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AC-DC conversion performance with asymetrical rnsic converters

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In this paper we propose a method to reduce by 20%-30% of the reactive elements (capacitors and inductances) of rectifiers with near sinusoidal input currents (RNSIC). This method consists of the parallel connection of two RNSIC converters of the same type, dimensioned for half of the converted nominal power and whose entry currents are phase-shifted with an angle of 30°-40° by the correct choosing of the inductances on the AC part. Thus, it results a sufficient compensation of the type 5 current harmonics generated in the power grid when the capacitors and inductances of the two rectifiers are lowered accordingly. A reduction of the holding current (the idle current) I_{min} by the same percentage is achieved in this way. The new converter, named asymmetrical RNSIC, is economically and technically more competitive compared to the three-phase six-pulse full-bridge diode rectifier with passive filters.

I. Introduction

AC-to-DC rectifiers have a gradually more important role as power electronics systems grow in numbers. Most of the power electronics applications use this type of three-phase rectifiers [1]-[3]. The three-phase six-pulse full-bridge diode rectifier from Fig. 1(a) is a widespread circuit configuration, with two possible alternatives.

The first alternative, a three-phase rectifier with constant DC current, has a practically zero value for the side inductances L_S. A L_fC_f filter is connected on the DC side of the rectifier. Fig. 1(b) shows the waveform of the i_R current. The intensities of harmonic components $I_{(n)}$ of the phase current can be ascertained in terms of the fundamental frequency component $I_{(1)}$ as $I_{(n)} = I_{(1)}/n$, where n is the harmonic order n= 5,7,11,13... The I_d constant current has the advantage of increasing the life time of the capacitors used in the DC link [2].

The second alternative, the three-phase rectifiers with supplementary AC side inductances L_S and without any DC link inductance, has the waveform of the i_R shown in Fig. 1 (c). The total harmonic line current distortion (THD) factor of the current is higher than the equivalent one in the first alternative, this being the reason why the second alternative is used for inferior powers. The rectifier is considered to have a practically constant DC voltage if the capacitor C_f has a sufficient capacitance.

In conclusion, typical AC currents are far from a sinusoid. The power factor is also very low due to the harmonic contents in the main line current. Furthermore, these harmonics may lead to more harmonic losses in the utility grid and may cause electrical resonance, triggering large overvoltages [1].

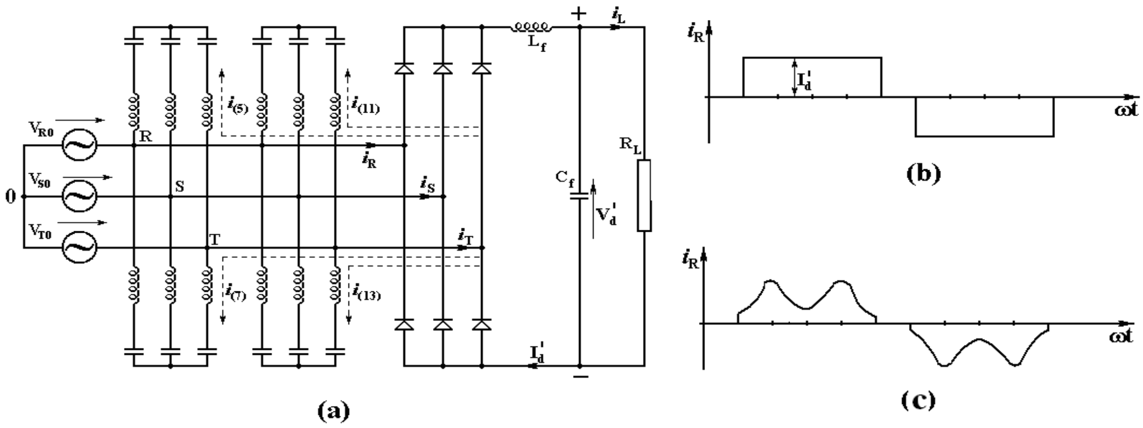

Fig.1 Three-phase six-pulse full bridge diode rectifier with passive filters,
(a) Classical configuration;
(b) Current waveform i_R with additional inductance L_f in DC link and L_s=0;
(c) Current waveform i_R without any DC link inductance L_f and with AC inductance L_s.

The first option to lower current harmonics is to use normal passive filters (CPFs) made of LC series circuits. But these passive filters may have some important disadvantages by injecting the corresponding current into the AC side [1]-[4].

The use of an active power filter (APF) consisting of voltage – or current – source pulse width – modulated harmonics present in the AC lines is one way to surmount the disadvantages of the passive filter, by injecting the corresponding current into the AC side. But the active filters have the following disadvantages: (1) Impediments in obtaining larger rated current source with a fast current response and (2) Increased initial and operational costs [5].

The use of a PWM rectifier can equally reduce the higher order current harmonics generated by a three-phase AC-DC converter [2], [6]. Although the PWM rectifier has near sinusoidal input currents, it also has some significant drawbacks compared to the three-phase diode rectifier: larger commutation losses, increased costs, EMI - related problems and inferior dependability.

Recently, new rectifiers with a low content of superior harmonics for the input currents have been described in the works [7] – [10]. This work proposes a new method for increasing the performance of these converters in such a manner as to make them technically and economically competitive with three-phase diode rectifiers with passive filters.

II. Features of the rnsic converters

Two variants of RNSIC (Rectifier with Near Sinusoidal Input Current) converters have been proposed, that practically eliminate the current input harmonics [7]-[10]. The operation of these converters is not influenced by the voltage or current harmonics from the power grid, thus avoiding resonance phenomena.

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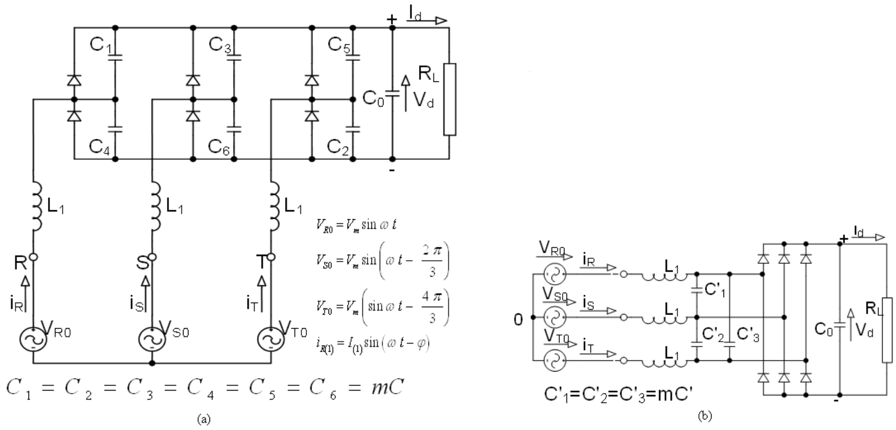

Fig. 2 Variants of RNSIC converters.
(a) RNSIC – 1 with six DC capacitors connected in parallel with diodes;
(b) RNSIC – 2 with three AC capacitors connected in the AC side.

The RNSIC-1 variant, shown in Fig.2(a), has six DC C_1-C_6 capacitors with a capacity equal to mC (m is the reduction coefficient). If only one converter is used between the source and the consumer, then m=1. If two paralleled converters are used, according to Fig.3, then m can be adopted lower than 0.5 (0.4, for example) because a compensation of the type 5 and 7 current harmonics generated in the electrical line is achieved. An economy is thus achieved in the power installed in the C_1-C_6 capacitors and L_1 inductances.

For a single RNSIC-1 converter, the following condition must be fulfilled:

$$0.05 \le L_1 C \omega^2 \le 0.10 \qquad (1)$$

to provide the practically sinusoidal i_R, i_S and i_T phase currents [7]-[10], where ω signifies the power grid pulsation.

The variation of the φ angle between phase voltage (for example v_{RO}) and the fundamental harmonic of the phase current (thus $i_{R(1)}$) is shown in Fig. 4(a) for the case of a single converter. The nominal rate, indicated in the F point, is considered for φ=0° and the loading resistance of nominal value R_{Lr}. Where V_d is the rectified average voltage, and $V_{ref} = 3\sqrt{3}V_m / \pi$ is the reference voltage specific for three-phase rectifiers with classical diodes. The V_d voltage can be established at a certain value by the load current I_d:

$$I_d = \frac{3I_{(1)}}{2\pi}(1 + \cos \omega t_1) \qquad (2)$$

where $I_{(1)}$ is the amplitude of the phase current fundamental, and t_1 is the time when the diodes of the RNSIC-1 converter begin to work. The ωt_1 angle varies between 35° and 45° for the nominal rate [8].

Two extreme cases can be pointed out in the operation of the RNSIC-1 converter. In the first case, if the load resistance R_L is null (V_d=0 and ωt_1=0°), the C_1-C_6 capacitors are short-circuited, and the angle $\varphi = +90°$ angle is inductive. In this case, the phase currents are also sinusoidal and have a maximum amplitude equal to I_{max}. In the second case, if the V_d function exceeds the value $\sqrt{3}V_m/(1-2L_1C\omega^2)$ the diodes of the RNSIC-1 converter stop conducting and the angle $\varphi = -90°$ is capacitive (thus $R_L=\infty$ and $\omega t_1=180°$). In this second case, the phase currents are equally sinusoidal and their amplitude has a minimum value I_{min}, called holding current.

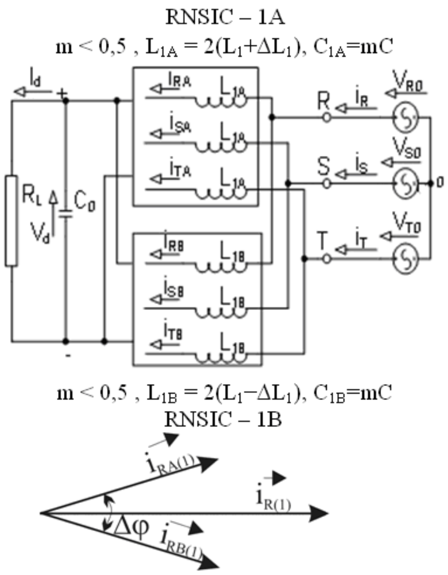

Fig. 3 Configuration of asymmetric RNSIC

The I_{max} / I_{min} ratio has the value [9].

$$\frac{I_{max}}{I_{min}} = \frac{(1-2L_1C\omega^2)}{2L_1C\omega^2} \qquad (3)$$

The second variant of RNSIC converter, abridged as RNSIC-2, has three C'_1-C'_3 capacitors on the AC part with capacities equal to mC', according to Fig. 2(b), [10]-[11]. The nominal P_{dr} power of a RNSIC converter has inverse variation with the reactance $L_1\omega$ and direct variation with susceptance $C\omega$ and $C'\omega$.

III. Increase of the ac-dc conversion performance with asymetrical rnsic converters

We present hereunder a technically and economically competitive method for the AD-DC conversion, especially at average and high powers. Instead of a single RNSIC-1 converter dimensioned for nominal output power $P_{dr}=V_{dr}I_{dr}$, two converters for the same type for powers equal to P_{dr} / 2, paralleled connected according to Fig.3. The fundamental harmonic input currents in these converters from the same phase of the power supply (for example $i_{RA(1)}$ and $i_{RB(1)}$) have a phase shifting $\Delta\varphi_r = \varphi_M - \varphi_N$ between 30° and 40° in nominal operational state at R_{Lr} load

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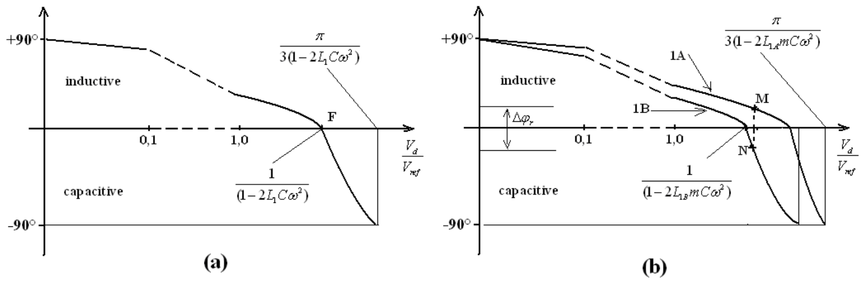

Fig. 4 Angle φ as a function of ratio V_d/V_{ref};
(a) single RNSIC-1 converter, *m*=1 according to Fig. 2(a);
(b) Configuration of two RNSIC – 1 converters connected in parallel, with L_{1A} and L_{1B} inductances, according to Fig. 3 (asymmetric RNSIC).

The inductance $L_{1A}=2(L_1+\Delta L_1)$ so that RNSIC-1A converter behaves inductive-resistive, and $L_{1B}=2(L_1-\Delta L_1)$ and the RNSIC-1B converter behaves capacitive-resistive for the power supply. The M and N operation points are on the two characteristics, according to Fig. 4(b), for the same value V_d of the output voltage. When the output power P_d varies between the maximum value and, corresponding to the nominal value and zero (thus for $R_L=\infty$), the phase-shifting $\Delta\varphi$ is practically constant until the RNSIC-1B converter is idle (φ_N= -90°). Follow-up $\Delta\varphi$ go to 0 until the second converter RNSIC-1A is idle (φ_M= -90°), according to Fig. 4(b). On the entire variation range of output power P_d, the THD% factor for the phase input currents i_R, i_S and i_T is maintained at acceptable values. The value of the phase-shifting $\Delta\varphi$, mentioned above, insures an important reduction of the type 5 harmonic in the power grid, knowing that the RNSIC converters have the largest input harmonic of this type. The ΔL_1 value ranges between 0.1 L_1 and 0.2 L_1 in order to accomplish the desired φ_M and φ_N phase-shiftings.

The amplitude of the fundamental harmonic current $I_{(1)}$ is increased for larger load currents I_d and the ratio $I_{SC} / I_{(1)}$ can be reduced (for example, less than 20), thus achieving a THD less than 5% for the phase currents, according to the IEEE standards 519 of 1992. I_{SC} signifies the amplitude of the short-circuit currents for terminals R, S and T. For reduced load currents I_d, the amplitude of the fundamental harmonic current $I_{(1)}$ is lowered. The ratio $I_{SC} / I_{(1)}$ ranges between 20 - 50 or 50 - 100, the THDs of the phase currents have to be less than 8% or 12% accordingly.

A converter equivalent to the asymmetrical rectifier from Fig.3 is defined, a single RNSIC-1 converter with the elements $L_{eq}=(L_{1A}+L_{1B})/4$ and $C=C_{1A}+C_{1B}=2mC$. For the equivalent converter, the value $L_{eq}C_{eq}\,\omega^2$ is lower than 0.05, thus the phase currents i_R, i_S and i_T have an unacceptably high THD% ratio for all the variation range of the load resistence.

The amplitude of the holding current of the asymmetrical converter I_{minAB} is lower by 20%-30% compared to the I_{min} obtained from a single standard RNSIC-1 converter and can be computed with the equation:

$$\frac{I_{\min AB}}{2V_m mC\omega}=\left[\frac{1}{(1-2L_{1A}mC\omega^2)}+\frac{1}{(1-2L_{1B}mC\omega^2)}\right] \quad (4)$$

Standard converter signifies the converter that insures, just like the asymmetrical adopted converter, practically the same output power P_d and values of the THD% factor lower than 5% for high load currents. For the standard converter, the elements L_{st} and C_{st} follow the optimal condition

$$L_{st}C_{st}\ \omega^2 = 0.06 \qquad (5)$$

The method proposed in the work allows the renunciation of the standard converter in favor of the asymmetrical converter, achieving a reduction of the power installed in the capacitors and inductances, and a reduction of the holding current. The partial currents of fundamental harmonic (for example $i_{RA(1)}$ and $i_{RB(1)}$) that pass through the inductances L_{1A} and L_{1B} are practically equal to half of the fundamental harmonic currents that go through the L_{st} inductances of the standard converter, for normal operation status. These L_{st} elements are higher than the L_{eq} inductances, thus stating that a reduction of inductances can be achieved through the use of the asymmetrical converter. The L_{1A} and L_{1B} are sized taking into account that half of the i_R, i_S and i_T currents corresponding to the standard and equivalent converters go through them. The reduction coefficient in the capacitors and inductances is given by the ratio r:

$$r = \frac{L_{eq}C_{eq}}{L_{st}C_{st}} \qquad (6)$$

In order to convert practically equal powers from AC to DC, it results that the reactive elements (capacitors and inductances) of the equivalent converter have to be reduced by $\sqrt{r}$ compared to the corresponding elements of the standard

IV. Experimental results

Experimental results confirm the theoretical conclusions presented in the work. In Table 1, we present as a function of R_L, the values of V_d, $I_{(1)}$, phase-shifting φ between the phase voltages and the fundamentals of the phase currents in the grid, the THD factor of the phase current and the ratio $I_{(5)}$ / $I_{(1)}$ between the magnitude of the 5th harmonic and $I_{(1)}$ for the RNSIC-1 standard converter, according to Fig.2(a).

In Fig.5, the waveforms for the partial currents i_{RA} and i_{RB} and total i_R are shown for $R_L = 30\Omega$. Although the partial currents can have a THD of maximum 10%-15%, the i_R current has a THD that fits within the limits set by appropriate standards for the various variation intervals of the I_{SC} / $I_{(1)}$ ratio, according to Table 3.

In Figs. 6(a) and 6(b) the waveforms of the DC current i_d are shown, for the case of $R_L = 30\Omega$ and $R_L = 100\Omega$. The waveform of the current i_d for the rated load resistor $R_{Lr} = 26\Omega$ allows the dimensioning of the filtering capacitor C_0. From our studies, it results that for the asymmetrical RNSIC converter as well as for the classical one with passive filters from Fig. 1(a), designed for the same rated output power, the same filtering capacitors C_0 and C_f are required. The equivalent and asymmetrical converters are smaller in size and have smaller costs as compared with the classic rectifier with passive filters, according to Fig. 1(a).

It is important to notice that the classical three-phase rectifier with diodes depicted in Fig.1(a) has a holding current equal with $I_{(1)tot}$, when the load resistance R_L

is infinite, due to the presence of passive filters at the input that behave as capacitive loads

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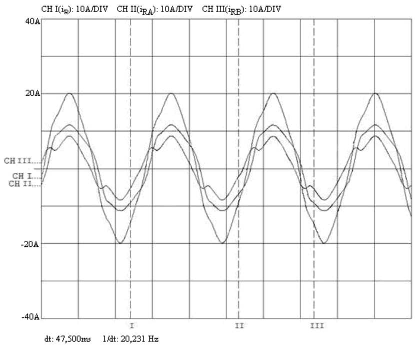

Fig.5 Experimental waveforms of the phase current i_R and the partial currents i_{RA} , i_{RB}.

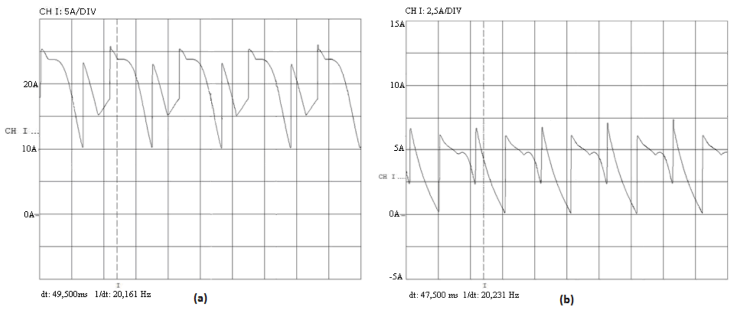

Fig. 6 Experimental waveforms of the current i_d: (a) for $R_L = 30\Omega$; (b) for $R_L = 100\Omega$

The ratio between the holding current (denoted I_{min} for the RNSIC converters and by $I_{(1)tot}$ for the rectifier with passive filters) and the rated current $I_{(1)r}$ varies between the following limits:

- 30%- 35% for the rectifiers with passive filters;
- 20% - 25% for standard RNSIC – 1;
- 18% - 20% for asymmetrical RNSIC.

From the above considerations it implies that the asymmetrical RNSIC converter has smaller size, smaller holding current and reduced cost as compared with the classical RNSIC converter, described in [10]. Possible applications of the asymmetrical RNSIC converter envisage especially medium and high power applications.

V. Conclusion: The operation of RNSIC AC-DC converters having practically sinusoidal currents at entry is not influenced by the presence of voltage harmonics or current in the power grid.

The method proposed in this paper, that consists in the parallel connection of two RNSIC converters with input currents phase-shifted by an angle of 30°-40°, allows the reduction by 20%-30% of the power installed in the reactive elements (capacitors and inductances) from the structure of these converters. Therefore, a decrease by 20%-30% of the holding current I_{min} results, that is defined for the case when the active converted power is cancelled.

The asymmetrical RNSIC converters, with DC or AC capacitors, have lower dimensions, costs, holding currents and power losses and provide increased safety conditions compared to the three-phase six pulse full-bridge diode rectifiers with classical passive filters.

Another significant feature of the new converter is that it has an increased voltage that is 15%-25% higher than the DC voltage obtained from a three-phase classical diode rectifier, which makes more suited for different uses.

VI. Acknowledgment

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VII. References

[1] N. Mohan, T. Undeanland, W. Robbins: POWER ELECTRONICS – Converters, Applications and Design, *John Wiley & Sons Inc.*, 1995, 200 – 248.

[2] M. Kazmierkowski, R. Krishnan and F. Blaabjerg: CONTROL IN POWER ELECTRONICS SELECTED PROBLEMS, *Academic Press*, 2002, 89 – 208.

[3] D. Alexa: Combined filtering system consisting of passive filter with capacitors in parallel with diodes and low – power inverter, Proc. Electr.Eng. – Elect. Power Appl., vol. 146, no.1, pp. 88 – 94, Jan. 1999.

[4] J. Arrilaga and N. Watson: Power Systems Harmonics, 2nd ed., New York, Wiley, 2003.

[5] H. Akagi, Trends in Active Power Conditioners, IEEE Transactions on Power Electronics, 1994, 9, 263-268.

[6] J.R. Rodrigues, J.W. Dixon, J.R. Espinosza, J. Pontt and P. Lazana: PWM Regenerative Rectifiers. State of Art, IEEE Trans. on Industr. Electronics, vol. 52, no.1, pp. 5 – 22, Jan. 2005.

[7] D. Alexa: Three-phase rectifier with almost sinusoidal input current, Electronics Letters, 2001, 37, 1148 – 1150.

[8] D. Alexa, T.C. Goras, A. Sirbu, I.V.Pletea, C. Filote and F. Ionescu: Analysis of the Two-quadrant Converter with Near Sinusoidal Input Current, IET Power Electronics, vol.1, 2008, no.3, pp.224-234.

[9] D. Alexa, A. Sirbu, D. Dobrea and T. Goras: Topologies of three-phase rectifiers with near sinusoidal input currents, IEE Proc. Electr. Power Appl., 2004, 151, 673-678.

[10] D.Alexa, A.Sirbu, I.V.Pletea, C.Filote, R.Chiper, "Variants of rectifier with near sinusoidal input currents—a comparative analysis with the conventional diode rectifier", *IET Power Electron.*, 2011, 4, (6), pp. 632–641.

[11] D.Alexa, A.Sirbu, I.V.Pletea, T.C.Goras, "Hybrid rectifier with near-sinusoidal input currents", IEEE Trans. Ind. Electron., 2012, 59, (7), pp. 2947–2958.

[12] I.V.Pletea, D.Alexa, D.D. Cepareanu, "Simulations of wind energy conversions systems with asymmetrically RNSIC", Review of Industrial Engineering Letters, 2015, vol. 2, no. 1, pp.1-9, ISSN 2409-2169.