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Analysis of average power at simistor phase adjustment

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The systems for phase adjustment of average power depend on the type of the load. The influence of an active load on the adjustment mode is considered in the paper. When different modes of operation are changing smoothly then the change in the familiar ways is inconvenient. A criterion for delivered average power (when the visual control is missing) is the indication of the measuring instruments that are plugged in the regulated electric circuit. The analysis, that is made and presented in the article, shows a highly nonlinear variation of the average regulated power at corresponding linear amendment of the parameters of the regulating element of the delay time. This leads to complicated settings in the operating mode. Through the made research of the process and the change in the control electric circuit is reached linearization of the delivered average power to the load.

Keywords: Average power, Simistors, Phase adjustment.

INTRODUCTION

From a long time the phase adjustment of the power on various consumers that are connected to the electricity network is used in various applications. Semiconductor switches with four-layer structure – thyristors and simistors are used in the simplest and most common devices as regulating element. The devices, which are manufactured on this principle, are used for phase adjustment of the power of light of incandescent electric lamps or for regulating the speed of rotation of electric motors. In both examples, the simplest way of control is the visual one. When the power of a heater appliance must be smoothly adjusted, this approach could not be used.

The research is reduced to analysis of the processes of action of an simistor regulator of active power to find the best modes of operation. For this purpose a model has been developed, relationships are derived and conclusions are formulated.

ANALYSIS

On Fig. 1a is presented a simplified circuit of a simistor phase regulator. The main element of the circuit is an electronic key – the simistor *S*, which is connected in series to a powerful resistor R_T.

The principle of phase adjustment consists in change of the average power that is fed to R_T [1; 2]. This is presented on Fig. 1b. After a certain delay time τ, a control pulse $u_{mst}(t)$ is generated from the beginning of each half-period of the network voltage. The control pulse unlocks the simistor *S* and through the resistor R_T flows current that forms voltage drop $u_R(t)$. As is known [3], the area enclosed by the characteristic $u_R(t)$ corresponds to the active energy that is dissipated by the load. When $\tau = 0$, maximum energy is supplied to the load. When τ increases, this energy decreases.

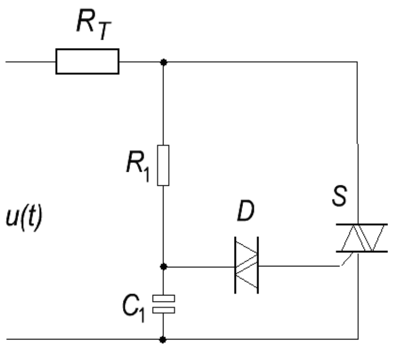

Fig. 1a. A simplified circuit.

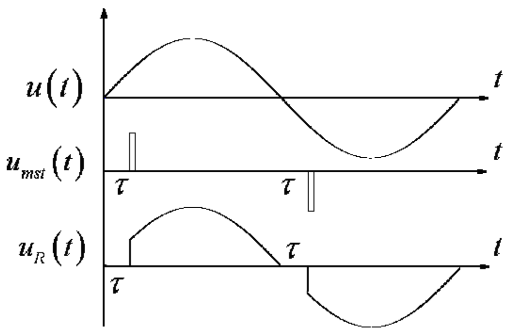

Fig. 1b. Instantaneous values of $u(t)$, $u_{mst}(t)$, $u_R(t)$.

The control of the simistor is reduced to formation of an impulse with certain delay time from the beginning of each half-period of the net-work voltage. The parameters of the electric circuit (elements R_1 and C_1) determine a value of τ.

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Then the analysis comes down to two modes of operation of the simistor regulator:

– researching of the relationship between the delay time τ and the average power $\overline{p}=\overline{p}(\tau)$;

– researching of the commutation circuit and selecting R_1 and C_1 so that there is matching of the changes of their parameters with the change of the average power.

Analysis of the relationship between the switch-on time of the simistor and the average power dissipated in the load

The parameters of the electric circuit are: an electricity network with an effective value of the voltage $U=220\ \text{V}$ and frequency $f=50\ \text{Hz}$. An active load R_T is included in the circuit.

The instantaneous values of voltage and current are:

$$u(t)=u_m\sin(\omega t+\psi_U),\ i(t)=i_m\sin(\omega t+\psi_i).$$

Consequently, the instantaneous power is as follows:

$$p(t)=u(t)i(t)=u_m i_m\sin(\omega t+\psi_U)\sin(\omega t+\psi_i). \quad (1)$$

From the condition of an active load in the circuit, the voltage and current are in phase $|\psi_U-\psi_i|=0$. Furthermore, the simistor from the circuit on Fig. 1a is locked at the end of each half-period, thus synchronizing the operation of the device with the beginning of each new half-period of the voltage and current. Therefore $\psi_U=\psi_i=0$.

After substituting in (1), the instantaneous power $p(t)$ is:

$$p(t)=u_m i_m\sin^2(\omega t)=\frac{u_m^2}{R_T}\sin^2(\omega t)=i_m^2 R_T\sin^2(\omega t). \quad (2)$$

The processes that are developing in the phase regulator do not depend on the value of R_T. In order to simplify the mathematical relationships that describe the processes, it is assumed that $R_T=1\,\Omega$. From here follows that:

$$p(t)=u_m^2\sin^2(\omega t) \quad (3)$$

or

$$p(t)=\frac{u_m^2}{2}[1-\cos(2\omega t)] \quad (4)$$

On Fig. 2 the relationships $p(t)$, $u(t)$ and $i(t)$ are presented graphically.

Due to the active nature of the load, the graphics of the $u(t)$ and $i(t)$ are same (Fig. 2). The instantaneous power $p(t)$ changes with the double frequency of the network voltage and it is entirely with positive values.

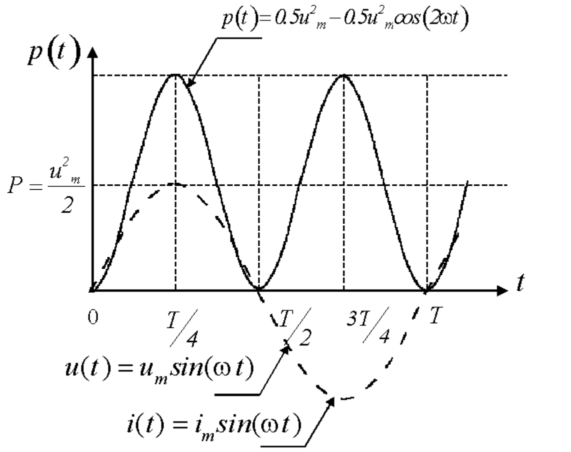

Fig. 2. Relationships $p(t)$, $u(t)$, $i(t)$.

The average power $\overline{p}$ for one half-period $\left(\frac{T}{2}\right)$ of $u(t)$ is determined by the expression [4]:

$$\overline{p}=\frac{2}{T}\int_{t_1}^{\frac{T}{2}}p(t)dt\,, \quad (5)$$

where t_1 is the delay time τ.

As a result of short transformations and analogous relationships, the average power $\overline{p}$ and the average voltage $\overline{u}$ are determined by the following formulas:

$$\overline{p}=\frac{u_m^2}{2}\left(1-\frac{2t_1}{T}\right)+\frac{u_m^2}{4\pi}\sin\left(\frac{4\pi t_1}{T}\right), \quad (6)$$

$$\overline{u}=\frac{u_m}{\pi}\left[1+\cos\left(\frac{2\pi t_1}{T}\right)\right]. \quad (7)$$

On Fig. 3 is presented the relationship $\overline{\overline{p}}=\overline{\overline{p}}(t_1)$.

In Table 1 are presented the values of $\overline{u}$ and $\overline{\overline{p}}$ at four points.

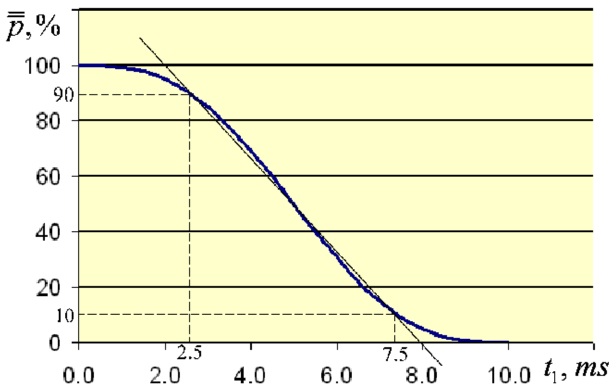

Fig. 3. Normalized average power value $\overline{\overline{p}}(t_1)$.

The normalized average power value $\overline{\overline{p}}=100\dfrac{\overline{p}(t_1)}{P}$, % is used instead of the average value of $\overline{p}$, where P is the average power dissipated in the load for the whole half-period of the network voltage.

The graphic on Fig. 3 is built as a result of calculations. The function $\overline{\overline{p}}=\overline{\overline{p}}(t_1)$ has a different character at dissimilar places. In general, it can be divided into three sectors: $0 \le t_1 \le 2.5\,\text{ms}$; $2.5\,\text{ms} < t_1 \le 7.5\,\text{ms}$; $7.5\,\text{ms} < t_1 \le 10\,\text{ms}$. For each of these sectors a different approach applies.

Table 1. Values of $\overline{u}$ and $\overline{\overline{p}}$ at four points.

t, ms	$\overline{u}$, V	$\overline{\overline{p}}$, %
0.0	198	100
3.7	139	75
5.0	99	50
6.3	59	25

Analysis of the commutation circuit

The commutation circuit consists three elements (Fig. 1a) – resistor R_1, capacitor C_1 and dinistor *D*. The formation of delay time τ is determined by the time of loading capacitor C_1. When the threshold value of the element *D* is reached, the dinistor is unlocked and almost all of the stored electrical energy in C_1 passes through the input of *S* and unlocks the simistor.

On Fig. 4 (without indexes) is presented an equivalent scheme of the idealized *RC* delay circuit.

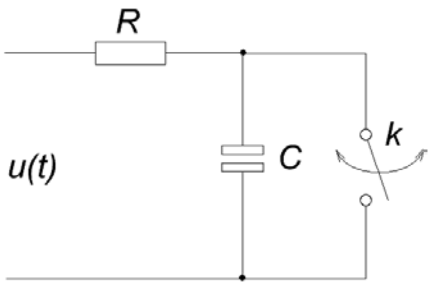

Fig. 4. *RC* block.

The commutator *k* replaces the dinistor *D* (Fig. 4). During the first commutation cycle (*k* is open) the capacitor *C* is loaded through *R*. During the second commutation cycle, when *k* is closed in a very short time, the capacitor *C* is unloading through *S* and unlocks it.

During the first commutation *k* the independent initial conditions of the circuit are recording:

$$t=0,\ u(t)=0,\ u_C(t)=0.$$

The classical method for researching of transient processes is applied [5]. An equation compiled by Kirchhoff's second law can be written for the circuit after commutation *k*:

$$u(t)=Ri+u_C(t)=RC\frac{du_C}{dt}+u_C(t), \tag{8}$$

where $u(t)=u_m\sin(\omega t)$ and $i=C\dfrac{du_C}{dt}$.

The characteristic equation is:

$$0=RCp+1 \tag{9}$$

$$\Rightarrow\ p=-\frac{1}{RC}=-\frac{1}{\tau}.$$

The voltage $u_C(t)$ is determined as sum of two components – established one and free one:

$$u_C(t)=u_C(\tau<<t)+Ae^{-\frac{t}{RC}}.$$

For finding the established mode of $u_C(\tau<<t)$ is used an operating method for representing the sinusoidal functions of the time in complex form.

The complex impedance of the circuit is:

$$Z=ze^{j\varphi}, \tag{10}$$

where z and φ are respectively its module and argument:

$$\begin{cases} z=\sqrt{R^2+x_C^2} \\ \varphi=arctg\dfrac{x_C}{R} \end{cases}. \tag{11}$$

After the transformations that are made, the complex recording of the established voltage on the capacitor $\dot{U}_C$ is:

$$\dot{U}_C=\frac{x_C U}{z}e^{j\left(-\varphi-\frac{\pi}{2}\right)}=U_C e^{j\left(-\varphi-\frac{\pi}{2}\right)}, \tag{12}$$

where $x_C=\dfrac{1}{\omega C}$ is the resistance of the capacitor.

Conversely, in the time domain the voltage is:

$$u_C(\tau<<t)=u_{Cm}\sin\left(\omega t-\varphi-\frac{\pi}{2}\right). \tag{13}$$

After determining of the integration constant and involving both components, $u_C(t)$ acquires the final form:

$$u_C(t)=u_{Cm}\sin\left(\omega t-\varphi-\frac{\pi}{2}\right)-u_{Cm}\sin\left(-\varphi-\frac{\pi}{2}\right)e^{-\frac{t}{RC}}. \tag{14}$$

SOLVING OF AN EXAMPLE CASE

From the analysis that is made in the first part of the section II (ANALYSIS) it becomes clear that the relationship $\overline{\overline{p}}=\overline{\overline{p}}(t_1)$ has three sectors.

The third sector ($7.5\ \text{ms} < t_1 \leq 10\ \text{ms}$) covers a time interval in which the average power does not exceed 10 % and in this case it can be ignored. The other two sectors are considered.

A capacitor with capacity $C = 100\ \text{nF}$ is chosen.

For the time interval $0 \leq t_1 \leq 2.5\ \text{ms}$ and by the relationship (14) the maximum value of $R = 82\ \text{k}\Omega$ is calculated. There is not such a standard value. By parallel connection of a resistor with variable resistance $R = 100\ \text{k}\Omega$ and a resistor with constant resistance $R = 470\ \text{k}\Omega$ a resistor with equivalent resistance $R_1 = 82.46\ \text{k}\Omega$ is obtained.

In a similar way for the time interval $2.5\ \text{ms} < t_1 \leq 7.5\ \text{ms}$ by parallel connection of a resistor with variable resistance $R = 500\ \text{k}\Omega$ and a resistor with constant resistance $R = 2.4\ \text{M}\Omega$ a resistor with equivalent resistance $R_2 = 414\ \text{k}\Omega$ is obtained.

One more resistor with constant resistance R_3 is connected in series to R_1 and R_2. Its task is to limit the maximum current through the control circuit. A resistor with resistance $R_3 = 4.7\ \text{k}\Omega$ is completely sufficient. The minimum delay in this case is $t = 0.69\ \text{ms}$, where $\overline{\overline{p}} = P = 100\ \%$.

CONCLUSION

There is no direct proportionality linear relationship between the average values of the voltage $\overline{u}$ and the power $\overline{p}$.

The relationship that exists is determined by the relationships (6) and (7). The knowing of $\overline{u} = \overline{u}(p)$ (for specific values of $\overline{p}$) facilitates the calibration process of the adjusting elements.

The conducted laboratory experiments show minor deviations from the calculated, mainly because of the tolerances in the parameters of the used elements.

REFERENCES

1. D. Nyurman, Power supplies, Technique, Sofia, 1999.
2. V. Milovanski, Force transformer’s impulse control of the power, in: Jubilee Scientific Conference (Proc.), Stara Zagora, p. 103, 2005.
3. S. Sharma, Basics of Electrical Engineering, I. K. International Publishing House Pvt. Ltd, New Delhi, 2015.
4. M. Wang, Understandable Electric Circuits, The Institution of Engineering and Technology, London, 2010.
5. T.A. Kuznetsova, E.A. Kulyutnikova, I.B. Kuharchuk, A. A. Ryabuha, Theory of linear electric circuits, part 1, PNRPU, Perm, 2012.