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Harmonic Reduction in 3 Phase Single Switch Boost PFC Converter

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ABSTRACT

Now-a- days semiconductor switches, new multilevel converter topologies and advanced converter modulation techniques have contributed to the expansion of voltage source converters (VSCs) to higher voltage and power ratings for utility-scale and motor drive applications. The main objective present with the Boost star three phase single switch converter is to reduce the harmonics and increase the performance of the Boost star 3- phase single switch converter. In this paper we reduce the harmonics in the boost star by using pulse width modulation technique. The paper deals with harmonic elimination pulse width modulation (HE-PWM) for three-phase, two-level boost star converter topologies. HE-PWM for the three-phase two-level converter is initially treated. Different formulations of HE-PWM based on relaxing the symmetry requirements, previously imposed, are investigated. New solution sets are calculated by imposing half-wave symmetry or completely eliminating the symmetry requirements. Based on multiple harmonic performance factors, an evaluation identifies the solution sets that exhibit superior harmonic performance. The theoretical and experimental analysis are verified through experimental work on a laboratory prototype.

Keywords: Power-factor-correction; three-phase; efficiency; Booster converter; Harmonic reduction signal

I.INTRODUCTION

The usage of semiconductor based drives is increased in past very few years. The Voltage source inverters are applicable for these drives as they provide power ratings from hundred to several megawatts. As we know that, in present time whole world is concerned in generation of energy without polluting the environment without wasting any amount of energy. A power factor (PF) correction converter plays a paramount role in ac-dc power conversions. By having PF we can get high PF and low harmonic noise. Active and passive are the two methods present in the PF correction. Active PF have high PF and small in size when compared with the passive PF converters. For implementing active 3-phase PF corrector converter there are many topologies and many control strategies are present [2-10]. By introducing and implementing three or more switches in the three phase PFC converter which produces input-current total harmonic distortion compared with those implemented with a fewer number of switches [8-11] and superior PF . But by introducing three-phase single-switch boost PF Corrector converter has featuring zero current turning on, for the switch, simple control for less cost, which makes the design more suitable for less power consumption and cost effective applications [10].

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In discontinues current mode, high filter converter design are needed to satisfy the elimination f EMI. If we increase the switching frequency, then the volume of the filter will be decreased, but switching loss will occur which leads decrease in the efficiency of the converter. Various methods are of switching losses were present in paper [14, 15] to increase the efficiency. In recent years much resonant architecture have been developed to produce zero current switching activity. The authors in paper [13] and [14] discussed, resonant techniques for producing the achieve zero-current switching (ZCS). In paper, [15] the author introduced active snubber circuit for producing ZCS. In all these architectures additional hardware design are needed which makes the design more complicated and the cost is high. To overcome these in this paper we proposed 3- phase single switch boost power factor corrector to decrease the area and power consumption.

II. LITERATURE SURVEY

In paper,[4] author described the 3-phase single-switch boost PFC converter which implemented in DCM to produce PFC. Featuring zero-current turning for the switch, ,easy to control and less cost, mainly converters are applicable in low to medium power and cost-effective applications. In these, the duty period is almost fixed with in a line cycle and has PF low and the 5th and 7^{th} harmonic currents will be present to control and reduce power and achieves the IEC61000-3-2 standard.

When increasing the output voltage (Vo) will causes increment in the power consumption level which makes the need of the higher voltage-rated switches [4]. Several techniques are available for reducing the input current harmonics of 3-phase single-switch boost PF corrector converter and have been discussed in paper [4–15]. By introducing 5th harmonic trap in the input will decrease the 5th harmonic in the input current and develops the PF, By having more circulating current flows through loop makes the design to decrease efficiency The circulating current contains the ac source and the trap filter [5].

The architecture of the inductor and EMI filter is more complicated by having variable switching frequency control will decrease the input current harmonic distortion. Introducing the 6^{Th} harmonic in the duty cycle is the best method [4, 11–15]. The design of 6th harmonic injection design, will has band-pass filter with severe phase-shift problem and this problem will not present constant [4,5]. To dissolve this problem the author in paper [10] and [11] proposed a architecture to solve the duty cycle problem.

Schenk [11] has explained that the harmonic injection is produced with the output voltage ripple, about the work explained and proposed in papers [4, 9–12] which are not produce the minimum input current harmonics distortion when input voltage is changed and also the load changes. These designs needed complex additional circuitry like phase-locking circuit and phase detecting to achieve proper synchronize the inject a proper signal with the proper input current.

In paper [11] author proposed and explained to reduce the harmonic injection problem by introducing a variable gain amplifier into the harmonic injection path so that the optimal harmonic injection problem with variable input voltage is solved but the problem will be unchanged if the load changes. In paper [15], the author introduced multiplier in the control circuit so that the input harmonic will be unchanged when the load changes.

The author Simonetti [15] proposed a duty cycle methodology for the 3-phased single switch boost PF corrector.

In the context of aforesaid observations, in this article, we propose a easy and simple architectures for increasing the PF correction in the 3-phase single switch Boost converter. By using variable duty period the PF improvement will occur variable input voltage and implementation of the design is simpler. Section.2 explains more in detail the PF analysis of the converter. Literature survey and the variable duty cycle control for PF improvement is discussed and presented in section.2. The method of arranging a duty cycle is more useful for the circuit implementation. Section.3 describes the result analysis of the proposed variable duty period and the fixed duty period in terms of the input current harmonics, boost inductor and

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the output voltage ripple, The results explains that, it has high PF and low input current harmonics and a high and a low output voltage ripple can be produced with variable duty period and is discussed in section.4. Finally section.5 describes the conclusion

III. PRINCIPLE OPERATION OF THREE-PHASE BOOST PFC CONVERTER

Figure. 1 shows the schematic diagram of the 3-phase single switch boost PF corrector converter. Fig.1b shows the input waveforms for the three-phase voltages given to the proposed work. The waveforms for the inductor currents in a duty cycle for [0, 60] is shown in fig.2. Let us consider a pure sine wave 3-phase voltage which is symmetric given to the boost converter and is explained as:

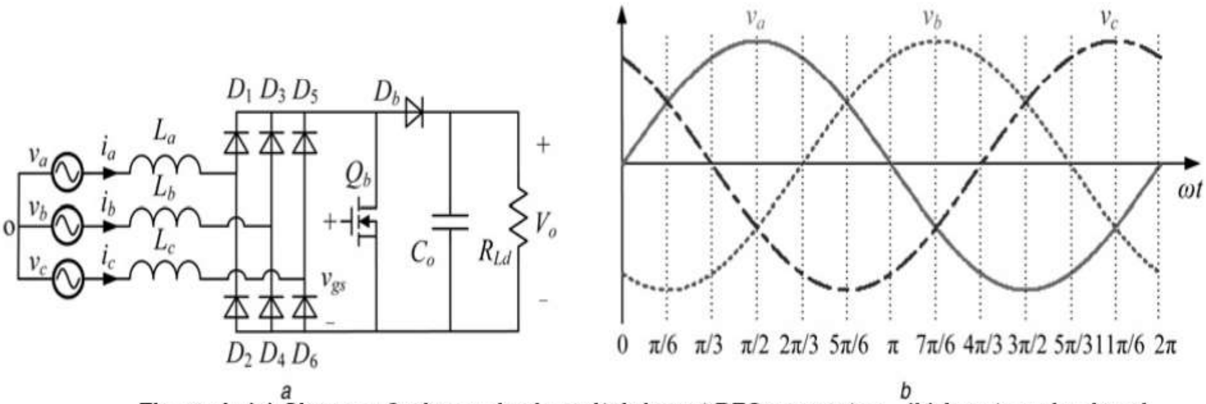
$$v_a = V_m \sin vt \quad (1)$$

$$v_b = V_m \sin (vt - 2\Pi/3) \quad (2)$$

$$v_c = V_m \sin (vt + 2\Pi/3) \quad (3)$$

where V_m= The phase voltages amplitude, and

v = The phase voltages angular frequency



a b
Figure 1: (a) Shows a 3-phase single-switch boost PFC converter (b) Input angle signal

For [0,180], the inductor current average value i_a for duty cycle is given as:

$$ia_{av} = Kn(wt)I0\left(\frac{n-1}{6}\right)\Pi \le Wt \le \frac{n}{6}\Pi \text{ where } n = 1,2,3,4,\dots 6 \quad (4)$$

where $I_0 = D^2_y Vo/(2Lfs)$,

Dy = the duty cycle,

Vo= output voltage,

fs= 1/Ts = switching frequency,

L = Inductance of input vector.

From equation 1 and equation .4, the average input power of phase a is derived as:

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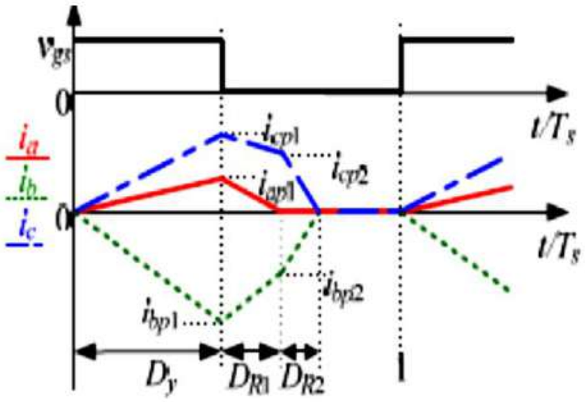

Figure 2: Shows Inductor current waveforms

The relationship between PF and M is given by the eq.6 and graph for PF and M is shown in Figure 3

$$P_{in\_a} = \frac{1}{Tline/4}\int_0^{Tline/4} v_a \quad i_{a\_av}\, dt = \frac{2I_0 v_m}{\Pi} \, X \sum_{n=1}^{3} \int_{(n-1)\Pi/6}^{n\Pi/6} kn(Wt) \sin Wt \, dWt \qquad (5)$$

Where T_{line}= line cycle

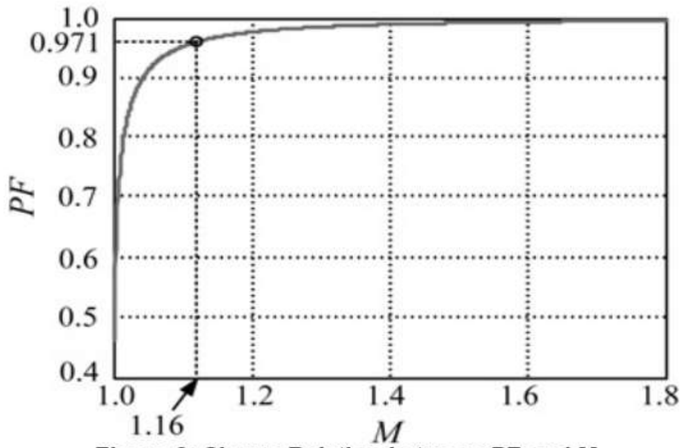

Figure 3: Shows Relation between PF and M

$$PF = \frac{P_{in\_a}}{\frac{Vm}{\sqrt{2}} I_{a\_rms}}$$

$$PF = \frac{\frac{4\int_0^{Tline/4} V_a i_{a_{av}}(t)dt}{Tline}}{\frac{Vm}{\sqrt{2}}\sqrt{\frac{4}{Tline}\int_0^{Tline/4} i_{a_{av}}^2(t)dt}} \qquad (6)$$

Ia_rms= the current in phase.

According to above equations, Figure.3 shows the input PF is plotted. It is observed that for higher PF there will be higher M value. When the output voltage is 750 V, the PF is 0.9710 for the phase input voltage of 264 AC. When M=1.160, there will be more harmonics in the input current. For achieving unity power factor the duty cycle should be variable.

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IV. RESULTS AND DISCUSSION

The experimental analysis and the validation of the proposed variable duty period, has been constructed and done the work in laboratory. The required specifications and the experimental components for the proposed work is tabulated in the Table.1. The input voltage, boost inductor current, input current and output voltage for fixed duty cycle and variable duty periods of different VAC of 176.0, 220.0 and 264.0 VAC inputs, respectively are shown in Fig4, Fig.5 and Fig.6 respectively.

When we observe that the input current is very near to sine wave in the fixed duty period when compared with the variable duty period. And at the same time the boost inductor current ripple of the variable duty cycle control is less when compared with the fixed duty cycle which are around position of 0, Π/3, 2 Π /3, Π , 4 Π /3 and 5 Π /3, and has increase around the position of Π /6, Π /2, 5 Π /6, 7 Π /6, 3 Π /2 and 11 Π / 6 when inductor has 125 mH, which is same like the fixed duty cycle control.

When the inductance of 155.0 mH increased, the inductor current ripple with variable duty period is decreased than input voltage period.

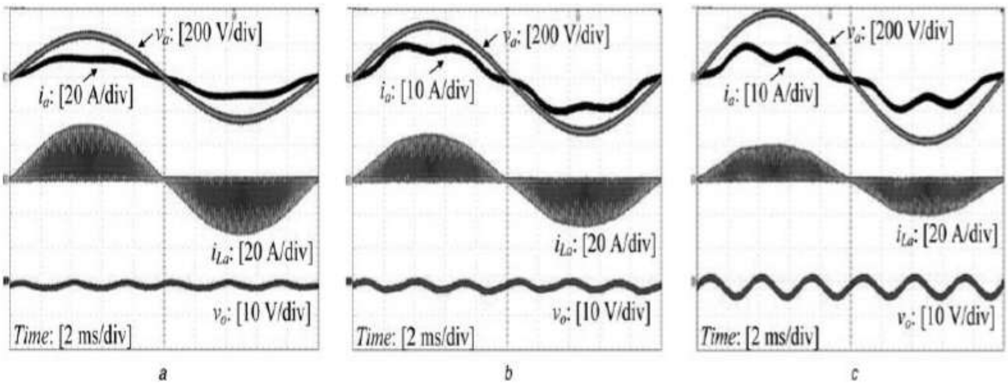

Figure 4:Shows Waveforms of input voltage, , inductor current, input current and output voltage with fixed duty period (a) @ 176.0 VAC input (b) @ 220.0 VAC input (c) @ 264.0 VAC input

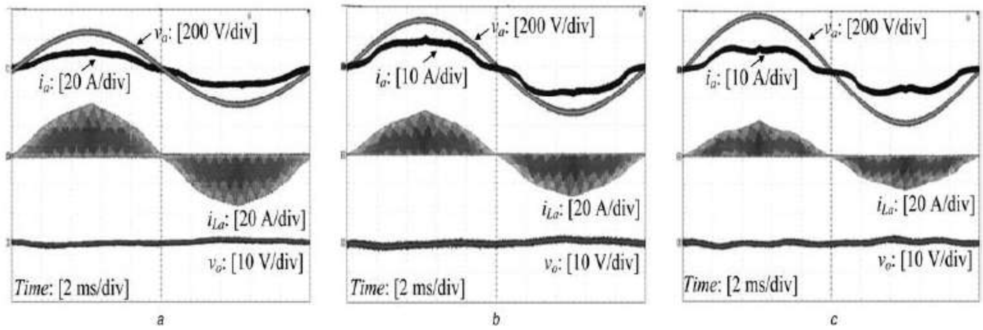

Figure 5:Shows waveforms of input voltage, inductor current, output voltage and input current with variable duty period and L=125mH (a) @ 176.0 VAC input (b) @ 220.0 VAC input (c) @ 264.0 VAC input

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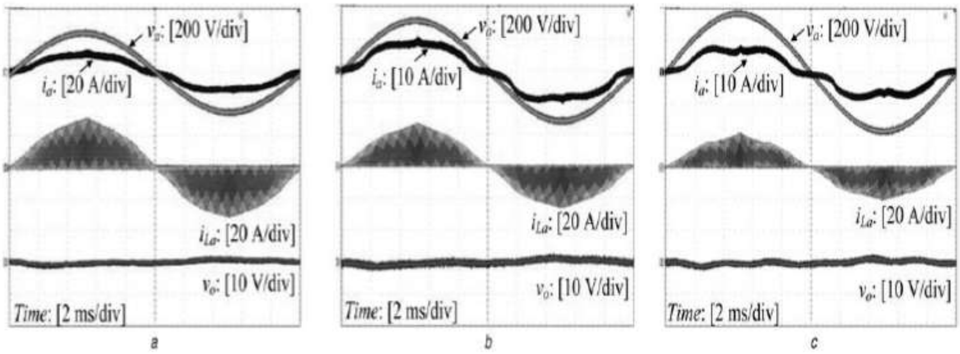

Figure 6:Shows Waveforms of input current, inductor current, output voltage, and input voltage with variable duty cycle control L =¼ 155 mH) (a) @ 176.0 VAC input (b) @ 220.0 VAC input (c) @ 264.0 VAC input

Table 1: Shows Specifications of the prototype

Phase Voltage	Output Voltage	Output Power	Switching frequency
Vin=220V +/- 50Hz	750.0V	3000W	30KHz

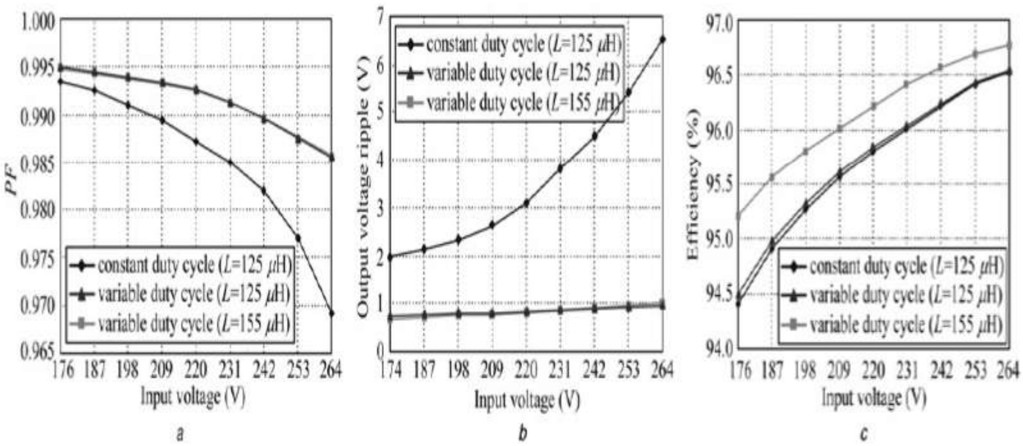

Figure 7: Shows Experimental results (a) PF measured (b) Output voltage ripple (c) Efficiency

The input PF, output voltage ripple curve and its efficiency at various input voltages and boost inductances of 155 and 125 mH are shown in Fig.7a and Fig.7b.Their efficiency is shown in fig.7c. The power factor is increased due to the variable duty cycle and at the same time the output voltage and the input voltage range is reduced. At high lines there will be improvement in the input PF and decrease in the output voltage. When we observe Fig.7c the efficiency is same with the boost inductor of 125mH for the fixed duty cycle and the variable duty cycle. when we increase the boost inductor to 155 mH, there will be increase in efficiency variable duty cycle control which leads to decrease in the inductor current ripple, for low line, where the conduction loss is high than the high line.

V.CONCLUSION

In this paper an optimum utilization control of duty cycles is proposed for 3-phase single-switch boost PFC converter. By having fixed and variable PF the harmonic present in the architecture is varied and having different boost inductors the efficiency of the converter is increased. Various parameters like input current, inductor current, output voltage, and input voltage have been calculated by having different inductances and different PF correctors. The proposed design is well suited for the transmission applications.

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