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SIMULATIONS OF WIND ENERGY CONVERSIONS SYSTEMS WITH ASYMMETRICALLY RNSIC

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ABSTRACT

The electric energy losses as well as electromagnetic pollution of the environment by the modern electric or electronic apparatus running in a commutating regime may be reduced to minimum with the help of power electronics, field which will be well developed in the next century in order to modernize industry, transport, telecommunications, etc. The paper present a wind generator system based on a new converter configuration with a asymmetrical rectifier with near sinusoidal input currents (Asim-RNSIC), we propose a method to reduce by 15%-25% of the reactive elements (capacitors and inductances) of a asymmetrical rectifiers with near sinusoidal input currents (Asim-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. The converter, named Asim-RNSIC, is economically and technically more competitive compared to the three-phase six-pulse full-bridge diode rectifier with passive filters.

Keywords: Power quality, Power converters, Power electronics, Renewable energy systems, AC/DC rectifiers, DC/DC converter.

Contribution/ Originality

The paper's primary contribution is finding that reduced to minimum electromagnetic pollution of the environment with the help of power electronics by the modern electric or electronic converters running in a commutating regime.

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1. 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. The three-phase six-pulse full-bridge diode rectifier from is a widespread circuit configuration. 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], [2]. The use of a PWM rectifier can equally reduce the higher order current harmonics generated by a three-phase AC-DC converter. 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 [3-6]. This paper 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. We propose in this paper a method to reduce by 15%-25% 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.

2. ASYMMETRICAL RNSIC CONVERTER PRESENTATION

The new converter, named asymmetrical RNSIC (Asim-RNSIC) is show in Fig. 1 and consists of two RNSIC – 1 converters with six DC capacitors, according to Fig. 2. The DC value can vary between (-C) and (+C), while the functioning of the RNSIC -1 converter remains the same. The phase currents i_R, i_S and i_T and the angle φ are not modified upon the variation of ΔC. Of course, the currents through the capacitors are proportional to the values of the associated capacitors.

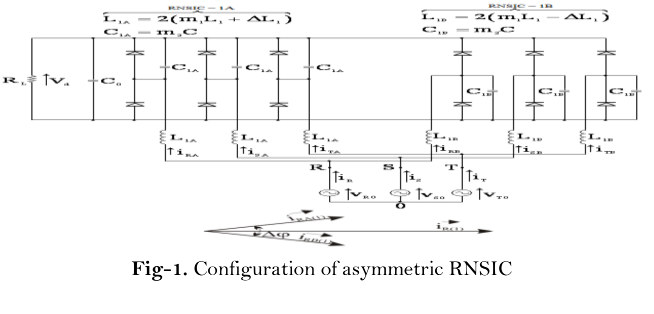

Fig-1. Configuration of asymmetric RNSIC

The RNSIC -1 has also three inductors L_1 which include the short circuit inductances L_s on each phase of the grid. Obviously, when constructing such a converter, one must consider inductors on each phase (L_1 - L_s).

In the case of passive filters, the values of the capacitors must be kept constant in time and with temperature, in order to get the tuning on a specified harmonic, objective which is quite difficult to achieve. For the RNSIC – 1 converter, it is possible that the values of the capacitors differ from one another, due to the fact that resonance is not necessary. The only condition which has to be imposed in this case is that the sums of the capacitors on the three branches to be equal.

That is:

$$C_1 + C_4 = C_3 + C_6 = C_5 + C_2 = 2C \qquad (1)$$

condition which can be easily assured by choosing the capacitors accordingly.

The value ΔC can be up to ±10% of C in order to take into account the fact that the capacitors have, by fabrication, such variations of C. Also, by choosing ΔC equal to (-C) or (+C) one can get for the RNSIC -1 three capacitors having the capacity 2C connected in parallel to the diodes D_4, D_6 , D_2 or D_1 , D_3 ,D_5 .

For a single RNSIC – 1 converter, wich respects the relation (1), the following condition must fulfilled:

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

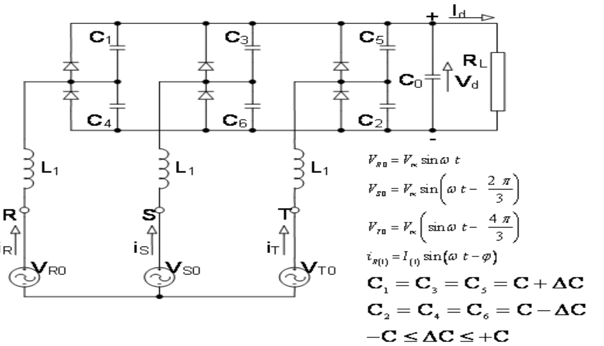

Fig-2. RNSIC – 1 converter with six DC capacitors connected in parallel with diodes

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.1.

The RNSIC –1A converter has three inductors $L_{1A}=2(L_1+\Delta L_l)$and three capacitors C_{1A}= m_1C (where m_1 and m_2 are reduction coefficients, less than 1), while RNSIC – 1B converter has three inductors $L_{1B}=2(L_1-\Delta L_l)$ and three capacitors C_{1B}= m_2C. 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.The inductance L_{1A}=2($L_1+\Delta L_l$) so that RNSIC-1A converter behaves inductive-resistive, and L_{1B}=2($L_1-\Delta L_l$) and the RNSIC-1B converter behaves capacitive-resistive for the power supply.

3. ASYMMETRICAL RNSIC CONVERTOR PRINCIPLE FUNCTIONING

The M and N operation points are on the two characteristics, according to Fig. 3, 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-1B is idle (φ_M= -90°), according to Fig. 3.

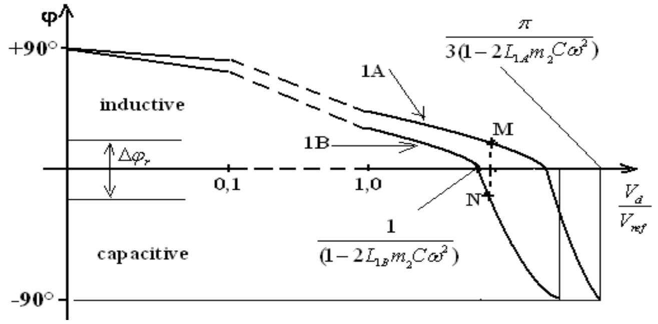

Fig-3. Angle φ as a function of ratio V_d/V_{ref}

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_l value ranges between 0.2L_l and 0.3L_l in order to accomplish the desired φ_M and φ_N phase-shiftings.

The angle ωt_1 vary between $35^0 - 45^0$ for the normal operating conditions.

There can be highlighted two extreme cases for the functioning of the RNSIC-1 converter. In the first case, if the load resistance R_L is null (so $V_d = 0$ and $\omega t_1 = 0^0$), the condensers $C_1 - C_6$ are short-circuited and the angle $\varphi = +90^0$ is inductive. In this case the phase currents are sinusoidal and have the maximum amplitude equal to $I_{\max}$. In the second case, if the tension V_d surpasses the value $\sqrt{3}V_m/\left(1-2L_1\omega^2\right)$, the RNSIC-1 converter's diodes are not conductive any more and the angle $\varphi = -90^0$ is capacitive (so $R_L = \infty$ and $\omega t_1 = 180^0$).

In this case, the phase currents are also sinusoidal and their amplitude has a minimal value $I_{\min}$,
also called maintenance current. The proportion $I_{\max} / I_{\min}$ has the value:

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

The nominal power P_{dr} of a RNSIC-1 converter is indirectly proportional with the reactance $L_1\omega$ and directly proportional with the susceptance $C\omega$.

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.1 is defined, a single RNSIC-1 converter with three inductances $\mathrm{L_{eq}} = \mathrm{L_{1A}} \| \mathrm{L_{1B}} = \mathrm{m_1 L_1} - \left(\Delta \mathrm{L_1}\right)^2 / \mathrm{m_1 L_1}$ and six capacitors $\mathrm{C_{eq}} = \mathrm{m_2 C}$.

For the equivalent converter, the value $\mathrm{L_{eq} C_{eq}} \omega^2 = \mathrm{m_1 m_2 L_1 C} \omega^2$ is lower than 0.5, 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 $I_{\min AB}$ 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:

$$\frac{I_{\min AB}}{2V_m m_2 C\omega} = \left[\frac{1}{(1-2L_{1A}m_2C\omega^2)} + \frac{1}{(1-2L_{1B}m_2C\omega^2)}\right] \quad (4)$$

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, show in Fig. 2, the elements $\mathrm{L_{st}} = \mathrm{L_1}$ and $\mathrm{C_{st}} = \mathrm{C}$ follow the optimal condition:

$$\mathrm{L_{st} C_{st}} \omega^2 > 0,06 \quad (5)$$

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 coefficients m_1 and m_2:

$$m_1 m_2 = \frac{L_{eq} C_{eq}}{L_{st} C_{st}} \qquad (6)$$

In order to convert practically equal powers from AC to DC, it results that the reactive elements (inductors and capacitors) of the equivalent converter have to be reduced by m_1 and m_2 compared to the corresponding elements of the standard converter.

Based on the chosen equivalent converter, the asymmetrical converter can be projected according to Fig. 1, the elements C_{1A} *and* C_{1B} are equal to $C_{eq} = 20\mu F$, [7]. The inductances L_{1A} and L_{1B} are adopted equal to 49 mH and respectively 35 mH (thus $\Delta L_1 = 3.5mH$) in order to obtain phase-shifting $\Delta\varphi$ close to 40°. The experimental results obtained for the asymmetrical converter are given in table 1.It is concluded from table 1 that: the method applied above at the asymmetrical converter is possible: (1) to lower the installed power in reactive elements (capacitors and inductances) with approx. 15%-25% and (2) from this results a same percentage reduction of the holding current I_{minAB}, compared to the standard converter RNSIC-1.

Table-1. The asymmetrical converter $\Delta L_1 = 3.5mH$, $L_{1A} = 49mH$, $L_{1B} = 35\ mH$, $C_{1A} = C_{1B} = 20\ \mu F$, $C_0 = 4000\mu F$, $V_m = 311V$, $f = 50Hz$.

R_L[Ω]	V_d[V]	I_L[A]	φ [°]	*THD* %	Admissible *THD%*	$I_5 / I_{(1)}$ [%]
20	521	30	+12.1	5.07	5	4.8
30	565	23.0	+0.2	4.74		4.6
40	588	18.8	-5.7	4.70		4.31
70	596	12.3	-26.9	7.31	8	6.79
100	602	10.1	-39.3	7.81		7.35
200	609	7.1	-55.4	8.87	12	8.26
600	618	4.91	-73.6	10.6		10.4
5k	674	4.29	-87.2	2.58		2.46
50k	684	4.26	-89.7	0.46		0.27

This statement can be proved with respect to the total parameters $LC\omega^2$ associated to one phase, which characterize the rectifiers in Figs. 1 and 2. For the case of the proposed method, the parameter $2L_{eq}C_{eq}\omega^2$ is equal to 0.0746.

For the assemblage with four passive filters (for the 5th, 7th, 11th and 13th harmonics) one must fulfill the tuning condition:

$$L_{(n)}C_{(n)}(n\omega^2)=1 \qquad (7)$$

in which $L_{(n)}$ and $C_{(n)}$ represent respectively the inductance and capacitance of the passive filter tuned on the n-th order harmonic.
So:

$$\sum L_{(n)}C_{(n)}\omega^2=\frac{1}{5^2}+\frac{1}{7^2}+\frac{1}{11^2}+\frac{1}{13^2}=0.07462 \qquad (8)$$

value, which is closed to the parameter $2\ L_{eq}C_{eq}\,\omega^2$ met at the equivalent and asymmetrical converters, designed for the same rated power as for the classical rectifier in Fig. 1.

4. SIMULATIONS RESULTS

Simulation results confirm the theoretical conclusions presented in the work. In Fig.4 the waveforms for the partial currents i_{RA} and i_{RB} and total i_R are shown for R_L=30Ω. Although the partial currents can have a THD% of approx. 10%-15% maximum, the $i_R$current has a THD% that fits within the limits set by applicable standards for the various variation intervals of the I_{SC} / $I_{(1)}$ ratio.

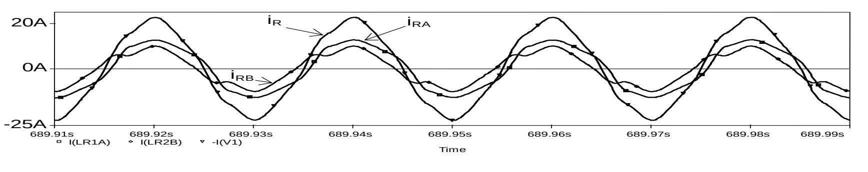

Fig-4. Simulations waveforms of the for asymmetric RNSIC phase current i_R and the partial currents i_{RA}, i_{RB}

Figure 5 presents a variable-speed wind system. The electricity produced by the induction generator SCIG is transferred into the network by means of a frequency converter. It is made up of a Asim-RNSIC converter, a boost converter and a PWM inverter connected to the supply grid.

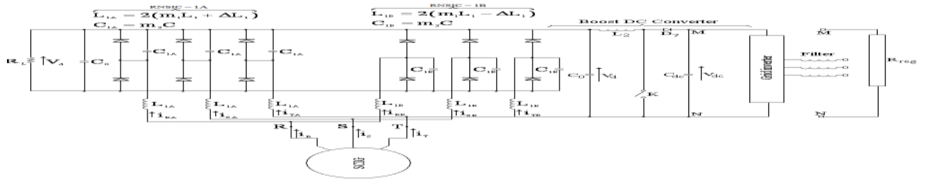

Fig-5. System of wind generator with a asymmetric rectifier with near sinusoidal input currents.

This converter has the following main advantages:

- it provides practically sinusoidal stator currents i_R, i_S, i_T to the induction generator, according to the functioning principle of RNSIC-1 converters [3-6, 8-11].
- it determines a practically constant magnetization current for the induction generator when its speed varies.

In order to get variable speed operation and stable DC bus voltage, a boost DC-DC converter could be inserted in the DC link, as shown in Fig. 5. The Asim-RNSIC converter output voltage V_d is amplified to the value V_{dc} at the input of the PWM converter connected to the grid.

The simulations results illustrated in Fig. 6 show that the wind system proposed in Fig. 5. Moreover, the wind system, according to Fig. 5, insures a lower content of high current harmonics for currents i_R, i_S and i_T. These two advantages result from the functioning principle of the Asim-RNSIC converter, which catches increasing attention for its simple configuration, high reliability, as well as the reduced cost. Comparing the different wind turbine topologies is respect to their performances in will reveal a contradiction between cost and performance to the grid. In our research, we have noticed that the size and losses of the boost converter result in important. As far as the three L_{1A}, L_{1B} inductances are concerned, they can be shrunk by 40-50% using the following method. The pulsation of the electromagnetic torque for the proposed wind system are within the normal limits and their effect can be mechanically reduced. The most important stator current harmonic is the 5th. Even if we use the method designed to reduce the L_{1A}, L_{1B} inductances, this harmonic does not exceed 7% of the fundamental harmonic.

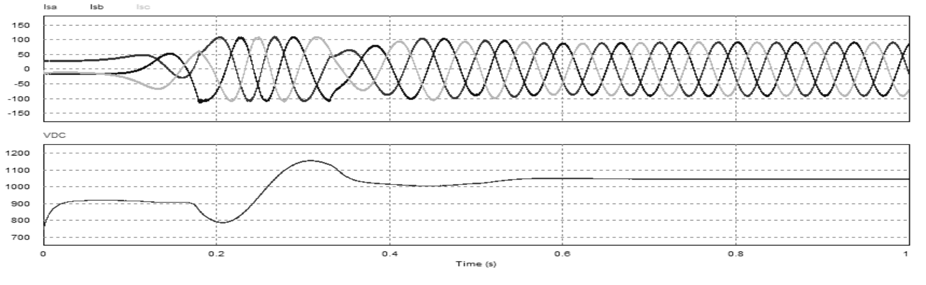

Fig-6. Wind system with Asim-RNSIC converter. (a) current i_R (b) Voltage v_d

5. CONCLUSIONS

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 the work, 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 15%-25% of the power installed in the reactive elements (capacitors and inductances) from the structure of these converters (Asim-RNSIC).

The asymmetrical RNSIC converter, 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 Asim-RNSIC 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.

6. ACKNOWLEDGMENTS

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