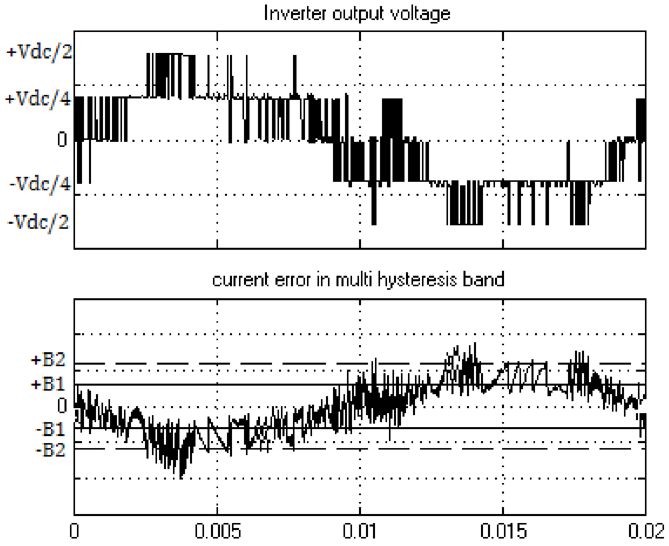

Fig-2: Multi Band hysteresis current control for FCMLI

Hysteresis current control technique for two level inverter has been proposed in several research papers [3, 4]. Some researchers have extended it to multi levelinverter. The proposed hysteresis multi band current controller tracks the reference compensating current and keeps source current almost sinusoidal.

In the proposed strategy reference compensating current is compared with the actual compensating current and error signal is applied to the current controller. The current error is compared with different hysteresis band as shown in fig. 2. Depending upon the magnitude and polarity of the current error, hysteresis current controller decides the inverter output voltage which should be applied to confine current error within band. If the position of error is within inner most band B, then zero voltage level is applied by selecting appropriate switching state. If the position of error is between bands B and B1, then voltage level $+V_{dc}/4$ or $-V_{dc}/4$ is applied for negative and positive error respectively. If error crosses outermost band B1 at that time extreme voltage level $+V_{dc}/2$ or $-V_{dc}/2$ is applied to force the current error in opposite direction.

The distortion of the current wave and inverter switching frequency largely depend upon the width of band. So, width of bands should be selected appropriately. The other determining factors are load value and input voltages.

5. FLYING CAPACITOR VOLTAGE CONTROL

Due to active power loss in the switching devices and unbalanced load condition, flying capacitor voltage changes. Flying capacitor voltage should remain constant so that switches are clamped at constant voltage level. For five level inverters, the capacitors C_2, C_3 and C_4 should be regulated at voltage level $3V_{dc}/4$, $V_{dc}/2$ and $V_{dc}/4$ respectively. Due to flexibility of switch selection for different output voltage level in MLI, flying capacitor voltage balancing under the hysteresis current control operation can be achieved.

This paper presents the flying capacitor voltage control strategy with better performance. Multi band hysteresis current regulator decides the output voltage level of any phase leg. Flying capacitor voltage regulator decides the switch combination by which the particular voltage level is obtained along with balanced capacitor voltage. Actual capacitor voltages V_{c2}, V_{c3} and V_{c4} are compared with their reference values V_{c2}^*, V_{c3}^* and V_{c4}^* respectively in zero band comparators. The errors of the capacitor voltages are sampled at constant sampling frequency. At a particular sampling instant if error is positive, then the particular capacitor should be charged. If the error is zero then no change in the state of capacitor is required and if the error is negative then the capacitor should be discharged.

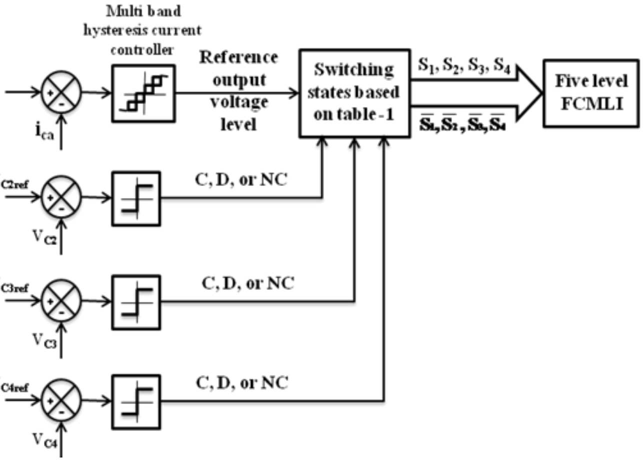

Fig- 3: Basic scheme for switching state generation for FCMLI

Fig. 3 shows the proposed control strategy. For example if the desired output voltage is $+V_{dc}/4$ and capacitor voltage errors are $E_{2a}=+1$, $E_{3a}=-1$ and $E_{4a}=0$, then C_2 should be charged, C_3 should be discharged and no change in the state of C_4 is required to maintain constant capacitor voltages.

Table-1: Selection of switching states for regulation of capacitor voltage

V_{an}	S_{1a}	S_{2a}	S_{3a}	S_{4a}	C_{2a}	C_{3a}	C_{4a}
$+V_{dc}/2$	1	1	1	1	NC	NC	NC
$+V_{dc}/4$	1	1	1	0	NC	NC	C
	1	1	0	1	NC	C	D
	1	0	1	1	C	D	NC
	0	1	1	1	D	NC	NC
0	0	0	1	1	NC	D	NC
	0	1	0	1	D	C	D
	0	1	1	0	D	NC	C
	1	0	0	1	C	NC	D
	1	0	1	0	C	D	C
	1	1	0	0	NC	C	NC
$-V_{dc}/4$	1	0	0	0	C	NC	NC
	0	1	0	0	D	C	NC
	0	0	1	0	NC	D	C
	0	0	0	1	NC	NC	D
$-V_{dc}/2$	0	0	0	0	NC	NC	NC

To fulfill above condition table 1 suggest the switch combination $S_1=1$, $S_2=0$, $S_3=1$, $S_4=1$. This switch combination leads to charging of C_2, discharging of C_3 and no change in the state of C_4. The next switch combination is applied at next sampling instant. In this table, C indicates charging, D indicates Discharging and NC indicates no change in voltage of particular capacitor. Table-1 suggests different switch combinations for different voltage levels. If the particular errors condition is not fulfilled by given switch combinations from table-1, then most favorable switch combination is selected.

6. RESULT AND DISCUSSION

The proposed scheme has been simulated and tested by MATLAB Simulink power system toolbox. Fig. 4 shows the simulation results of shunt active power filter. Fig. 4 [a] shows the five level output voltage of FCMLI. Fig. 4 [c] shows the non sinusoidal load current drawn by the diode bridge rectifier with R-L load.

The load current contains fundamental and harmonics component. Fig. 4 [d] is actual compensating current supplied by the active power filter, so that harmonic and reactive power demand of the load supplied by the APF and source current becomes almost sinusoidaland in phase with respective phase voltage. The source current of phase a, is shown in fig. 4 [b].

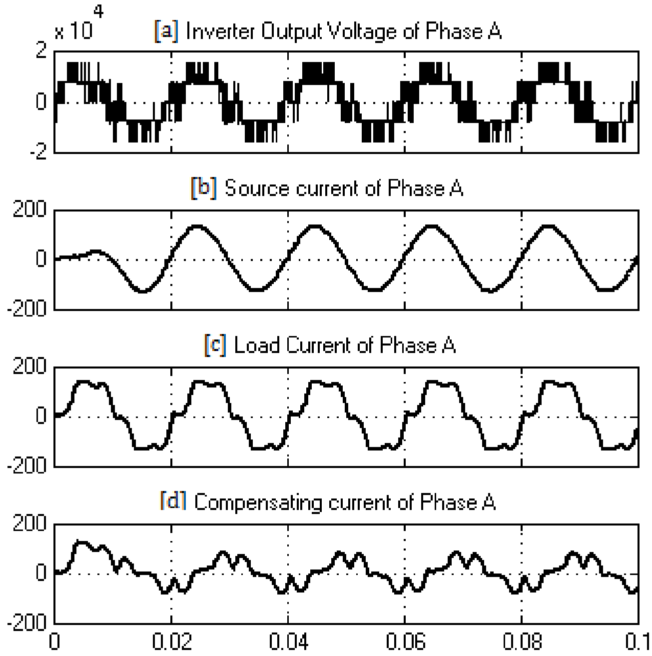

Fig- 4 [a] inverter output voltage [b] source current [c] load current [d] compensating current

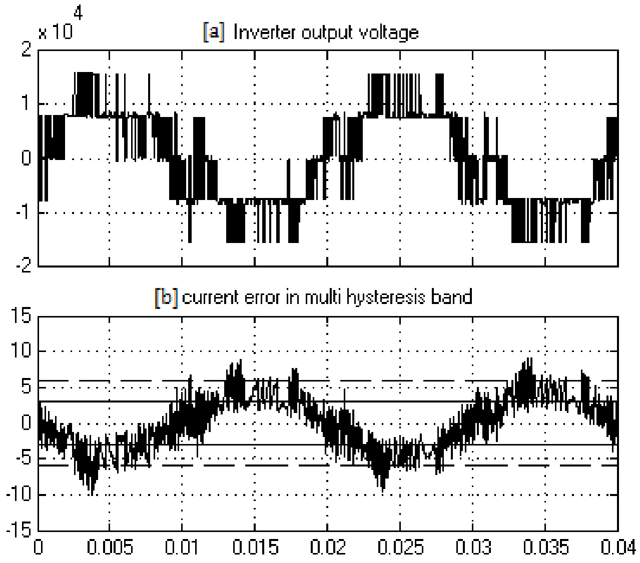

Fig- 5[a]: inverter output voltage [b] five level hysteresis current control

Fig. 5 shows the performance of FCMLI operating under multi band hysteresis current control. Fig. 5 [b] shows variation of phase a current error within different bands. The current error is confined within outermost band, so that actual compensating current tracks the reference current. The width of the outermost band is taken 5% of the peak value of phase a current. The width of the hysteresis band is selected by considering THD of source current and device switching frequency.

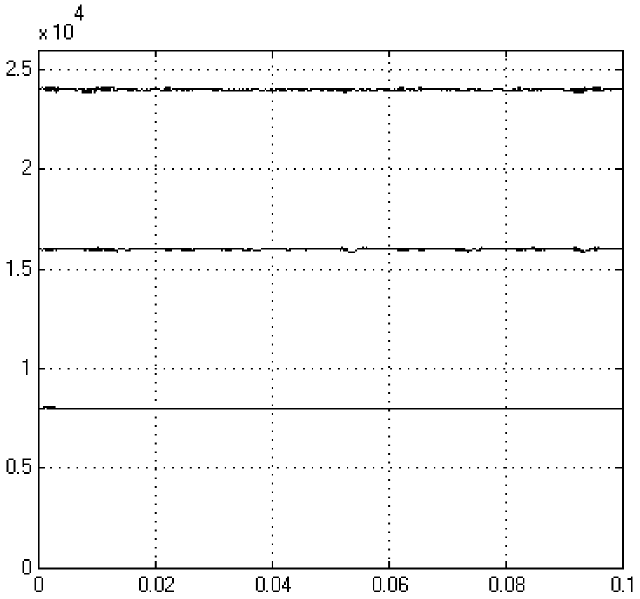

Fig- 6: flying capacitor voltages of phase a

The movement of current error in different bands generates different inverter output voltage levels like $-V_{dc}/2$, $-V_{dc}/4$, 0, $V_{dc}/4$, $V_{dc}/2$ as shown in fig. 5 [b], such that current error is confined within given band.

Fig. 6 shows the performance of proposed scheme to regulate voltage of flying capacitors. By using redundant switching states, the actual clamping voltages are tightly regulated around their reference values. So, all the switching devices are clamped at Vdc/4 voltage levels. Fig.6 shows the flying capacitor voltages of phase a, which are regulated at 3Vdc/4, Vdc/2 and Vdc/4.

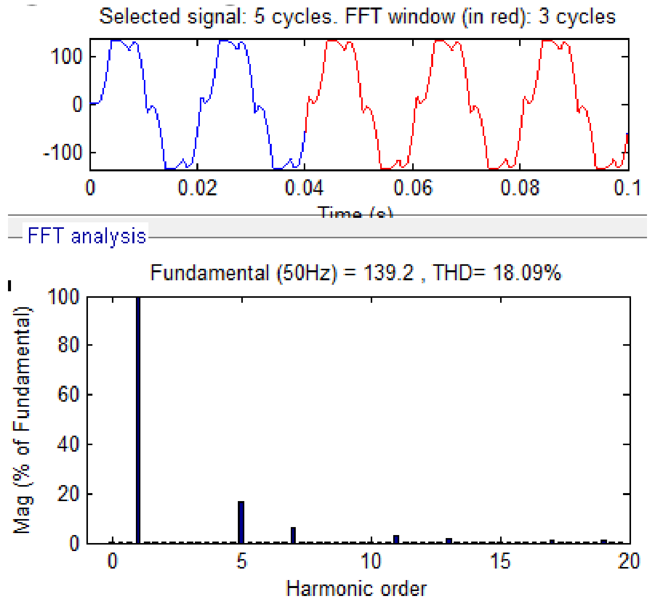

Fig-7 [a]: Load current of phase a and its harmonics spectrum

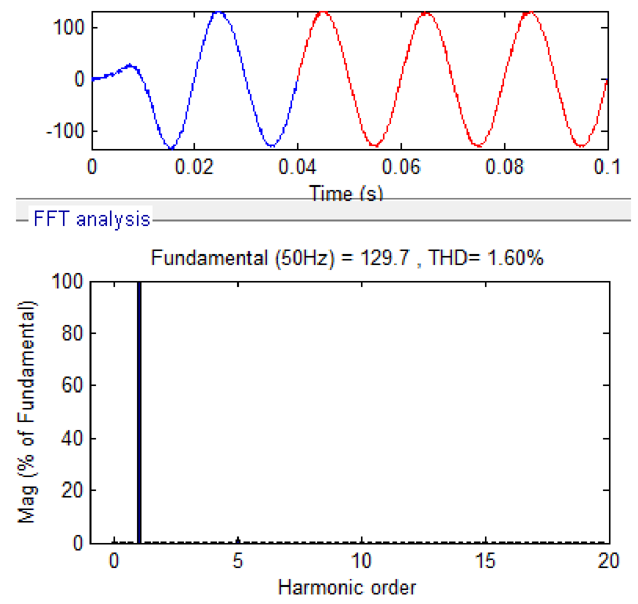

Fig- 7 [b]: Source current of phase a and its harmonics spectrum

Fig. 7 [a] shows the load current of diode bridge rectifier and its harmonics spectrum. The THD of load current is 18.09 %. Fig. 7 [b] shows the compensated source current after active filtering. As the FCMLI based APF fulfills the harmonics and reactive power demand of the load, source current becomes harmonics free and in phase with its phase voltage. The THD of source current is only 1.72%. which is acceptable value by IEEE-519 and IEC 61000.

7. CONCLUSION

In this paper, five level flying capacitor inverter based shunt active power filter has been proposed. Basic concept of APF based on instantaneous P-Q theory has been discussed. A multi band current hysteresis control for flying capacitor multi level inverter has been derived. The proposed multi band hysteresis current controller produces the desired output line currents and at the same time regulates the flying capacitor voltage using redundant switching states of the inverter. It offers the same advantages as offered by conventional hysteresis current controller at reduced device switching frequency. The validity of this technique in order to compensate current harmonics was proved on the basis of simulation results. The effectiveness of MLI based APF is found effective to meet IEEE-519 standard recommendations on harmonics level.

REFERANCES

[1] H. Akagi, Y. Kanazawa, A. Nabae, “Instantaneous reactive power compensators comprising switching devices without energy storage devices,” IEEE Trans. On Industry Applications, 1984, Vol. 1A-20, pp. 625-630.

[2] J. Rodriguez, J. S. Lai, and F. Z. Peng, “Multilevel inverters: a survey of topologies, controls and applications,” *IEEE Trans. Ind. Electron.*, vol. 49, no. 4, pp. 724–738, Aug. 2002.

[3] M. P. Kazmierkowski, and L. Malesani, "Current control techniques for three-phase voltage-source PWM converters: a survey," IEEE Trans. Ind. Electron., vol. 45, no. 5, October 1998, pp. 691-703.

[4] B. K. Bose, "An adaptive hysteresis-band current control technique for a voltage-fed PWM inverter for machine drive system," IEEE Trans. Ind Electron., vol. 37, no. 5, October 1990, pp. 402-408.

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