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# Comparative evaluation of the Single-phase "VIENNA I" and the Double Boost Effect "DBE" rectifiers under sliding mode current control

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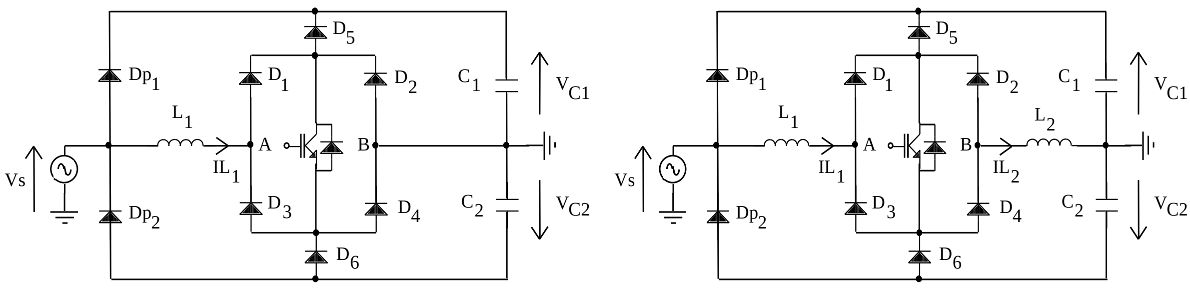
**Abstract:** Here a comparative evaluation of the single-phase "VIENNA I" and the "DBE" rectifiers is done. In order to improve the performances of the single-phase unidirectional VIENNA rectifier, a coil is added in convert's structure. The new structure so called "DBE" allows to get a "Double Boost Effect" during each half-period of the grid, then transmitting the stored energy to both DC capacitors. These structures operate in continuous current and PFC modes thanks to an AC side current control. An optimal current control strategy is developed based on the use of an analog current controller. This one operates in sliding mode with a control of the maximum switching frequency of the power switches. Experimental results show the accurate tracking of the proposed analog current controller and confirm the advantages of the DBE compared to the single-phase VIENNA.

**Keywords:** *Single-phase rectifier, Converter control, Power factor correction, Self-oscillating mode.*

## 1. Introduction

Unidirectional single-phase boost-type PMW rectifiers are widely employed in today's commercially available power supplies featuring PFC circuits [3]. Thus, many AC/DC rectifiers are currently investigated [1][3][4][5][6][7]. They have to operate in case of instabilities, they must be reliable, the distorsion of the input currents must be as lower as possible [1] and the power factor must be as high as possible too. So, these specifications can be reach when Boost Effect topologies are involved in the rectifiers. Then, many rectifiers are compared in [3][5] taking into account some of the criteria. In this paper, the single-phase "VIENNA I" (Fig.1(a)) and the Double Boost Effect "DBE" rectifiers (Fig.1(b)) are investigated where the core of the "DBE" involves two coils.




(a) Single-phase "VIENNA I" (b) "DBE" rectifier

**Fig. 1: Unidirectional Single-Phase Rectifier**

This work also concerns the targeted extremely low input current distortion and the high PFC. It is the reason why here, an accurate and robust controller is requested. It operates in sliding mode and it has been used in AC/DC conversion [6]. It gives birth to a self-oscillating mode, then also controls the maximum switching frequency of the power devices.

The full paper will focus on the current control performances versus all the localisation of the current sensor. Indeed, the "DBE" rectifier has been investigated in [1], nevertheless the current under control was done on the L2 coil. Here, the "DBE" current control is done on the L1 coil and this improves the THD.

## 2. The Double Boost Effect "DBE" rectifier

Now, in order to simplify the study of the different states of the single-phase "VIENNA I" and "DBE" topologies, the semi-conductors are considered ideal and the rectifier is unloaded. The diodes Dp1 and Dp2 are used to preload the capacitor C1 and C2 respectively in the positive and negative half-periods of the mains voltage. Both rectifiers operate in continuous and PFC modes and the power on transient is finished.

## 2.1 Positive mains voltage

When the switch K is closed (see Fig. 2 (a)), the diodes D1 and D4 are in the ON states and the current goes through the coil $L_1$, the diode D1, the switch K, the diode D4 and the coil $L_2$. Therefore the coils $L_1$ and $L_2$ store the energy.

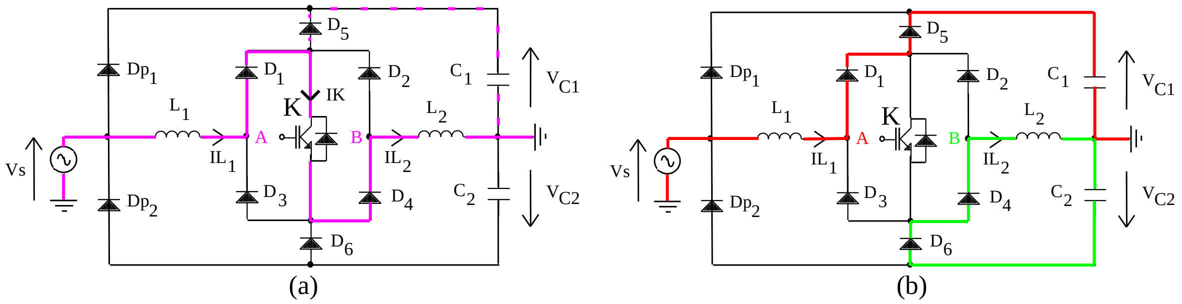



**Fig. 2: Positive current paths: (a) closed switch, (b) open switch [3]**

During a very short time, a small part of the current $i_{L1}(t)$ goes to the diode D5 and the capacitor $C_1$.

When the switch K is open (see Fig. 2 (b)), the diodes D1, D4, D5 and D6 are in the ON states and one of the currents goes through the coil L1, the diode D1, the diode D5 and the capacitor C1. Another current goes through the coil L2, the diode D4, the diode D6 and the capacitor C2. Simultaneously, the energy stored in the coils L1 and L2 is transferred to both capacitors. Then a "Double Boost Effect" is performed.

Now α depicts the PWM is duty cycle. Then the low frequency model of the power rectifier, when the mains voltage is positive i.e. where $\omega t \in ]0;\pi[\mathrm{mod}[2\pi]$, is given by [3]:

$$\frac{V_{C1}(t)}{V_{S\max}\times\sin(\omega t)} = \frac{1}{1-\alpha}\times\frac{L_1}{L_1+L_2} + \frac{L_2}{L_1+L_2} - \frac{L_1\times i_{L1\max}\times\omega\times\cos(\omega t)}{V_{S\max}\times(1-\alpha)\times\sin(\omega t)} \quad (1)$$

$$\frac{V_{C2}(t)}{V_{S\max}\times\sin(\omega t)} = -\frac{\alpha}{1-\alpha}\times\frac{L_2}{L_1+L_2} + \frac{L_2\times i_{L2\max}\times\omega\times\cos(\omega t)}{V_{S\max}\times(1-\alpha)\times\sin(\omega t)} \quad (2)$$

The equation (1) shows that a Boost effect occurs on the capacitor $C_1$ and the equation (2) shows that a Buck-Boost effect occurs on the capacitor $C_2$.

In short it can be noticed that assuming the coil $L_2$ value equals to zero, these equations describe the single-phase VIENNA power cell too.

## 2.2 Negative mains voltage

When the switch K is closed (see Fig. 3 (a)), the diodes D2 and D3 are in the ON states and the current goes through the coil $L_1$, the diode D3, the switch K, the diode D2 and the coil $L_2$. Therefore the coils $L_1$ and $L_2$ store the energy.

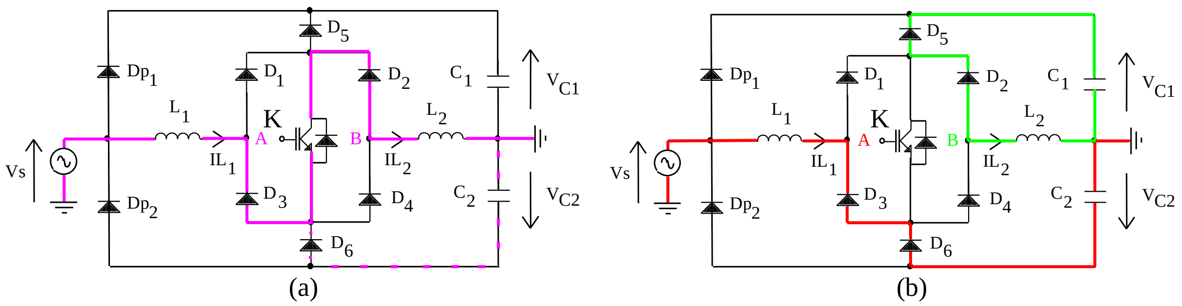



**Fig. 3: Negative current paths: (a) closed switch (b) open switch [3]**

During a very short time, a small part of the current $i_{L1}(t)$ goes to the diode D6 and the capacitor $C_2$.

When the switch K is open (see Fig. 3 (b)), the diodes D2, D3, D5 and D6 are in the ON states and one of the currents goes through the coil L1, the diode D3, the diode D6 and the capacitor C2. Another current goes through the coil L2, the diode D2, the diode D5 and the capacitor C1. Simultaneously, the energy stored in coil L1 and coil L2 is transferred to both capacitors.

Using the duty cycle α, where $\omega t \in ]\pi;2\pi[\mathrm{mod}[2\pi]$, the low frequency model of the power rectifier, when the mains voltage is negative, is given by [3]:

$$\frac{V_{C2}(t)}{V_{S\max}\times\sin(\omega t)}=\frac{1}{1-\alpha}\times\frac{L_1}{L_1+L_2}+\frac{L_2}{L_1+L_2}-\frac{L_1\times i_{L1\max}\times\omega\times\cos(\omega t)}{V_{S\max}\times(1-\alpha)\times\sin(\omega t)} \tag{3}$$

$$\frac{V_{C1}(t)}{V_{S\max}\times\sin(\omega t)}=-\frac{\alpha}{1-\alpha}\times\frac{L_2}{L_1+L_2}+\frac{L_2\times i_{L2\max}\times\omega\times\cos(\omega t)}{V_{S\max}\times(1-\alpha)\times\sin(\omega t)} \tag{4}$$

A “Double Boost Effect” occurs again. A Boost effect on the capacitor $C_2$ and a Buck-boost effect on the capacitor $C_1$.
In short it can be noticed that assuming the coil $L_2$ value equals to zero, these equations depict the single-phase VIENNA power cell too.

# 3. The self-oscillating phase-shifted modulator and current controller

The next figure shows a basic scheme where the chosen current controller has been used in DC/AC converters. It runs in sliding mode and offers an accurate current control. At high and low frequencies, it operates in different ways, i.e. at high frequency it operates for frequency switching control and at low frequency it operates for current control. The transfer functions $F_1(p)$ $F_2(p)$ and $R_T$ depict the load voltage to current transfer function, a second order low-pass filter transfer function and a current sensor transfer one, where:

$$F_1(p)=\frac{I(p)}{U(p)}=\frac{1}{R+Lp}=\frac{1}{R}.\frac{1}{1+\tau_1 p} \tag{5}$$

$$F_2(p)=\frac{1}{1+2\xi p/\omega_0+p^2/\omega_0^2} \tag{6}$$

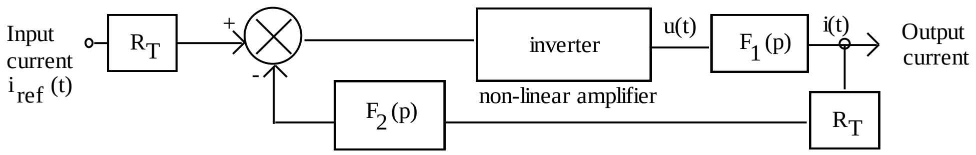



**Fig. 4: Scheme of the inverter current control loop**

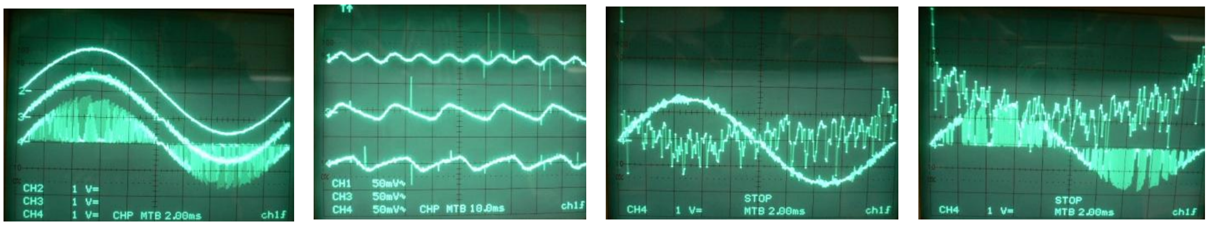
The inverter feeds the voltage signal u(t) to the load which is assumed to be inductive (R,L). The linear part of the system becomes a third order low-pass transfer function H(p). By considering the H(jω) phase rotation versus frequency, a voluntary self-oscillation occurs. At the oscillation frequency $f_{osc}$, $F_1$ produces a phase rotation nearly equal to -90 degrees and the second order low-pass filter $F_2$ too.

# 4. Experimental results

Now, experiments are done using both rectifiers. In both cases, the coil L1 current is under control. Most of the parameter values are identical. They are given by f = 50Hz (frequency), $V_{in}$ = 70Vrms (mains voltage), $I_{refmax}$ = 6A (mains current reference), C1 = C2 = 2200µF (DC bus capacitors), R = 298Ω (single load resistor).

## 4.1 Single-Phase “VIENNA I” experimental results

Here there is a single coil L1 which equals 3mH. Thus, the next figures show the experimental results.

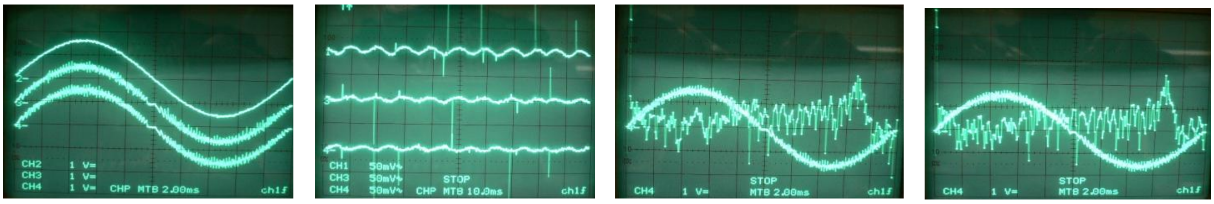


(a) IL1ref, IL1and IL2 (b) VC1, VC2 and Vdc (c) IL1 current and FFT IL1 (d) IL2 current and FFT IL2

**Fig. 5: Experimental results single-phase “VIENNA I” rectif**

## 4.2 Double Boost Effect “DBE” rectifier experimental results

Here there are two coils involved in the topology, where $L_1$ equals 820µH (AC side coil’s inductance) and $L_2$ equals 2200µH. The next figures illustrate the experimental results, where the AC side L1 coil current is under control.



(a) IL1ref, IL1and IL2 (b) VC1, VC2 and Vdc (c) IL1 current and FFT IL1 (d) IL2 current and FFT IL2

**Fig. 6: Experimental results "DBE" rectifier, current control of the coil $L_1$**

### 4.3 Comparison between the Single-phase "VIENNA I" and Double Boost Effect "DBE" rectifier

Now, the performances of the single-phase "VIENNA I and the "DBE" rectifier are compared. By viewing Fig. 5(a) and the third curve, i.e. without the L2 coil, the current ripples in IL2 path are very high, i.e. in the case of the single-phase VIENNA rectifier. It is not the case (see Fig. 6(a) and the third signal), when using the DBE rectifier. The spectrums Fig. 5(d) and Fig. 6(d) prove it. At low frequency, the intermodulation line amplitudes of the current going through the IL2 path, i.e. considering the single-phase VIENNA, are around of -20dB/30dB whereas they are around of -50dB/60dB for the DBE rectifier. The ripple frequency of the DC output voltages (capacitor C1 and C2 separately) is twice as high when using the DBE rectifier (see Fig. 6(b)) in comparison with the single-phase VIENNA (see Fig. 5(b), second and third curves). The ripple amplitude of the DC output voltages is lower when using the DBE (see Fig. 6(b)) in comparison with the single-phase VIENNA (see Fig. 5(b)). Thus, it could be possible to use lower values for the capacitor when using the DBE rectifier core. From this analysis, to avoid the presence of high variation of current (di/dt) going through the ground connection, the DBE rectifier is preferred to the single-phase VIENNA. From the equations and the desired performances it is possible to optimize the values of the coil L1 and the coil L2. Furthermore, here the results show that the IL1 current Total Harmonic Distortion of the DBE rectifier is lower when the control current is done on the coil L1 in comparison with [3] where it was done on the coil L2. This is normal because here it is the AC side coil current, which is under control.

## 5. Conclusion

A comparative study between the single-phase "VIENNA I" and the "DBE" rectifier has been done. Thanks to an itemized analysis, the experimental results show that the "DBE" rectifier presents much more advantages. Using two coils, the current ripple going through the "IL2 path" is greatly reduced and this is better for EMC. The current control on the L1 coil is better than on the L2 coil. It permits to reach a very low THD, so a better PFC. Moreover, such performances are reached thanks to a patented current controller, which runs in sliding mode.

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