Power Quality Enhancement by implementation of Vienna Rectifiers over Conventional Diode Bridge Rectifiers

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***Abstract* -Efficient control of power has popularized the use of power electronic components and the challenges in their implementation have forced the developers to develop auxiliaries and schemes for their trouble free operation and control but the very approach is making the power system and equipment extensive and complex. Thus has arisen a need to obtain a device that is robust, highly efficient, and simple as a diode-based rectifier and also able to benefit from the PWM rectifier capability to reduce the line current harmonic content. This paper presents highly efficient three-phase high power- factor hybrid rectifiers assembled by the parallel connection of a three-phase diode-bridge rectifier and series dc–dc boost converter with a three-level unidirectional pulse width modulated VIENNA six-switch rectifiers. In order to evaluate the studied vienna rectifiers an efficiency comparison with conventional PWM rectifiers is performed.**

***Index Terms*—Ac–dc converter, boost, buck, comparison, evaluation, PFC rectifier, PFC, PWM rectifier, rectifier, three-phase, Diode bridge rectifier (DBR), VIENNA rectifier.**

I. INTRODUCTION

The development of a high power-density three-phase ac/dc converter has been a hot topic in power electronics due to the increasing requirement in applications like electric vehicles, aircraft, and aerospace, where lightweight or a small volume is required. With the emerging high-frequency device technology [2], the operating frequency of the converter can be potentially pushed to tens of kHz to hundreds of kHz at high voltages and high power conditions. The extended switching frequency range brings opportunities to further improve the power density of the converter.

The family of non-regenerative three-level rectifiers is characterized by reduced number of active switching devices, high PF, and low voltage stress, which make it a suitable topology for medium- and high-power applications with high power density. The Vienna rectifier originally evolved from these topologies, where together with the latter new ones forms a family of functionally equivalent circuit topologies [3], [4].

Due to the development in semiconductor devices, magnetic materials, capacitor and cooling technologies, Vienna rectifiers remain as one of the preferred candidates when power density is a design objective [5], [6], [8]. Electrical or hybrid vehicles where both power density and reduced weight are of most importance have become a potential user for this kind of rectifiers. Also, the Vienna rectifiers have also been recently considered for industrial motor drives [9]– [11] and UPS systems. The term "Vienna type rectifiers" is usually used to represent the whole non-regenerative three-level boost rectifier family. First, in order to reduce the volume of the converter and increase the power density, particularly in some applications as mentioned before, the inductance of the input filter needs to be reduced. Therefore, the discontinuous-conduction mode (DCM) period will be increased for every half line period.

Second, due to the high device stresses and problems with conducted emission, the use of converters operating in DCM is limited to the low-power range (less than 250 W), hence, the converters for the higher power range are commonly designed for continuous-conduction mode (CCM). Due to the flexibility, decreased cost, and increased performance of digital controllers, various digitized control strategies were widely developed and reported [15]–[18].With a DSP controller, a fixed switching frequency during the entire power range can be realized even when fast load changes occur [19], or when low switching frequencies are undesirable.

II. VIENNA RECTIFIERS

The VIENNA rectifier is a three-switch rectifier that features a split output DC-rail. Control is only required for three switches, which makes it a far easier implementation than the two switch-rectifiers and the H-bridge (three floating switches, three switches referenced to ground). Control effort is still significantly higher than the single switch implementations, but the input current distortion of the VIENNA rectifier, of approximately 8.2%, is far less than that of the single-switch implementations and is on par with the H-bridge and the two-switch and three-switch implementations. The most significant disadvantage of the VIENNA rectifier is the high boost ratio and hence, the high output voltage required. The VIENNA rectifier basically functions as a two-switch boost rectifier (for the dual-boost constant switching frequency controller), with one of the switches switched at the line frequency and two switches switched at high frequency. With one switch permanently on for a 60° control block, the VIENNA rectifier can be seen as two independent boost rectifiers, one for boosting C1 and the other for boosting C2. Thus it can be seen that the minimum boost voltage over C1 and C2 will be the maximum line-to-line voltage of the input. The switch losses and diode losses for the Hbridge and the VIENNA rectifier are comparable, with both rectifiers having the same harmonic distortion. An added advantage of the VIENNA rectifier is that modules are available where all of the semiconductors of a power stage bridge leg are present.

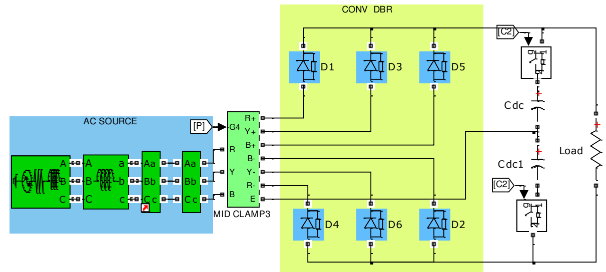
III. PHYSICAL DECOUPLING OF THREE-PHASE VIENNA RECTIFIER

The topology for a three phase three level three switch Vienna rectifier is shown in figure 1, where six diodes in a bridge configurations form an uncontrolled conventional rectifier while three additional controlled switches are connected to the neutral point Vn of three-phase line voltage and is connected with the output capacitors C1 and C2. The output capacitor is selected to be large enough so that the output voltage can be regarded as a constant. When the neutral point is introduced, this converter can be decoupled into three single-phase three-level PF correction converters. Phase A, phase B, and phase C can each be controlled as an individual PFC converter [20]. In order to simplify the analysis, the parameters of each phase are supposed to be the same. The physical decoupled single-phase topology is shown in Fig. 2.

It should be noted that Ro has not been connected to the neutral point Vn. As shown in Fig. 2, when the circuit is operating at steady state, the output voltage of C1 and C2 are equal; therefore, the neutral point of Ro, Vn can be regarded as the equipotential point of Vn.

IV. VIENNA RECTIFIER TOPOLOGY

The topology for Vienna rectifier under study is shown in figure 1 where the AC voltage source may be considered as grid with an inductance L1, while the uncontrolled three phase rectifier along with three controlled switch diode clamp combination forms the neutral or midpoint clamp for controlling the output voltage and power factor.



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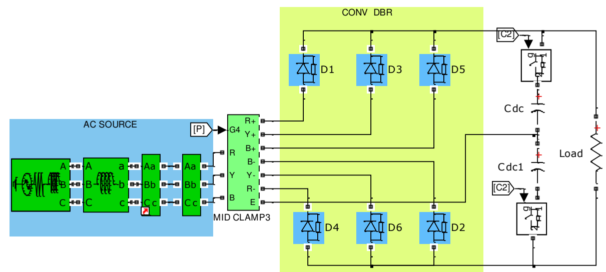


(b)

Fig. 1. (a) Three level bidirectional-switch Vienna Rectifier (b) Three Switch midpoint clamper

V. SV-PWM CONTROLLER FOR VIENNA RECTIFIERS

The control structure of the VR is shown in Fig. 2, In order to increase the output voltage control range, a third harmonic is impressed upon the reference current input to the mains voltage feed-forward signal [6].

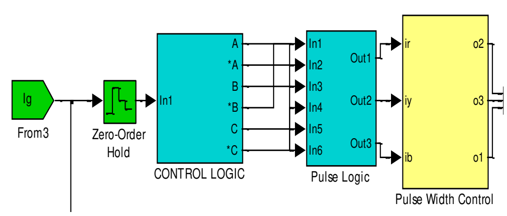
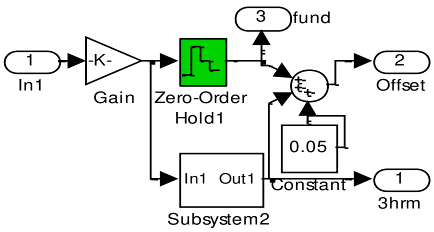


Fig.2: Vienna Pulse Controller

The balancing of the capacitive midpoint clamp with the output voltage, can be implemented by adding an offset i0∗ to the phase current reference values As shown in Figs. 3. A 15% third harmonic offset is introduced into the reference current input and a 5% DC offset to account for voltage imbalances at midpoint clamp.



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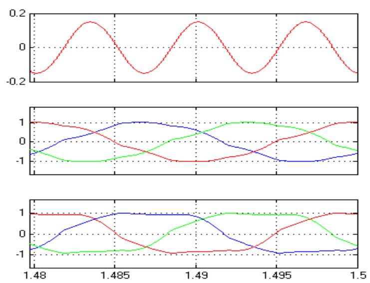

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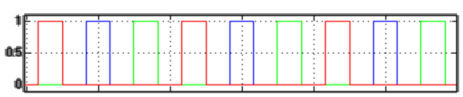
Fig.3: Third Harmonic & DC offset (a) Subsystem (b) Waveforms

For the generation of switching vectors the state of input voltage is split into sectors of 60˚ the corresponding switching states are derived thereafter as shown in and Table1, for the input phase currents ia> 0, ib< 0 and ic> 0, the switching state is 101, while when ia> 0, ib< 0 and ic<0, redundant switching state 100 is required to facilitate proper introduction of switch into the midpoint clamp circuit for voltage formation on the ac side.



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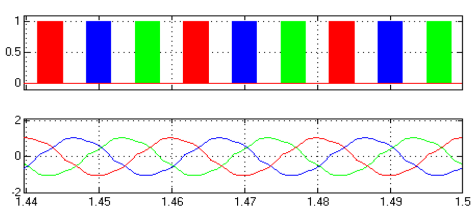


(b)

Fig.4: PWM pulse and Fundamental reference. (a) For Pulse width of 60˚ (b) for pulse width of 30˚

For proper operation of Vienna rectifiers it must be ascertained that the outgoing current vector must be aided for effective and timely commutation and for the same function a PWM pulse with a tune able duty ratio is utilized to switch on the selected device for predetermined duration. the target vector is synthesized by the basic vectors of $\vec{U_4}$, $\vec{U_2}$, *and* $\vec{U_3^+}$, $\vec{U_3^-}$.. It is supposed that the dwell times for each basic vector are, respectively, T4, T2, and T3, which should satisfy

$$T_4\vec{U_4} + T_3\vec{U_3} + T_2\vec{U_2} = \vec{U_{\text{ref}}} \quad (1)$$

where T2, T3, and T4 are supposed to be normalized by switching frequency Ts. The vectors length of U2, U3, U4, and Uref are supposed to be normalized by Vdc. As mentioned before, the length of U2 is supposed to be 2/3. m is supposed to be the modulation index, so

$$m = \sqrt{3}|U_{\text{ref}}|. \quad (2)$$

Table 3: Switching States

Output Voltage States (R Y B)	Switching States (*Si*) (1 ON , 0 OFF) (*Sa SbSc*)
1 0 1	101
1 0 0	011
1 1 0	110
0 1 1	101
0 0 1	011
1 0 0	110

A positive offset $i*$ 0 > 0 leads to an increase of the relative ON-time of switching state (100) compared with state (011) and a negative offset $i_0*<$ 0 to a relative decrease compared with state (100). Correspondingly, mainly the lower or upper output capacitor is charged, and thus the two output voltages u_{pM} and u_{Mn} can be balanced.

VI. SIMULATION RESULTS

The simulation model prepared for the discussed Vienna rectifiers was prepared using Matlab® Simulink R2012(b) for a 400V resistive 1kW load, the model thereafter was simulated for a sampling period of 10µs using ode45-Tustin solver in variable step discrete mode.

The simulation model prepared was investigated in steps for a conventional diode rectifier, a diode midpoint clamp and a capacitive midpoint clamp Vienna converter and comparative results for the three topologies were obtained. For higher utilization of DC link voltage third harmonic offset and for capacitor voltage balancing DC offset techniques are also used.

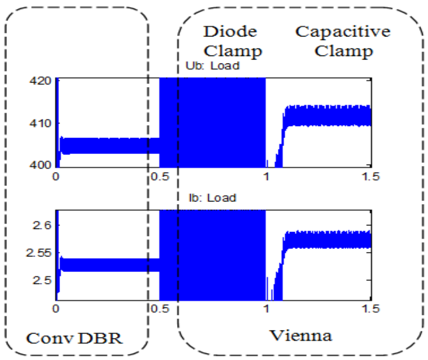


Fig.5: Output DC Voltage and Currents

Figure 5 shows the obtained output DC voltage and currents and as is marked for the first 0.5 seconds the Vienna is operated as a conventional diode bridge rectifier with a DC link capacitance of 100μF, while in the interval of 0.5 to 1 seconds the diode midpoint clamp Vienna rectifier is operated and in the last interval of 1 to 1.5 seconds the capacitive midpoint clamp Vienna rectifier is operated. And as is seen the magnitude of output voltage and power delivered to the load in increased upon the introduction of Vienna rectifier. The diode clamp though produces much higher voltages but the voltage ripples are also enormous while the capacitive counterpart not only produces higher voltages but also produces much lower ripples and the load power remains fairly balanced.

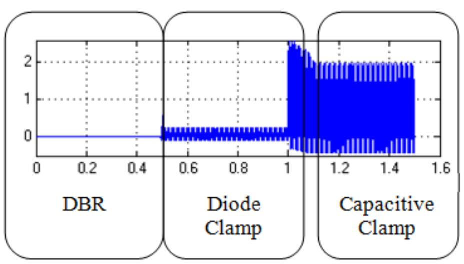


Fig.6: Midpoint Clamp Currents

The midpoint clamp provided in a Vienna rectifier provides a path for the balancing current which arises to compensate for the voltage imbalances between the DC link capacitances. The midpoint clamp current for the simulated model is shown in fig.6. Where the diode clamp circuit has a much lower mid clamp currents but eventually had much higher ripples in output DC voltages.

The input voltage to the Vienna rectifier model is fed through a stringent 2 KVA source, and thus the switching harmonics are evidently impressed upon the source voltages on account of controlled switching of bidirectional switches. The source current though are absolutely unaffected by the switching operation and are majorly sinusoidal.

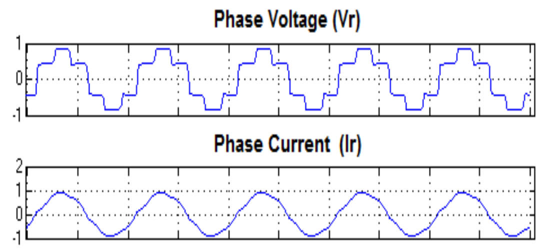
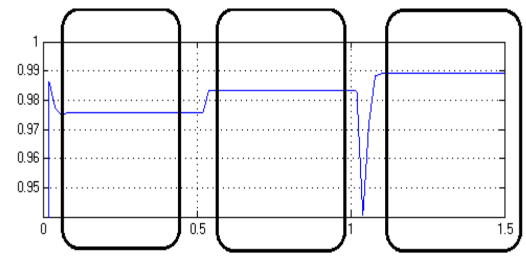
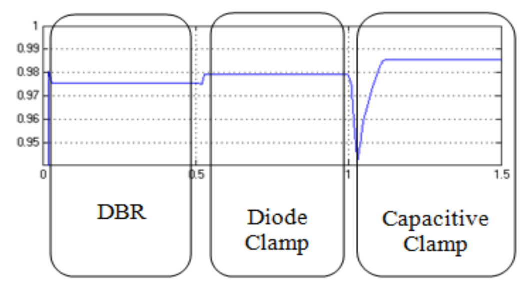


Fig.7: Input AC p.u. Phase Voltages & Currents

The same load of 1kW when supplied in sequence by a DBR, Diode clamp Vienna and a capacitor clamp Vienna rectifier, the Vienna rectifier out shadows the DBR giving much better power factor as is shown in figure 8. Where a power factor of 0.989 is obtained as compared to 0.975 for a conventional rectifier.



(a)



(b)

Fig.8: Input Power Factor (a) for Pulse width of 60˚ (b) for plse width of 30˚

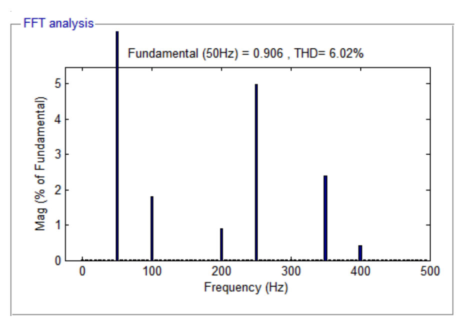


Fig.9: Harmonic Current analysis

The harmonic analysis of the input source current and voltages was also followed where the voltage wave had a total harmonic distortion of 24.1% while the current total harmonic distortion was merely 6.02% shown in fig.9, without the use of any filtrating equipment.

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VII. CONCLUSION

With reference to the simulation results shown above it is observed that the Vienna rectifiers possess superior performance and power factor improvement capabilities for a comparable harmonic introduction into the connected system. Further the window of power factor correction can be altered by varying the pulse width of Vienna rectifier pulses. The result shown in fig.5 show that the output voltage in increased w.r.t. a conventional diode bridge rectifier by 2.5% and the power factor is also improved by a considerable 1.2%. The device thus is favorable for use in high voltage high power applications where it shall certainly eliminate the requirement of buck/boost converters and would offer the same degree of control and cost justification.

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