THREE PHASE RECTIFIER TOPOLOGY WITH PRACTICALLY SINUSOIDAL INPUT CURRENTS

By D.Alexa, I.V.Pletea, N.Lucanu, E.Coca, L.Ţigaeru
Technical University of Iasi, Faculty of Electronics and Telecommunications
alexa@etc.tuiasi.ro,
ivpletea@etc.tuiasi.ro

Abstract: A three-phase low-harmonic rectifier configuration is presented. For a large current variation load, the circuit designed to improve the waveform of the current drawn from the utility grid. Analytically obtained results are experimentally verified.

I. INTRODUCTION

In most power electronic equipments, such as AC motor drives, switch-mode DC power supplies, static frequency converters, DC servo drives, converters for fast charging of a battery bank, and so on, use such uncontrolled three-phase rectifiers. Commonly, a line-frequency three-phase diode rectifier bridge is used to convert line frequency AC into DC, in accordance with Fig.1(a). the rectifier output is a DC voltage whose average magnitude $V_d^{'}$ is uncontrolled. A filter L_fC_f is connected at the DC side of the rectifier. In the DC side is a constant current $I_d^{'}$, in accordance with Fig.1(b). the harmonic components $I_{(n)}$ of the phase currents i_R, i_S and i_T can be determined in terms of the fundamental frequency component $I_{(1)}$ as $I_{(n)} = I_{(1)}/n$, where n = 5,7,11,13,… To draw a conclusion, an important disadvantage of three-phase, six-pulse, full-bridge diode rectifier is the introduction of superior harmonics of input currents of inadmissible values in the power supply [1] – [3].

A first alternative to reduce the current harmonics is the usage of classical passive filters (CPF) made of LC series circuits. However, passive filters have the following drawbacks [1] – [7]:

- Filtering characteristics are strongly affected by the source impedance;
- Amplification of the currents on the source side at specific frequencies can appear due to the parallel resonance between the source and the passive filter;
- Excessive harmonic currents flow into the passive filter due to the voltage distortion caused by the possible series resonance with the source.

Additionally, the passive filters with the same order do not have a uniform load level when connected to the same distribution network. For instance, in Fig 2, it is considered the case of two electrical energy consumers which introduce n order harmonics current into supply network. Filter CPF1 is designed to serve consumer 1, while CPF2 is intended to serve the other consumer. Ideally, for n order harmonics, both filters should have zero impedance. In this case, the ideal paths of the superior harmonic currents are sketched in Fig 2 with dashed lines. In reality, the following relations are valid:

$$\left| jn\omega L_1 + \frac{1}{jn\omega C_1} \right| = \Delta z_1 \tag{1}$$

$$\left| jn\omega L_2 + \frac{1}{jn\omega C_2} \right| = \Delta z_2 \tag{2}$$

in which Δ_{Z1} and Δ_{Z2} values are positive and close to zero . If $\Delta_{Z1} > \Delta_{Z2}$ a fraction of n order harmonic generated from consumer 1 flows into CPF2 and overloads it with the possibility of destroying it, while CPF1 remains less stressed. After disconnecting CPF2 by using overload protection or destruction, CPF1 will be disconnected since it is overloaded because of the passing through of the harmonic current generated from the second consumer. In conclusion, the usage of the classical passive filters for superior harmonics current reduction in the distribution networks is not considered to be a reliable solution.

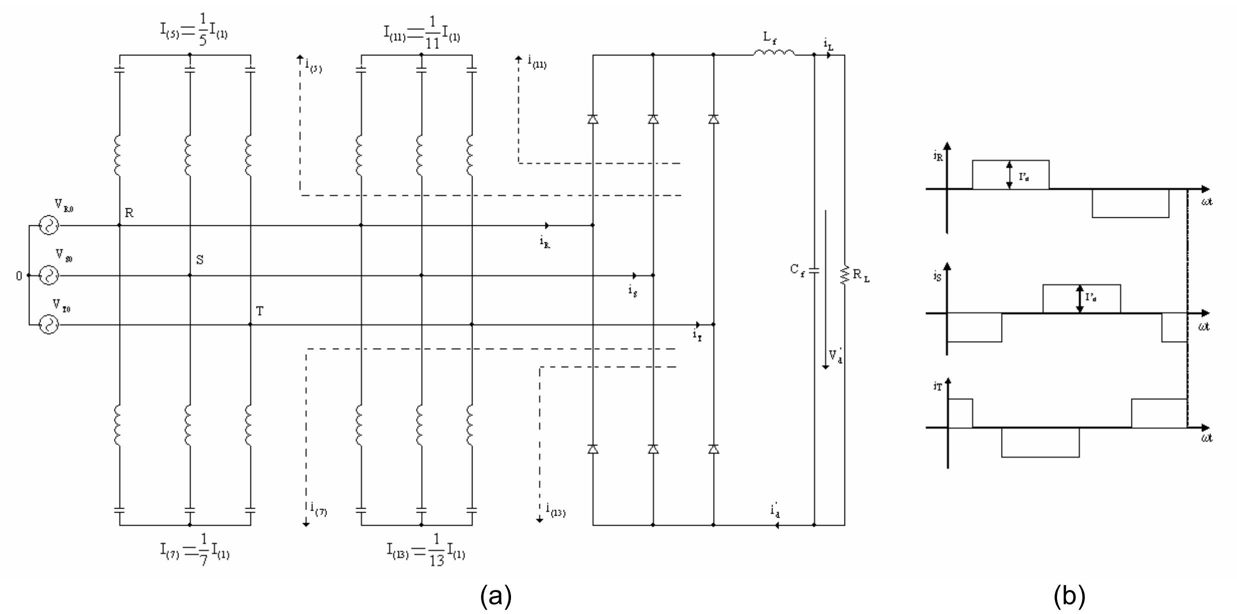

Fig.1 Three-phase six-pulse, full bridge diode rectifier with passive filters.
(a) Classical configuration (b) Current waveforms.

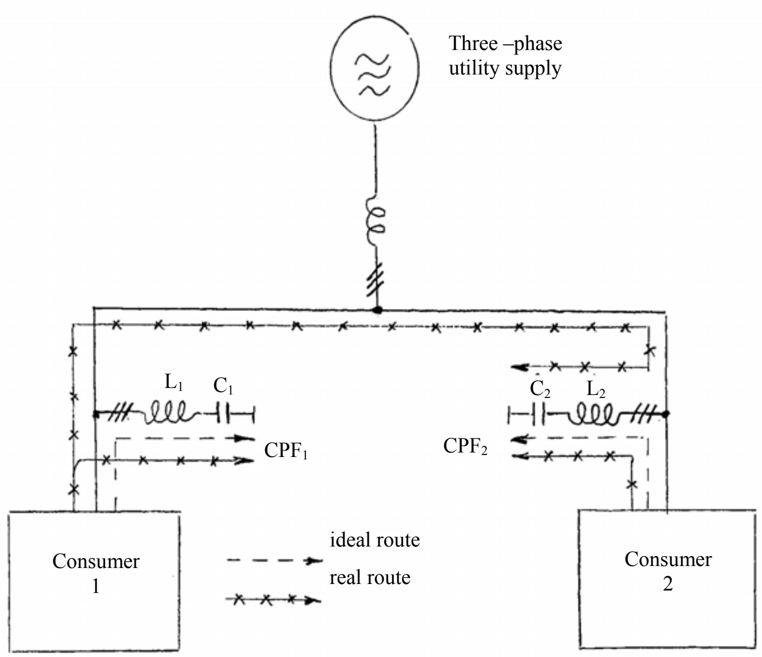

Fig. 2. Ideal and real routes of harmonic currents

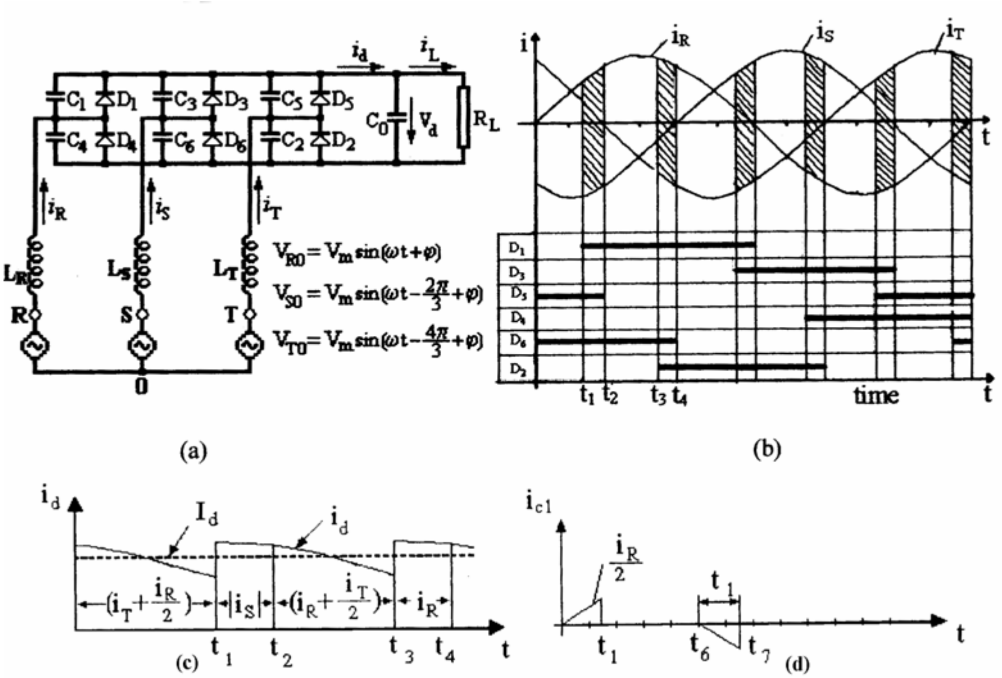

Fig.3 Three-phase rectifier with practically sinusoidal input currents. (a) New configuration. (b) AC current waveforms. (c) DC current i_d. (d) Waveform of the capacitor current i_{C1}.

Active power filters (APF) consisting of voltage or current source PWM inverters have been studied and put into practical use because they have the ability to overcome the drawbacks inherent to passive filters [2] – [6]. The active filter eliminates the harmonics that are present in the AC lines by injecting the compensating current into the AC side. However, the active filters have the following draw backs:

- Difficulty to construct large – rated current source with a rapid current response;
- High initial and running costs.

Several proposals to rating reduction in active power filters have been studied based on a combination of active filters and passive filters (hybrid filters) [4], [5]. To conclude, the hybrid filters present the following important short comings [6], [7]:

- The size of the passive filter is large due to the bulky AC capacitors (the rating of this filter represents about half the rating of the harmonic producing load);
- The control scheme is very complex and the safety in operation is reduced. When the active filter is not working, there are certain conditions when the passive filter can be damaged;
- High initial and running costs.

Obviously the reduction of higher current harmonics generated by a three-phase AC-DC converter can be obtained as well using a PWM rectifier.

The first version of such a rectifier was proposed in [8].

II. NEW THREE - PHASE RECTIFIE4R TOPOLOGY

In Fig.3(a) is presented a new three-phase uncontrolled rectifier, which is able to assure a very low harmonic injection in the power supply. The capacitors C_1 – C_6 have the same value “C”, and can be DC capacitors for smoothing, supporting, discharge. Inductances L_R, L_S and L_T have the same value "L" and are connected at the AC side. L and C values fulfil the following condition

$$0{,}05 \leq LC\omega^2 \leq 0{,}1 \qquad (3)$$

for the phase currents i_R, i_S and i_T from the electric main would be practically sinusoidal, in accordance with Fig.3(b). for example, between zero and t_1 the diodes D_3 and D_6 are in conduction and i_R current charges the capacitor C_4 from zero to V_d and discharges C_1 from V_d to zero. Between t_1 and t_2 the diodes D_1, D_5 and D_6 are in conduction, and so on. The working principle to this rectifier can be explained by the help of the stages which last for one third of the mains period $T = 2\pi/\omega$ [9].

In order to design the RASIC converter (Rectifier with Almost Sinusoidal Input Current) it is necessary to determine the duration t_1 for the charging or discharging of the capacitors $C_1 - C_6$ using the relation, in accordance with Fig.2(c):

$$V_d = \frac{1}{C}\int_0^{t_1} \frac{i_R^{(1)}}{2} \cdot dt \qquad (4)$$

and so:

$$\begin{aligned} V_d &= \frac{3V_m\omega_0^2}{2(\omega_0^2-\omega^2)}\left[\sin(\omega t_1+\varphi)-\sin\varphi\right]+ \\ &+\left\{\frac{2\pi V_d\omega_0}{3\omega}-V_d\omega_0 t_1-\frac{3V_m\omega_0^3}{2\omega(\omega_0^2-\omega^2)}\cdot\right. \qquad (5) \\ &\left.\cdot\left[\cos(\omega t_1+\cos\varphi\right]\right\}\cdot\frac{(1-\cos\omega_0 t_1)}{\sin\omega_0 t_1} \end{aligned}$$

where the angular frequency ω_0 fulfills the condition $3LC\,\omega_0^2 = 1$.

Another important parameter of the RASIC converter is the mean rectified current I_d:

$$I_d = \frac{1}{2\pi}\int_0^{2\pi} i_d\, d\,\omega t \qquad (6)$$

which can be calculated by the help of Fig.3(c):

$$\begin{aligned} I_d &= \frac{3V_m}{2\pi L\omega}\Big[\sin(\omega t_1+\varphi)+\sin\varphi+ \\ &+\left(\omega t_1-\frac{4\pi}{3}\right)\cos\varphi+ \qquad (7) \\ &+\frac{2V_d}{3V_m}\left(\frac{2\pi}{3}-\frac{\omega t_1}{2}\right)^2\Big] \end{aligned}$$

In order to ensure a smaller higher harmonic content in the AC mains, the angle ωt_1 is recommended to very between the limits:

$$25^0 \leq \omega t_1 \leq 45^0 \qquad (8)$$

and supposing that the waveform of the phase current is practically sinusoidal:

$$i_R \simeq I_{max} \sin \omega t \qquad (9)$$

in this case the rms current I_{CRMS} that flows through such a capacitor is limited by:

$$0{,}0461 \cdot I_{max} \leq I_{CRMS} \leq 0{,}1066 \cdot I_{max} \qquad (10)$$

Due to the fact, that the currents that flows through the capacitors $C_1 - C_6$ have small values as compared with I_{max}, in order to get the necessary ωt_1 angle, it implies that one has to choose (for continuous operation) capacitors with relatively large rated capacitance C_R and rated voltage V_R. This condition is better fulfilled by the DC capacitors, as, for example, those in the series B 25355 for Smoothing, Supporting, Discharge [10].

Converters in Fig.1(a) and 3(a) can be compared from the currents flowing through their devices point of view, supposing they are dimensioned for the same load current i_L. At the rectifier in Fig.1(a), if one has to suppress the current harmonics in the AC mains using passive filters for the orders 5, 7, 11 and 13, the overall sum of the rms currents flowing through the AC capacitors of the passive filters is several times larger than the overall sum of the rms currents flowing through the DC capacitors in the converter from Fig.3(a). Moreover, AC capacitors have to be chosen for voltages V_R for greater than for the DC capacitors, due to the overstresses that can appear in the case of the passive filters.

From the above description of the working principle of the RASIC converter one can easily deduce that its efficiency is greater than that of the AC-DC converters presented in Fig.1(a) and in [5] or [11].

III. POSSIBLE APPLICATIONS OF THE RASIC CONVERTER

One of the possible interesting applications of the AC-DC converter in Fig.3(a) is for the static frequency converters with DC voltage link, designed for supplying with variable voltage and frequency the three-phase induction motor drives. In this case, the asynchronous drives are connected to the outputs of the PWM three-phase inverters. Due to the fact that the output of a RASIC converter has the V_d voltage with 10-15% larger than the reference voltage $V_{dr} = 3\sqrt{3}\,V_m / \pi$ obtained from a three-phase classical diode rectifier in accordance with Fig.1(a), it implies that the output of the PWM inverter one can get the rated voltages for the three phases supplying the induction motor drive. In this way, there is no need to apply an overmodulation PWM technique (as, for example, methods of PWM pattern generation with third harmonic injection or with partially constant modulating waves).

REFERENCES

[1] K.Heumann: "Basic Principle of Power Electronics". Springer Verlag, Berlin, 1986.

[2] N.Mohan, T.Undeland and W.Robbins: "POWER ELECTRONICS - Converters, Applications and Design", John Wiley&Sons inc., 1995.

[3] H.M.Rashid: "POWER ELECTRONICS HANDBOOK", Academic Press, 2001.

[4] H.Akagi: "Trends in Active Power Conditioners". IEEE Trans.on Power Electronics, vol.9, no.3, 1994, pp.263-268.

[5] Z.Wang, Q.Wang, W.Yao and J.Liu: "A Series Active Power Filter Adopting Hybrid Control Approach". IEEE Trans.on Power Electronics, vol.16, no.3, 2001, pp.301-310.

[6] D.Alexa: "Combined Filtering System Consisting of Passive Filter with Capacitors in Parallel with Diodes and Low-Power Inverter". IEE Proceedings on Electric Power Applications, vol.146, no.1, 1999, pp.88-94.

[7] D.Alexa and A.Sîrbu: "Optimized Combined Harmonic Filtering System". IEEE Trans.on Industrial Electronics, vol.48, no.6, 2001, pp.1210-1218.

[8] D.Alexa and V.Prisacaru: "Selbstgefűhrte Stromrichter fur Umkehr antriebe, die keine Blindleistung des Speisenetzes benotigen". ETZ-A (Elektrotechnische Zeitschrift-A), vol.94, no.3, 1973, pp.158-161.

[9] D.Alexa: "Three-phase rectifier with almost sinusoidal input current". ELECTRONICS LETTERS, vol.37, no.19, 2001, pp.1148-1149.

[10] *** Siemens Matsushita Components Guide. Capacitors for Power Electronics, 1996.

[11] P.Pejovic and Z.Janda: "An Analysis of Three-Phase Low-Harmonic Rectifiers Applying the Third Harmonic Current Injection". IEEE Trans.on Power Electronics, vol.14, no.3, 1999, pp.397-407.