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Total Harmonic Distortion Alleviation by using Shunt Active Filter

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ABSTRACT: *This paper presents a new topology for multilevel Current source converter. The new converter uses parallel connections of full-bridge cells. Also by Adding or removing the full-bridge cells, modularized circuit layout and packaging is possible, where the number of output current levels can also be easily adjusted. Using adequate levels, the multilevel current converter generates approximately sinusoidal output current with very low harmonic distortion. Based on this converter a shunt active filter has been modeled. The simulation results of the lacking shunt active filter and through shunt active filter in controlled rectifier shows that the THD alleviation by means of shunt active filter.*

Key words: *Multilevel Converter, Shunt Active Power Filter, Power Quality*.

I. INTRODUCTION

Recently multilevel power conversion technology has been a very rapidly growing area of power electronics with good potential for further developments. The most attractive applications of this technology are in the medium to high-voltage range[1] Multilevel converters work more like amplitude modulation rather than pulse modulation, and as a result:

• Each device in a multilevel converter has a much lower dv/dt The outputs of the converter have almost perfect currents with very good voltage waveforms because the undesirable harmonics can be removed easily,
• The bridges of each converter work at a very low switching frequency and low speed semiconductors can be used and
• Switching losses are very low [2].

The general function of the multilevel converter is to synthesize a desired output voltage from sev- eral levels of DC voltages as inputs. The DC volt- age sources are available from batteries, capacitors, or fuel cells. There are three types of multilevel con-verters:

• Diode-Clamped Multilevel Converter
• Flying-Capacitor Multilevel Converter
• Cascaded-Converters with Separated DC Sources

The first practical multilevel topology is the diode-clamped multilevel converter topology and first in-troduced by Nabae in 1980 [3]. The converter uses capacitors in series to divide the DC bus voltage into a set of voltage levels. To produce N levels of the phase voltage, an N −level diode-clamp converter needs N-1 capacitors on the DC bus. The flying capacitor multilevel converter proposed by Meynard and Foch in 1992 [4], [5]. The converter uses a ladder structure of the DC side capacitors where the volt-age on each capacitor differs from that of the next capacitor. To generate N −level staircase output volt-age, N − 1 capacitors in the DC bus are needed.Each phase-leg has an identical structure. The size of the voltage increment between two capacitors de-termines the size of the voltage levels in the out-put waveform The last structure introduced in the paper is a multilevel converter, which uses cascade converters with separate DC sources and first used for plasma stabilization [6], it was then extended for three-phase applications [7]. The multilevel converter using cascaded-converter with separate DC sources synthesizes a desired voltage from several independent sources of DC voltage. A primary advantage of this topology is that it provides the flexibility to increase the number of levels without introducing complexity into the power stage. Also, this topology requires the same number of primary switches as the diode-clamped topology, but does not require the clamping diode. However, this configuration uses multiple dedicated DC-busses and often a complicated and expensive line transformer, which makes this a rather expensive solution. In addition, bidirectional operation is somewhat difficult (although not impossible) to achieve [8]. Modularized circuit layout and packaging is possible because each level has the same structure, and there are no extra clamping diodes or voltage balancing capacitor. The number of output voltage levels can be adjusted by adding or removing the full-bridge cells The converters that were focused upon were volt-age source converters, with multilevel voltage wave-forms. These converters divide the total input voltage among a number switches, and allow a reduction of the voltage harmonics. As mentioned, these are the most commonly used and best-understood multilevel converters. The most multilevel converters discussed in the literature are multilevel voltage source con verters [9]. However, in many current applications, such as shunt active filters, active power line conditioners, VAR compensations etc., we need to use multilevel current converters. This paper presents a new multilevel current converter. Then the proposed multilevel current source converter is the core of a shunt active filter, which is obtained based on this converter. The proposed new multilevel current converter consists of a set of par-allel single-phase full-bridge converter units. The AC current output of each levels full-bridge converter is connected in parallel such that the synthesized current waveform is the sum of the converter outputs. In other words, for high current applications many switches can be placed in parallel, with their current summed by inductors.

II. THE PROPOSED MULTILEVEL CURRENT CONVERTER

II.1.The Proposed Topology

The full-bridge topology is used to synthesize a three-level square-wave output current waveform. The full-bridge configuration of the single-phase current source converter is shown in Fig1.

In as single-phase full-bridge configuration, four switches are needed. In full-bridge configuration, by

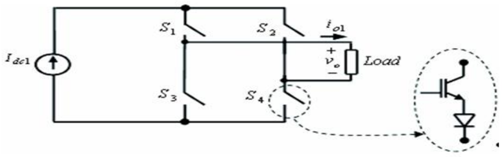


Fig.1. A multi level current converter

Turning the switches S_1 and S_4 on and S_2 and S_3 off a current of I_{dc1} is available at output i_{o1}, while reversing the ing the operation we get current of i_{dc1}. To generate zero level of a full-bridge converter, the switches $S_1$and S_3 are turned on while S_2 and S_4 are turned off or vice versa. The typical output waveform of full bridge of single-phase multilevel shown in Fig.1 is shown in Fig. 2

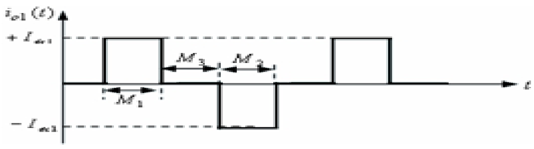


Fig.2. Typical output wave form of three level configuration

The three possible levels with respect to above discussion are shown in Table 1. Note that S_1 and S_2 should not be open at the same time, nor should S_3 and S_4. Otherwise, an open circuit would exist across the DC current source.

Table 1: output current with corresponding conditions

MODES	CONDUCTING SWITCHES	OUTPUT CURRNT
1	S1,S4	$+I_{dc1}$
2	S2,S3	$-I_{dc1}$
3	S1,S3 or S2,S4	0

Fig.3 shows equivalent circuits of the proposed topology at different modes.

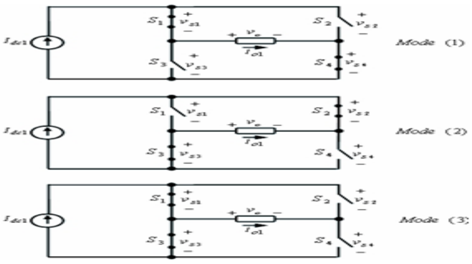


Fig.3. The Equivalent Circuits of the Proposed Topology at Different Modes

From Fig. 3, the instantaneous switches voltages of each module are given in Table2

Table 2: Instantaneous switches voltages

Mode	Vs1	Vs2	Vs3	Vs4
1	0	Vo(t)	Vo(t)	0
2	-Vo(t)	0	0	-Vo(t)
3	0	Vo(t)	0	-Vo(t)

Using parallel connections of many converters like the one shown in Fig. 1, we can synthesize multi-level current converter. The general function of this multilevel current source converter is to synthesize a desired current from several independent sources of DC currents. Fig. 3 shows a single-phase struc-ture of a parallel converter with a separate DC cur-rent source. By different combinations of the four switches, S_1−S_4, each full-bridge converter can gener-ate three different current outputs, $+I_{dc1}$, $-I_{dc1}$ and zero current. The AC outputs of each of the different level of full-bridge converters are connected in par-allel such that the synthesized current waveform is the sum of the converter outputs. An output phase current waveform is obtained by summing the output currents of the converter bridges:

$$I_{ON}(t) = i_{o1}(t) + i_{o2}(t) + \cdots + i_{on}(t) \qquad (1)$$

Where N is the number of parallel bridges [10].

In the following we propose a new method for determining the levels of different DC current sources, which are used in the proposed multilevel converter.

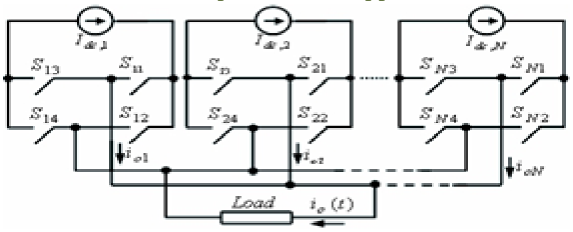


Fig.3. Single phase parllel multilevel current source converter

II.2. DETERMINING THE LEVELS

If all DC current sources in Fig. 3 are equal to I_{dc} the converter is then known as symmetric multilevel current source converter. With having a number of full-bridge converter units, this technique results in an output current of the converter that is almost sinusoidal.

The maximum output current of the N paralleled multilevel current source converter is

$$I_{MAX} = N * I_{dc} \quad (2)$$

In this topology; the number of overall output current(S) is given by:

$$S = 1 + 2N \quad (3)$$

For example, a 13-level multilevel current source converter using the technique can be implemented as shown in Fig. 4. In Fig. 4, i_{o1} to i_{o6} are DC current supplies, which are from either regulated inductors or separated DC sources.

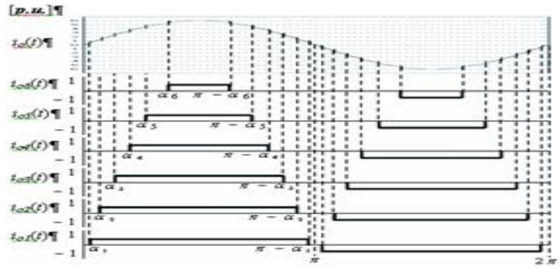


Fig.4 The 13 level converter output

III. THE SHUNT ACTIVE FILTER BASED ON MULTILEVEL CURRENT SOURCE CONVER-TER

III. 1.SHUNT ACTIVE FILTER PRINCIPLE

In recent years, the usage of modern electronic equipment has been increasing rapidly. These elect-ronic equipments impose nonlinear loads to the AC main that draw reactive and harmonic current in ad-dition to active current. In order to overcome these problems, different kinds of active power fil-ters, based on force-commutated devices, have been developed. Particularly, shunt active power filters, using different control strategies, have been widely investigated. These filters operate as current sources, connected in parallel with the nonlinear load generat-ing the current and the current harmonic components required by the load. However, shunt active filters present the disadvantages that are difficult to imple-ment in large scale where the control is also compli-cated. To reduce the drawbacks, the proposed solu-tion in this paper is to use a multilevel current source converter. A shunt active filter consists of a controllable voltage or current source. This topology is shown in fig.5 it consisting of DC link capacitor C, power electronic switch and inductor Lf.

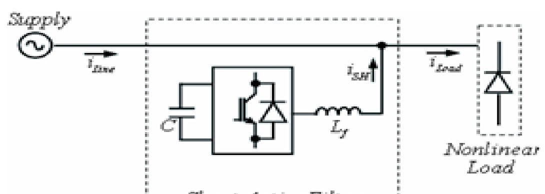


Fig.5 configuration of voltage source converter based on shunt active filter

III.2. SUGGESTED SHUNT ACTIVE FILTER

Fig.6 shows the schematic of the suggested shunt active power filter consisting of the new multilevel current source inverter with a control unit, to solve the power quality problems. The operation of the shunt current source multilevel inverters is based on the injection of current harmonic, i_{SH} , which is in phase with the load current, $i_{Load,}$ thus eliminating the harmonic current of the line(supply) current iLine. Now, suppose that the load current can be written as the sum of the fundamental and harmonic current as in equation (4)

$$i_{Load} = i_{Load,Fund} + i_{Load,Harmonics} \quad (4)$$

Then the injected current by shunt inverter should be:

$$i_{SH} = i_{Load,Harmonics} \quad (5)$$

With resulting the line current

$$i_{Line} = i_{Load} - i_{SH} \quad (6)$$

$$i_{Line} = i_{Load\,,Found} \quad (7)$$

As it is seen, the equation (7) only contains the fundamental component of the load current and thus free from the harmonics.

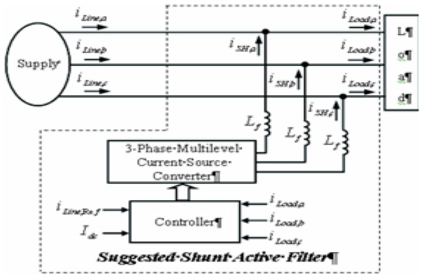


Fig.6. Suggested Shunt Active filter configuration

IV. WITHOUT SHUNT ACTIVE FILTER

The industrial loads usually have complex nonlinear dynamics. In connecting nonlinearities to a power network, they induce some undesirable distortions to the sinusoidal signal of the network. For showing this effect, a three phase controlled rectifier is used as a nonlinear load connected to grid Fig.7 shows the circuit of a three-phase controlled rectifier. The input phase voltages can be written as:

$$v_a = v_m sinw_i t \quad (8)$$

$$v_b = v_m \sin\left(w_i t - {2\pi}/{3} \right) \quad (9)$$

$$v_c = v_m \sin\left(w_i t + {2\pi}/{3} \right) \quad (10)$$

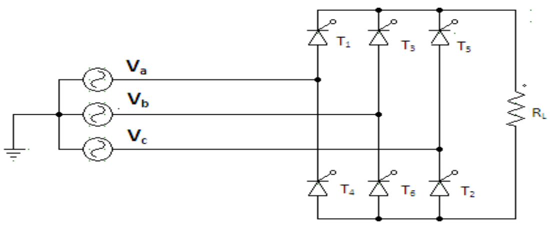


Fig.7. Three Phase Controlled Rectifier as a Nonlinear Load

If the load is assumed a pure resistance, the output current Peak is:

$$I_{MAX} = {\sqrt{3}V_m}/{R_L} \quad (11)$$

In this study, the parameters of the system are as $V_m = 110\sqrt{2}\,V, w_i = 100\pi \; and \; R_L = 40$ohms Fig.8 shows waveforms of input line voltages, load current and line currents. As the Fig.8 shows, nonlinear loads may pollute power lines seriously with their high levels harmonic current and reduction in power factor. Fig.9 depicts the Fast Fourier Transform of ac utility line current Harmonics up to the 20th have been considered. The THD of the input current of the rectifier also the ac utility line current is 103.87%.

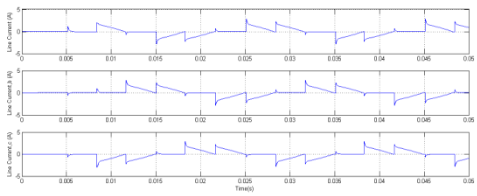


Fig.8. The Outputs of Controlled Rectifier

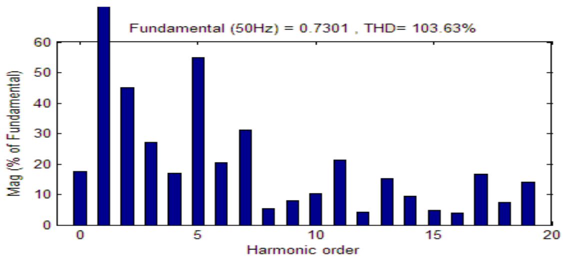


Fig.9. FFT analysis of the line current of Controlled Rectifier

V. WITH SHUNT ACTIVE FILTER

The ability of shunt active filters to suppress these problems has attracted a great deal of attention to these systems. This paper proposed a new struc-ture for shunt active filter based on multilevel cur-rent source converter. For showing the capability of the proposed shunt active filter, a 13 level multilevel current source converter as shown in Fig.10. Fig.11. Shows a single phase structure of the

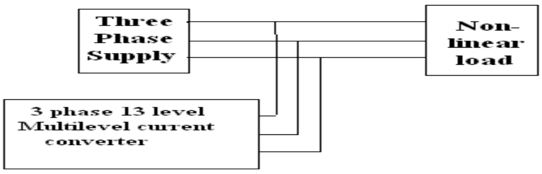


Fig.10. 13 level current converter

Multilevel converter. The converter consists of seven full-bridges with all current sources are equal to *Idc*. Fig. 12 shows the load, line and shunt active power filter output currents. The shunt active power filter with multilevel current converter is able to successfully compensates reactive power and mitigate current harmonics distortions with excellent transient performance.

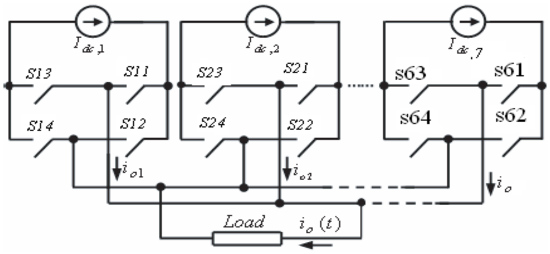


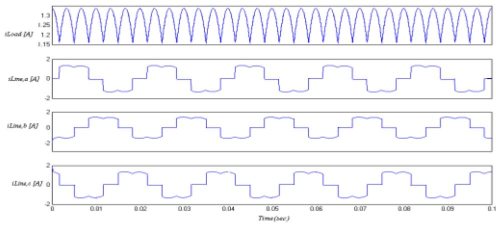
Fig.11. Single-Phase 13-Level Multilevel Current Converter Used in the Shunt Active Filter System

Fig.13. depicts the Fast Fourier Transform of ac utility line current Harmonics with shunt active filter up to the 20th have been considered. The THD of the input current of the rectifier also the ac utility line current is 12.66%.

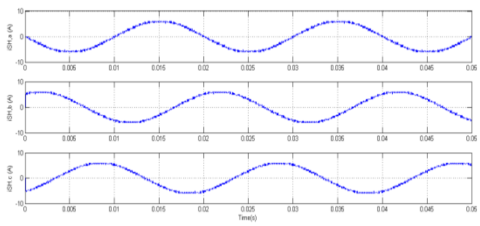
VI. CONCLUSION

In this paper, a new topology for multilevel current source converters has been presented. The most important feature of the system is being convenient for expanding and increasing the Number of output levels. The proposed strategies generate a current with minimum error with respect to the sinusoidal reference. Therefore, it generates very low harmonic distortion.

Load currents



Shunt active filter currents



Line currents

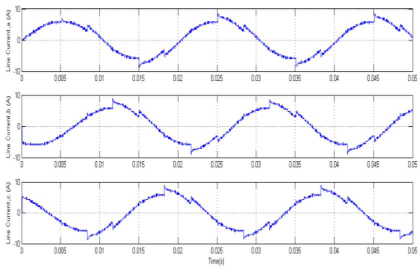


Fig.12. Load, Shunt Active Filter and Line Output Currents

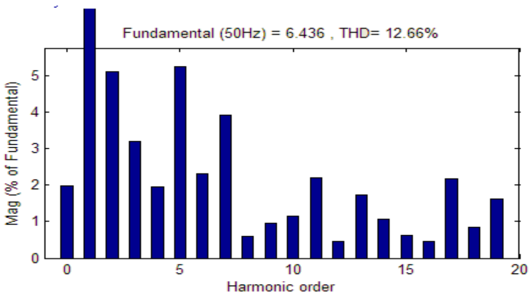


Fig.12. FFT analysis of the line current $i_{A,}$ at ac utility connected through shunt active filter

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