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Input Current Shaping and Efficiency Improvement of A Three Phase Rectifier by Buck-Boost Regulator

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Abstract **—Three phase rectifiers are commonly used in high power applications for their low cost and ease of operation. Rectifiers have non-linear characteristics and draw non sinusoidal input current from ac sources. This causes a number of problems in the power distribution networks. Increase in reactive power, low input power factor, input voltage distortion etc. are some of those problems. In this respect, switch mode regulated rectifiers offer efficient, compact and high efficiency operation. The improvement of input current is possible by addition of Buck, Boost, Buck-Boost or Ĉuk regulator with single or three phase rectifiers. Pulse width modulation (PWM) technique is used to control the switching devices of these regulators. In this paper, a three phase full wave diode rectifier is analyzed with Buck-Boost regulator. The work shows, when a variable carrier frequency is applied for different duty cycle, the THD of the input current is low and the overall efficiency is more than 80% for lowest and highest output voltages. It provides the facility of control of output voltage to lower and greater than the input voltage efficiently by variation of duty cycle. Previously Buck regulated rectifiers were reported with good power factor and input current THD for constant voltage output. The work of this research will allow variable voltage.**

I. INTRODUCTION

DC power supply is widely used in electronic equipments. There are two types of power supply, regulated and unregulated. Unregulated dc supply is used where fixed voltage is not required. Reliable and stable operation requires regulated dc supplies. The regulation can be performed by using Buck, Boost, Buck-Boost and Ĉuk regulators. Several techniques are available to improve the power factor and the shape of input current. Single phase or three phase diode bridge rectifiers between source and load are used in many applications. But, only single phase rectifiers with resistive load draws sinusoidal current from the load. All other rectifiers' input currents are non-sinusoidal in nature.

II. REVIEW

An AC voltage regulator based on Buck-Boost conversion principle has been proposed in [1]. The AC Buck-Boost regulator has the ability to regulate the output voltage to the desired value. The input power factor of the regulator varies and it decreases with duty cycle. Due to very low input power factor, the input current becomes high and distorted, which causes higher loss. As a result, the efficiency tends to be low. Design of the input and output filter has the lack of proper freewheeling path.

In universal-input Power Factor Correction (PFC) applications, the capability of providing both step-up and step-down conversion is attractive because the output DC voltage can be set to any value. However, conventional single-switch Buck-Boost topologies, including the plain Buck-Boost, fly back, SEPIC, and Ĉuk converters [2], [3] have increased component stresses, component sizes, and reduced efficiency compared to the Boost converter.

To enable a unity power factor operation of the 3-phase Buck boost rectifier, a constant inductor current is required [4], [5].The load in combination with a conventional high dynamic voltage control, would result in periodic peak currents in the Buck-Boost inductor and in the input/mains current. These current distortions make a unity power factor operation of the converter impossible. Hence, a control strategy, which will achieve unity power factor having accurate regulation of output, is desirable. A three-phase PWM regulated rectifier has been proposed in [6]. A Ĉuk-Ĉuk bidirectional ac-dc converter with power regenerating capability is presented in this reference. The scheme is very complex and difficult to implement. Simplicity is a high consideration to design a regulator. In [6] input current was high and no analysis has been reported to reduce the input current.

A three phase rectifier based on Boost topology has been proposed in [7]. Drawback of the proposed method is that the output voltage is very sensitive to the change in duty cycle. Large EMI and series resonating filters have been used in the scheme. A switch mode regulator based on Ĉuk principle has been proposed in [8] to regulate ac voltage to a desired value irrespective of the input voltage and load. This regulator voltage provides a negative polarity regulated output voltage. It has the ability to change the output voltage widely by varying the duty cycle. But limited range of variation of load and input voltage has been reported. No suggestion has been made to improve the input current.

A single stage push-pull Boost converter has been proposed in [9]. The proposed structure includes a Boost inductor, coupling capacitor and a capacitor network, a step-down transformer and four diodes for switching. Coupling capacitor in the circuit should be nearly infinity to achieve low ripple input current. The amount of leakage reactance and mutual reactance is very high due to transformer and inductive network which influence the regulation and the efficiency of the Boost converter. The proposed model without transformer may be helpful to reduce such problem and become more useful.

III. PROPOSED WORK

A new modified Buck-Boost regulator is investigated and reported to improve the shape of the input current of a three phase diode rectifier. The work includes new variable frequency control scheme of a Buck-Boost regulator 3-phase rectifier. It is expected that this study will yield a three phase rectifier with improved power quality which will be practically implementable for medium power application.

IV. PROPOSED BUCK BOOST REGULATOR WITH INPUT FILTER AND VARIABLE CARRIER FREQUENCIES

A new topology is introduced here to improve the efficiency. The circuit diagram of the proposed Buck-Bost regulator is shown in Figure 1.

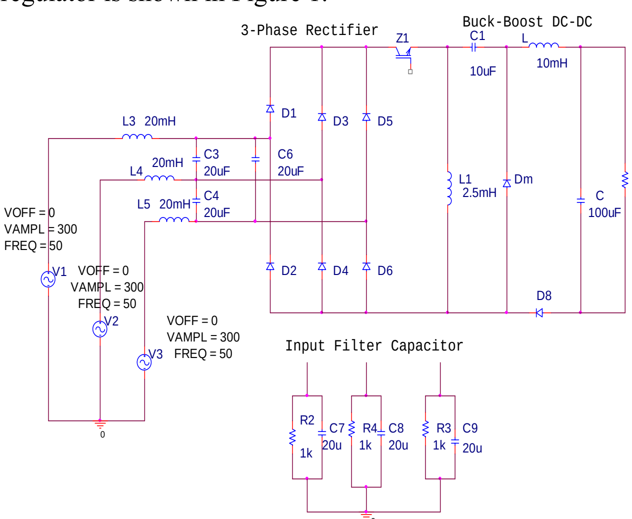

Fig. 1: Circuit diagram of three phase Buck-Boost rectifier with passive input filter and variable carrier frequency

A mixed passive filter is applied at the input side. A lift circuit is used between the load and the regulator. So, the output voltage is positive. The important factor is that the switching frequency is not maintained constant here. The switching frequency is varied from 1.43 kHz to 6.66 kHz (for 10% duty cycle to 60% duty cycle).

V. OPERATION OF THE PROPOSED CIRCUIT

The operation of the proposed circuit can be described in two modes. The mode 1 begins when the transistor is switched ON at t= 0. The input current, which rises, flows through Inductor L_1 and C_1, L, C and load. As the Capacitor C_1 and freewheeling diode D_m is interchanged at the proposed regulator, positive current will flow through the load and the output voltage will be positive. During mode 2, transistor is switched off and the current, which was flowing through inductor L, would flow through L, C, load and D_m. The energy stored in the inductor L would transferred to the load and the inductor current would fall until transistor is switched ON again in the next cycle .The simplified circuit diagram and simulated operational waveforms are shown in the following Figures 2-7. Typical wave shapes of input current, output current, output voltage, FFT of input current, power factor and efficiency are shown in Fig. 8 to 13. The performance parameter is shown in Table 1. The variation of power factor, Efficiency, output voltage, THD and switching frequency with respect to duty cycle is shown in Figure14-18. It is evident that for duty cycle above 40%, the power factor remains above 0.8. Below D=0.4, the power factor degrades. The efficiency of the converter is always above 80% as the duty cycle was varied from 10% to 60%. THD of the input current remained below 7% and output voltage changed from 180V-800V.

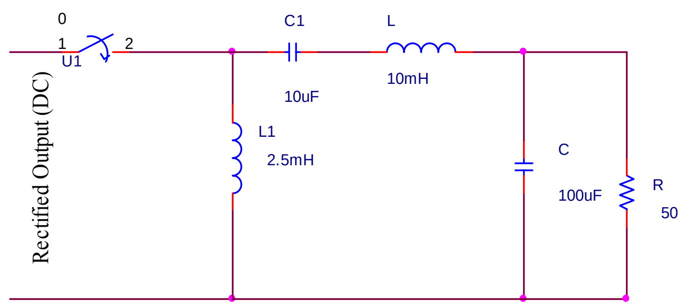

Fig. 2: Mode 1(transistor is ON)

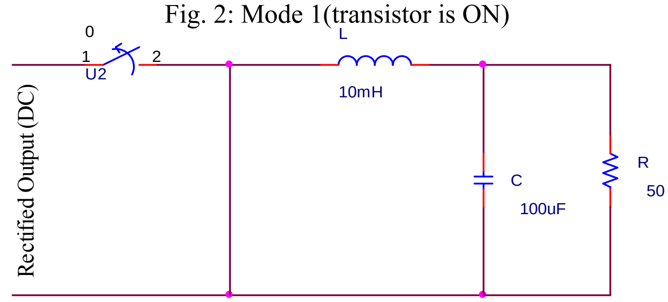

Fig. 3: mode 2(transistor is OFF)

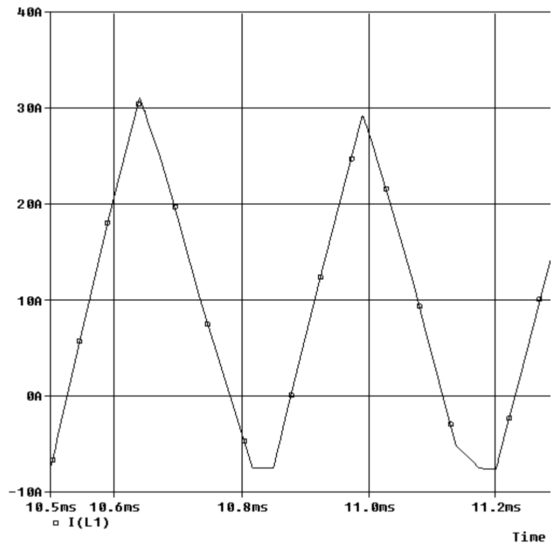

Fig. 4: Current through L_1 in mode 1

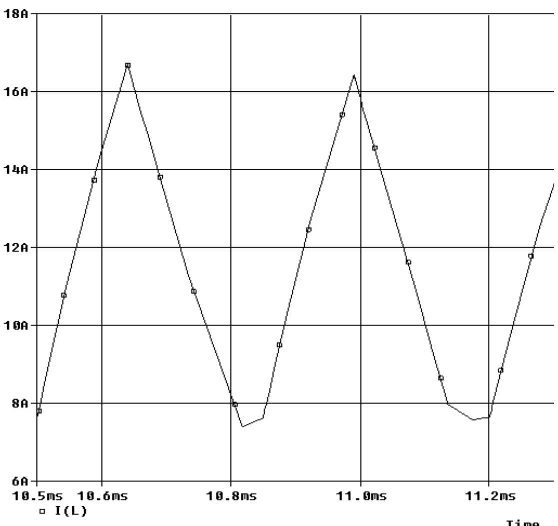

Fig. 5: Current through L in mode 2

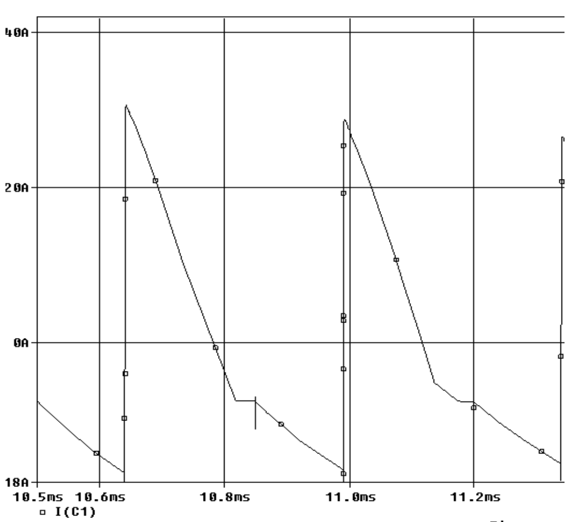

Fig. 6: Current through C1

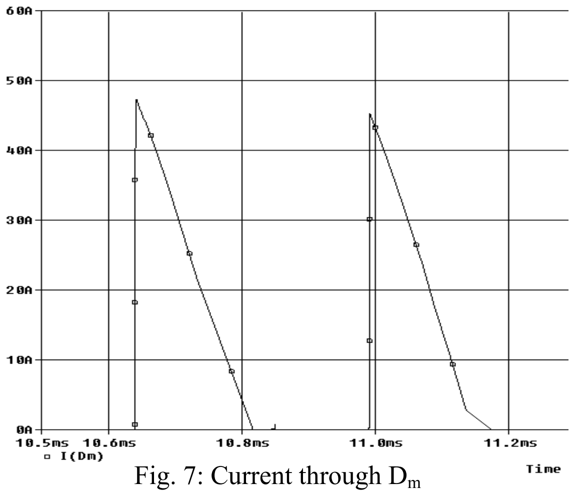

Fig. 7: Current through D_m

VI. TYPICAL INPUT CURRENT, OUTPUT CURRENT, OUTPUT VOLTAGE, FFT OF INPUT CURRENT, EFFICIENCY AND POWER FACTOR OF A BUCK-BOOST REGULATED THREE PHASE RECTIFIER FOR DUTY CYCLE = 60%, CARRIER FREQUENCY =6.66 KHZ

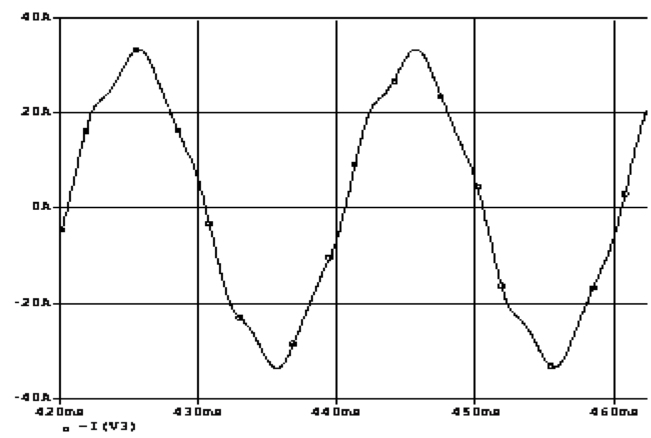

Fig. 8: Typical input Current of a Buck-Boost regulated three phase rectifier with passive input filter

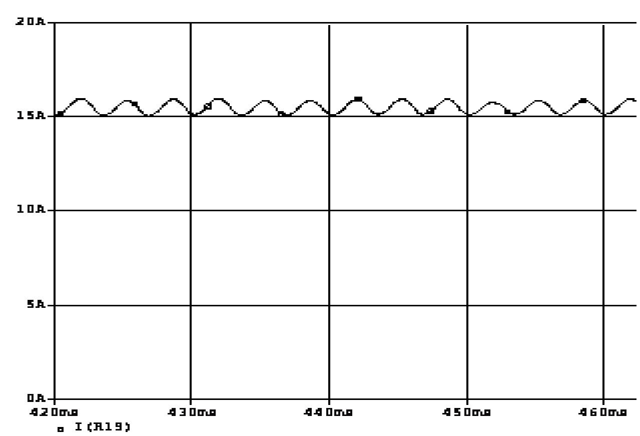

Fig. 9: Typical output Current of a Buck-Boost regulated three phase rectifier with passive input filter.

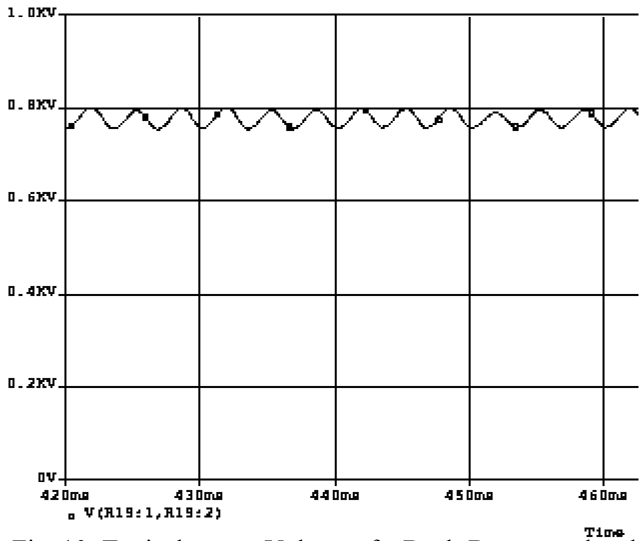

Fig. 10: Typical output Voltage of a Buck-Boost regulated three phase rectifier with passive input filter.

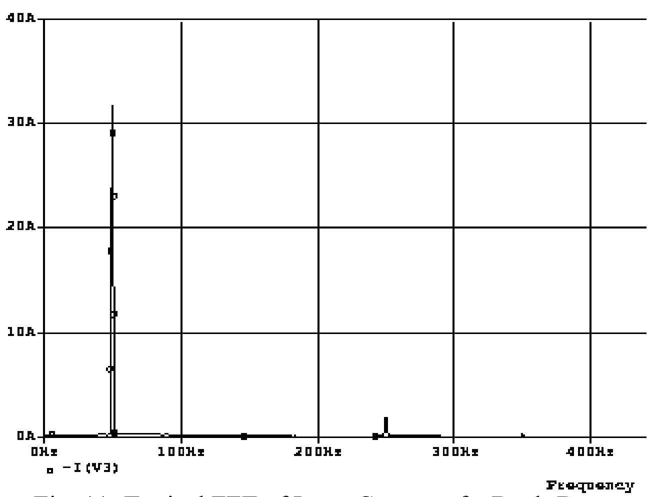

Fig. 11: Typical FFT of Input Current of a Buck-Boost regulated three phase rectifier

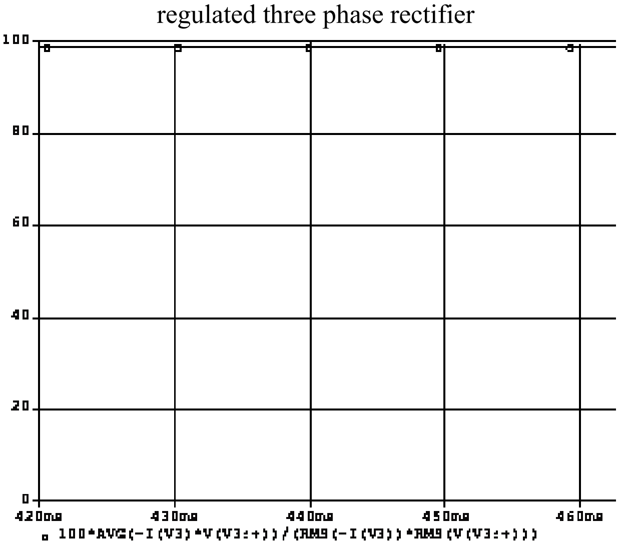

Fig. 12: Efficiency of a Buck-Boost regulated three phase rectifier.

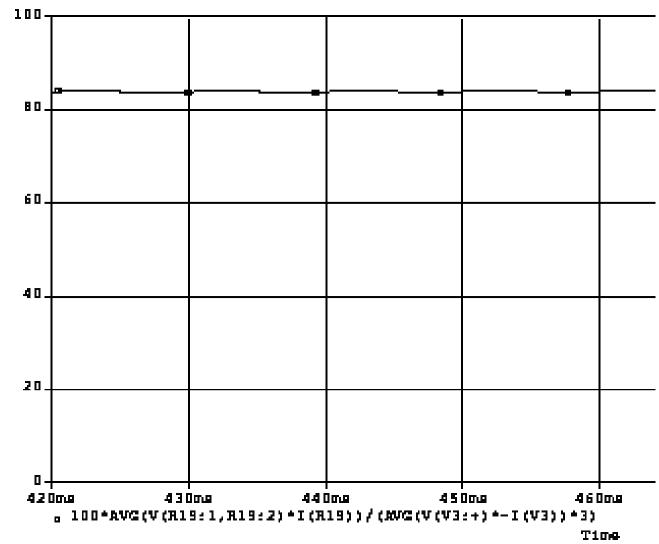

Fig. 13: Power Factor of a Buck-Boost regulated three phase rectifier with passive input filter

TABLE 1. PERFORMANCE PARAMETER OF BUCK-BOOST REGULATOR

D (%)	THD (%)	PF (%)	I_{in}(rms) amp	V_{in}(P)volt	V_{out}(dc) volt	I_{out}(dc) amp	(η)%	f_C (KHz)
10	5.12	21	6.5	300	180	4	80	1.43
20	3.75	45	7	300	300	6	95	2.00
30	4.37	68	8	300	400	8	95	2.50
40	5.47	83	10	300	500	10	96	2.86
50	6.31	93	12.5	300	600	12	92	3.33
60	6.38	99	22.5	300	800	16	85	6.67

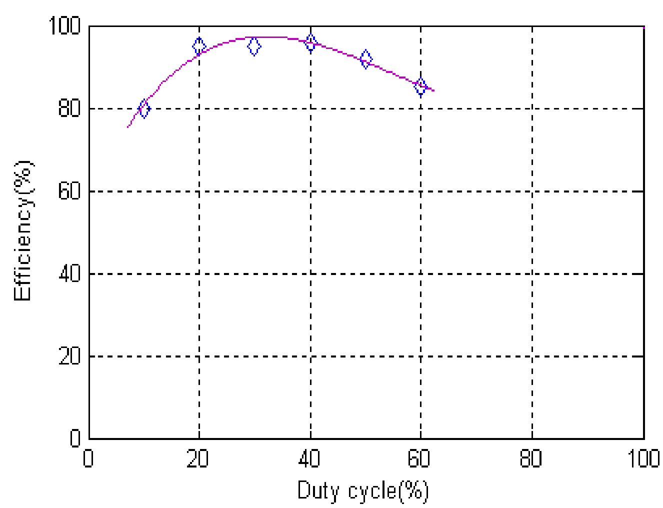

Fig. 14: Duty cycle vs power factor

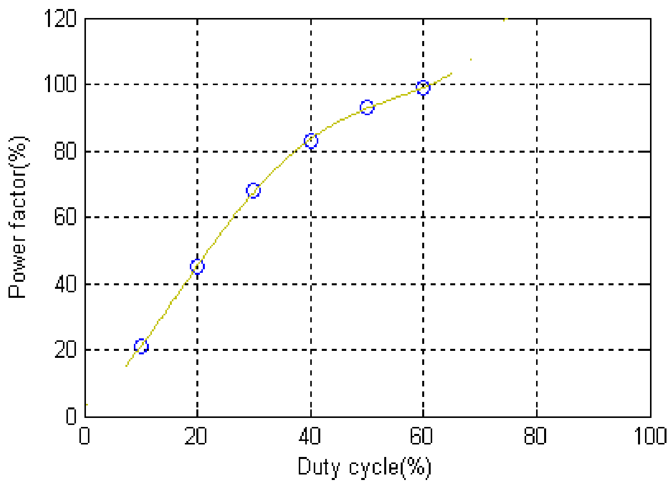

Fig. 15: Duty cycle vs efficiency

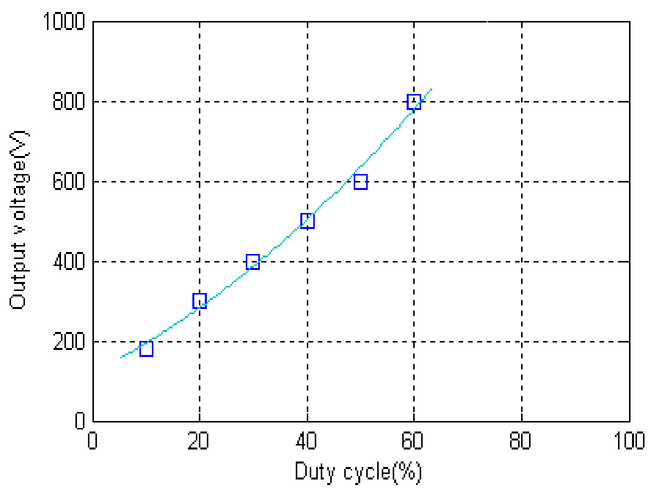

Fig. 16: Duty cycle vs output voltage

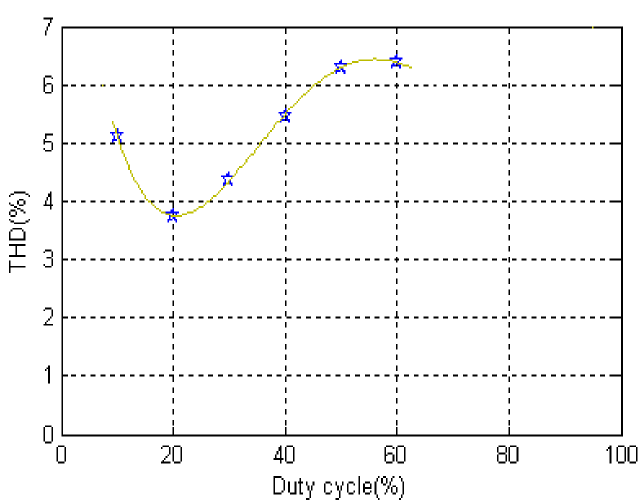

Fig. 17: Duty cycle vs THD (%)

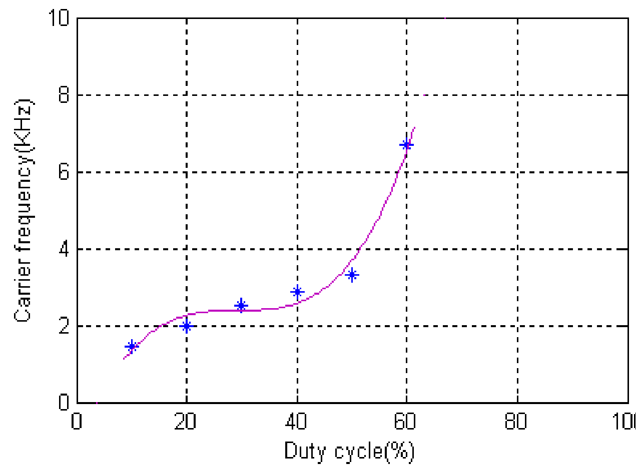

Fig. 18: Duty cycle vs switching frequency

VII. RESULTS AND DISCUSSION

The quality of input current indicates the good performance of a rectifier. Distortion free sinusoidal input current is a major consideration in a rectifier design. Many techniques have been developed by researchers in previous works. But large size of input filters are required to minimizes the distortion. Another important thing is, regulated output voltage both below and above the input voltages are required in many cases. Only Ĉuk and Buck-Boost regulators are able to supply regulated voltage below and above the input voltage. In this paper, a Buck-Boost regulator with modification is proposed for improvement of input current and efficiency of a three phase rectifier.

At first a three phase full wave diode rectifier has been studied. The input current was found non sinusoidal pulsating and THD was found 25%. Then a passive input filter has been employed to make the input current sinusoidal. Then the THD and efficiency was found 2% and 94% respectively. But the input filter was very large (L=20mH, C= 100uF) with increase in input current. As a result the VA rating of the rectifier increases and weight becomes large. The output voltage was not controllable.

To overcome the problems, a Buck-Boost regulated three phase rectifier has been studied without input filter. It was observed that the input current was highly distorted with large THD, though the efficiency was good. The output voltage is controllable. To improve the shape of input current of Buck-Boost regulated three phase rectifier with passive input filter was studied. The switching frequency was kept constant. It was found from the analysis that the THD has improved for many of the duty cycles, but the overall efficiency of the regulator was not acceptable at all duty cycles. It was also observed that efficiency and THD cannot be kept at the desired level simultaneously with change in duty cycle.

To improve the overall efficiency and to maintain the THD of the input current at acceptable limit a new topology was proposed and studied. A mixed passive filter was introduced at the input side of a Buck-Boost regulator. At the same time, the switching frequency was varied from low to high frequency together with the variation duty cycles. A lift circuit was added in between the load and the Buck-Boost regulator, which makes the output voltage positive. It was found that THD remained under 7% at all duty cycle. The output voltage was variable from 180 volts to 800 volts with more than 80% efficiency. The value of input current was also acceptably low.

VIII. CONCLUSION

In DC-DC converter regulated three phase rectifier, during the change of the output voltage by varying the duty cycle, it has been observed that the power factor changes and becomes very low. To maintain the power factor high at all duty cycle for variable output voltage, a new control strategy is suggested which will keep the power factor close to the unity and keep the THD and efficiency at acceptable levels. Switching losses and EMI interference is not considered in this paper. The lowest output voltage of the proposed converter is 180 V with acceptable performance.

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