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Hybrid Multilevel Topology Based High Power Quality Inverter

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***Abstract*— An ever increasing demand of high power quality inverters that much less pollute the grid has enhanced researchers' interests in Multilevel Inverter topologies. This paper investigates Neutral point clamped (NPC) inverter topology for designing a high power quality inverter for miscellaneous applications specially for AC motor drives , as Induction motors draw the major chunk of power from grid. It is found that NPC is the most suitable topology for AC motor drives applications. Moreover, a hybrid NPC-H bridge topology further improves the power quality by mitigating harmonic contents to very low level.**

Keywords*— NPC, Inverter, Hybrid topology, Multilevel, AC motor drive, Power quality

I. INTRODUCTION

Power quality is now a major concern of utilities. Many quality parameters such as Total harmonic distortion(THD), harmonic Factor(HF) etc forms the basis of performance analysis of inverters. These are the main elements of many power applications such as Variable speed Motor Drives, Active filters, FACTS etc. The benefits of using Power Electronics converters are manifold but the main drawback is the deterioration of quality of Power supply system. These are known to pollute the grid with high frequency unwanted harmonics which lead to increased losses and decreased efficiency besides lowering down supply Power factor. The requirements set by IEEE for permissible harmonic contents in the Inverter output is ≤5% [1] Conventional SPWM converters require high frequency switching for chopped alternating square wave output so as to lower down the harmonic contents but it also require filters at the output stage (Fig.,1). High frequency voltage transitions lead to EMI problems and increased switching losses.

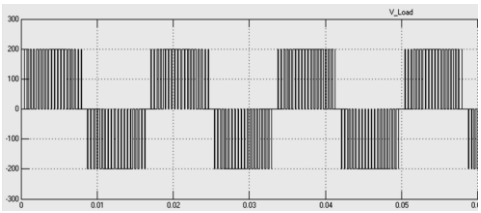

Fig.1 *PWM output of a conventional 2-Level(2L) converter*

On the other hand, use of inverter driven motors are now being considered as potential energy saving method for industrial, commercial and residential load [2].However, low power quality inverters lead to supply system deterioration and become the major contributor to grid pollution. Multilevel inverters (MLI) presents an alternative for avoiding these undesirable traits and also make it possible to design inverters for MV and HV applications [3]. These generate near sine-wave, (instead of square) by synthesizing multiple input DC voltages (termed levels) and has many advantages e.g., low THD, reduced dv/dt stress on switches, low EMI, independent operation of switches connected in a string, ride through power and voltage rating limitations of available semiconductor switches and low switching losses because of the ability to work at power switching frequency [4].

II. MLI TOPOLOGIES & WORKING

A. *Conventional and Hybrid Topologies*

Many topologies of MLI are available for various industrial applications[5]. Among these Neutral point clamped (NPC), Flying Capacitor(FC) and Cascaded H-bridge(CHB) inverter are the basic topologies. The CHB is formed by several H-bridges connected like chain links. It utilizes minimum number of switches but requires multiple separate DC voltage sources such as batteries, PV modules, Fuel cells etc and therefore are suitable for applications such as power conversion from PV / Fuel cells, and battery powered Electric Vehicle (EV/HEV). For industrial motor drives, the main impediment is availability of multiple DC sources for H-bridge cells. The FC topology generates output voltage levels through pre-charged input DC capacitors and also requires additional capacitors for voltage balancing. However to maintain capacitor voltage balancing, high frequency switching is necessary[6]. NPC topology proposed by Nabae[7], is widely used in industrial applications upto 6kV. This topology is formed by dividing input DC source voltage by means of Capacitor string and various capacitor voltages are tapped and added together to synthesize a stepped Sine wave. The number of input DC capacitors are one less than the required output voltage steps (or levels).It mainly introduces a zero-volts level into the conventional inverter's output voltage. The basic NPC inverter is shown in Fig.2 and

can be seen as having two additional switches in the middle, of otherwise single phase conventional half-

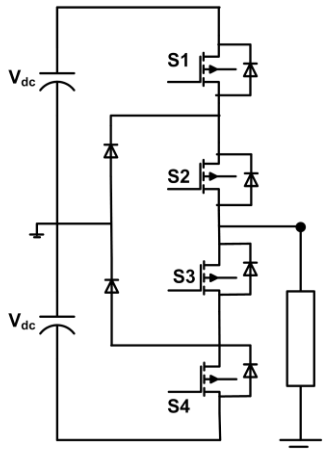

Fig.2. *Single leg of Neutral point clamped Inverter*

bridge Inverter. Each switch is clamped through diode(s) to the neutral point formed at the junction of two equally charged input DC capacitors. The capacitors must remain equally charged or balanced to obtain a perfect zero or reference level for upper (positive) and lower(negative) side capacitor voltages. A three phase converter is realized by adding two more phase legs which are supplied by the same input DC capacitors as for the phase legNo.1. Thus, it precludes the requirement of separate DC sources for each phase and is the main cause of attraction for Industrial AC motor drives applications.

B. Working Principle Of NPC Topology

An NPC converter leg consists of four switching devices (MOSFETS/IGBTs), two diodes and two input capacitors to produce a three- level voltage output. For an 'm-level' output, the required input DC capacitors are 'm-1'. When a 3-phase inverter is designed for m-levels per phase, it provides '2m-1' levels line to line, thus achieves higher quality output. On the input side, bipolar three phase half wave rectifier system can be used for this purpose as it provides perfect neutral reference point. In a NPC converter, clamping diodes serve to provide neutral (0-level)to the output when middle two switching devices are on. This function of NPC is most important when extended to two or three legs structure. To minimize gate logic, the gating scheme has inverted logic such that $S1 = \overline{S3}$ and $S_2 = \overline{S4}$. The topology, however, suffers from large number of clamping diodes when number of levels is increased. It is also affected by capacitor unbalancing problem, when the output levels are increased above 3-Levels phase to neutral (or 5-level phase to phase)[8]. To overcome this problem, redundant switching states are used with advanced modulation technique such as SVM but due to complexity of control, it has been so far restricted to 3L phase to neural in many MV industrial drives [9].The NPC has been implemented in numerous applications of Industrial drives. As this topology can easily employ back to back configuration; it has been used for regenerative braking applications such as conveyors for mining industries [10]. Moreover, many hybrid topologies have been worked out for MLI. Among them, Hybrid NPC-H-bridge topology [11] places NPC legs in the conventional H-bridge. This way, a single phase NPC-H bridge produces a 5-level output as each NPC leg is able to generate 3-levels. The benefit is enhanced power quality and low THD at the inverter output.

III. DESIGN OF SINGLE PHASE NPC INVERTER

In this section, designing of conventional single phase NPC and thereafter a Hybrid NPC design is discussed.

A. Basic NPC Inverter Design

A single phase 3-level NPC is designed using 4 MOSFET switches and clamping diodes. To minimize switching losses, power frequency switching (time period T=20ms) is performed and the design is simulated using MATLAB-Simpower Blockset in SIMULINK. Choosing a delay (0-level) of 1.9ms ($\alpha 1 = 0.597°$) for Positive and negative levels, the FFT analysis in Powergui (Fig. 3b) shows THD of only 27% with all even harmonics almost vanished and no DC offset. Thus the topology achieves much better quality output even at fundamental switching frequency(50Hz)which a conventional 2-level converter can give only by resorting to high frequency switching i.e., SPWM.

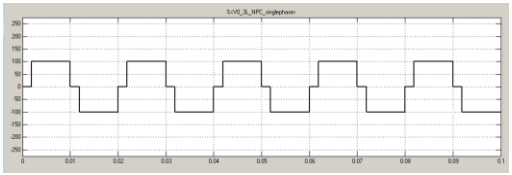

Figure 3a. *Output of a 3L NPC*

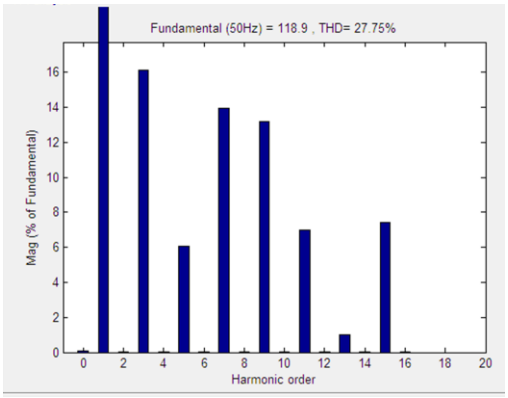

Fig 3b *FFT Analysis of 3L converter output*

B. Hybrid NPC-H Bridge Inverter design

This topology places NPC legs in conventional H-bridge (Fig. 4). As each NPC leg gives a 3-L output; the potential difference between the two NPC legs is a 5-level output Thus the converter power quality is even higher now. Table 1 shows the switch states of NPC legs to achieve a 5-level output. Following the Sine

wave pattern, the switching instants for all levels are determined, and design is simulated in MATLAB-SIMULINK. and performance of inverter is analyzed using FFT tool in powergui. The converter output (Fig.5a) and the corresponding Harmonic profile

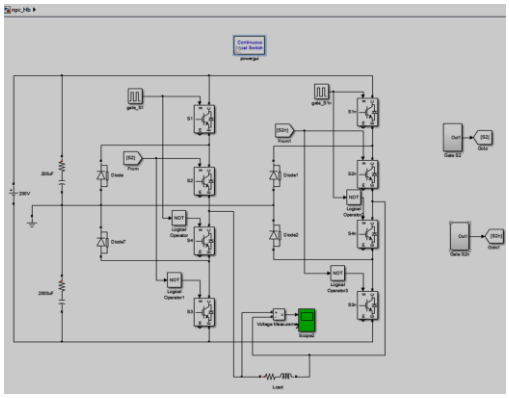

Figure 4 *MATLAB simulation of Single phase NPC_H bridge*

TABLE I. SWITCH STATES FOR 5L OUTPUT

NPC Leg a		NPC Leg b		Converter output
V_a	*Switch* state	V_b	*Switch state*	$V_{ab} = V_a - V_b$
0	S2,S3=1	0	S2n,S3n=1	0
$+V_{dc}$	S1,S2=1	0	S2n,S3n=1	$+V_{dc}$
$+V_{dc}$	S1,S2=1	$-V_{dc}$	S3n,S4n=1	$+2V_{dc}$
$-V_{dc}$	S3,S4=1	0	S2n,S3n=1	$-V_{dc}$
$-V_{dc}$	S3,S4=1	$+V_{dc}$	S1n,S2n=1	$-2V_{dc}$

(Fig.5b) shows significant reduction in THD to 17.19% without SPWM. This exhibits high quality output while minimizing switching losses, increased efficiency and simple control strategy of the converter.

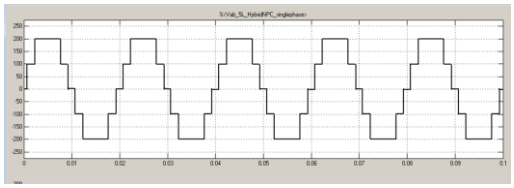

Figure 5a. *Converter output of 5L NPC_H bridge*

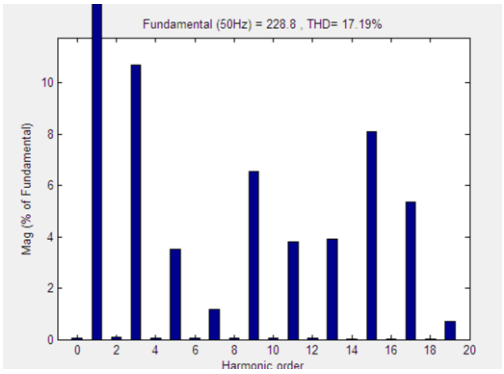

Figure 5b. *FFT analysis in Powergui of 5L NPC-H bridge*

In Fig 5b, Harmonic profile shows considerable 3rd,5th and 7th harmonics. These can be eliminated easily by selective harmonic elimination techniques which are very much suitable for Multilevel Inverter and inverter may be deigned without any filter requirement [12].However, if minimization of THD is targeted, then using switching angles $\alpha_1 = 12.8°$ and $\alpha_2 = 41.8°$ as suggested by Carlos et al. [13], yields further reduction of THD to 16.43%, as shown by FFT analysis in powergui, (Fig. 6)

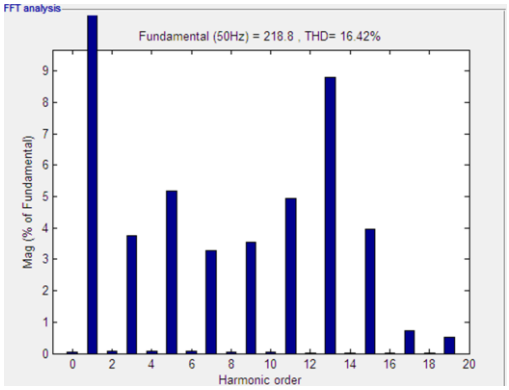

Figure 6. *THD minimization using* $\boldsymbol{\alpha_1 = 12.8°}$ *and* $\boldsymbol{\alpha_2 = 41.8°}$

C. *Hardware implementation*

The simulated model of hybrid NPC topology is implemented through hardware for a 220V inverter. The prototype consists of two High side MOSFETs IRF9640 and two low sides n-channel MOSFETS IRF840. The input DC link stage comprises a 3-phase rectifier to achieve minimum ripple contents. The rectified DC is split by means of DC link capacitors of 2200µF. These serve to filter out non DC components from the rectified input voltage. Hardware based model (Fig.7a and 7c) of the NPC converter was realized using fundamental switching frequency. For gate-drive logic, Arduino programmer was used owing to its easy serial interface and programming features. The prototype successfully generated 5-level output waveform. Fig.7b shows a proper 5 level output waveform of the converter . The multilevel output waveform as shown in Fig.,7(b) producing peak voltage of 80 volts in two steps of 40,40 volts. Also included in the module is DC voltmeter which measures the DC link voltage and the input three phase high power snubber resistors and capacitors for reduced switching stress on the MOSFETs.

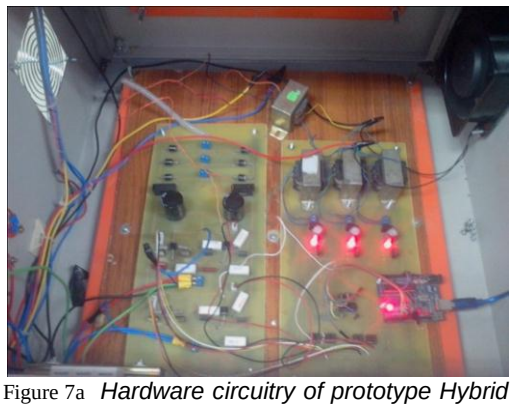

Figure 7a *Hardware circuitry of prototype Hybrid NPC Inverter*

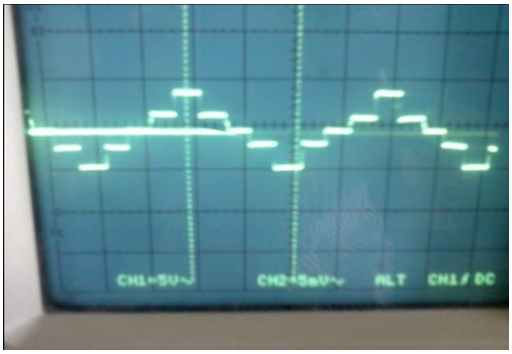

Figure 7b *5 Level output of prototype model*

Figure 7c *The complete Prototype Model*

CONCLUSION

Hybrid-NPC inverters provide high quality output voltage and can be operated at fundamental(power) frequency switching. This greatly simplifies control, reduces switching losses and excludes unwanted harmonic content in converter output. Thus use of Multilevel Hybrid NPC Inverters, instead of conventional SPWM inverters, can greatly help reducing grid pollution that is caused by nonlinear loads.

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