INTERNATIONAL JOURNAL FOR TRENDS IN ENGINEERING & TECHNOLOGY
VOLUME 5 ISSUE 2 – MAY 2015 - ISSN: 2349 - 9303

A Five – Level Integrated AC – DC Converter

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Abstract— This paper presents the implementation of a new five – level integrated AC – DC converter with high input power factor and reduced input current harmonics complied with IEC1000-3-2 harmonic standards for electrical equipments. The proposed topology is a combination of boost input power factor pre – regulator and five – level DC – DC converter. The single – stage PFC (SSPFC) approach used in this topology is an alternative solution to low – power and cost – effective applications.

Index Terms— AC – DC power conversion, five – level converter, harmonic standards, power factor and SSPFC.

I. INTRODUCTION

In recent years the term power quality has been heard more frequently because of its impact on the users of electric power. With the rapid rise in the use of electrical equipment in recent years, power converter manufactures are being pressed by regulatory to implement some form of power factor correction (PFC) in their products [1]. Therefore, low input current harmonics and high input power factor are more and more becoming mandatory performance criteria for power converters.

The non – linear electronic loads connected to the electrical lines degrade power quality because, among other things, they reduce the power factor and introduce harmonic currents into power lines. Therefore, to comply with harmonic standards such as IEC1000-3-2, input power factor correction has to be introduced [3]. IEC 1000-3-2 establishes limits to all equipments with input current less than 16 A. The class D single – phase equipment has a special wave shape and a fundamental active input power between 75 W and 600W.

So far a variety of passive and active PFC techniques have been proposed. The passive techniques may be the best choice in many low – power and cost sensitive applications but, the active PFC techniques are used in the majority of applications due to their superior performance. The active PFC converters can be implemented using either the two – stage approach or the single – stage approach.

The two – stage approach is the most commonly used approach where an active PFC stage is employed as the front – end which establishes a loosely regulated high – voltage DC bus at its output, which serves as the input voltage to a conventional DC/DC stage with a tightly regulated output voltage. While the two – stage approach is a cost – effective approach in high power applications, its cost effectiveness is diminished in low power applications due to additional PFC power stage and control unit.

A low cost alternative solution to this problem is to integrate the active PFC input – stage with the isolated DC/DC output stage. Compared to two – stage approach, the single – stage approach uses only one switch and controller to shape the input current and to regulate the output voltage.

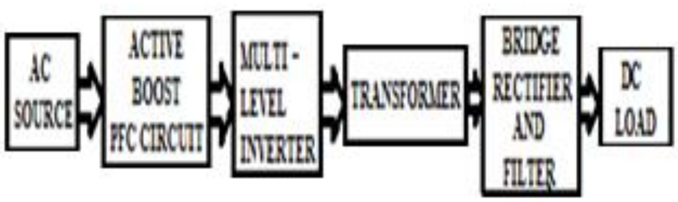

Fig. 1. Block diagram of five – level integrated AC – DC converter

These harmonic standards can be satisfied by adding passive filter elements to the traditional passive diode bridge rectifier/LC filter input combination, but the converters would be very bulky and heavy due to the size of low – frequency inductors and capacitors [2], [8]. It has been found that implementing a modern, high – performance and cost – effective active power factor correction often can help in reducing the total system cost and increase the efficiency of AC power use.

Using an active PFC circuit in the power supply offers a number of benefits. First, the peak current in the input rectifiers and line filter capacitors is reduced. Second, it can be configured to pre – regulate the bulk DC bus voltage, which offers several significant advantages. Third, allowing the minimum duty cycle, this in turn results in lower peak current stress and lower dissipation in power switches [4], [5].

There have been several publications about SSPFC which are widely used in industry, as they are cheaper and simpler converters [6]. Research on the topic of high power AC – DC SSPFC has proved to be more challenging and thus there have been fewer publications [7], [9], [10]. Previously proposed SSPFC converters have certain drawbacks:

(1) Lack of energy – storage capacitors across the primary side of DC bus.
(2) Two converter stages in certain topologies, that allows the power transferred from input to output to be processed only once.
(3) Varying switching frequency control for resonant converters which makes it difficult to optimize their design.

In this paper, a new single – stage AC – DC converter that does not have the drawbacks of previously proposed single – stage converter topologies is proposed. The paper introduces a new converter, explains its configuration, features and design.

II. CIRCUIT CONFIGURATION

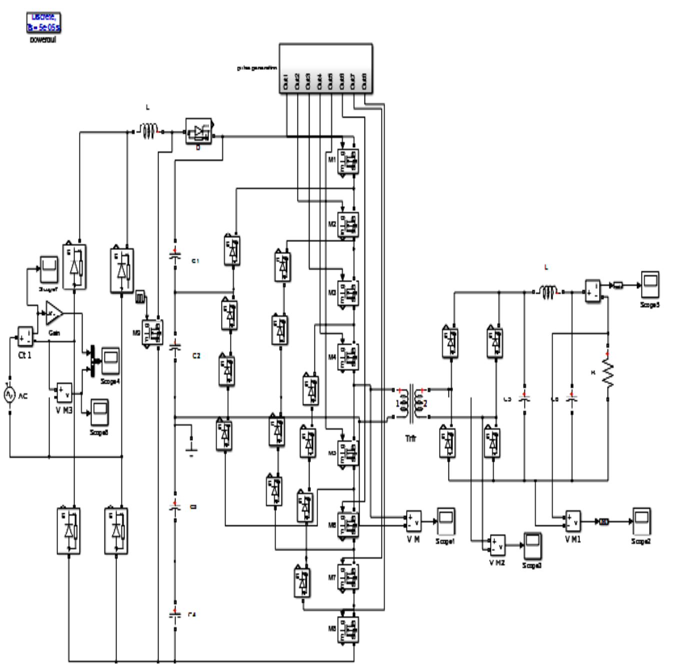

Fig. 2. Simulation circuit of five – level integrated AC – DC converter

The basic circuit configuration of the new five – level integrated AC – DC converter is shown in Fig. 1. In this single – stage topology, AC – DC conversion circuit and DC – DC conversion circuit are integrated together. The active boost pre – regulator shapes the input current and maintains the current harmonics within limits as specified in IEC 1000-3-2. Since a multi – level inverter is used, they can be operated at a lower switching frequency and the switching stress across the device can be considerably reduced. They can also produce high voltage levels with low THD.

TABLE I
INPUT CURRENT HARMONIC LIMITS FOR CLASS D EQUIPMENTS

HARMONIC NUMBER n	CLASS D mArms / W
ODD	
3	3.4
5	1.9
7	1.0
9	0.5
11	0.35
13	0.296
15 through 39	3.85/n
EVEN	
2	-
4	-
6	-
8 through 40	-

The proposed converter topology satisfies the international standard IEC 1000-3-2 for class D single – phase electrical and electronic equipments as listed in the above Table I.

III. CONVERTER DESIGN

A procedure for the design of the converter is presented in this section and is demonstrated with an example using MATLAB. The converter is to be designed with the following parameters for the example:

1) Input voltage: V_{in}= 90 - 265V_{rms};
2) Output voltage: V_o= 12 V;
3) Switching frequency: $f_{SW}=1/T_{SW}$ = 50 kHz;
4) Input current harmonics: IEC1000-3-2 for Class D electrical equipment.

$$T_{SW} = \frac{1}{f_{sw}} \quad (1)$$

Input inductor,

$$L_{in,max} < \frac{V_{bus,min}^2 D_{max}(1-Dmax)^2}{2P_{o,max} f_{sw}} \quad (2)$$

Output inductor,

$$L_{o,min} \geq \left(\frac{v_o^2}{0.5p_{o,max}}\right)\left(\frac{1-D_m}{2}\right)\left(\frac{T_{sw}}{2}\right) \quad (3)$$

A. DIODE BRIDGE RECTIFIER

$$V_{peak} = \left(V_{secondary,rms} \times 1.414\right) - 1.4 \quad (4)$$

$$V_{dc,avg} = \frac{2V_p}{\pi} \quad (5)$$

B. DC – DC BOOST CONVERTER

$$L = \frac{V_{in}(V_{out} - V_{in})}{\Delta I_L \times F_s \times V_{out}} \quad (6)$$

$$I_F = I_{out(max)} \quad (7)$$

I_F = average forward current of the rectifier diode
$I_{out(max)}$ = maximum output current necessary in the application

$$\frac{V_{out}}{V_{in}} = \frac{1}{(1-D)} = \frac{I_o}{I_{in}} \quad (8)$$

C. DIODE CLAMPED MULTI – LEVEL INVERTER

Blocking voltage of clamping diodes

$$V_{diode} = \frac{m-1-k}{m-1} \times V_{dc} \quad (9)$$

Where 'm' is assumed as the number of levels,
Number of clamping diodes (j)

$$j = (m-1) \times (m-2) \quad (10)$$

Number of capacitors at the DC side (c)

$$c = m - 1 \qquad (11)$$

Each capacitor has same voltage E_m, which is given by;

$$E_m = \frac{V_{dc}}{m-1} \qquad (12)$$

Where 'm' denotes number of levels.

Number of freewheeling diodes (d)

$$d = 2(m-1) \qquad (13)$$

IV. CONVERTER FEATURES

The proposed converter has the following features:

1) Reduced cost compared to two – stage converters:
The proposed converter may seem expensive, but the reality is, it can be cheaper than a conventional two – stage converter as it replaces a switch and its associated gate drive circuitry with four diodes. This considerably reduces the cost of single – stage converter, even though the components count seems to be increased.

2) *Better performance:*
The high frequency operation of switches increases the efficiency of the converter and reduces the output ripple, as each section of the converter can be made to operate in an optimal way. The size of transformer and other passive components can be reduced as the frequency of input voltage is inversely proportional to the size of components used.

3) *Increased design flexibility:*
The converter used is a multi – level converter, which can be operated with high DC – bus voltage. There are advantages of operating it with higher DC – bus voltage or with standard DC – bus voltage. This gives the designer options as to how to optimize the design of the converter for other factors such as efficiency profile and cost. It should be noted that this design flexibility makes the design of the five – level converter to be much simpler than that of a single – stage two – level converter or that of a single – stage three – level converter as the DC – bus voltage can be fixed to a desired level that is considered appropriate.

V. SIMULATION RESULTS

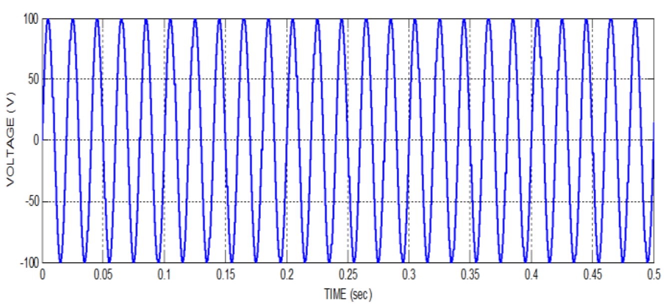

Fig. 3. Input voltage

Sinusoidal input voltage obtained from the AC lines shown in Fig. 3. is directly given to the diode bridge rectifier. This low frequency voltage need not be stepped down before supplying it to the rectifier as it is done in the linear power supply which is an advantageous feature of this topology.

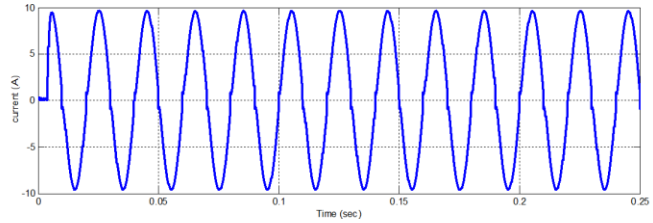

Fig.4. Input current

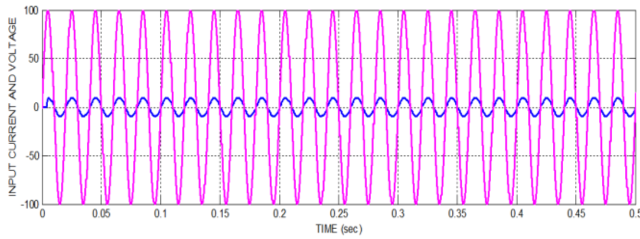

Fig. 5. Input voltage and current

The active boost topology used for input power factor correction, which aligns the input voltage in phase with the input current. Though the input current is in phase with the voltage, it is slightly distorted due to the non – linear loads.

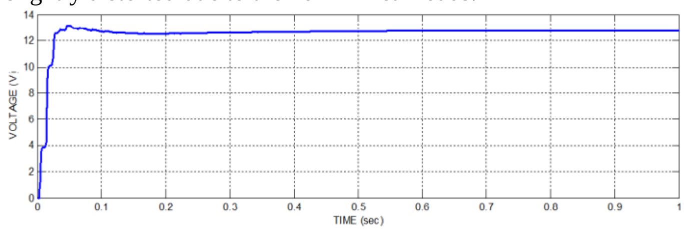

Fig. 6. Output voltage

The output voltage obtained from this topology has reduced ripple content as it is passed through a pi filter before supplying it to the load.

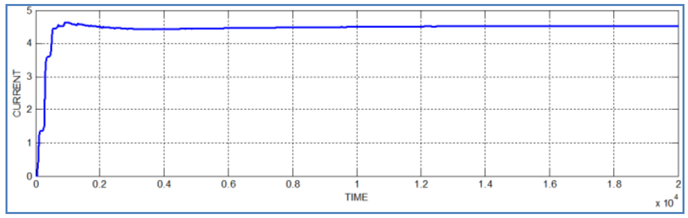

Fig. 7. Output current

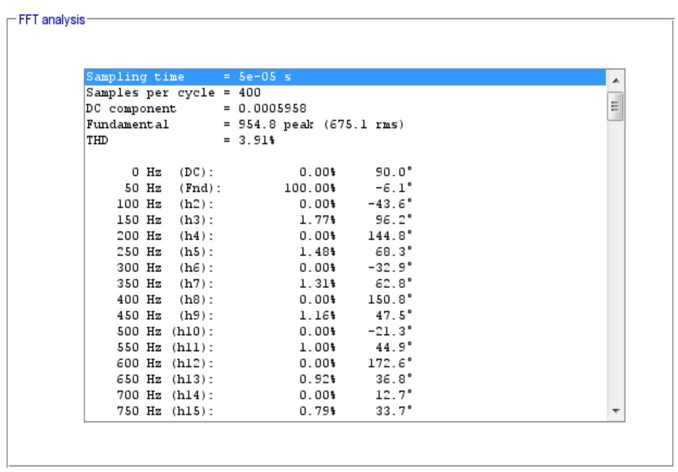

Fig. 8. List of harmonic order

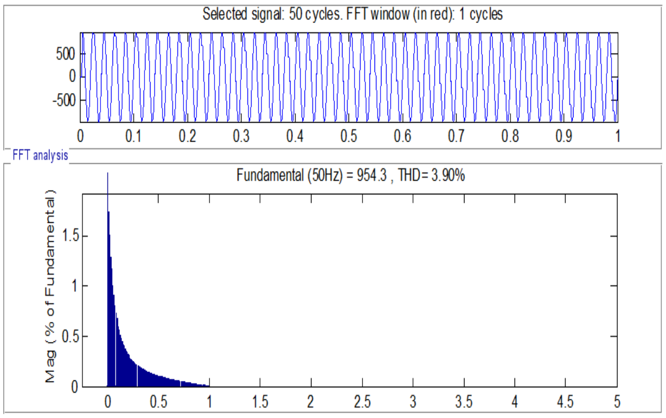

Fig. 9. FFT analysis of five – level integrated AC – DC converter

Fig. 8 and 9 shows input current total harmonic distortion (THD) of the proposed converter. The THD of the proposed converter is 3.91%. The input current harmonics of the proposed converter is complied with the IEC 1000-3-2 class D requirements as the measured power factor is above 0.9.

VI. CONCLUSION

A new multilevel single – stage AC – DC converter that performs input PFC and output voltage regulation is proposed in the paper. The outstanding feature of this converter is that it combines the performance of active boost pre – regulator and multi – level DC – DC converter. The paper introduces the proposed converter, explains its configuration, features and discusses its design. The proposed converter complies with the IEC 1000-3-2 class D specifications and achieves an almost unity power factor at 48 V_{rms} line voltage.

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