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Researches Regarding the Pollution with Harmonics by the Frequency Converters

This paper presents a study regarding the influences produced by the tension and current superior harmonics if there are used frequency converters for variable speed action. There are also shown results recorded in different points of interest along with conclusions regarding which are the most suitable converters to be chosen in practical applications.

Keywords: *static converter, PWM signals, induction motor, harmonics analysis.*

1. Introduction

The use of static converters brings tension and current harmonic pulsations, capable to produce important disturbances to the consumer or the electrical energy supply network.

Reducing the harmonic effects stays among the static converter designers, but also in attention of equipments users.

Is useful to know the influence that different types of frequency converters which have over the supply networks and over electrical action drives.

Transmission, amplifying and compensation of the deforming power raise the following problems:

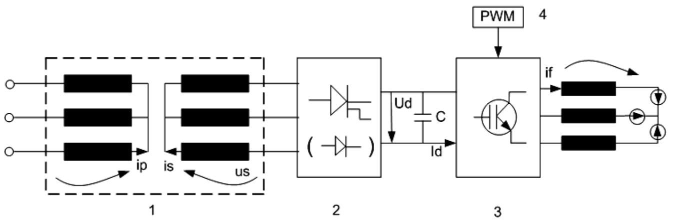
- limitation of current and tension harmonics production;
- limitation of harmonics propagation in the industrial installations (lines, equipments);
- compensation of the deforming regime.

The unsinusoidal currents supplies are the static converters in rectifier and / or inverter regime. And these can be the saturated iron core inductances and alternative current machines (synchronous or asynchronous), along with the inverters.

The superior harmonic presence in the supplying networks has negative implications on the electric energy quality, the efficiency and the telecommunication equipments. The current harmonics lead to additional losses in coils by Joule effect and in the magnetic circuits due to the eddy currents and hysteresis. To all of this it can be added the appearance of pendulum couples to the electric machines shafts.

2. Theoretical considerations.

The principle scheme of the most used static frequency converter is presented in figure 1.



1. adaptation transformer
2. rectifier bridge
3. filter
4. IGBT transistor inverter
5. PWM signals generator

Figure 1. Principle scheme of the static frequency converter

The transformer connections may be: Y / Y, Δ / Y, Y / Δ, Δ / Δ.

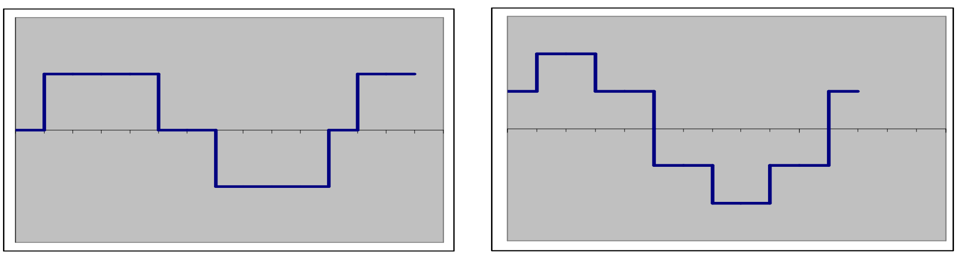
The rectifiers' types that frequently enter in the converter componence are:

- uncommanded three-phase bridges
- three-phase bridges complete commanded with thyristors
- three-phase bridges complete commanded with IGBT transistors

In the case of three phased bridges the alimentation from the transformer with the Y / Y and Δ / Y, the secondary and primary's currents have the same waveform and they don't have the continuous current component.

$$i(t) = \frac{2\sqrt{3}}{\pi} I_d \left(\cos \omega t - \frac{1}{5} \cos 5\omega t + \frac{1}{7} \cos 7\omega t ..... \right), \qquad (1)$$

where I_d is the average value of the rectified current.



a. b.

Figure 2. The current waveform through the primary winding of the transformer: a) for Y / Y, Δ / Y connections; b) for Y / Δ, Δ / Δ connections.

In case of three phased rectifying bridges fed from the transformer with Y / Y, Δ / Δ connections, the development of the current in Fourier series is:

$$i(t) = \frac{2I_d}{\pi}\left(cos\,\omega t + \frac{1}{5} cos\,5\omega t - \frac{1}{7} cos\,7\omega t..... \right) \tag{2}$$

For the complete commanded bridges, the level of the current harmonics depends of the command angle α. The harmonic's phase angle is influenced by: the transformer connection, the rectifier supply tension, the load impedance and the command angle.

The main indicators of the deforming regime are:

- the active power

$$P = V_0 \cdot I_0 + \sum_{\nu=1}^{\infty} V_\nu \cdot I_\nu \cdot cos\,\varphi_\nu \tag{3}$$

where

$$V(t) = V_0 + \sum_{\nu=1}^{\infty} V_{m\nu}\, sin(\nu\omega t + \alpha_\nu)$$

$$i(t) = I_0 + \sum_{\nu=1}^{\infty} I_{m\nu}\, sin(\nu\omega t + \alpha_\nu - \varphi_\nu)$$

are unsinusoidal parameters.

- the reactive power

$$Q = \sum_{\nu=1}^{\infty} V_\nu \cdot I_\nu \cdot sin\,\varphi_\nu \tag{4}$$

- the deforming power

$$D = \sqrt{S^2 - P^2 - Q^2} \tag{5}$$

- the apparent power

$$S = \sqrt{\left(V_0^{\,2} + \sum_{\nu=1}^{\infty} V_\nu^{\ 2} \right) \cdot \left(I_0^{\,2} + \sum_{\nu=1}^{\infty} I_\nu^{\ 2} \right)} \tag{6}$$

- the harmonic distortion factor

$$THD[\%] = 100 \sqrt{\sum_{\nu=2}^{\infty} \frac{I_\nu^2}{I_1^2}} \tag{7}$$

3. Command techniques and the PWM inverter structure.

In the present action structures, indifferent of the used method for speed adjustments, the asynchronous motor supplying aims to be done in general from static converters of frequency, which are able to modify the amplitude and the feeding tension frequency (due to the large complexity of the regulation algorithms).

The most utilized feeding structure is formed by an uncontrolled rectifier and an inverter with modulation in width for impulses, named PWM inverter (figure 3.1). This is build usually with IGBT or MOS power transistors.

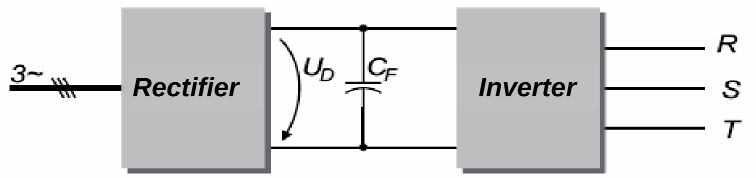


Figure. 3 Block Scheme of C.S.F with P.W.M inverter

For the vector command, the inverter can be regarded as a tension source or, in most of the cases, as a current source. The essential elements that need to be take in consideration in designing the current loops by PWM inverters, called in this case current invertors, are: necessity to insure a tension reserve in order to allow imposing certain values for the current amplitude through the motor (this aspect appears in general at high speeds and can be excluded by assuring a supply continuous tension sufficient for the desired application) and the commutation frequency which, in order to insure the best performances, has to be as high as possible, but lower than the maximal working frequency of the semiconductor devices used.

The duration modulation of impulses (PWM) is the process by which the conduction intervals of contacts fragment looking a conductive content of out-going tension harmonics of the inverter. In the meantime high dynamics performances are obtained. The tension impulses modulated in duration after a sinusoidal law is obtained by comparing a sinusoidal tensions three-phase system (modulating signal) with a triangular tension signal. The three sinusoidal tensions are phase altered among them with 120^0. The f_1 frequency of the modulating signal is equal with the fundamental harmonic frequency of the out-going tension of the inverter. The f_t frequency of the triangular signal must have a higher value than f_1 of at least two times. The quality of the wave shape of the out-going tension is much better as the f_t frequency is higher.

CSF with inverters based on out-going tension impulses modulation after a sinusoidal law (PWM) principle point out some important advantages compared with CSF with intermediate circuit of variable continuous tension, such as:

- out-going tension ahs a reduced number of low frequency harmonics;
- high dynamics performances are obtained;
- higher power factor;
- larger scale of out-going frequency.

So the amplitude of the out-going tension and frequency are adjusted by the inverter command. This is the main disadvantage of CSF with PWM inverters (the command block scheme is much more complex). Therefore was designed and produced specialized integrated circuits for PWM type in order to eliminate this disadvantage. Meanwhile were developed numerical command techniques (digital PWM).

The main command block scheme of the induction motor with PI regulator is shown in the figure below:

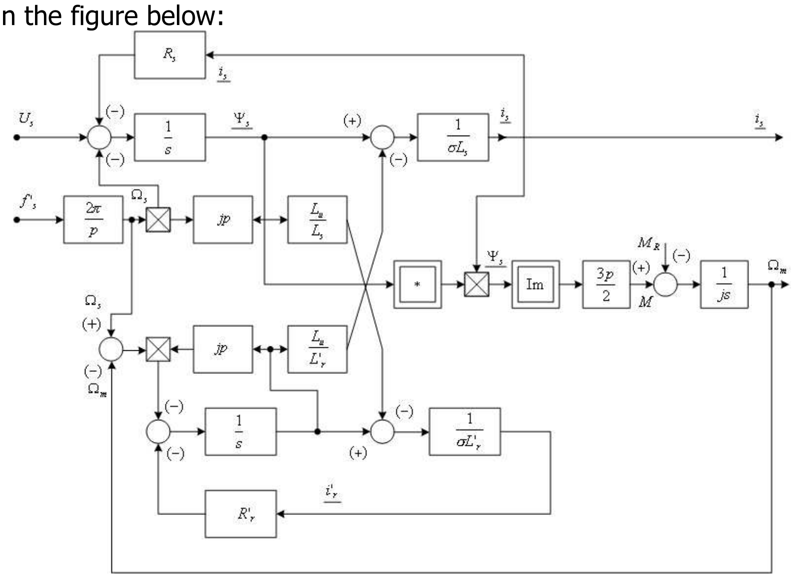


Figure. 4 Block Scheme of the induction motor with P.W.M inverter

The induction motor is modulated with the block-diagram from Figure 4, taking in consideration the PI type regulator of the motor command.

In Figure 5 is shown the block-scheme proposed and applied by the authors for commanded PWM inverter.

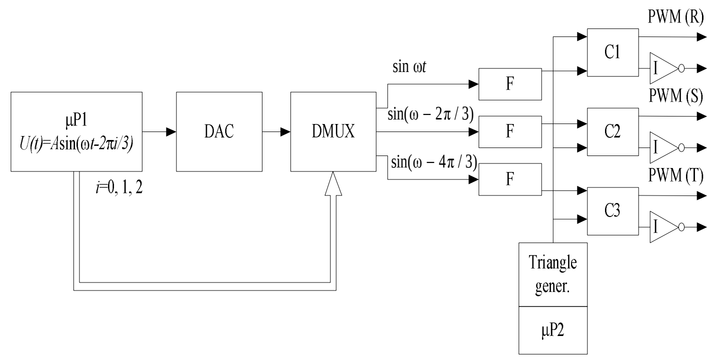
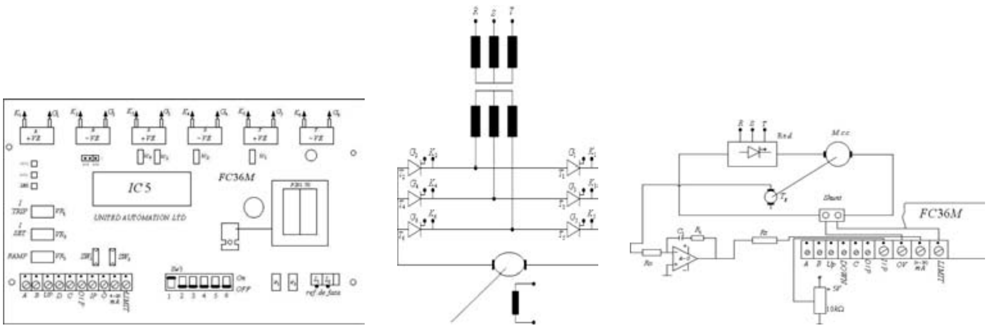


Figure 5. The generation scheme of the PWM signals to command the inverter

The regulation scheme of the complete commanded rectifier bridge is showed in figure 6.



a) b) c)

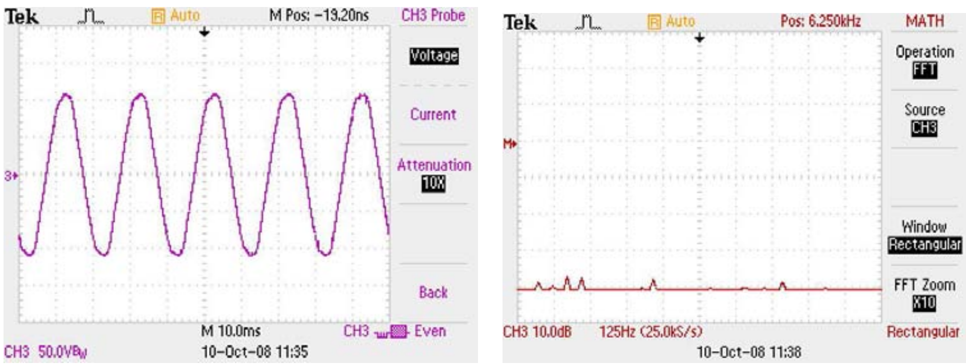
Figure 6. The rectifying bridge command scheme:

a) The electrical command scheme with microcontroller; b) The power scheme
c) Adaptation of command device to the control of the rectifying bridge

4. Experimental Results.

After the experiments, the following results have been obtained:

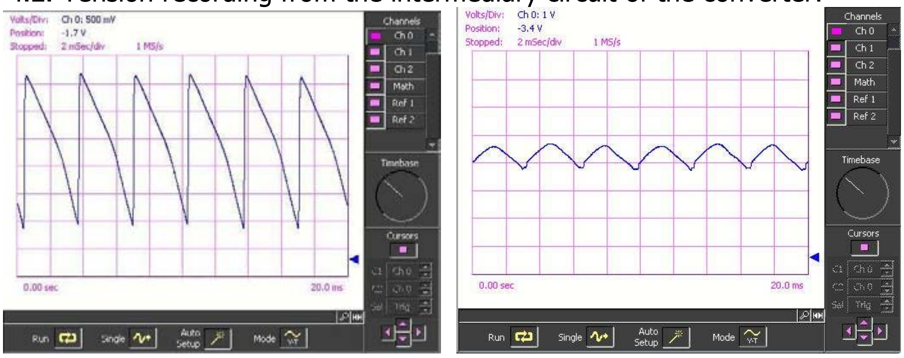
4.1. Wave form and harmonic analysis of the phase tension



a) b)

Figure 7. Tension harmonic analysis at the converter's input (50 Hz)
a) waveform of line voltage; b) harmonics analysis of line voltage.

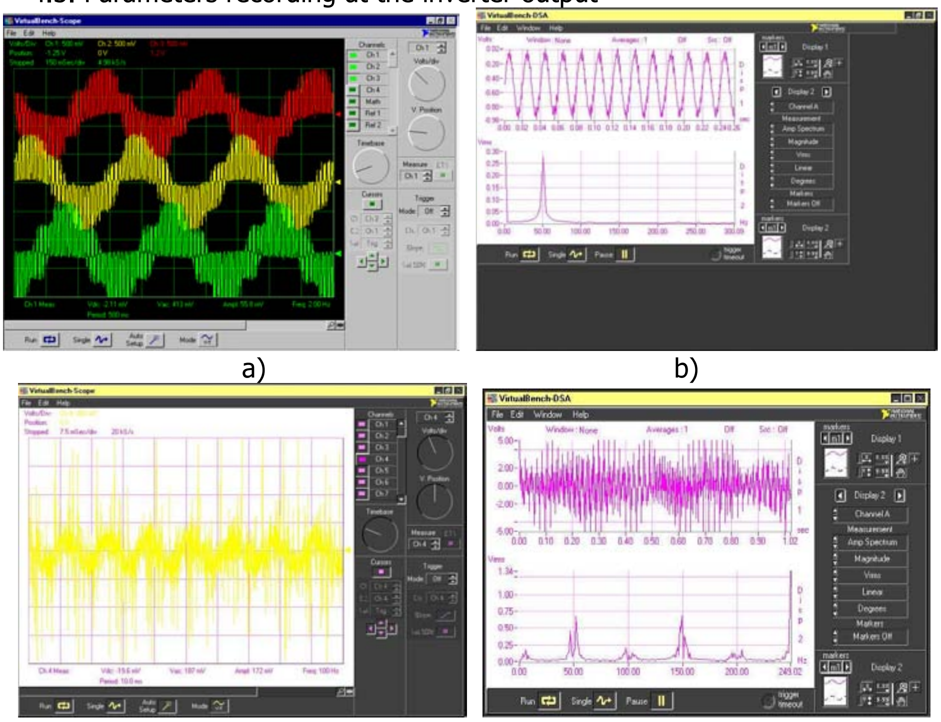
4.2. Tension recording from the intermediary circuit of the converter:



a) b)

Figure 8. Wave form of the straighten tension for a complete commanded three-phase bridge: a) U_{da2}=47,2V; b) U_{damin}=78,6V

4.3. Parameters recording at the inverter output



a) b) c) d)

Figure 9. Wave form and harmonic analysis of the motor phase voltage: a) symmetrical three-phased phase voltage - f=12 Hz; b) filtered phase voltage f=50 Hz; c) current phase waveform - f=100 Hz d) current spectral analysis - f=50.

5. Conclusion

After performing the experiments, have resulted the following conclusions:

- Utilization of commanded rectifiers determines a higher pollution with harmonics of the supply network compared with the uncommanded ones;
- For medium and high power is imposed the presence on the converter supply of some filtration inductance;
- The evaluated generation techniques for the PWM signals determines a low content of tension harmonics at the inverter's output;
- The motors force inductivity value give an influence in the harmonic content of the current;
- The low level of the harmonic distortion reduces the excess losses.

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