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Multilevel Inverter Control Using Sliding Mode Control -A Review

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Abstract: multilevel inverters (MLIS) are known as highly efficient inverters and slowly replacing single level inverters in industrial and domestic applications. In this paper, some of the recently proposed sliding mode control multilevel inverters reviewed. There are many control methodologies available in research adaptive control, fuzzy logic control, artificial neural network control, model predictive control and sliding mode control. All this control techniques sliding mode control (SMC) is a best control technique for control static and dynamic state.

Keywords: sliding mode control, multilevel inverter, grid voltage, grid current.

I INTRODUCTION

The SM control is a type of nonlinear control which has been developed mainly for the control of variable structure system. Sliding mode control is a combination control law and switching logic. A nonlinear time-dependent switching system defined by the following equation:

$$\dot{\mathbf{x}}(t) = g(\mathbf{x}(t)) + \varphi(\mathbf{x}(t)) \cdot u(t)$$

Where x(t) is the state-variable vector in an n-dimensional space Rn; g(.) and ϕ(.) are smooth vector fields in the same space; and $u(t)$ is the discontinuous control action expressed as

$$u(t) = \begin{cases} U^{+} & \text{if } \; S(\mathbf{x}, t) > 0 \\ U^{-} & \text{if } \; S(\mathbf{x}, t) < 0 \end{cases} \quad ;$$

Where $U+$ and $U-$ are either scalar values or scalar functions of $\mathbf{x}(t)$; and $S(\mathbf{x}, t)$ is the instantaneous feedback-tracking trajectory of the system and is a predetermined function of the state variables. Typically, for ease of design and implementation, $S(\mathbf{x}, t)$ is chosen as a linear combination of the weighted values of the state variables [1].

In this paper is organized as follows: Sec.II presents SMC controlled multilevel inverters. Sec.III presents SMC controlled 3-phase 3-level inverters. Sec.IV presents SMC control single phase inverters.

II SLIDING MODE CONTROL MULTILEVEL INVERTERS

A. Grid Connected Seven-Level Packed U-Cell Inverter [2]

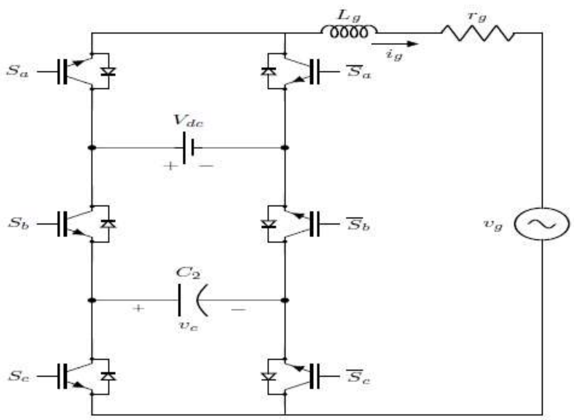


Fig.1. Grid-connected seven-level packed U-cell inverter

Author hamza makhamreh et. all (2019) presented seven level PUC grid connected inverter. This topology got seven level output voltage with less number of switches (six switches). Authors an effective and robust finite- control-set SMC introduced for gird connected inverter [2]. Table .1 shows switching pattern for seven level inverter.

Table 1:PUC7 Switching States and Output Terminal Voltages

index (i)	s_1	s_2	s_a	s_b	s_c	v_i	$v_i\|_{v_c=E}^{v_{dc}=3E}$
1	+1	0	1	0	0	v_{dc}	$3E$
2	+1	−1	1	0	1	$v_{dc}-v_c$	$2E$
3	0	+1	1	1	0	v_c	E
4	0	0	1	1	1	0	0
	0	0	0	0	0	0	0
5	0	−1	0	0	1	$-v_c$	$-E$
6	−1	1	0	1	0	$-v_{dc}+v_c$	$-2E$
7	−1	0	0	1	1	$-v_{dc}$	$-3E$

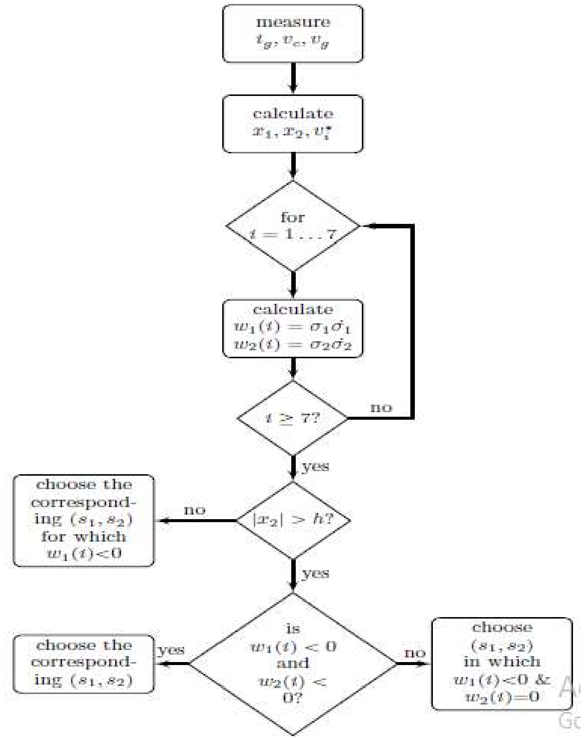


Fig.2. flowchart of finite control set-sliding mode control algorithm

Fig .2 shows control FCS-SMC algorithm. This controller measures the grid voltage and current values, and then it calculates the system error.

Three experimental tests conducted in reference [2] first test dynamic response, second test parameter mismatch test and third test voltage ride-through capability test. In Dynamic response test Output current reached reference current under, fast response 100% change in the grid reference current. In voltage ride-through capability test voltage sag and voltage swell tests were conducted. In grid voltage sag test, a reduced by 15% the grid voltage rms and grid voltage swell test, an increased by 15% of the grid voltage. In both sag and swell tests the effective of the FCS-SM controller injects a pure sinusoidal grid current.

B. SMC for Packed U-Cell Inverter [3]

Autor f. sebaaly et. all introduced (2019) SMC for packed U-cell five level (PUC5) grid connected inverter[3]. Fig.3. shows proposed inverter topology. The simulation results the reference current and the measured current waveforms were almost identical.

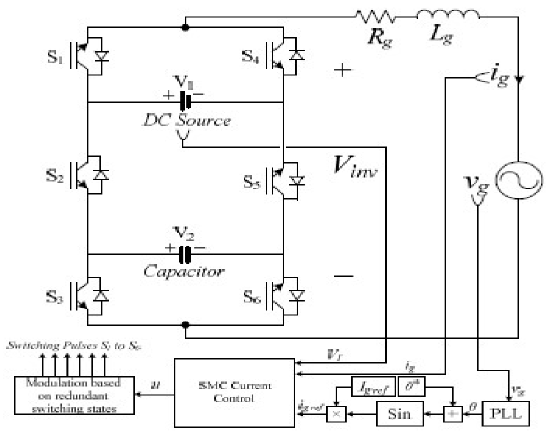


Fig.3. Five level packed U-Cell inverter

C. SVM Based SMC for Grid Connected 3L-NPC Inverter [4]

Fadia sebaaly et. all (2016) presented space vector modulation (SVM) based sliding mode control (SMC) for grid-connected three level neutral point clamped inverter. This hybrid technique decoupled the current and voltage loops, controlled independently [4].

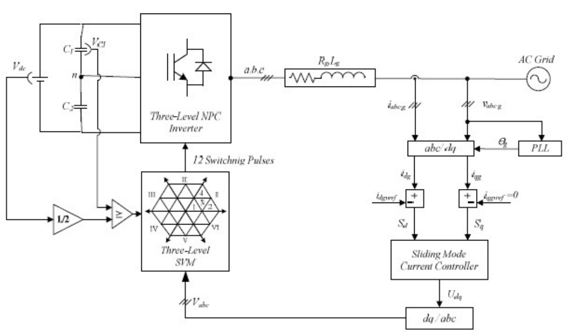


Fig.4. grid-connected 3-level NPC inverter

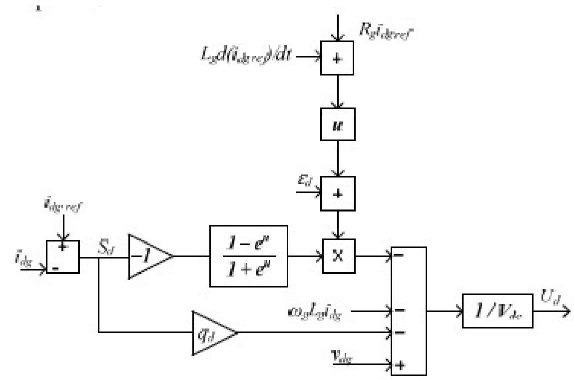


Fig.5 d-axis sliding mode control

This paper sliding mode current controller designed, two sliding surfaces were considered. One is direct grid current and second indirect grid current. Fig.5. shows direct axis sliding mode control. In this paper three phase to two phase transformation used (abc to dq) and controlled dc parameters using SMC controller.

In this reference [4] paper different experimental tests verified, steady state and dynamic state results verified. The output results good dynamic performance, grid connected inverter output current reaches to the international standards IEC and IEEE, the THD of the line current obtained 1.8% with Power factor =0.997

D. Grid Connected Trinary Hybrid Multilevel Inverter [5]

Miguel vivert et. all. (2017) presented a variation of sliding mode control to supply current to the grid by a trinary hybrid multilevel inverter. Fig.6 shows a schematic of the trinary hybrid multilevel inverter. Reference [5] explains in detail the operation of the inverter. In nonlinear system PI controller does not has a good response when the reference current has on leading or lagging.

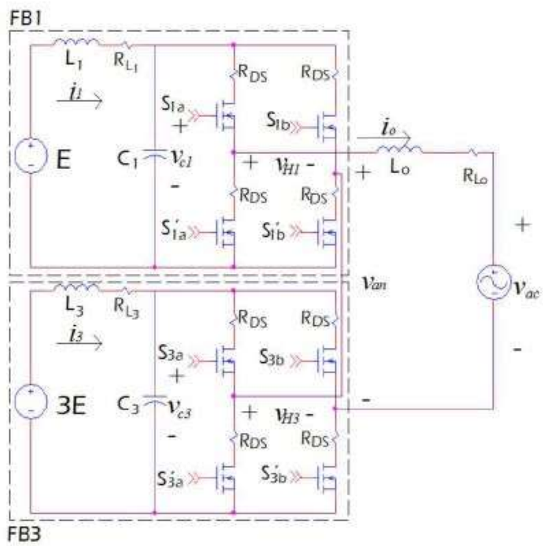


Fig.6 Grid connected Trinary Hybrid Multilevel Inverter (THMI)

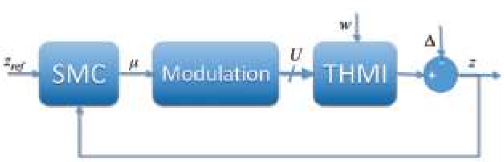


Fig.7 block diagram of closed loop system

The simulation results trinary hybrid multilevel inverter output current never losses the reference current while the input voltage source varying from 130V to 170V. Compared SMC and PI controller results; sliding mode control presents a relative error considerably lower than the PI controller, SMC better tracking response and higher disturbance elimination.

E. Fuzzy-Sliding Mode Control Seven Level Cascaded H-Bridge Inverter

Dual star Induction motor (I.M) drive fed by multilevel inverter presented in reference [6]. Fig.8. shows Fuzzy-sliding mode control (FSMC) methodology speed control for an indirect filed oriented control method of multi-phase induction motor drive. In this paper two control techniques applied induction motor. The first one based on a linear PI controller and second one non-linear fuzzy sliding mode.FSMC responded very quickly reference speed (1000, 2000 and 2500 rpm) step change condition. Experimental results verified motor speed response, torque response in different modulation index levels. Compared simulation results FSMC and PI controller, FSMC track very quickly, dynamic performance, stability robustness compare to conventional PI controller.

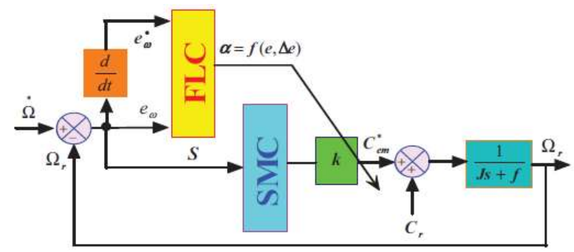


Fig.8 Block diagram fuzzy sliding mode.

F. Active and reactive power control in MLI based DG system using SMC.

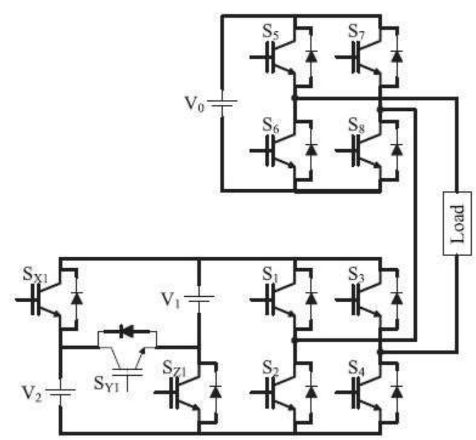


Fig.9 Reduce switch count 11-level asymmetrical MLI

Reference [7] presented reduced switch count switched series/parallel converter.

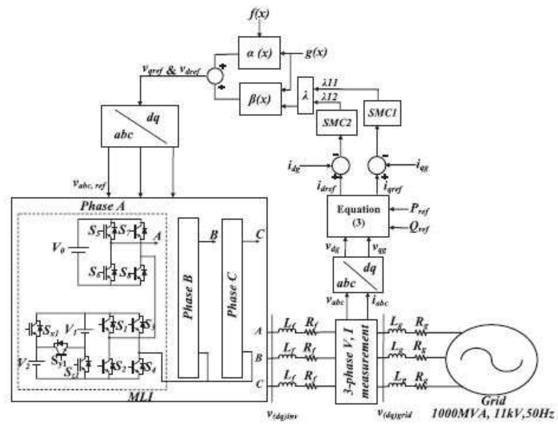


Fig.10 Active and reactive power control using sliding mode control

In [7] multilevel inverter based Distributed Generation (DG) System supplied power to the grid. The DG system output voltage 11kV connected to grid, the THD in output voltage 11.93%. Three experimental tests conducted this paper first test real power change reference was changed from 0.8 to 1 p.u and reactive power reference was changed from 0.3 to 0.4 p.u at 17s. The performance of PI was on equality with SMC, except for the slight delay in settling at the new reference powers. In second test real power changed from 1 to 0.8 and reactive power changed from 0.4 to 0.3. Fig.17. PI results a large undershoots when compared with SMC. In third test reference active power constant and reactive power changed from 0.4 to 0.3 pu. The THD in output voltage 11.93%. Simulation results compared sliding mode control (SMC) and PI controller. The MLI with sliding mode control override the frequency disturbances.

G. SMC For Cascaded MLI

Auther vinh quan nguyen et. all (2019) presented nine level inverter. The experimental results both case the balanced and unbalanced of DC sources, dynamic response, reduced common-mode voltage, reduces the number of switches [8].

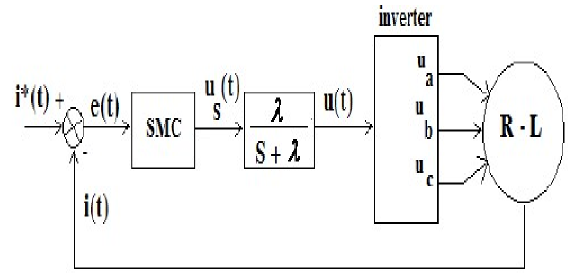


Fig.11. the SMC scheme with a low passes filter.

III SLIDING MODE CONTROL 3-PHASE 3-LEVEL MLI

Author J.Fernando et.al (2000) presented space vector alpha-beta sliding mode current controller for 3-phase multilevel inverters. The main objective of the proposed controller reducing current harmonics in 3-phase multilevel inverter under steady. Fig.11 shows simulation results output current step from 2A to 4A and 4A to 2A, obtained fast transient response and the balanced three phase output currents. The laboratory prototype results verified 200V, 3KW three phase three level inverter [8-9].

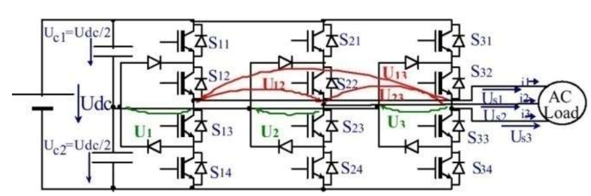
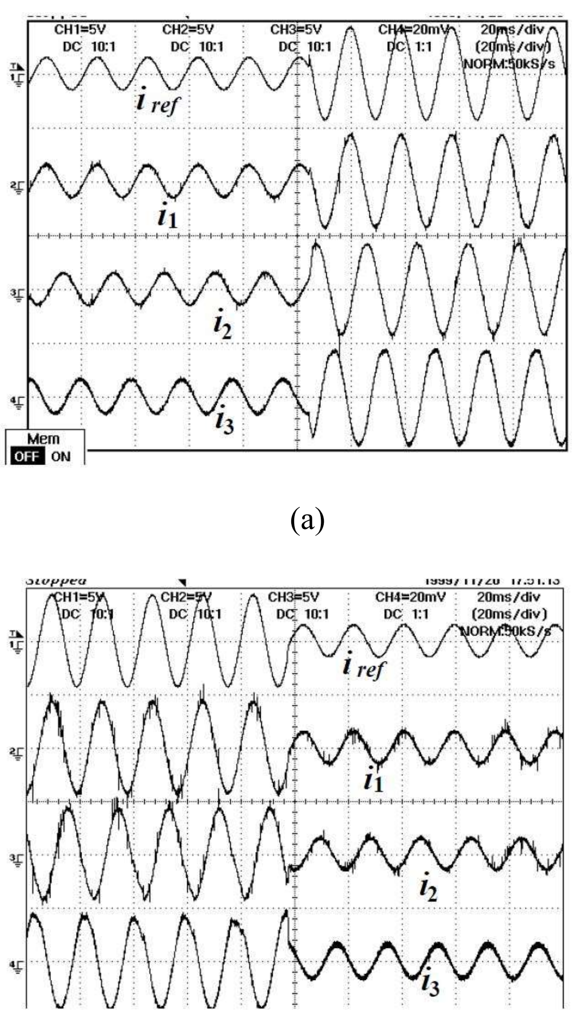


Fig11. Three phase Neutral point clamped inverter



(a)

(b)

Fig. 12 output current step change (a) 2A to 4A (b) 4A to 2A

Author sena huseinbegovic et.all. (2012) presented SMC based direct power control (DPC) of 3-phase grid connected MLI. The proposed methodology controlled active and reactive power independently, compared results direct and indirect selection of switching sequence during various reactive and active power references. The THD factor of the output current 4% direct selection of switching sequence and 5% indirect selection sequence. SMC used for direct selection of switching and SVM used for indirect selection of switching sequence. SMC based direct power controller good dynamic response, low sensitivity to parameter variations and easy implementation compare to DPC-SVM [10].

Authors kalyanraj and lenin prakash (2016) presented constant frequency sliding mode current control [11] based 3-phase grid connected MLI for distributed generation system. The main objective of proposed methodology reducing output current harmonics in grid connected inverter, the presented inverter parameters input DC supply 415V and output voltage 110V and load resistance and inductance are 5 ohms, 16.5mH. The results obtained good dynamic reaction in reference current step change condition from 3A to 6A and current THD 2.62.

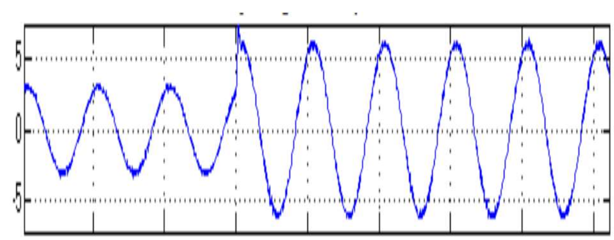


Fig.13. Inverter output current step change from 3A to 6A

Author Natalia M.R. santos et. al. (2014) presented fault tolerant control in three level active NPC inverter using SMC controllers. The proposed methodology maintains balanced three phase output currents under fault operation [12]. Saban ozdemir et. all (2018) presented SMC based 3-phase 3-level two-leg NPC inverter for distributed generation system. The proposed [13] inverter topology reduced 4 switches, 2 diodes compare to conventional three phase NPC inverter. SMC methodology good transient response reference current step change condition from 10A to 20A. THD levels of the grid currents 1.01% and 0.51% for 10A and 20A. fig13. Showing single phase output current.

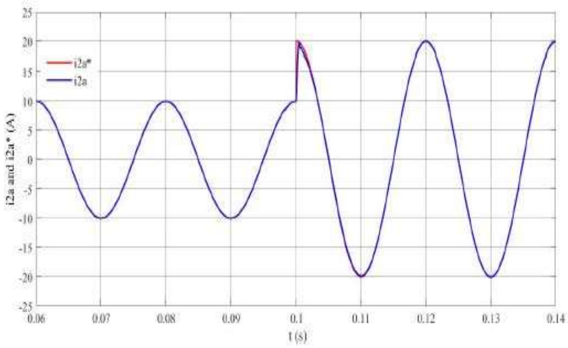


Fig.14 transient response of load current (i_{2a}) and current and reference current (i_{2a}^{*}) step change from 10A to 20A

IV SLIDING MODE CONTROL SINGLE PHASE INVERTERS

Author hasan komurcugil (2010) presented rotating sliding surface for single phase UPS. Rotating sliding mode controlled UPS verified simulation results . The THD of the output voltage 3.11 % and the fundamental amplitude as 195.5V. The main advantage of the rotating sliding surface low THD compare to other SMC, good dynamic response of the UPS inverter [14]. Author hasan komurcugil (2011) presented fast terminal sliding mode control (FTSMC) for 1-ph USP inverters. FTSMC simulation results compared conventional TSMC, FTSMC output voltage198.6 THD 2.79 and conventional TSMC output voltage 195.7 THD 3.79. FTSMC steady-state error lower compare to conventional TSMC [15]. Author hasan komurcugil (2012) presented rotating sliding line based SMC for single phase UPS inverter and simulation results verified in Matlab, the results are good dynamic response and output voltage of THD is 2.66 [16]. The single phase VSI injects an ac current with the requirement of specific frequency and minimum THD into the grid via a robust second-order sliding mode control [17]. In [18] multi input multi output (MIMO) based SMC for single phase inverter presented, this control technique achieved good results under steady state response and dynamic response, steady state error at output is zero due to proportional resonant (PR). The experimental results were obtained from the setup OPAL-RT platform.

In [19-20] single phase grid connected inverter and single phase UPS inverter, the results were obtained very fast output-voltage and current responses to various nonlinear load disturbances. The output current good dynamic response current change from 10A to 20A and back to 10A, the output current THD 1.4 %.
Sliding mode control based DC link three phases Z-source inverter presented in [21]. Sliding mode control controlled both input DC voltage and output voltage. Fig.4 shows inverter input capacitor voltage with good tracking and rejected input disturbances.
Majority of the researchers proposes the various control methodologies on Sliding Mode Control (SMC) inverter output parameters like voltage and current [22-23] sliding mode control single phase inverter, [24] second order sliding mode control, [25] adaptive fuzzy sliding mode control,

V CONCLUSION

In this paper an extensive review of the state-of-the-art implementation of SMC for multilevel inverters and single- phase inverters.

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