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CURRENT TYPE PWM RECTIFIER USED IN INDUSTRIAL APPLICATIONS

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Abstract: *In this paper are presented the results from simulations, which have been performed in program Pspice. A current type PWM rectifier was simulated and some controlling methods were applied in the models. There are several control methods, which can be used for controlling PWM current type rectifier. For example triangular PWM, vector PWM, delta control or phase control. In the paper are presented the waveforms for all the controlling methods mentioned above, their comparison and analyze. The most significant output parameters from the simulations are the shapes of input currents and harmonic spectrums of input currents.*

Key Words: ***Current type PWM rectifier, Simulation, Pspice, Control, Plasma furnace.***

1. INTRODUCTION

Power electronics circuits are widely used in industrial equipment, such as frequency changers, motor drive systems, common rectifiers etc. Such systems generate large harmonic currents with well-known adverse effects, for example low-power factor (displacement factor, distortion factor) and low-efficiency. The displacement factor directly affects the running and installation cost of equipment and the distortion factor, which is a measure of the level of current harmonics, adversely affects the power system by causing interference with other equipment and distortion of supply voltage waveform [1].

2. CURRENT TYPE PWM RECTIFIER

All those problems appear when common rectifiers are used. For example in plasma melting, it means when a common rectifier is used as a power source for a plasma furnace. This technology was widely used in the past, but now all those disadvantages mentioned above limit this technology. Therefore, utility power quality has become an important issue. The current type PWM AC to DC converter has a smoothing reactor on the DC side (it can be considered as an armature winding of a DC motor). In such rectifiers a passive LC filter has to be inserted on the AC side to reduce the current harmonics due to the PWM operation. The configuration is shown on the fig. 1.

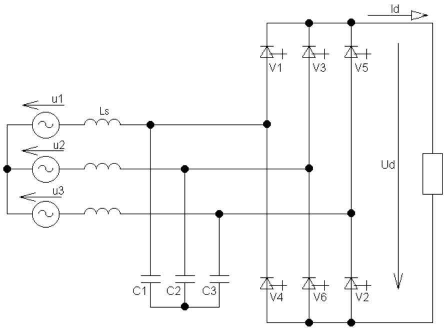

Fig. 1. *Current type PWM rectifier.*

Low pass filter on the primary side of a current type PWM rectifier causing quasi-sinusoidal current taken from the mains. So the low pass filter must be designed to eliminate all high harmonics except the first harmonic. The inductance L_s is the inductance of the mains. An additional inductance can be inserted in series with inductance L_s, but it would increase the costs of the equipment. So the capacitance of the filter must be adjusted.

3. CONTROL METHODS

A current type PWM rectifier can be controlled by several controlling methods. The most classical method for controlling rectifiers is the phase control. Also this algorithm can be applied on the current type PWM rectifier. Modern methods use PWM for controlling PWM rectifiers. So it can be classical triangular PWM or vector PWM. Those methods are widely used because provide better shape of input current.

4. PHASE CONTROL

Phase control is classical method for controlling rectifiers. It's well known mainly from controlling of common rectifiers. The principle of this method consists in sending pulses to the switches according to the fig. 2. The duration between two pulses is exactly and always 60 degrees i.e. 3,33ms. So for 3,33ms is on the converter still the same switching combination. The switching frequency is fixed and it can't be chosen. It is 300Hz [2].

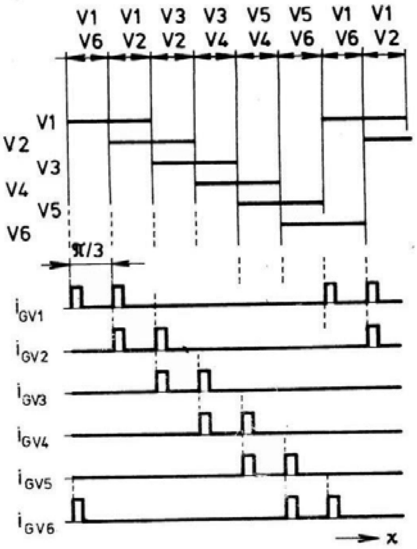

Fig. 2. *Tacts and switching diagram.*

5. DELTA CONTROL

The second method in view is delta control. This method comes from the hysteresis regulation. However the hysteresis doesn't come from dead-zone of controller, but discreet sampling. Delta modulation is a discreet method for controlling converters, where in discreet moments set by modulation period (chosen 1/10kHz) is done:

1. The evaluation of diferencies between requested and actual input currents.
2. The determination of switching combination (Tab. 1.) for the next period to minimalize the diferencies between requested and actual values of input currents [3].

Tab1. *Switching combinations for delta modulator.*

Condition	Switching combination
$Dif_1 < Dif_2 < Dif_3$	V4 V5
$Dif_3 < Dif_2 < Dif_1$	V1 V2
$Dif_1 < Dif_3 < Dif_2$	V3 V4
$Dif_2 < Dif_3 < Dif_1$	V1 V6
$Dif_2 < Dif_1 < Dif_3$	V5 V6
$Dif_3 < Dif_1 < Dif_2$	V2 V3

Where $Dif_1 = I_{1R} - I_{1A}$ $Dif_2 = I_{2R} - I_{2A}$ $Dif_3 = I_{3R} - I_{3A}$.

6. TRIANGULAR PWM

Triangular PWM is also used for controlling common rectifiers. The principle of the method is made by comparison of three sinusoidal reference signals u_{ref1}, u_{ref2}, u_{ref3}, with triangular signal u_t. In case of current type PWM rectifier the frequency of sinusoidal reference signals is 50Hz according to input voltage. All those reference signals have phase equaled to 120 degrees. The frequency of the triangular signal is much higher (at least 10 times) than the frequency of reference sinusoidal voltages. This frequency was chosen to 10kHz to compare this method with other methods. According to the results of the comparisons the switching combination is determined (Tab. 2.). There are three comparisons exactly. Each sinusoidal reference voltage (linked with respectively with each phase) is compared with triangular signal.

Tab2. *Switching combinations triangular PWM.*

Condition	Switch in phase in lead
$u_{ref1} > u_t$	V1
$u_{ref1} < u_t$	V4
$u_{ref2} > u_t$	V3
$u_{ref2} < u_t$	V6
$u_{ref3} > u_t$	V5
$u_{ref3} < u_t$	V2

7. VECTOR PWM

The last examined method is probably the most sophisticated method called vector PWM. There are two variables needful to evaluate output switching combination. The first is requested phase of the input current vector, the second is requested amlpitude of the vector. Vector modulator must do following steps:

1. Locate the sector the current vector is in (according to fig. 3.).
2. Evaluate the right, left and zero vector (according to fig. 3.).
3. Evaluate the switching times for determined vectors.
4. Perform all vectors with respective switching times.

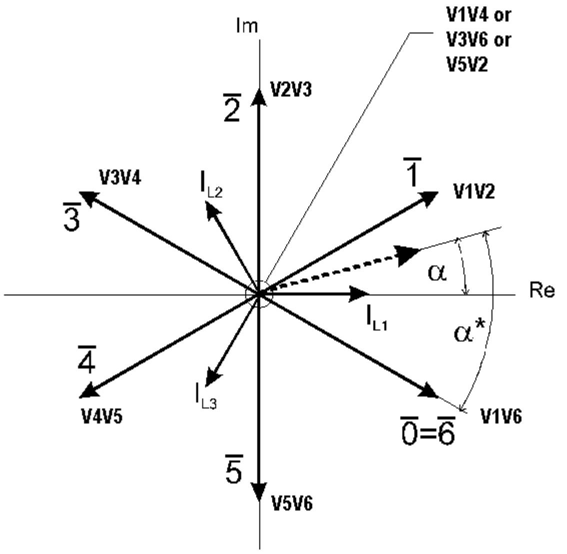

Fig. 3. *Current vectors in 3-phase system realized by switching combinations of current type PWM rectifier.*

Each sector has 60 degrees. The requested phase of the requested current vector brings the information about sector where the vector is placed. So if the sector is known, the switching combination is also known. So next is needful to evaluate the switching times for each vector of the evaluated switching combination (fig. 4.).

y_1 is proportional to $T_1 + T_2$, y_2 to T_0, y_3 to $T_1 + T_2 + T_0$ and β to $\dfrac{T_2}{T_1 + T_2}$.

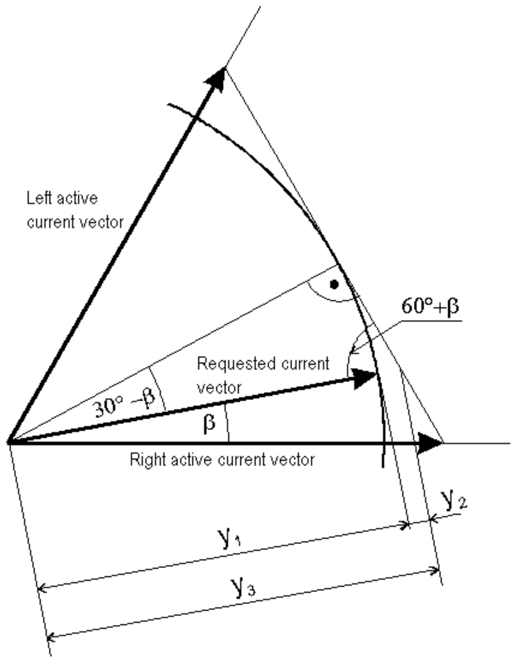

Fig. 4. *The evaluation the switching times for the vectors of a switching combination.*

Whole switching period is:

$$T = T_1 + T_2 + T_0 \tag{1}$$

To simplify next calculations it's good to roll requested vector for 30 degrees:

$$\alpha^* = \alpha + 30° \tag{2}$$

Then current sector is:

$$s = \frac{\alpha^*}{60°} \tag{3}$$

where *s* is quotient after division and *x* is remainder. S is also the position of the right active current vector *x* is:

$$\frac{T_2}{T_1 + T_2} = x \tag{4}$$

The position of the vector in the sector is:

$$\beta = x \cdot 60° \tag{5}$$

From the fig. 3. following equation is valid:

$$\frac{T_1 + T_2 + T_0}{\sin 90°} = \frac{T_1 + T_2}{\sin(180° - 90° - (30° - \beta)} \tag{6}$$

and the switching period is:

$$T = \frac{T_1 + T_2}{\sin(60° + \beta)} \tag{7}$$

To control the amplitude of the final vector, it's reasonable to modify equations (6) and (7) to the following expression:

$$T_1 + T_2 = T \cdot m \cdot \sin(60° + \beta) \tag{8}$$

where *m* can gather values in the range from 0 to 1. If the variable *m* is 1, it means that switches are fully opened for whole switching times $T_1 + T_2 + T_0$. Finally the switching times are:

$$T_1 = T \cdot m \cdot (1 - x) \cdot \sin(60° + \beta) \quad \text{or}$$
$$T_1 = T \cdot m \cdot (1 - x) \cdot \sin((1 + x) \cdot 60°) \tag{9}$$

$$T_2 = T \cdot m \cdot (x) \cdot \sin(60° + \beta) \text{ or}$$
$$T_2 = T \cdot m \cdot x \cdot \sin((1 + x) \cdot 60°) \tag{10}$$

$$T_0 = T \cdot [1 - m \cdot \sin(60° + \beta)] \quad \text{or}$$
$$T_0 = T \cdot [1 - m \cdot \sin((1 + x) \cdot 60°)] \tag{11}$$

8. HARDWARE REQUIREMENTS

To realize all those methods mentioned above, it's needful to have powerful microprocessor system, which can provide high compute power able to calculate very fast the switching times, evaluate correct switching combinations a realize it. So it's reasonable to use signal processor system. Phase control and triangular PWM can be realized by analog system with operational amplifiers. For other two algorithms digital processor system is needed.

9. SIMULATION RESULTS – DELTA CONTROL

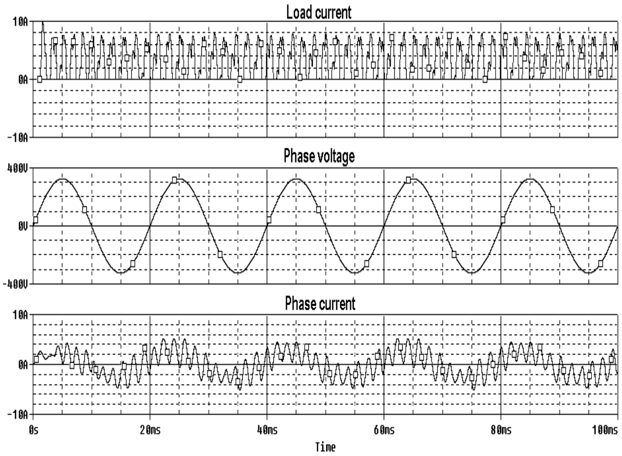

Fig. 5. *Graphs of phase current, phase voltage and load current – Delta control.*

10. SIMULATION RESULTS – PHASE CONTROL

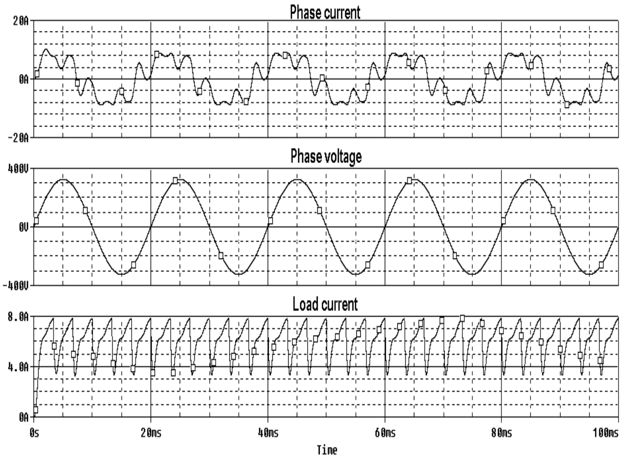

Fig. 6. *Graphs of phase current, phase voltage and load current – Phase control.*

11. SIMULATION RESULTS – TRIANGULAR PWM CONTROL

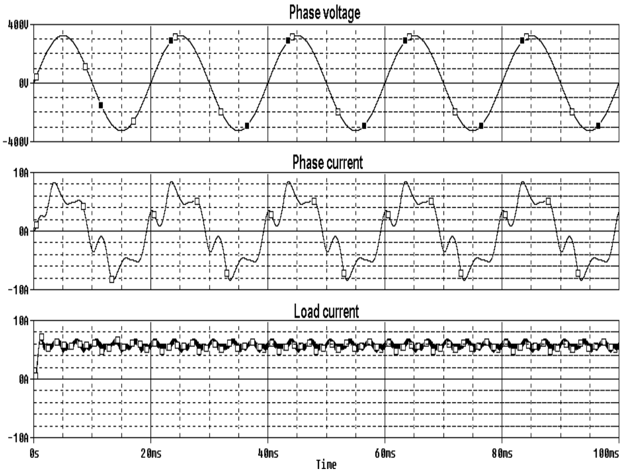

Fig. 7. *Graphs of phase current, phase voltage and load current – Triangular PWM control.*

12. SIMULATION RESULTS – VECTOR PWM CONTROL

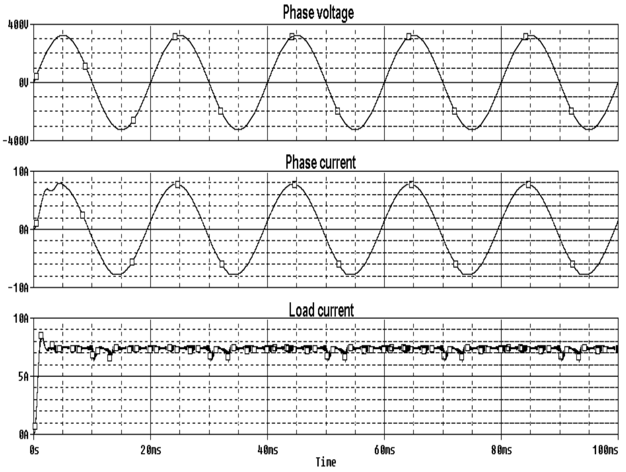

Fig. 8. *Graphs of phase current, phase voltage and load current – Vector PWM control.*

13. CONCLUSIONS

As it was mentioned above, all simulations were made in simulation program Pspice. As a load was chosen resistance R=50Ω in series with inductance L=10mH. Those parameters were so chosen because next there were made real measurings on the load with those parameters and so to provide the best conditions for comparing simulation a measuring results. Switching frequency was 10kHz (of course except phase control). Voltage of the main was 3x400V. The parameters of the low-pass filter were following. The capacitances were $C_1= C_2= C_3=$ 18μF and the inductances of the filter were L_s=10mH. Those components are in our laboratory so it's parameters were used in simulations. As models of switches were chosen switches IXYS IXGH10N60.

Above there were presented graphs of the most significant values in the circuits of all mentioned methods. Phase voltages are mentioned precisely sinulosoidal. Diferences are in currents. The most important are input current. The worst characteristics provide from this point of view delta control. This switching method is not able to provide as high current as other methods. Also the shape of output current is not acceptable. This current is not even for the parameters of circuit even continuos. So the inductance of the load is not able to smooth the current enough. So in the waveform of the current there are spikes. On the other hand the best solution is vector PWM control. The shape of the input current is quasisinusoidal and so it has low amount of high harmonic in its shape. The input currents of other two methods are more deformed so it has more high harmonic. All three remaining methods provide continuous output currents. Triangular PWM and phase control have one advantege. It can be realized by analog circuits, other methods don't.

14. REFERENCES

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