# AC CURRENT PULSE - WIDTH CONTROL REGULATOR WITH LINEAR REGULATION

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**Abstract:**

*In this paper a method of operation of an ac regulator is presented with a pulse - width control of the keys in which a linear dependence between the active power in the regulator load and the regulation angle as well as between the first harmonic amplitude of the voltage in the load and the regulation angle is achieved. The method allows a more accurate control of the processes in the system - AC regulator - load and a voltage minimization distortion in the network at relatively high powers.*

## 1. INTRODUCTION

The development of power semiconductor elements electronics increases the possibilities to improve the methods of operation of the AC regulators/ACR/ and respective technological processes, provided by them to a large extent.

Conditions for application of impulse methods of regulation are created [1, 2, 7], according which higher performance factor, faster operation and possibilities to model the law of voltage variation in the ACR load.

To attain a more regular load loading(minimum voltage distortion) of the network power supply source [7, 9], wide - impulse methods of control of the power semiconductor switches of ACR are used. The frequency of switches operation is much higher from the one of the power supply source.

The methods of regulation, employed in the ACR are characterized most of all by a nonlinear dependence between the active power in the regulator load and the regulation angle, as well as between the first harmonic amplitude of the load voltage and the regulation angle, respectively, [1, 6].

In this paper the method of operation of an monophase AC regulator with a pulse-width switch control is presented at which a linear dependence between these quantities is achieved. This dependence has a determing role as in the analysis of the energy distribution in elements of the ACR network so for the more accurate control of the processes in the system ACR - load.

## 2. DESCRIPTION OF MONOPHASE AC REGULATOR OPERATION METHOD

In Fig. 1 a monophase ACR, composed of a couple couterconnected Gate turn-off (GTO), [4] thyristors $T_1$, $T_2$ and a load R feeded by a sinusoidal (network) voltage $u(\theta)$, $u(\theta) = U_m \sin(\theta)$, $\theta = \omega.t$ - angular frequency, is presented.

The operation method of the configuration is shown in Fig. 2, illustrating the graphics of the couple of thyristors voltages, $T_1T_2$, $u_{T_1T_2}$ and the voltage of the load R, $u_R$ against $\theta$ is presented.

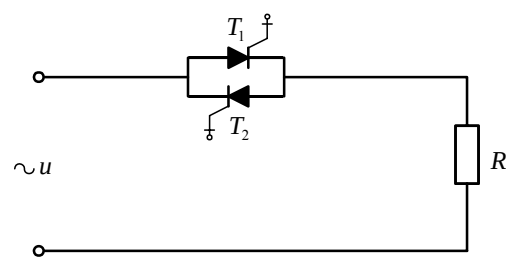


Figure 1. AC regulator with a GTO thyristors couple

The periodical load voltage $u_R$ is separated to four quarters of period, each of them numerated as q / q=1÷4/.

Each quarter of the period contains 2n /n=1 ÷ ∞/ pulses. The pulses with number p /p=1÷n/ from the first and second halves of each quarter period are symmetry located with respect to its middle.

Pulses width p equals the angle $\alpha$. Root mean square (RMS) voltage regulation on the load is performed by a variation (increase or decrease) of the value of angle $\alpha$, where $\alpha \in (0, \alpha_{\max})$, $\alpha_{\max} = (\pi/2)(1/2n)$. The interval between each two pulses/ in each half of the quarter period/equals an angle $\gamma$. The pulse with number $p = n$ lies at a distance angle $\beta$ from the middles $\pi/4$, $3\pi/4$ ; $5\pi/4$, $7\pi/4$ / of the quarter periods, to which is belongs.

Two cases for angle $\beta$ are suggested. The first one is at $\beta = \gamma$. The quantity $\gamma$ is determined as follows: $\gamma = (\pi/2 - 2n\alpha)/2n$. The second angle is $\beta = \gamma/2$, where $\gamma$ is given by the formula: $\gamma = (\pi/2 - 2n\alpha)/2n - 1$.

In the first case the beginnings of pulses p=1, 2…n can be fixed, and the duration of their variation can be accomplished by moving their ends. In the second case, when changing the angle $\alpha$ only the first pulses of quarters of periods/p=1/ remain fixed. After the angle $\gamma$ is calculated by the ACR control system each subsequent pulse /p=2…n/ is shifted to an angle $\gamma$ towards the previous one, according the numeration, presented in Fig.2.

The analytic results for the first harmonic amplitude and RMS load voltage for the two cases of regulation are equal for angle values of, $\beta$, $\beta = \gamma$ and $\beta = \gamma/2$.

## 3. ANALYSIS OF MONOPHASE AC REGULATOR WITH A PULSE - WIDTH SWITCH CONTROL OPERATION

The RMS load voltage $U_R$ can be determined as, [7]:

$$U_R = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}[u_R(\theta)]^2\,d\theta} \qquad (1)$$

The expression (1) for operation method of regulator presented in Fig. 2 can be given

by the following:

$$\frac{U_R}{U} = \frac{1}{\sqrt{\pi}} \sqrt{\{\sum_{q=1}^{4}[\sum_{p=1}^{n}(\int_{\theta_1(p,q)}^{\theta_2(p,q)} \sin^2\theta d\theta + \int_{\theta_3(p,q)}^{\theta_4(p,q)} \sin^2\theta d\theta)]\}}\ , \qquad (2)$$

$$U = U_m / \sqrt{2}\ ,$$

$$\theta_1(p,q) = (p-1)(\alpha+\gamma) + (q-1)\frac{\pi}{2};$$

$$\theta_2(p,q) = (p-1)(\alpha+\gamma) + \alpha + (q-1)\frac{\pi}{2},$$

$$\theta_3(p,q) = \frac{\pi}{2} - [(p-1)(\alpha+\gamma)+\alpha] + (q-1)\frac{\pi}{2}\ ;$$

$$\theta_4(p,q) = \frac{\pi}{2} - [(p-1)(\alpha+\gamma)] + (q-1)\frac{\pi}{2}.$$

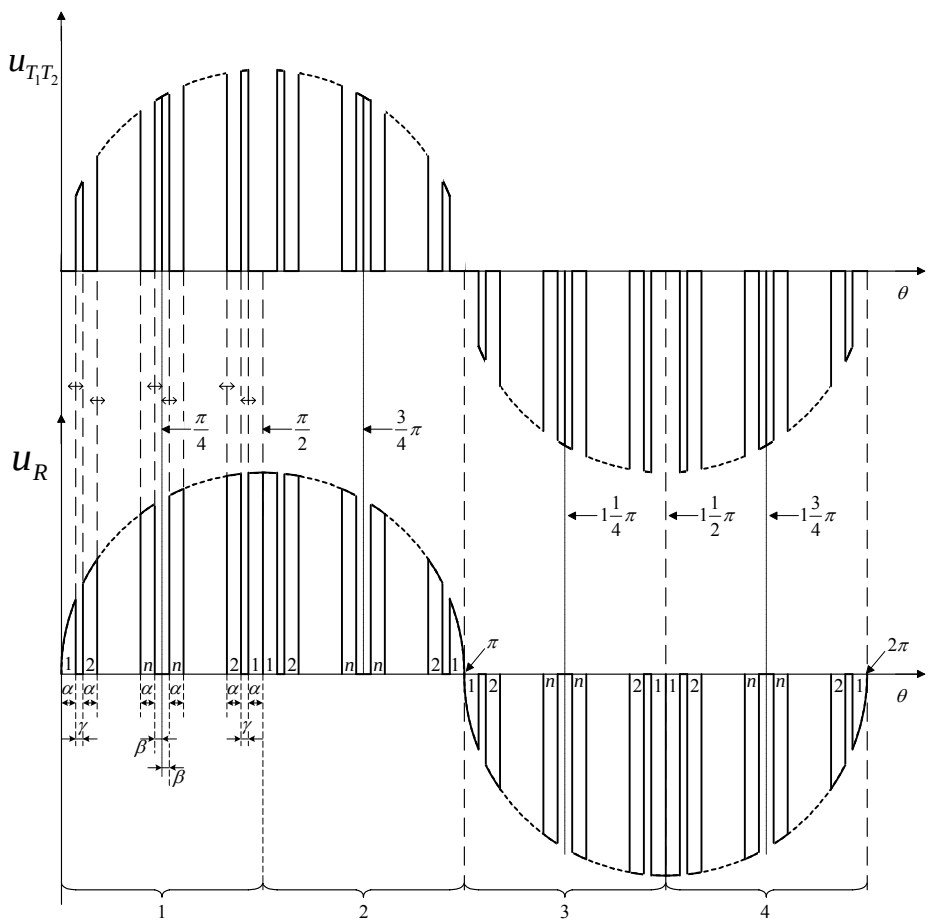


Figure 2. Graphics of thyristors couple voltage, $u_{T_1T_2}$ and load voltage, $u_R$

If $q = const$, then it can be written, that

$$\sum_{p=1}^{n}\left(\int_{\theta_1(p,q)}^{\theta_2(p,q)} \sin^2\theta d\theta + \int_{\theta_3(p,q)}^{\theta_4(p,q)} \sin^2\theta d\theta\right) = n\alpha \ .$$

Hence the expression (2) is given by:

$$\frac{U_R}{U} = \sqrt{\frac{\theta_r}{\pi}}; \theta_r = 4n\alpha \ . \tag{3}$$

The half-cycle of voltage $u_R$ consists 4n pulses with width equal to an angle $\alpha$. Accordingly the thyristor burning angle $\theta_r$, [1] is equal to $4n\alpha$.

The generalized thyristor burning angle $\beta$ is determined by, [2]:

$$\beta = \pi - \theta_r \tag{4}$$

Hence, in introducity the angle $\beta$ the expression (3) can be written as:

$$k_U = \frac{U_R}{U} = \sqrt{\frac{\pi - \beta}{\pi}} \tag{5}$$

The analytic form of regulation characteristic as a function of the values of angle $\beta$ is seen from the expression (5). In per unit system (PU) this characteristic is presented in Fig. 3, by means of factor $k_U = U_R / U$.

The first harmonic magnitude of load voltage $U_R(1)_m$ can be expressed as follows:

$$U_R(1)_m = \frac{1}{\pi}\int_0^{2\pi} U_m (\sin\theta)^2 d\theta \tag{6}$$

$$U_R(1)_m = U_m \frac{\sum_{q=1}^{4}\left[\sum_{p=1}^{n}\left(\int_{\theta_1(p,q)}^{\theta_2(p,q)} \sin^2\theta d\theta + \int_{\theta_3(p,q)}^{\theta_4(p,q)} \sin^2\theta d\theta\right)\right]}{\pi} \tag{7}$$

$$U_R(1)_m = U_m \frac{4n\alpha}{\pi} \tag{8}$$

When presenting the generalized burning angle $\beta$ through the burning one $\theta_r$, see equation (4), the analytic form of regulation characteristic $U_R(1)_m$ can be derived as:

$$k_{Um} = \frac{U_R(1)_m}{U_m} = \frac{\pi - \beta}{\pi}. \tag{9}$$

The latter is shown graphically in PU in Fig. 3, by the coefficient $k_{Um} = U_R(1)_m / U_m$ versus $\beta$.

Based on equation (3) for power $P_R$, $P_R = U_R^2 / R$ and energy $W_R$, $W_R = P_R / f$ in load it can be obtained, respectively:

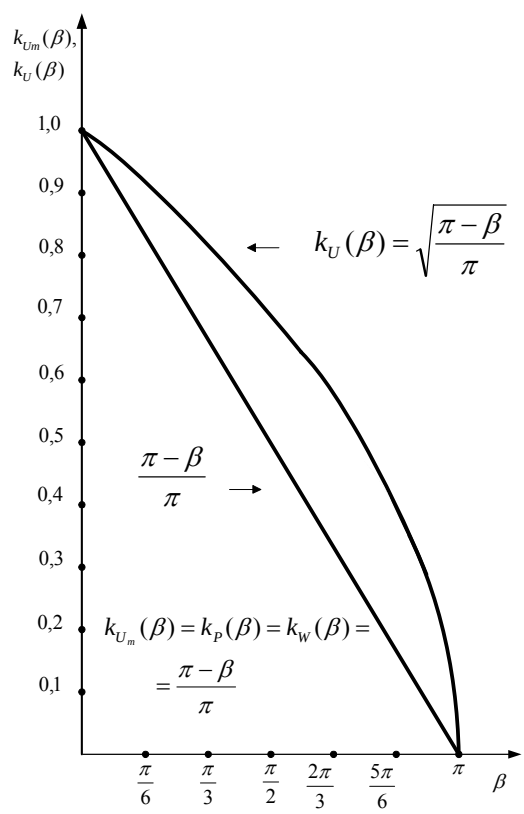


Figure 3. Regulation characteristic $k_{Um} = U_R(1)_m / U_m$ against the angle values $\beta$ ( in PU system).

$$P_R = P_m \frac{\theta_r}{\pi}; P_m = \frac{U^2}{R} \tag{10}$$

$$k_P = \frac{\pi - \beta}{\pi}; k_P = \frac{P_R}{P_m} \tag{11}$$

$$W_R = W_m \frac{\theta_r}{\pi}; W_m = \frac{P_m}{f} \tag{12}$$

$$k_W = \frac{\pi - \beta}{\pi}; k_W = \frac{W_R}{W_m} \tag{13}$$

The quantities $P_m$ and $W_m$ are constants for the regulator under the condition that the supply voltage, load value and power supply frequency $f$ do not vary. There are the maximal power and energy, respectively evolved on the load when $\theta_r = \pi$.

Expressions (11) and (13) give in analytical form the regulation characteristics for power $P_R$ and energy $W_R$ as a function of angle $\beta$. In relative units (PU system) these characteristic (coefficients $k_P$ и $k_W$) are represented graphically in Fig. 3.

## 4. CONCLUSIONS

As a result of the theoretical analysis of AC regulator with a pulse-width switch control operation a linear dependence between the following quantities is proved:

- the first harmonic amplitude of load voltage $U_R(1)_m$ and the generalized regulation burning angle $\theta_r$, i.e. $U_R(1)_m = U_m \theta_r / \pi$;
- the energy $W_R$ (or power $P_R$) dissipated in the load and the burning angle $\theta_r$, i.e. $W_R = W_m \theta_r / \pi$ and $P_R = P_m \theta_r / \pi$.

The theoretical model worked out permits a technological process control optimization in the areas of: heat treating, thermoregulation and electric motor drivers.

A further study is needed to analyse the distortion of the net voltage by the AC regulator which in the ideal case is vanishingly small.

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