Lab no. 10

SINGLE-PHASE BRIDGE RECTIFIERS WITH VOLTAGE FILTERS

1. Introduction

The line-commutated rectifiers provided with voltage filters have different operating features compared with the same rectifier topologies provided with current filters, even if the rectifier is uncontrolled (made with diodes) or phase-controlled (made with thyristors). For this reason it is necessary to have a separate study for these converters in combination with the voltage filters. The most used voltage filters are the pure capacitive filters (*C*) or the inductive-capacitive filters (*L-C* → filters of the second order). By their use it is expected to obtain a DC voltage with a better form factor to supply the DC loads which are sensitive at this parameter as the power electronics converters which make the DC/DC conversion (DC/DC converters) or those who make the DC/AC conversion (inverters).

The power electronics equipments which provide output DC voltages, fixed or adjustable, regulated or unregulated, with or without electrical isolation from the input are named ***DC sources*** or ***DC voltage sources***. The single-phase full-bridge rectifier with voltage filters can be included in the DC sources category. This type of rectifier is frequently used in low-power applications, below 1kW. The most used version is the single-phase full-bridge rectifier with diodes. The phase-controlled single-phase rectifiers, with thyristors, is rarely included in the DC sources because they can operate only in certain conditions, complying with some restrictions regarding the control, as we are going to see in the section 3 of the current paper. The result obtained with the help of this rectifier version is a filtered DC voltage with the possibility of adjusting between two closed limits.

2. Analysis of the uncontrolled rectifier provided with a voltage filter to the output

Fig.10.1 shows a single-phase full-bridge rectifier with diodes and a capacitive filter (C_f) supplied in two variants:

- directly from the utility power grid – Fig.10.1(a);
- via a line-frequency transformer – Fig.10.1(b).

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For the rectifier analysis the C_f capacity is considered high enough in order to filter very well the output DC voltage. Thus:

$$v_d(t) \approx V_d = constant \tag{10.1}$$

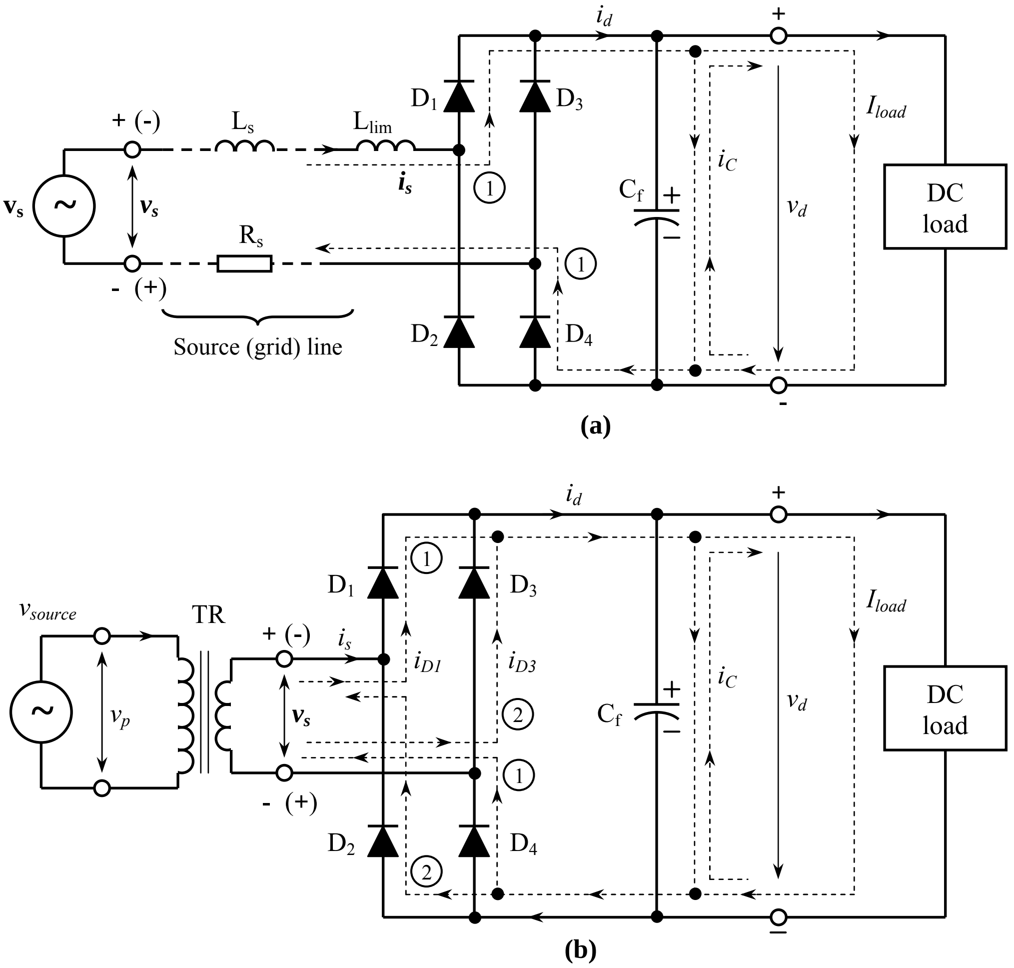

Fig. 10.1 Single-phase full-bridge rectifier with capacitive filter supplied:
(a) directly from the utility grid; (b) via a line-frequency transformer.

The voltage across the capacitive filter is seen by the rectifier as an active load that contains its own DC source. In contrast with the active *R-L-E* load, on the i_d current path, there is not an important inductance to maintain the continuous current conduction through the rectifier and so, the converter operates in discontinuous current mode. Consequently, the moments when the diodes begin to conduct the i_d current are placed when the source voltage is higher than the V_d voltage (see Fig.10.2). During the time intervals in which the voltage $v_s(t)>V_d$, the only circuit elements which limit the charging current of the C_f capacitor are:

- The AC source and the grid impedance ($R_s+\omega L_s$) when the rectifier is connected directly to the utility grid. If this impedance is low and the current peaks ($I_{d(\mathrm{peak})}$) are high, it is indicated to add a limitation inductance L_{lim} (Fig.10.1.a);
- The AC source and the grid (line) impedance plus the transformer impedance, all reported to the secondary windings, if the rectifier is supplied by a line-frequency transformer.

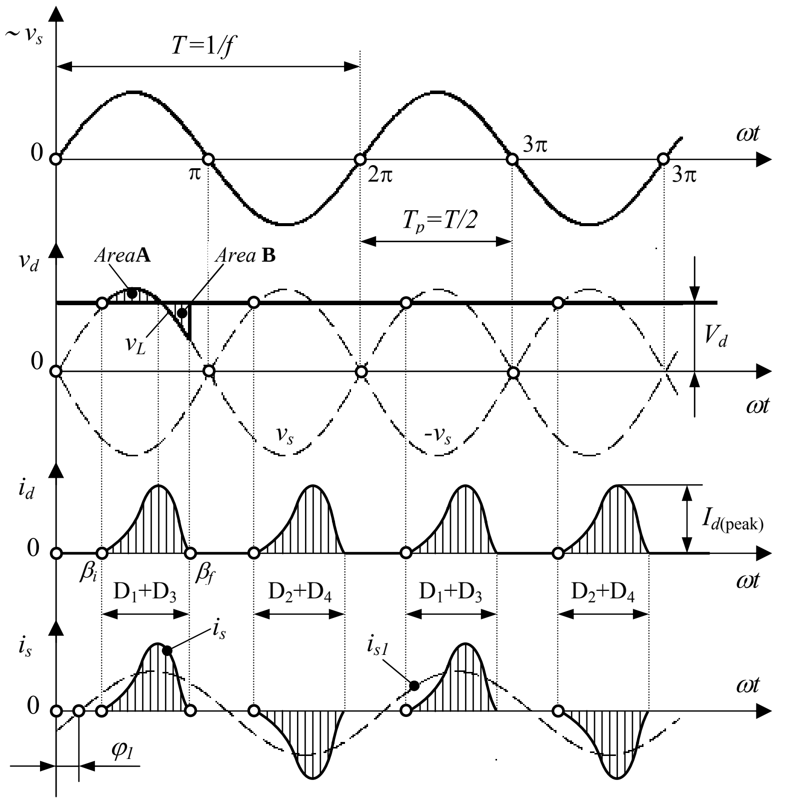

Fig. 10.2 The waveforms corresponding to a single-phase uncontrolled rectifier provided with a voltage filter at the output (ideal case $V_d \approx$ const. and L_s high).

Further, it will be analyzed the situation of a rectifier whose equivalent inductance seen at its input L_s ($= L_{source} + L_{line} + L_{TR} + L_{\mathrm{lim}}$ etc.) is high enough to neglect the voltage drop across the resistance R_s and to limit the current peaks $I_{d(\mathrm{peak})}$ at a reasonable value for the diodes in a maximum DC load condition. In this situation, as is presented in [1] (Mohan et al.), can be calculated the expression of the i_d current and the time intervals during which that current exists. Thus, after the moment $\omega t = \beta_i$ when $v_s(t)$ exceeds the V_d value, the i_d current starts to flow through the rectifier and the voltage equation, in an approximate form is:

$$v_L(t) \approx v_s(t) - V_d \tag{10.2}$$

where $v_L(t)$ is the voltage drop across the inductance L_s. Its waveform is shown in Fig.10.2 considering the x-axis on the V_d voltage level.

Knowing that $v_L(t) = L_s \cdot \frac{di_d(t)}{dt}$ a differential equation is obtained by which the expression of current $i_d(t)$ can be calculated and therefore its waveform can be plotted:

$$\frac{di_d(t)}{dt} = \frac{1}{L_s} \cdot (\sqrt{2} \cdot V_s \sin \omega t - V_d) \tag{10.3}$$

During the time intervals where $v_s(t) > V_d$ the voltage $v_L(t) > 0$ and the $i_d(t)$ current increases ($\frac{di_d(t)}{dt} > 0$). When $v_s(t)$ equals again V_d, ($\frac{di_d(t)}{dt} = 0$) the i_d current reaches a maximum after which follows another time interval during which it decreases ($\frac{di_d(t)}{dt} < 0$).

During the last time interval $v_s(t) < V_d$, the V_d voltage tends to reversely bias the diodes in conduction, but the i_d current still flows based on the energy accumulated by the L_s inductance in the previous time interval, when the current was increasing. Because the inductance value is low, the accumulated energy in its electromagnetic field is also low and the i_d current flows during a limited time interval after the moment when $v_s(t) = V_d$. In a normal operation, the i_d current flow stops before the next half wave of the AC voltage $v_s(t)$ ($\beta_f < \pi$).

The limits of the time interval during which the i_d current flows, expressed in electrical degrees, respectively the initial angle β_i and the final angle β_f, can be calculated if we know the value of the DC voltage V_d, the rms value V_s and inductance value L_s:

- $v_s(t) = U_d \Leftrightarrow \sqrt{2} \cdot V_s \sin \beta_i = V_d \Rightarrow \beta_i = \arcsin \frac{V_d}{\sqrt{2} \cdot V_s}$ (10.4)

- The equation (10.3) can be rewritten as:

$$di_d(\omega t) = \frac{1}{\omega \cdot L_s} \cdot (\sqrt{2} \cdot V_s \sin \omega t - V_d) \cdot d(\omega t) \tag{10.5}$$

If we integrate the equation (10.5) on the interval [β_i, ωt], where $\omega t \le \beta_f$, it is obtained:

$$\int_{\beta i}^{\omega t} di_d(\omega t) = \frac{1}{\omega \cdot L_s} \cdot \int_{\beta i}^{\omega t} (\sqrt{2} \cdot V_s \sin \omega t - V_d) \cdot d(\omega t) \iff$$

$$i_d(\omega t) - i_d(\beta_i) = \frac{1}{\omega \cdot L_s} \cdot \left[\sqrt{2} \cdot V_s \cdot \int_{\beta i}^{\omega t} \sin \omega t \cdot d(\omega t) - V_d \cdot \int_{\beta i}^{\omega t} d(\omega t) \right]$$

Considering that at the moment $\omega t = \beta_i$ the current $i_d(\beta_i) = 0$ it results:

$$i_d(\omega t) = \frac{1}{\omega \cdot L_s} \cdot \left[\sqrt{2} \cdot V_s (\cos \beta_i - \cos \omega t) - V_d (\omega t - \beta_i) \right] \qquad (10.6)$$

The right limit of the i_d flow time interval can be obtained knowing that the time:

$$i_d(\beta_f) = 0 \qquad (10.7)$$

If in the equation (10.6) we consider $\omega t = \beta_f$ and we take into account the equality (10.7) we obtain:

$$\begin{aligned} &\sqrt{2} \cdot V_s (\cos \beta_i - \cos \beta_f) - V_d (\beta_f - \beta_i) = 0 \iff \\ &V_d \cdot \beta_f + \sqrt{2} \cdot V_s \cdot \cos \beta_f = V_d \cdot \beta_i + \sqrt{2} \cdot V_s \cdot \cos \beta_i \end{aligned} \qquad (10.8)$$

In equation (10.8) we know V_s, V_d, β_i values and we can determine by numerical methods the electrical angle β_f.

Considering that the $i_d(t)$ waveform repeats at each half cycle, during each pulse time period $T_p = T/2$, this current starts from zero and ends also in zero [$i_d(\beta_i) = i_d(\beta_f) = 0$] the integral of the voltage drop across the inductance L_s, applied on a time period T_p, is zero:

$$v_L(\omega t) = L_s \cdot \frac{di_d(\omega t)}{dt} \Rightarrow di_d(\omega t) = \frac{1}{\omega L_s} \cdot v_L(\omega t) \cdot d(\omega t) \Rightarrow$$

$$\int_0^{Tp} di_d(\omega t) = \frac{1}{\omega L_s} \cdot \int_0^{Tp} v_L(\omega t) \cdot d(\omega t) \iff$$

$$i_d(\beta_f) - i_d(\beta_i) = 0 - 0 = \frac{1}{\omega L_s} \cdot \int_0^{Tp} v_L(\omega t) \cdot d(\omega t) \Rightarrow$$

$$\int_0^{Tp} v_L(\omega t) \cdot d(\omega t) = 0 \iff Area\ \mathrm{A} + Area\ \mathrm{B} = 0 \qquad (10.9)$$

During the negative half waves of the supply AC voltage the phenomena related to the i_d current evolve identically because the diodes D_2, D_3 are on and they reverse the voltage $v_s(t)$ at the rectifier output during these time intervals. Thus, for the equivalent circuit through which flows the i_d current, the voltage source appears as a module of the AC voltage: $|v_s(t)|$.

The i_d current sustains the load current I_{load} and charges the C_f capacitor with the consumed energy during the time intervals in which this current interrupts:

$$i_d(t) = i_C(t) + I_{load} \tag{10.10}$$

During an operating time period (T_p), the i_C current flows in both directions. In reality, this AC current (non-sinusoidal) causes variations (ripples) of the output voltage, across the C_f filter capacitor (over the V_d average value an alternative component overlaps) – see Fig.10.3. In steady states (I_{load} = const.) the v_d voltage value from the beginning cycle $V_{d(\min)}$ is equal with the value of the end of cycle, as shown in Fig.10.3

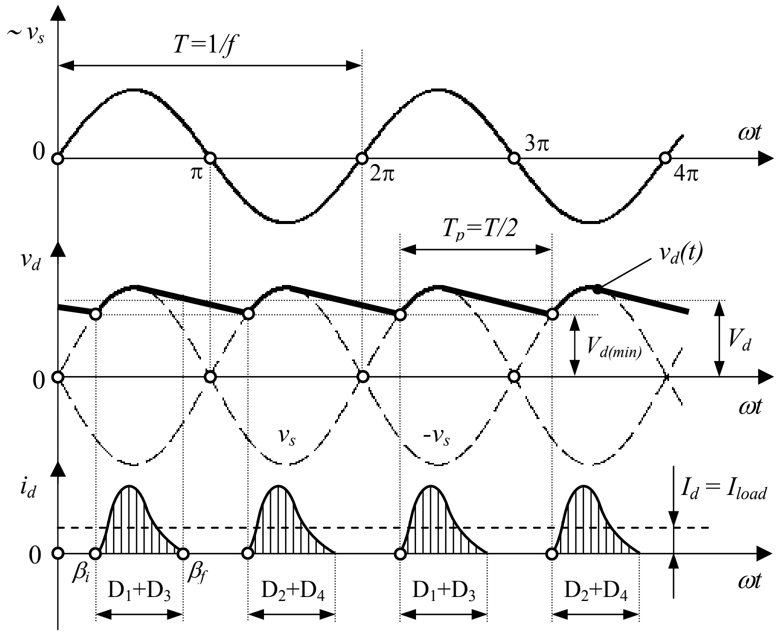

Fig. 10.3 Variations (ripples) of the output voltage v_d (across the filter capacity) in real conditions (C_f and L_s have limited values).

The instantaneous value of the charge/discharge current of the C_f capacitor is given by the known equation:

$$i_C(t) = C_f \frac{dv_d(t)}{dt} \;\Rightarrow\; C_f \cdot dv_d(t) = i_C(t) \cdot dt \qquad (10.11)$$

In steady states conditions the average value of the current through the C_f filter capacitor is zero (I_C =0). This affirmation can be proven if we integrate the equation (10.11) on a T_p time period, considering the time origin at the beginning of these intervals:

$$I_C = \frac{1}{T_p}\int_0^{Tp} i_C(t)\cdot dt = C_f \cdot \int_0^{Tp} dv_d(t) = C_f\left[v_d(T_p) - v_d(0)\right] = \\ = C_f\left[V_{d(\min)}) - V_{d(\min)}\right] = 0 \qquad (10.12)$$

Applying the average value formula to the (10.10) equation and considering the equality (10.12) we obtain:

$$\frac{1}{T_p}\int_0^{Tp} i_d(t)\cdot dt = \frac{1}{T_p}\int_0^{Tp} i_C(t)\cdot dt + \frac{1}{T_p}\int_0^{Tp} I_{load}\cdot dt \;\Rightarrow \\ \Rightarrow\; I_d = I_{load} \qquad (10.13)$$

The equation (10.13) highlights the fact that the average value of the i_d current is always equal with the load current value or, otherwise, ***the average (DC) component of the i_d current flows through the rectifier DC load and the AC component (the current ripple) flows through the capacitive filter.***

According to the Lab no.8, *the output average voltage provided by a rectifier that operates in discontinuous current mode depends on the load current*:

$$V_d = f(I_{load}) \rightarrow \text{Load characteristic} \qquad (10.14)$$

Thus, while the current absorbed by the DC load increases, the DC voltage V_d, measured across the capacitive filter, decreases – see Fig.10.4. On the other hand, if the load current decreases, tending to zero, the V_d voltage, tends to the amplitude value of the v_s sinusoid:

$$I_{load} \rightarrow 0 \;\Rightarrow V_d \rightarrow V_{s(\max)} = \sqrt{2}\cdot V_s \qquad (10.15)$$

In many applications it is important to know the dependence (10.14). For this, it will be applied the average value formula to the i_d current expression (10.6):

$$I_{load} = I_d = \frac{1}{T_p}\int_0^{Tp} i_d(t)\cdot dt = \frac{1}{\pi}\int_{\beta i}^{\beta f} i_d(\omega t)\cdot d(\omega t) = \\ = \frac{1}{\pi}\cdot\frac{1}{\omega L_s}\cdot\int_{\beta i}^{\beta f}\left\{\sqrt{2}\cdot V_s[\cos\beta_i - \cos(\omega t)] - V_d[(\omega t) - \beta_i]\right\}\cdot d(\omega t) \qquad (10.16)$$

The equation (10.16) suggests a reverse dependence $I_{load} = f(V_d)$ and can be calculated if the V_d voltage value is known. Because in practice it is important to know the V_d value for a certain DC load value, the scientific literature [1] recommends to draw the ***load characteristic*** $V_d = f(I_{load})$ for a certain DC source with the help of the (10.16) equation. For this purpose we must know the rms value of the supply voltage V_s and the value of the inductance L_s, seen by the rectifier at its input. Next, we can calculate the coordinates of some points through which the graph will be drawn, choosing progressive descending values for V_d, starting with $\sqrt{2} \cdot V_s$ value and continuing with $V_{d1} > V_{d2} > V_{d3} >.....$, as shown in Fig.10.4.

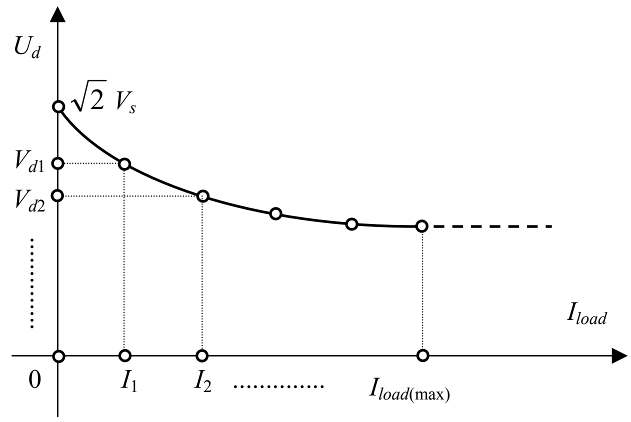

Fig. 10.4 Load characteristic $V_d = f(I_{load})$ for an uncontrolled rectifier provided with a capacitive filter at its output.

Excepting the value $V_d = \sqrt{2} \cdot V_s$ that fixes the coordinates for the first point of the characteristic and according to the relation (10.15), for every V_d value the electric angles β_i and β_f will be calculated with the help of equations (10.4) and (10.8), respectively. If, for a certain value the condition $\beta_f < \pi$ is respected, then we can calculate the load current, introducing the known values in the (10.16) equation. So we can determinate the points (I_1, V_{d1}), (I_2, V_{d2}) etc. The load current for that $\beta_f = \pi$ is the $I_{load(\max)}$ value and represents the maximum limit for which the rectifier is standing in the normal operating range. Having the load characteristic shown in Fig.10.4 we can determine the DC voltage value V_d from the source output for a certain load I_{load}.

An important aspect related to the operation of the rectifiers with capacitive filter is the ***grid pollution phenomenon***. If we analyze the current waveform absorbed by the rectifier from the utility power grid (see Fig.10.2) we can see that this is discontinuous and consistently non-sinusoidal. As well, a phase shift (φ_1>0) appears between the fundamental harmonic of the current i_{s1} and the waveform of the source voltage v_s. Consequently, *the power factor (PF) of the single-phase rectifier provided with the voltage filter at the output, is low*:

$$PF = \frac{I_{s1}}{I_s} \cdot \cos\varphi_1 \approx 0.5 \ldots 0{,}75 \tag{10.17}$$

The greatest contribution to the power factor deterioration is the weight of the current high harmonics and the least contribution is the fundamental harmonic phase shift (displacement power factor) because:

$$\cos\varphi_1 \approx 1 \ldots 0{,}9 \tag{10.18}$$

The lowest value of the displacement power factor ($\cos\varphi_1$) is obtained for large loads currents. A beneficial effect on the power factor is the increasing inductance from the i_d current path. Therefore, a supplementary reactance can be the L_{lim} inductance from the AC side, as shown in Fig.10.1(a), or the L_f inductance added in DC side, before the filter capacity C_f – see Fig.10.5.

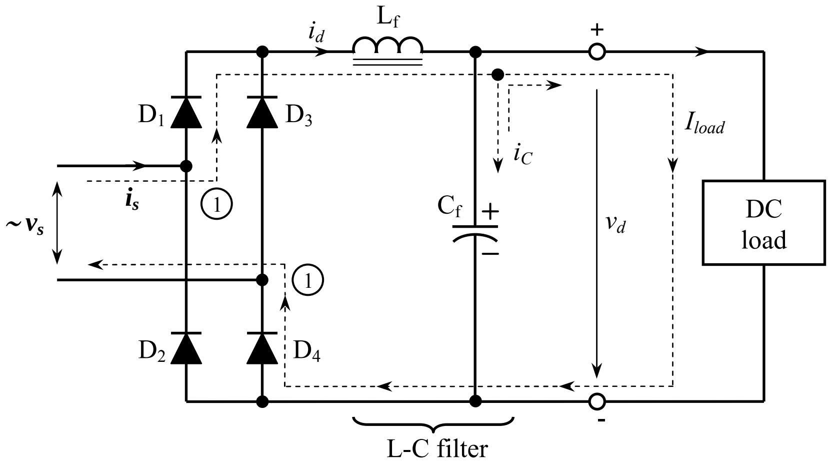

Fig. 10.5 Single-phase full-bridge rectifier provided with *L-C* voltage filter.

By using the L_f inductance, well dimensioned, it can be eliminated the limitation resistance R_{lim} inserted temporary in the circuit (in the position of inductance L_f shown in Fig.10.5) with the limitation role of the initial C_f charging current. On the other hand, the presence of L_f inductance will determine:

- reducing the weight of high harmonics (increasing the I_{s1}/I_s ratio from the power-factor equation) by flattening the i_s current half-waves, approximating them more to a sinusoidal waveform;
- reducing the crest factor of the i_s current that will lead to the „stress" reduction of the diodes which will not anymore conduct important repetitious current peaks;

- an slight increase of the phase shift φ_1 (decrease of the $\cos\varphi_1$) that scarcely affects the power factor compared with the benefit effects mentioned above;

3. Analysis of the phase-controlled rectifier provided with a voltage filter to the output

The solution of using a phase-controlled rectifier provided with an output voltage filter is recommended only in special applications. The objective of this combination consists in the possibility of adjusting the output DC voltage V_d between two closed limits for a certain load current value I_{load}. A possible application is the DC sources for the square-wave inverters. For this type of inverters, to adjust the rms value of the output AC voltage in concordance with the frequency (concordance used for the *U/f* speed control of the asynchronous motors), it is necessary to modify the value of the DC voltage that supplies the square-wave inverter. The ***DC bus*** between the rectifier and the inverter includes, obligatorily, a capacitive filter. So the rectifier that feeds this bus can be a phase-controlled one with a capacitive filter at its output. A modern alternative to the use of the phase-controlled rectifiers, with thyristors, in the frequency converters structure, is constituted by the active rectifiers, such as the PWM rectifiers or uncontrolled rectifiers associated with the ***P****ower* ***F****actor* ***C****orrection* (PFC) circuits.

If at the output of a *phase-controlled rectifiers with thyristors* is used a voltage filter, it is recommended that it will be of the *L-C* type, as shown in Fig.10.6.

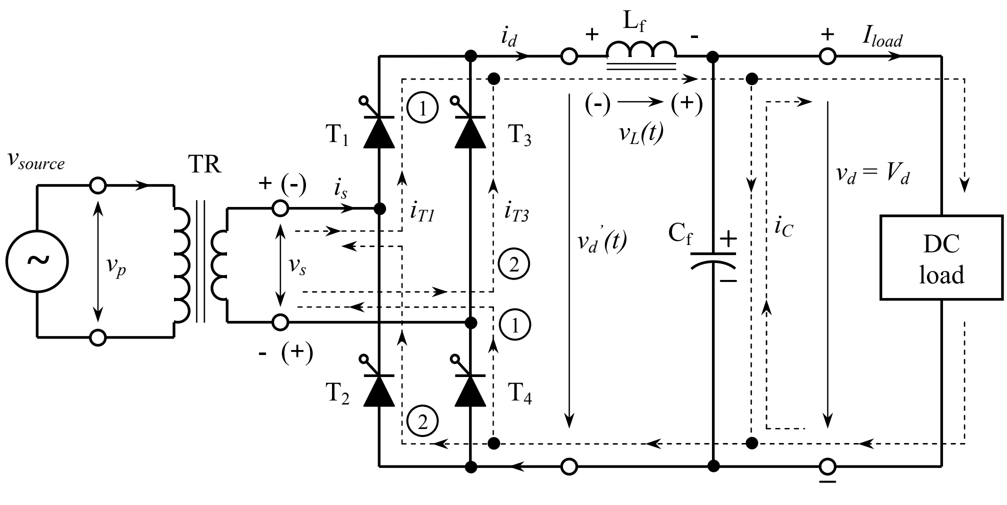

Fig.10.6 Single-phase phase-controlled rectifier provided with a voltage filter of *L-C* type at its output.

Being a single-phase rectifier, the voltage filter must be large, considering the low frequency (f_p = $1/T_p$ = 100Hz) of the pulses that must be filtered. Besides the C_f capacitor, the filter inductance L_f is also important because it can ensure a continuous (uninterrupted) i_d current when the DC load has certain values. So, the rectifier operates in ***continuous current conduction mode*** and the voltage $v_d^{'}(t)$ from the rectifiers output (before the *L-C* filter) has the same waveform as the output voltage $v_d(t)$ corresponding to the single-phase rectifier with current filter presented in the Lab no.8. Therefore, results the adjustment probability of the ***average value*** of the $v_d^{'}(t)$ voltage and implicit of the $v_d(t)$ voltage, without load current dependence:

$$v_d^{'}(t) = v_L(t) + v_d(t) \;\; \Rightarrow$$

$$V_d^{'} = \frac{1}{T_p}\int_0^{Tp} v_d^{'}(t)\cdot dt = \frac{1}{T_p}\int_0^{Tp} v_L(t)\cdot dt + \frac{1}{T_p}\int_0^{Tp} v_d(t)\cdot dt \qquad (10.19)$$

Because the i_d current value from the beginning of the T_p time period is the same with the value from the end of this time interval $\left(i_d(t)|_{t=0} = i_d(t)|_{t=Tp}\right)$, according to the equation (10.9), the integral of the $v_L(t)$ voltage on the T_p time period is zero and the equation (10.19) becomes:

$$V_d^{'} = \frac{1}{T_p}\int_0^{Tp} v_d^{'}(t)\cdot dt = \frac{1}{T_p}\int_0^{Tp} v_d(t)\cdot dt \; = V_d = V_{d0}\cos\alpha \qquad (10.20)$$

It must be taken into consideration that, once the output DC voltage decreases, there is the possibility of the load current to decrease. Also, there is the possibility of the DC load decreasing. In both situations the average current through the filter inductance decreases because, according to the equation (10.13), $I_d = I_{load}$. So, the accumulated energy in the L_f field decreases and below a certain threshold ($I_{load} < I^*$) the rectifier passes in the discontinuous conduction mode.

The ***discontinuous conduction mode*** of operation can hardly be avoided for the single-phase rectifier shown in Fig.10.6 because the L_f inductance included in a *L-C* voltage filters is not so large as in the case of a *L* current filters, considering the limitations concerning the size, weight and price of the *L-C* filter. From this reason, it must take into consideration that the rectifier should operate well in discontinuous conduction mode. The first measure was discussed in the Lab no.8 where we saw that the thyristors can't be controlled with a delay angle below α_{min} given by the G point (see Fig.8.11) because before this point the thyristors can't enter into conduction if we use short trigger pulses on the gate terminal.

Considering that, in discontinuous conduction mode of operation, the DC voltage V_d varies along with the load value, the G point is moving with it and the α_{min} angle changes. In the absence of a fixed landmark to avoid the possibility of the thyristors un-firing, we can use trigger pulses with large width or modulate impulses (repetitive trigger pulses – see Fig.10.7). In this way it doesn't matter that the ascending edge of the trigger pulse is in the left of the G point ($\alpha<\alpha_{min}$), due to the trigger pulse persists, the thyristors turn-on as a diode after the condition $|v_s(t)| > V_d$ is accomplished. In this case, the waveforms correspond to an uncontrolled single-phase rectifier; these waveforms are shown in Fig.10.2 and Fig. 10.3.

To highlight the adjust possibility of the V_d output DC voltage, in Fig.10.6 is shown the waveforms when the delay angle is in the ranges:

$$k\pi + \alpha_{\min} \le \alpha < (k+1)\pi - \alpha_{\min}, \quad k = 0, 1, 2, \; ..... \tag{10.21}$$

with the specification that α_{min} angle varies simultaneously with the V_d value.

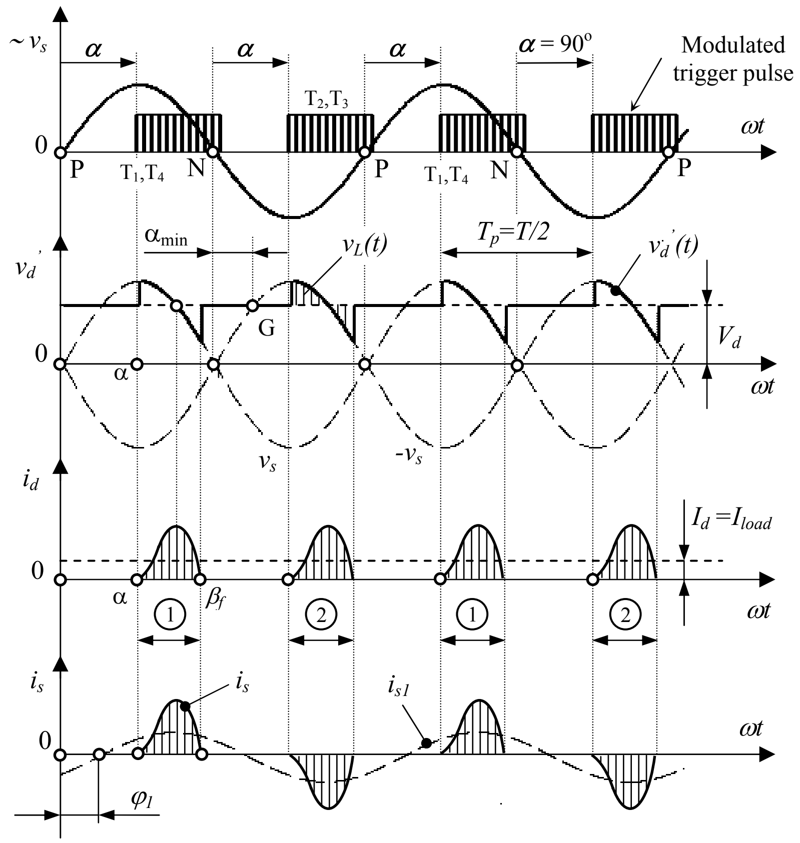

Fig.10.7 Waveforms corresponding to a single-phase full-bridge thyristors rectifier with a voltage filter (discontinuous-current conduction mode).

If the (10.21) control condition is respected, in discontinuous conduction mode the filtered voltage from the rectifier output is dependent on both the delay angle and the current load:

$$V_d = f(\alpha, I_{load}) \tag{10.22}$$

Considering that with the V_d adjusting, the I_{load} current is also changed most of the time, it results that through the delay angle the output DC voltage can be adjusted in a narrow range:

$$V_{d(\min)} \le V_d \le V_{d(\max)} \tag{10.23}$$

This is a limitation of the phase-controlled rectifier provided with voltage filter that operates in discontinuous conduction mode, limitation that must be considered when the rectifier is integrated in a certain application. According to the type of the DC load and the current range, it must be determined the limits between which can be adjusted the V_d output voltage.

This type of DC source pollutes also the utility power grid. The power factor is lower in the case of phase-controlled rectifier than in the case of the uncontrolled rectifier because the phase shift φ_1 between the fundamental harmonic of the line current i_{s1} and the wave of the AC voltage v_s is larger in the phase-controlled rectifier case (see Fig.10.2 compared with Fig.10.3)

4. Laboratory application

The experimental study of a single-phase uncontrolled full-bridge rectifier provided with a voltage filter will be performed on a lab DC source. It is a double DC source special conceived to supply four-quadrant choppers and inverters with a half bridge topology. The block diagram of the source is presented in Fig.10.8.

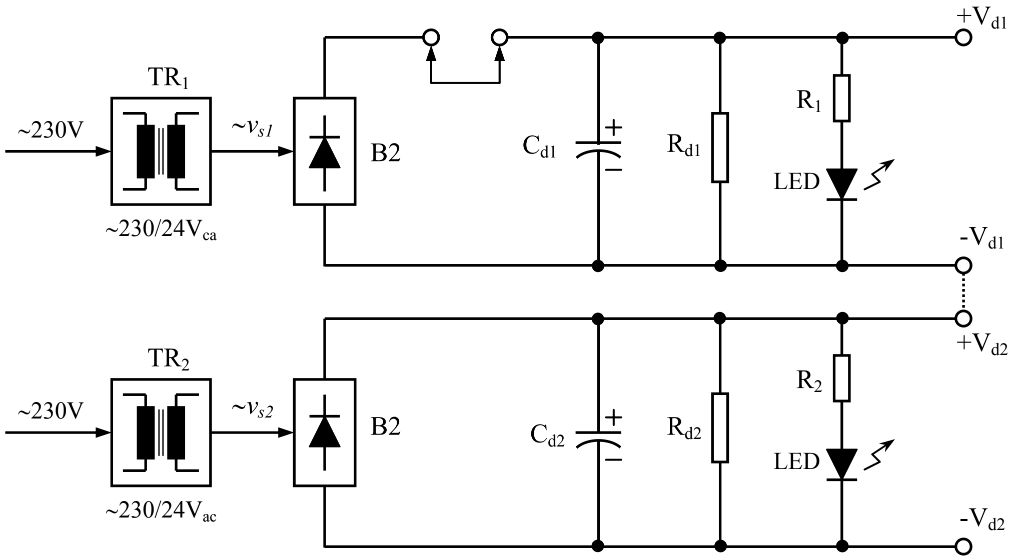

Fig.10.8 Double DC source achieved with single-phase bridge rectifiers (B2).

To assemble the laboratory setup with the block diagram shown in Fig.10.8 and the image shown in Fig.10.9 it will be used one of the two B2 full-bridges as power integrated module (PIM) included in the DC double source. It is the upper module because it has banana socket connectors through which can be inserted the filter inductance (L_f) between the rectifier and the filter capacitor (C_{d1}) in order to obtain an L-C filter. How other circuit elements will be interconnected to get the experimental setup is shown in Fig.10.9.

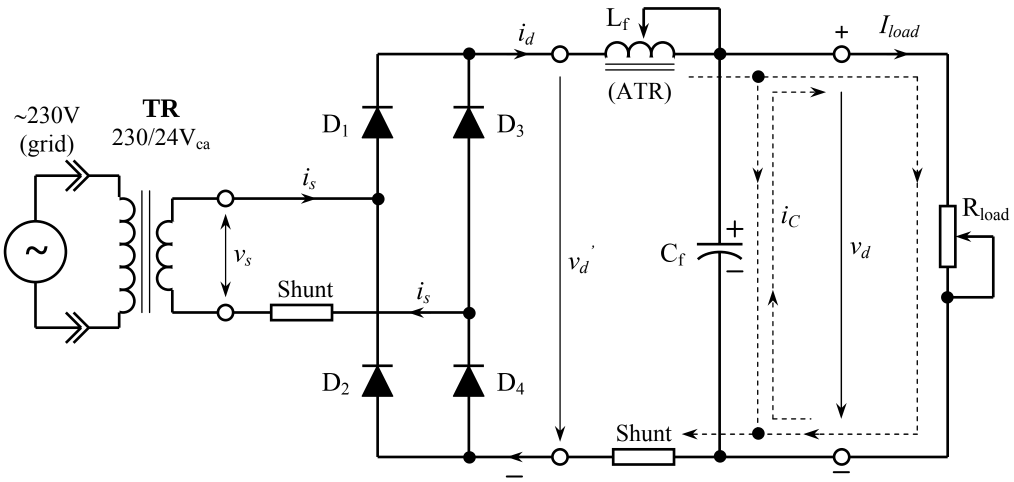

Fig.10.9 Block diagram of the laboratory setup → single-phase full-bridge diodes rectifier with voltage filters.

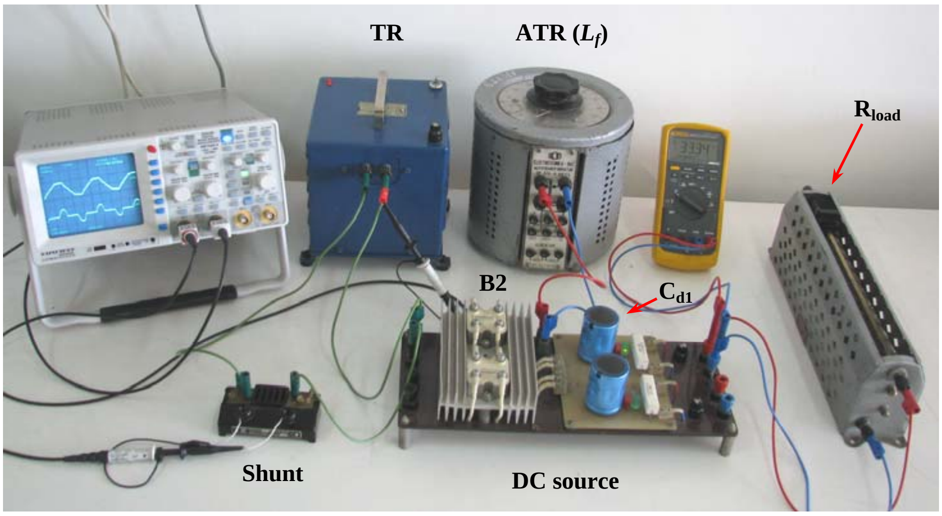

Fig.10.10 Image of the laboratory application (on the oscilloscope the v_s and i_s waveforms).

The circuit elements used to perform the laboratory setup are:

- a line-frequency transformer (TR) necessary to supply the rectifier with a low voltage ($24V_{ac}$);
- a single-phase full-bridge (B2) with diodes (PIM module);
- an autotransformer (ATR) in the position of the filter inductance (L_f);
- a rheostat in the position of the variable load resistance (R_{load});
- a shunt with the help of which we can see the currents i_d and i_s waveforms.

All the circuit elements can be interconnected with the help of lab conductors with bananas plugs, as shown in the Fig.10.10. It will be used a voltmeter to measure the value of the output DC voltage V_d and a two spots oscilloscope to display the v_d, i_d waveforms, respectively v_s, i_s waveforms. The oscilloscope must have the capacity to make the Fourier analysis, to show the harmonics spectrum of a displayed signal.

5. Objectives and procedures

1. It will be studied the theoretical aspects concerning the operation of the single-phase full-bridge diodes rectifier in combination with the capacitive and capacitive-inductive filter, respectively: the i_d and V_d equations, load characteristic, phenomenon of harmonic pollution, power factor, etc.
2. It will be studied the theoretical aspects concerning the operation possibility of the single-phase full-bridge thyristors rectifier in combination with the L-C filter: continuous conduction mode, discontinuous conduction mode, control aspects, adjustments possibilities of the output DC voltage etc.
3. It will be performed the laboratory setup with the block diagram shown in Fig.10.9, it will be started the operation with a capacitive filter (without L_f – the cursor of the autotransformer in zero position) and it will be displayed the v_d, i_d and v_s, i_s waveforms, respectively, for different DC loads.
4. It will be used the oscilloscope Fourier analysis option to display the harmonic spectrum of i_s current and then it will be calculated the power factor using the equations (10.17) and (10.18).
5. It will be observed the ripple increasing and the average value decreasing of the v_d output voltage along with the load resistance decreasing (increasing of the I_{load}).
6. It will be measured the average value V_d in correspondence with the I_{load} for different values of the R_{load} and it will be drawn the load characteristic $V_d = f(I_{load})$ for a capacitive filter.

7. It will be inserted the filter inductance L_f by using the autotransformer cursor and it will be evaluated the effect of the *L-C* filter on the i_d and i_s waveforms.
8. It will be used the oscilloscope Fourier analysis option for i_s current to calculate the power factor in the presence of the L-C filter.
9. In the same conditions (L-C filter) it will be displayed the $v_d^{'}$ and v_d waves on the oscilloscope and it will be explained the difference between the two waveforms;
10. It will be drawn again the load characteristic for a certain L_f value and it will be compared with the first version (without L_f).

Fig. 8.13 Other DC sources achieved in the Power Electronics Laboratory with single-phase full-bridge rectifiers, capacitive filters and braking circuits.

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