Rectifier with Near Sinusoidal Input Currents vector-controlled for AC motor drive

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Abstract: This paper is presented a three – phase rectifier, which is able to assure a very low harmonic injection in the power supply (RNSIC converter = Rectifier with Near Sinusoidal Input Currents).

Keywords: power electronics, harmonic reductions, three – phase rectifiers.

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1. Introduction

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

A large majority of the power electronics applications such as switching DC power supplies, AC motor drives, static frequency converters, DC servo drives, and so on, us e such uncontrolled three – phase rectifiers [1].

The three – phase, six – pulse, full bridge diode rectifier is a commonly used circuit configuration. A filter L_fC_f is connected at the DC side of the rectifier. In the three – phase rectifier, the AC side inductance is assumed to be zero and the DC side is replaced by a constant DC current I_d. The rms harmonic component $I_{(n)}$ of the phase current can be determined in terms of the fundamental frequency component $I_{(1)}$ as:

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

where n represents the harmonic number, n = 5,7,11,13,… To draw a conclusion, typical AC current waveforms in the three – phase diode rectifier circuits are far from a sinusoid. The power factor is also very poor because of the harmonic contents in the line current. Moreover, these harmonic contents cause additional harmonic losses in the utility system and may excite electrical resonances, leading to large over voltages [1], [2], [3], [4].

Obviously, the reduction of higher current harmonics generated by a three – phase AC – DC converter can be obtained as well using a PWM rectifier [1], [5], [6].

In Figure 1 is represented a two – quadrant frequency converter with PWM converter at the input for monitoring and regenerative braking in AC motor drive. When the induction machine works like an engine, PWM converter 1has the bill of PWM rectifier, and if the induction machine works like a generator, PWM converter 1 has the bill of PWM inverter. It can be seen from the scheme from Figure 1, that the transistors T_1-T_6 work continuously.

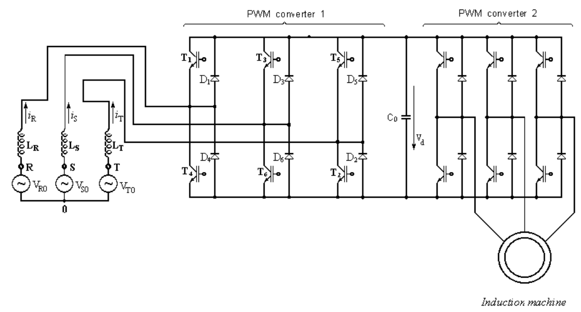

Fig. 1. Two – quadrant frequency converter whith PWM rectifier at the input for monitoring and regenerative braking in AC motor drive.

Because of rapid changes in voltages and currents within a switching converter, PWM rectifier equipment is a source of electromagnetic interference (EMI) with other equipment as well as with its own proper operation. The EMI is transmitted in two forms: radiated and conducted [1].

Even if the PWM rectifier has almost sinusoidal currents at the entrance, it presents the following important disadvantages comparing to the three-phase rectifier with diodes:

- Higher commutation loss;
- Higher cost;
- Less working safety.

2. RNSIC Converter Configuration

In Figure 2(a) we present an AC – DC converter generating reduced higher current harmonics in the mains, named in what follows for short RNSIC (**R**ectifier with **N**ear **S**inusoidal **I**nput **C**urrent) [7], [9]. Such a rectifier does not necessitate on the AC side classic passive filters, active filters or hybrid filters. The capacitors $C_1 - C_6$ have the same value C and they are DC capacitors (for example, those in the series B25355 for Smoothing, Supporting, Discharge) [9]. The inductors L_R, L_S and L_T have the same value, denoted by L, and they are connected on the AC side. The values of L and C fulfill the condition:

$$0{,}05 \le LC\omega^2 \le 0{,}10 \tag{2}$$

in order for the phase currents i_R, i_S and i_T to be practically sinusoidal, according to Figure 2(b). ω denotes the mains angular frequency.

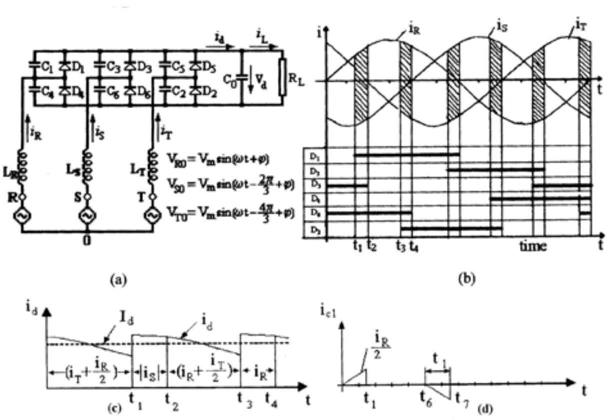

Fig. 2 T hree – phase rectifier with practically sinusoidal currents new configuration; (b) AC current waveforms; (c) DC current i_d; (d) waveform of the capacitor current i_{c1}

In Figure 2 (b) are presented the wave forms of i_R, i_S and i_T currents, and the conduction times of the D_1-D_6 diodes, for a I_d current of relatively large value, as in Figure 2(c). It can be seen that there are two or three diodes in conduction at a certain moment of time. For an average value of I_d, in conduction can be one or two diodes at a certain moment of time. Of course, at small load current i_L and, thus, small current I_d, in conduction can be only one diode or none.

For the 3 cases presented above, considering that the i_R, i_S and i_T currents are almost sinusoidal and have the magnitude I(1) function of the loading resistance R_L, I_d current can be obtained with the relation:

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

The angle φt_1 when the D_1-D_6 enter in conduction varies between the nominal value $(\varphi t_1)r$ and the maximum value equal to 180°. The nominal value $(\varphi t_1)r$ is defined for φ=0° and R_L/R_{Lr}=1 and it is between 45° and 60°.

There are two extreme case during RNSIC converter functioning. In the first case, if $R_L = 0$ (and so $V_d = 0$ and $\omega t_1 = 0$), the capacitors $C_1 - C_6$ short – circuited and the angle $\varphi = +90^0$ is inductive. In this case, the phase currents are sinusoidal and have maximum amplitude, equal to I_{max}. In the second case, if the voltage V_d exceeds the value $\frac{\sqrt{3}V_m}{\left(1-2LC\omega^2\right)}$, the diodes $D_1 - D_6$ do not conduct any more and the angle $\varphi = -90^0$ is capacitive (and so $R_L = \infty$ and $\omega t_1 = \pi$). For this last case, the phase currents are also sinusoidal and the amplitude has a minimum value I_{min}.

The ratio $\frac{I_{max}}{I_{min}}$ has the value:

$$\left|\frac{I_{max}}{I_{min}}\right| = \frac{\left(1-2LC\omega^2\right)}{2LC\omega^2} \tag{4}$$

Due to the fact that the rms currents I_{CRMS} that flow through the capacitors $C_1 - C_6$ have small values as compared with I_{max} according to Figure 2(d), it implies that one has to choose (for continuous operation) capacitors with relatively large rated capacitance C_R and rated voltage V_R. The condition is better fulfilled by the DC capacitors [7], [8].

3. Measurement and Control Algorithm

The drive control is a standard indirect vector-controlled algorithm. The efficiency controller is based on Rosenbrock's method [10], [11], [12], [13]. Sampling input voltage and current, the active power is computed in the following way:

$$P_1 = \frac{1}{T}\int_0^T v(t)\, i(t)\, dt \tag{5}$$

The rms value for the current containing harmonics can be evaluated with:

$$I^2 = \frac{1}{T}\int_0^T i^2(t)dt \tag{6}$$

For the input voltage, the rms value can be calculated with:

$$V^2 = \frac{1}{T}\int_0^T v^2(t)dt \tag{7}$$

and assuming no ha rmonics containing, i.e., sinusoidal waveform we have:

$$V = \frac{V_{1\,peak}}{\sqrt{2}} = V_1 = \frac{V_{peak}}{\sqrt{2}} \tag{8}$$

The fundamental current value I_1 is computed with the described SHT method, considering the fundamental frequency equal to 60Hz. The power measurement algorithm is displayed in Figure 3. The computer may calculate all power quantities in real time, although it is also possible to save in memory only the following values: P_1, Q_1 and S and to obtain other magnitudes using a simple electronic spread-sheet once the drive has stopped. Because the whole algorithm is computed digitally, the above integrals are transformed into simple sums, what means:

$$\begin{aligned} P_1 &= \frac{1}{T}\sum v_k\ i_k \\ I^2 &= \frac{1}{T}\sum\ i_k^2 \end{aligned} \tag{9}$$

In the implemented vector-controlled drive, the flux Φ is decremented by changing the flux current reference, i_{sd*}. On the other hand, the main purpose of the implemented power measurement algorithm is to analyze powers in a v ector-controlled induction motor drive when the flux is reduced in order to decrease losses with the described method.

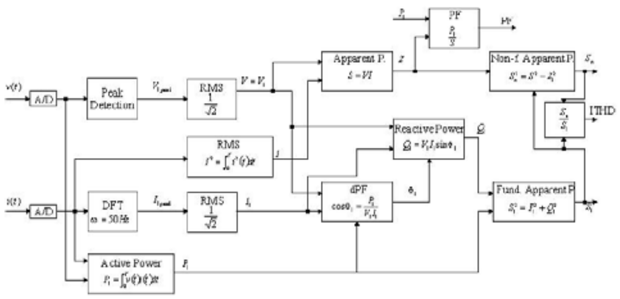

Fig. 3: Power measurement algorithm diagram.

In Figure 4 presents MATLAB model for converter with AC motor.

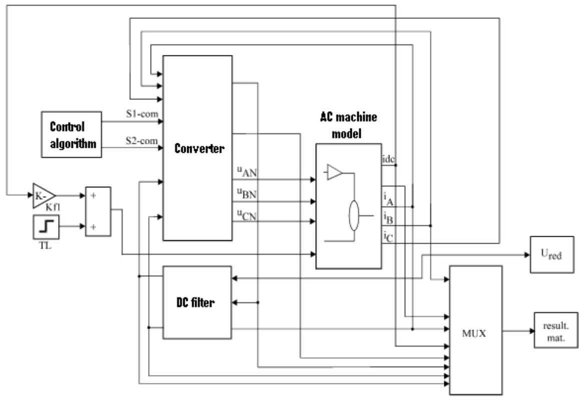

Fig. 4. Matlab model for converter with AC motor

In Figure 5 presents algorithm for control based on vector-controlled induction motor drive. Obtained relations:

$$\begin{aligned} u_{AN} &= \frac{U_1}{3}(-S1-S2) + \frac{U_2}{3}(2-S1-S2) \\ u_{BN} &= \frac{U_1}{3}(2S1-S2) + \frac{U_2}{3}(2S1-S2-1) \\ u_{CN} &= \frac{U_1}{3}(2S2-S1) + \frac{U_2}{3}(2S2-S1-1) \end{aligned} \tag{10}$$

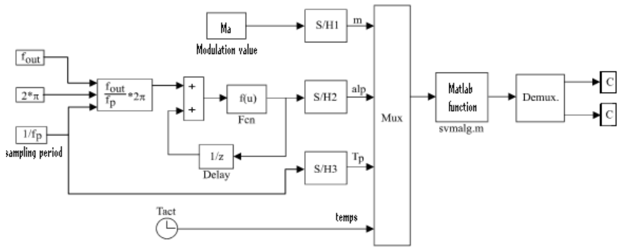

Fig. 5. Matlab model for vector-controlled induction motor drive

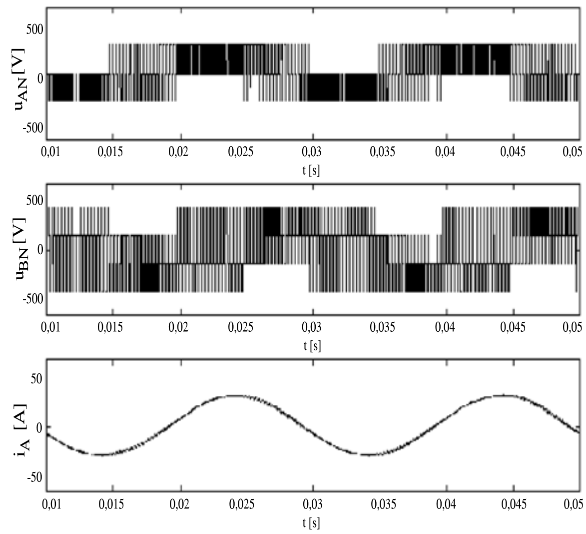

Fig. 6. Simulations results for current and tension.

Moreover, the simulations results for current and tension are presented in Figure 6. Lastly, the harmonics characteristics are presented in Figure 7.

4. Conclusions

The adjustment of the active power transmitted to the utilization network can be obtained through the proper control of the PWM inverter, without the necessity that the induction generator has a i n PWM rectifier. The reliability and the efficiency can be increased while the cost can be decreased. This solution can be applied to the system with small hydro generators.

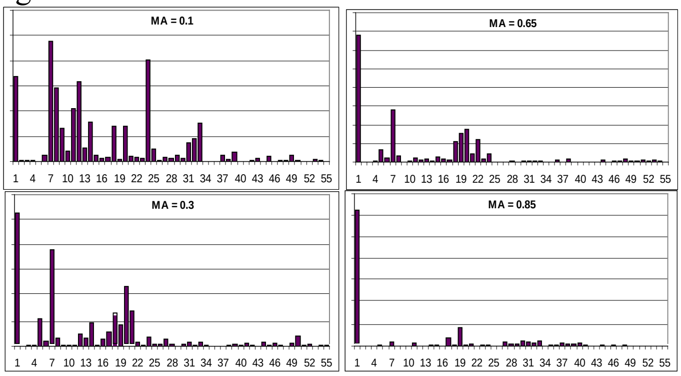

Fig. 7 Harmonics characteristics

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Conflicts of Interest

The author(s) declare no potential conflicts of interest concerning the research, authorship, or publication of this article.

Contribution of individual authors to the creation of a scientific article (ghostwriting policy)

The author(s) contributed in the present research, at all stages from the formulation of the problem to the final findings and solution.

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