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An Analysis of Three-Phase Low Harmonic Diode Rectifier with Capacitor Connected on the AC Side

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Abstract –An analysis of a three-phase low harmonic diode rectifier equipped with inductors, capacitors connected on the AC side and diodes is presented. Inductors and capacitors are used in conjunction with the three-phase diode bridge rectifier to improve the waveform of the currents drawn from the utility grid.

Keywords: Rectifiers, Power quality, Power converters

I. INTRODUCTION

In most power electronics applications, the AC input power supply, in the form of 50 or 60 Hz sine wave AC voltage provided by the electric utility, is converted to a DC voltage. As power electronic systems proliferate, AC-to-DC rectifiers are playing an increasingly important role.

II. RNSIC CONFIGURATION

A large majority of the power electronics applications use such uncontrolled three-phase rectifiers. The three-phase, six-pulse, full bridge diode rectifier is a commonly used circuit configuration. The rms harmonic components $I_{(n)}$ of the phase current can be determined in terms of the fundamental frequency component $I_{(1)}$ as :

$$I_{(n)} = \frac{I_{(1)}}{n} \qquad (1)$$

where n represents the harmonic number, n = 5,7,11,13... To draw a conclusion, typical AC currents are far from a sinusoid. Because of the harmonic contents in the line current, the power factor is also very poor. Likewise, these harmonics cause traditional harmonic losses in the utility grid and may excite electrical resonance, leading to large overvoltages.Therefore,governments and international organizations have introduced new standards (in the United States, IEEE 519 and in Europe, IEC 61000-3) which limit the harmonic content of the current drawn from the power line by rectifiers.

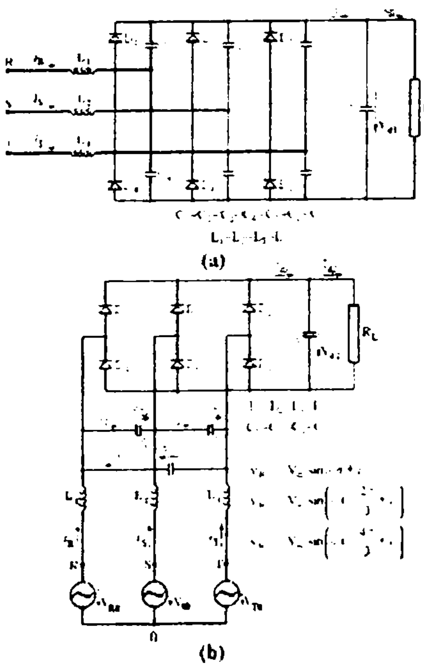

Fig. 1. Constructive variants for the RNSIC converter
(a) with six DC capacitors on the DC side, named RNSIC-1
(b) with three AC capacitors on the AC side, named RNSIC-2

One way to reduce the current harmonics is the usage of classical passive filters (CPF) made of LC series circuits. But they have some disadvantages as follows:

- 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;
- Excesive harmonic currents flow into the passive filter due to the voltage distorsion caused by the possible series resonance with the source.

An alternative to overcome the drawbacks of the passive filter is to use an active power filters (APF) consisting of voltage or current source PWM inverters. By injecting the compensating current into the AC side, the active filter eliminates the harmonics

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that are presented in the AC side lines. Enyway, the active filters have the following drawbacks:

- Difficulty to construct large-rated current sourcewith a fast current response;
- High initial and running costs.

Using a PWM rectifier, we can obtain the reductin of higher order current harmonics generated by a three-phase AC-DC converter. Even though, the PWM rectifier it has near sinusoidal input currents, and has some important limitations: larger commutation losses, higher costs, EMI-related problems and less reliability as compared with the three-phase diode rectifier.

A new rectifier with near sinusoidal input currents was proposed recently, which generates reduced higher order current harmonics in the mains. This rectifier is named in what follows, for short, RNSIC-1. As presented in Fig. 1(a), contain three inductors L_1, L_2 and L_3 of equal inductance values, L and six DC capacitors C_1-C_6 of equal capacitance values, C. For large variations of the load resistor R_L, it was shown that the total harmonic line current distortion factor (THD) can be maintained less than 5% if one fulfils the condition:

$$0.05 \leq LC\omega^2 \leq 0.1 \qquad (2)$$

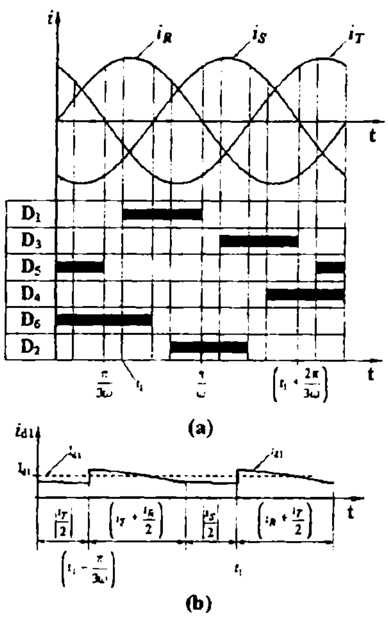


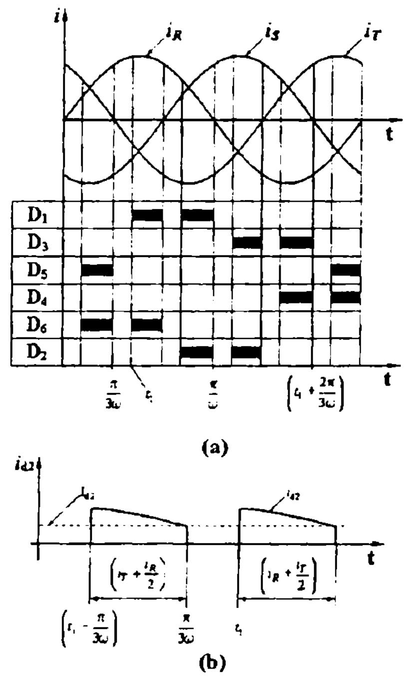
Fig. 2. Waveforms for small values of the I_{d1} current for RNSIC-1 ($\pi/3 \leq \omega t_1 \leq \pi$)
(a) AC current waveforms
(b) DC current i_{d1}

We propose, in what follows, a new converter configuration, named RNSIC-2, as presented in Fig. 1(b). In order to reduce the higher order harmonics generated in the ac mains, this circuit is characterized by the fact that it has the capacitors C_1', C_2' and C_3' connected on the AC side. Inductors and capacitors are used in conjunctions with the three-phase diode bridge rectifier to improve the waveform of the currents drawn from the utility grid.

One of the most important property of the RNSIC-2 converter is that the voltages applied across the capacitors C_1', C_2' and C_3' are limited to $\pm V_{d2}$.

In Fig. 2 and Fig. 3 are presented the waveforms of the phase currents and the conduction intervals of the diodes, for small values of the I_d current. Studying this two figures can be deduced the difference between the working principles of the two variants. In the case of the RNSIC-1 converter, two, one or no diode can conduct and the angle ωt_1 can vary between $\pi/3$ andπ. For the RNSIC-2 converter, two or no diode can conduct and the angle ωt_1 can vary between $\pi/3$ and $2\pi/3$. For this last converter the discontinuous current mode appears, according to Fig. 3(b).

This situation can not be considered as a drawback since the value of I_{d2} is small and the capacitors C_0 is dimensioned in the rated operation for large values of I_{d2}.



Fi . 3. W ll lues of he I_{d2} cu re for RNSIC- ($\pi/3 \leq \omega t_1 \leq 2\pi/3$)
(a) AC current waveforms
(b) DC current i_{d2}

An application using RNSIC converter is a static frequency converter with DC voltage link, designed for supplying with variable voltage and frequency the three-phase induction motor drive, as in Fig. 4(a). Due to the fact that the output of a RNSIC-2 converter has the V_{d2} voltage with 15%-20% larger than the reference voltage V_{ref} obtained from a tree-phase classical diode rectifier, it implies that at the output of the PWM inverter one can get the rated voltages for the three phases supplying the induction motor drive.

The gain is that is no need to apply an overmodulation technique (as, for example, methods of PWM pattern generation with third harmonic injection or with partially constant modulating waves).

The rectifier rated voltage $V_{dr}=V_{ref}/(1-3LC'\omega^2)$ exceeds the reference value V_{ref} ($V_{dr}=kV_{ref}$, where $k=1/(1-3LC'\omega^2)$ is an overvoltage coefficient varying between 1.15-1.25). This is the reason for which one can get stator phase voltages, V_S, applied to the induction machine, surpassing practically with the same coefficient k the rated voltage V_{Sr}, according to Fig. 4(b). From this figure, it result that the motor supplied from a frequency converter with RNSIC-2 connected at its input is used more efficiently even at frequency larger than the rated one, f_r. In this case, the region of functioning at a rated nominal torque T_{emr} is larger, and the power obtained from the motor at frequencies larger than f_r is larger.

Some other applications of the RNSIC-2 converter can be:

- charging of battery banks;
- supplying DC voltage to consumers having loads varying between narrow limits, of maximum 1:5, as the ratio $I_{max}/I_{min\ 2}$ is smaller than that of the RNSIC-1 converter;
- supplying DC voltage to isolated consumers, situated at relatively large distances from the utility grid. The RNSIC-2 converters act as voltage boosters even at unity power factor and so, one can compensate for the voltage drops on the power lines.

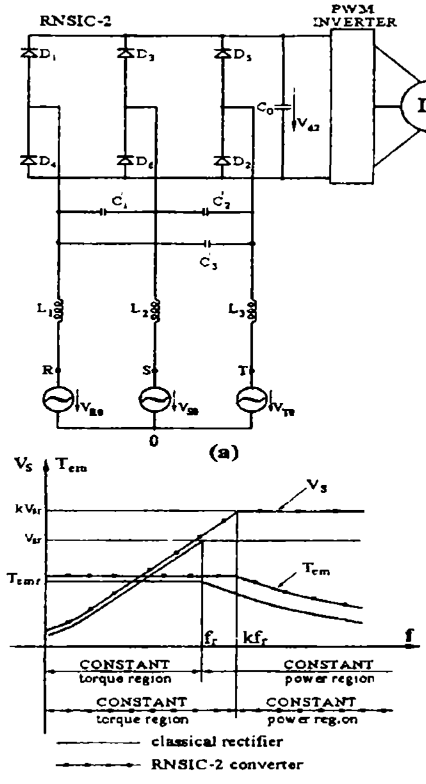


Fig. 4. Frequency converter with RNSIC-2
(a) Basic configuration
(b) Induction machine characteristics and capabilities

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