Power Factor Improvement in a Three Phase Circuit by using Vienna Rectifier and Buck-Boost Converter

Navila Rahman Nadi, Srabanty Ahmed Shaon

Abstract—Power factor is the ratio of true power or watts to apparent power or volt amps. The rapid placement of power electronic system in residential, commercial and industrial sides has energized the longing of an improved power factor to reduce the loss and cost. Good power factor deducts the losses and costs and ensure the longevity of electrical mechanism at a greater extent. Continuous researches are taking places everywhere. Several ways are invented to regulate it. As a part of those continuous researches, we worked under the challenge of the achieving the acme point in PFI segment. We utilized Vienna Rectifier and Buck-Boost Converter to design a PFI circuit. And at last, our design helped the power factor for being high as far as possible practically.

Index Terms— Apparent Power, Buck-Boost Converter, Power Factor, PFI circuit, Vienna Rectifier.

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1 INTRODUCTION

MOST of the industrial and domestic loads are inductive and operate at a low lagging power factor. A low power factor at the load means higher line losses in the system [1]. The process of increasing the power factor without changing the loads or altering the voltage or the current to the original load is known as power factor improvement [2]. Three level rectifiers with reduced number of switches (such as the Vienna Rectifier) to improve the input power quantity of rectifier systems have been receiving wide interest in the past few years [3]. The previous work was a new carrier based pulse-width modulation control algorithm proposed for such converters to eliminate the low frequency harmonics in the line current while achieving unity power factor at the rectifier input terminals [4]. The operating constraints of the Vienna Rectifier with the carrier based modulation strategy are examined carefully, and the proposed control algorithm ensures that appropriate voltage/current directional constraints are met [5].

Utility companies are concerned about the relationship between Real Power and Apparent Power because the system is built based on kVA and billed to the customer based on kW. They justify power factor penalties because poor factor requires a physically larger installation than would otherwise be required. In large industrial facilities with significant power consumption, utility company penalties can be significant, amounting to hundreds or thousands of dollars per month [6]. In fact, companies can obtain the history of billing from the utility company to profile the last twelve months of consumption and associated power factor penalties

In addition to eliminating utility company penalties, correcting low power factor by installing power capacitors can add capacity back into the power distribution system [7]. Load on transformers can be reduced by the installation of power capacitors because raising the power factor on a kW load reduces kVA. By adding capacitors, you can add additional kW load to the power distribution system without altering the kVA.

The addition of capacitors can also have a positive impact on system voltage drop because of the decrease in current and its relationship to the distance that power must travel through the distribution system [8]. In other words, a capacitor installed at the end of a long feeder or run of bus duct will have the impact of improving voltage from its point of installation back to the main service.

2 SYSTEM MODEL

2.1 Optimized Model

A prominent boost-type three-level topology (Vienna Rectifier), which proved to represent a cost-effective and highly efficient solution for switched-mode rectifiers, is inspected toward its operation at discontinuous conduction mode (DCM). This mode of operation occurs not only at high input voltage in conjunction with low load currents but even at medium loading in the vicinity of mains voltage zero crossings. When this circuit is operated in DCM, additional measures are required for improved behavior to avoid conflicts with requirements on total harmonic distortion and regulations as well as safe operation in terms of voltage balancing and overvoltage protection. A detailed analysis of DCM and associated states is performed enabling determination and location of error voltages. Basic rules for the location of error voltages can be found. This leads to a novel optimized modu lation and control scheme, facilitating designs without additional inductance. Selected simulation and measurement results prove the enhanced modulation scheme.

2.2 Illustration

The following Fig.1 represents the model of power factor improvement circuit by using Vienna rectifier. The complete circuit consists of three parts. The first part is the Vienna Rectifier in which the input 30V p-p ac voltage is rectified to 30V dc voltage. The MOSFET are triggered using a Square pulse of 30V, of which Pulse Width is .8ms and Time period is 3ms.Second part is the Buck-Boost inverter, where the MOSFETs are triggered using a square pulse of 11V, which pulse width is 8ms and time period is 20ms. The third and final part of the circuit is the inductive load of 1mH and 1ohms.

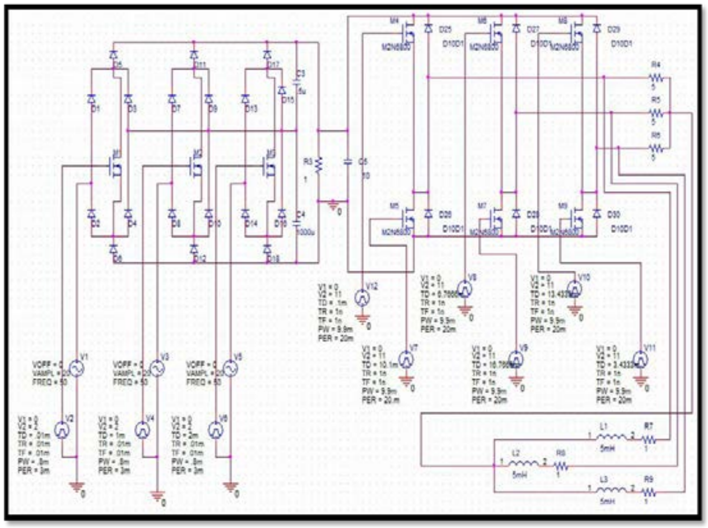

Fig. 1. Complete diagram of three Phase circuit

In this unipolar scheme the legs of the inverter are controlled separately by comparing carrier triangular wave vcar with control sinusoidal signal v_c and $-v_c$ respectively. This SPWM is generally used in industrial applications. The number of pulses per half-cycle depends upon the ratio of the frequency of carrier signal (fc) to the modulating sinusoidal signal. The frequency of control signal or the modulating signal sets the inverter output frequency (fo) and the peak magnitude of control signal controls the modulation index ma which in turn controls the rms output voltage. The area of each pulse corresponds approximately to the area under the sine wave between the adjacent midpoints of off periods on the gating signals. If t_{on} is the width of nth pulse, the rms output voltage can be determined by

$$V_o = V_s \left(\sum_{n=1}^{2p} \frac{2t_{on}}{T} \right)^{1/2}$$

The amplitude modulation index is defined as:

$$m_a = \frac{\hat{V_c}}{\hat{V}_{car}}$$

Where, $\hat{V_c}$ = peak magnitude of control signal (modulating sine wave)

$\hat{V}_{car}$ = peak magnitude of carrier signal (triangular signal)

The frequency modulation ratio is defined as:

$$m_f = \frac{f_{car}}{f_c}$$

Whe $\hat{f_c}$ = frequency of control signal (sine signal)

$\hat{f}_{car}$ = frequency of carrier signal (triangular signal)

3 PERFORMANCE ANALYSIS OF THREE PHASE POWER FACTOR IMPROVEMENT BY USING VIENNA RECTIFIER

The system described above is simulated using PSPICE. The main purpose of these circuits, firstly the Vienna Rectifier converts 30v ac to 28v dc, and then the buck-boost circuit corrected the power factor by average current control technique. The inner loop has a current error amplifier which improves the PF by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to the line voltage hence the load current comes in phase with the input voltage. Thus by improving the power factor maximum active power can be delivered to the load.

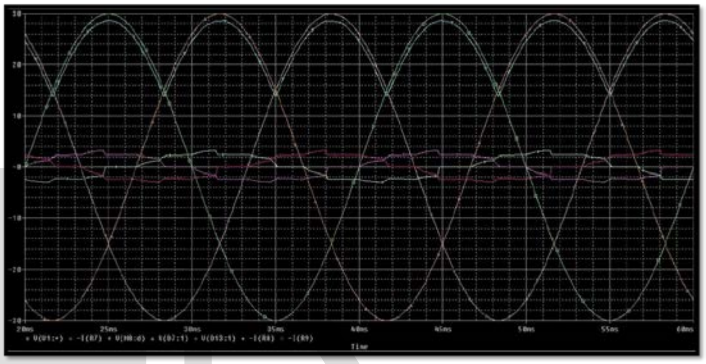

Fig. 2. Input and Output Voltage wave shapes

From Figure 2 it is found that the voltage is 30V peak to peak and the output dc voltage is approximately 28v.

Now we increase the load to 1mH from 8mH. For increasing load, we see that the unity of the PF of the previous circuit configuration has gone. Because the buck-boost circuit configuration cannott handle this load. So our circuit needs to reconfigure. We have to change the corresponding Pulses Width of the square pulses triggering the MOSFETs of Buck-Boost inverters to back the PF unity again. The output of at this situation is shown in Fig. 3.

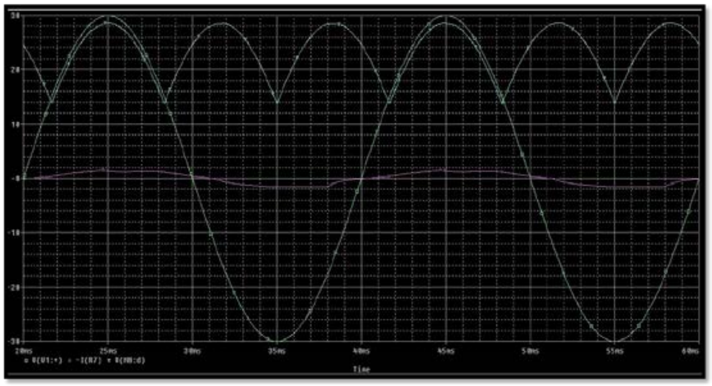

Fig. 3. Input & Output Voltage wave shapes after increasing load

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In Fig.3 we found that, for increasing the load we have departed PF lagging about 1ms from unity .So, we have to change the corresponding Pulse Widths of the square pulses triggering the MOSFETs of Buck-Boost inverters.

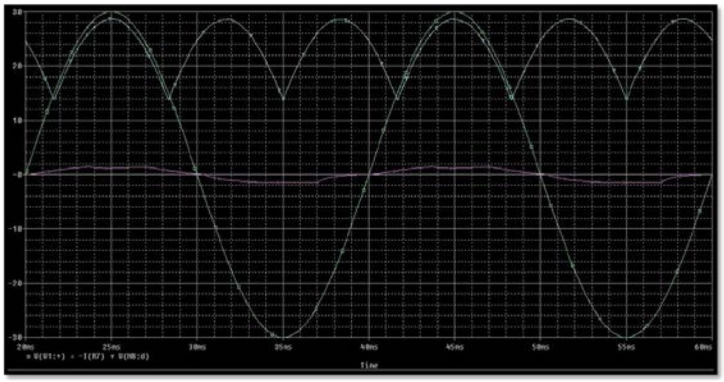

Fig. 4: Input and Output Voltage wave shapes after changing pulse width

Fig. 4 shows that, when we increased the inductive load, the PF was departed from unity. For this reason we had to make the PF unity with the inductive load of 8mH, by changing the corresponding Pulses Width of the square pulses triggering the MOSFETs of Buck-Boost inverters. Here the MOSFETs are triggered using a square pulse of 11V, which is pulse width, is 7ms (changed from 8ms) and time period is 20ms. For increasing the pul se width power factor improves by properly shaping the input current in accordance with its reference.

4 CONCLUSION

The Vienna Rectifier approach to achieve 3-Phase power factor correction offers many advantages and convenient, user-friendly features as compared to the two-level, six-switch boost PWM Rectifier. Amongst them are: continuous sinusoidal input currents with unity power factor and extremely low distortion; no need for a neutral wire; reduction in voltage stress and switching losses of power semiconductors by almost 40%; immunity towards variation or unbalance in mains 3-Phase voltages or absence of one of the phases; wide mains voltage range: 320VAC to 575 VAC; very low conducted common-mode EMI/RFI; very high efficiency of the order of 97.5%, say, for power levels of 10 KW and input line voltage of 400 VAC and short circuit immunity to failure of control circuit. The paper describes the Vienna Rectifier"s power stage and control techniques, with particular emphasis on modular construction. The Vienna Rectifier is useful wherever six-switch converters (3 phase) are used for achieving sinusoidal mains current and controlled output voltage, when no energy feedback from the load into the mains is required. In practice, use of the Vienna Rectifier is advantageous when space is at a sufficient premium to justify the additional hardware cost. It is possible to separately control the input current shape in each branch of the diode bridge by inserting a bidirectional switch into the node. Switch controls the current by controlling the magnetization of the inductor. Switched on charges in the inductor, drives the current through the bidirectional switch. Deactivating the switch increases the current to bypass the switch and flow through the freewheeling diodes. This results in a negative voltage across the inductor and drains it. This demonstrates the ability of the topology to control the current in phase with the mains voltage (Power Factor Improvement capability).

5 FURTHURE SCOPE OF FUTURE WORK

The following improvements are suggested for future studies:
An auxiliary power supply can be added so that the rectifier and inverter control circuitry so that they can operate without the need for an external power supply.
A device used to suppress voltage transients in electrical systems (snubber) can be added to improve the overall efficiency and noise performance.
Soft-switching techniques can be introduced to improve efficiency and to improve noise performance.
And, Future studies can implement the digital or analogue controller on hardware and compare the results to that of manual controller used in this thesis.

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REFERENCES

[1] Bendre and Venkataramanan, G. (2003), "Modeling and design of a neutral point regulator for a three level diode clamped rectifier", in Conf. Rec. IEEE Ind. Appl. Soc. Annu. Meeting, Salt Lake City, UT, pp. 1758–1765.

[2] Malinowski, M., Jasinski, M. and Kazmierkowski, M. P. (2004) "Simple direct power control of three-phase PWM rectifier using space-vector modulation (DPC-SVM)", IEEE Trans. Ind. Electron., vol. 51, no. 2, pp. 447–454.

[3] Kolar, J. W. and Drofenik, U. (1999) "A new switching loss reduced discontinuous PWM scheme for a unidirectional three-phase/switch/level boost type PWM (VIENNA) rectifier", in Proc. 21st INTELEC, Copenhagen, Denmark, pp 21-29

[4] Key, T. S. and Lai, J. S. (1993) "Comparison of standards and power supply design options for limiting harmonic distortion in power systems" IEEE Trans. Ind. Appl., vol. 29, no. 4, pp. 688–695.

[5] Youssef, H. , Fnaiech, F. and Al-Haddad, K. (2003) "Small signal modeling and control design of a three-phase AC/DC Vienna converter" in Proc. 29th Annu IEEE IECON, Roanoke, VA, , pp. 656–661.

[6] Qiao and. Smedley, K. M (2003) "Three-phase unity-power-factor star connected switch (VIENNA) rectifier with unified constant-frequency integration control", IEEE Trans. Power Electron., vol. 18, no. 4, pp. 952– 957.

[7] Venkataramanan, G. and Sharma, N. (2005) "Design considerations for reactive elements and control parameters for three phase boost rectifiers" in Proc. Int. Elect. Machines Drives Conf., San Antonio, TX, , pp. 1757–1764.

[8] Venkataramanan, G. and Wang, B. (2004) "Dynamic modeling and control of three phase pulse width modulated power converters using phasors," in Proc. 35th Annu. IEEE Power Electron. Spec. Conf., Aachen, Germany, pp. 2822-2829.