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THREE-PHASE AC CHOPPER SUPPLIED FOR INDUCTION MOTOR

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ABSTRACT: *In the paper the results of simulation researches of the induction motor, which is supplied from three phase ac chopper at multiple conducting of the power switches, are presented. In the machine model the stator circuits are presented in natural coordinates, while the rotor cage is replaced the circuits in $\alpha - \beta$ system. In the researches the professional programs such as Matlab-Simulink, have been used.*

I. INTRODUCTION

The ac chopper is the power electronic converter, which is included between the mains and the load. In such circuit the setting of the rms output voltage is possible by controlling of conduction time of the power switches creating ac chopper. The ac choppers at single-time and at multiple conducting of the power switches in period of the supply voltage are differentiated. In the ac chopper at single-time conducting of the power switches the switching frequency is equal the frequency of the mains while in the ac chopper at multiple conducting of the power switches the switching frequency is much higher than the frequency of the mains. Nowadays, ac choppers, in which thyristor SCR fulfill a role of the power switches, are used. In such Circuits the rms output voltage is setting by change thyristor firing angle; minimal firing angle depends on the power factor cosϕ. Such ac choppers are usually employed such as light control, heater control, and soft start. Properties of the thyristor ac chopper are already known. Information's about this circuit can find in many publications [3]. In second solution of the ac choppers the power switches full controlling (power) transistor, thyristor GTO, thyristor SCR with a switch off circuit) are used. At multiple conduction each power switches creating ac chopper are turn on and off at frequency much higher than the frequency of the mains. The setting of the rms output voltage is possible e.g. by changing conduction time of the power switches at constant the switching frequency (change of chopper duty cycle). Thanks to such work lower harmonic contents waveform output voltage is obtained thus there is better circuit power factor. This solution of ac chopper, thanks own advantages, gives new possibilities using the ac choppers in driving circuits with the inductive machine in softstart.

II. THREE-PHASE AC CHOPPER

Three-phase ac choppers are analyzed basing on single-phase ac chopper. This paper describes symmetrically three-phase ac chopper at multiple conducting of the power switches (Fig.1). Three-phase ac chopper consists of three single-phase circuits; every phase of ac chopper contains two power switches (S1, S2 – Fig.1). Each ac switch is a pair of inverse-parallel connected power transistors and diodes. Power switches are treated as ideal, i.e. during conducting state switches resistance equal zero (voltage drop in conducting switches is omitted) and in non-conducting state switches resistance tends to infinity. The switching frequency can be any, but most often it is a multiplicity of frequency of the supply voltage. Thanks to such work lower harmonic contents waveform output voltage is obtained [1]. The relation of switching frequency and frequency of the supply voltage is defined as (Fig.2).

$$n = \frac{T}{T_P} = \frac{f_P}{f} \qquad (1)$$

Where:

T – Period of the supply voltage,

T_P – Switching period,

f – Frequency of the supply voltage,

f_P – switching frequency.

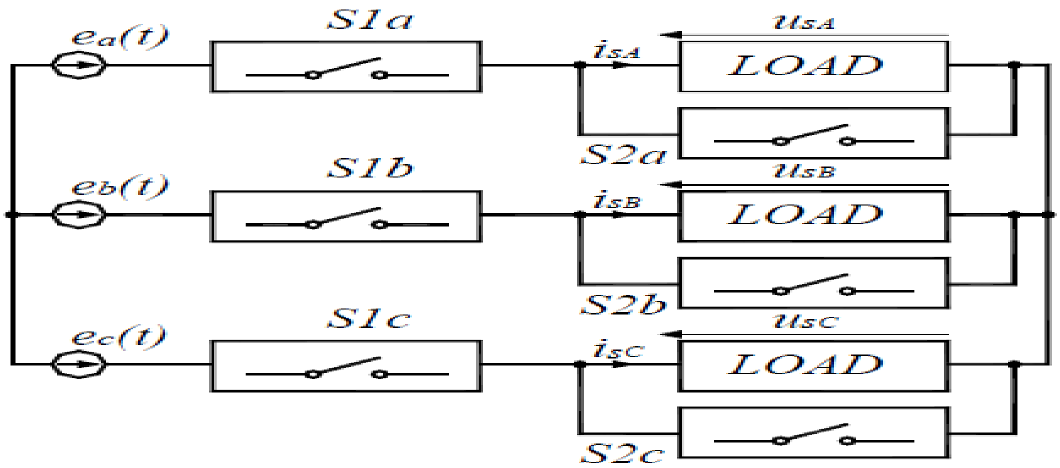

Fig. 1 Three-phase ac chopper

In switches S1, S2 are presented. The rms output voltage can be controlled by changing of chopper duty cycle ε, which is defined as Fig.2 waveforms of the phase output voltage $u_{SA}(t)$ and the switching algorithms of the power switches S1, S2 are presented. The rms output voltage can be controlled by changing of chopper duty cycle ε , which is defined as:

$$\varepsilon = \frac{t_{on}}{T_P} \tag{2}$$

For switching algorithms of the power switches S1, S2, which is shown in Fig.2, one can prove [1] that the relative rms phase output voltage in ac chopper from Fig.1 is defined as:

$$U_{RMS(r)} = \frac{U_{RMS}}{\frac{U_{zm}}{\sqrt{2}}} = \sqrt{\varepsilon} \tag{3}$$

Where: U_{zm} – amplitude of the supply voltage.

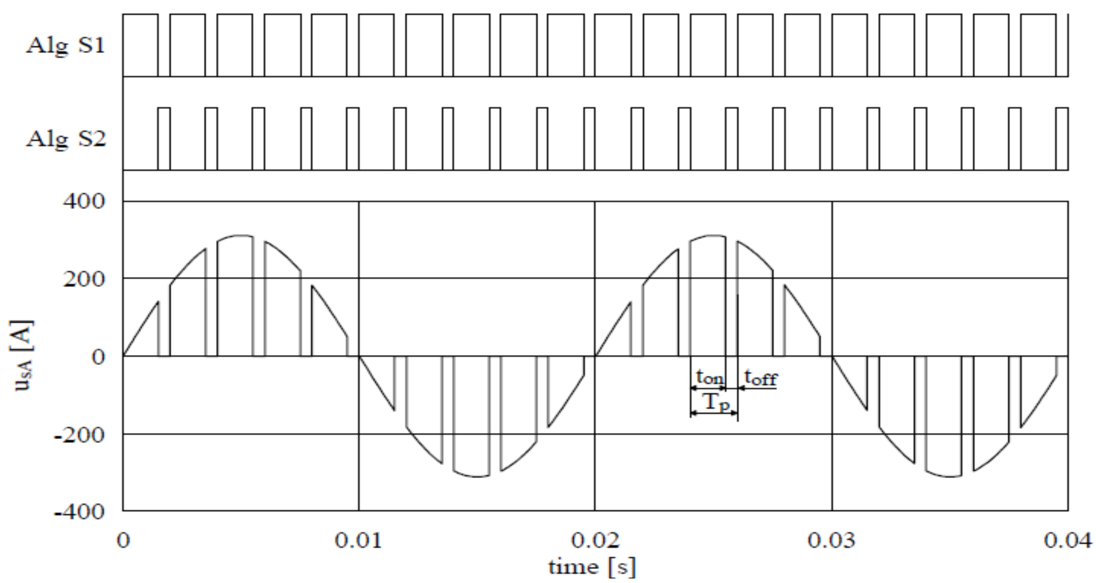

Fig.2 Waveform of voltage in the circuit from Fig.1 at multiple conducting of the power switches at switching frequency f_p=500 Hz and duty cycle ε =0, 75.

III. MATHEMATICAL MODEL OF THE INDUCTION MOTOR

In simulation researches the mathematical model of the induction machine, which schema is represented in Fig.3, is used. In the model is accepted following assumptions:

- Symmetrical stator and rotor windings,
- Monochromic electromagnetic field distribution,
- Linear saturation curve,
- Omission of iron losses.

In case of supplying of the induction machine from circuit, which contains the power electronic converter, comfortably is to use the mathematical model of machine, in which the stator is presented by natural co-ordinates as well as the rotor is presented by transformed co-ordinates. Such solution enables supplying the machine deformed voltage and replacement of the differential equations, which describe currents of the rotor bar cage, supplementary circuits in axis $\alpha - \beta$.

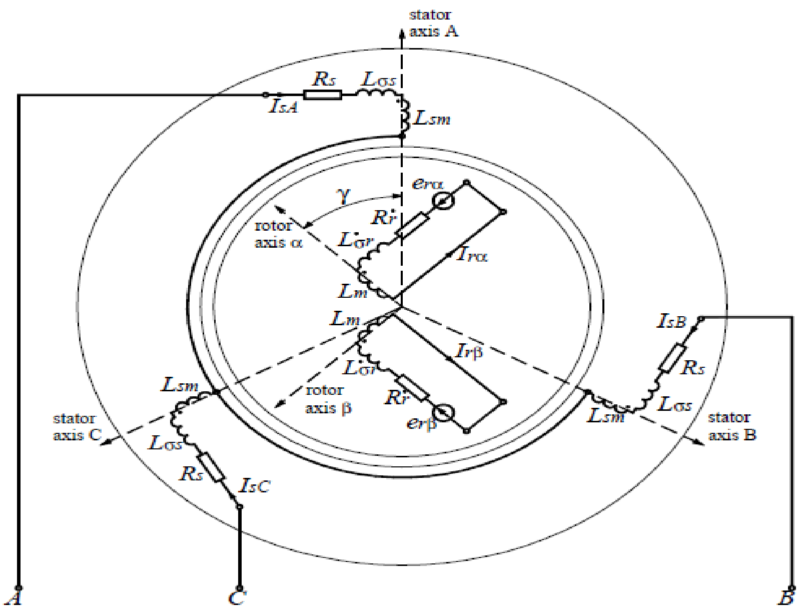

Fig.3 Mathematical model of the induction motor.

For the mathematical model of the inductive motor as Fig.3 and for coordinates $\alpha - \beta(w_x = 0)$, equations describing the model can be expressed:

$$\begin{bmatrix} u_{sA} \\ u_{sB} \\ u_{sC} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 & 0 \\ 0 & 0 & R_s & 0 & 0 \\ 0 & 0 & 0 & R_r^* & 0 \\ 0 & 0 & 0 & 0 & R_r^* \end{bmatrix} \begin{bmatrix} i_{sA} \\ i_{sB} \\ i_{sC} \\ I_{r\alpha} \\ I_{r\beta} \end{bmatrix} + \frac{d}{dt} \begin{bmatrix} \psi_{sA} \\ \psi_{sB} \\ \psi_{sC} \\ \Psi_{r\alpha} \\ \Psi_{r\beta} \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \omega \\ 0 & 0 & 0 & -\omega & 0 \end{bmatrix} \begin{bmatrix} \psi_{sA} \\ \psi_{sB} \\ \psi_{sC} \\ \Psi_{r\alpha} \\ \Psi_{r\beta} \end{bmatrix} \quad (4)$$

Where vector of the flux linkage is defined as:

$$\begin{bmatrix} \psi_{sA} \\ \psi_{sB} \\ \psi_{sC} \\ \Psi_{r\alpha} \\ \Psi_{r\beta} \end{bmatrix} = \begin{bmatrix} L_{\sigma s} + L_{sm} & -\frac{1}{2}L_{sm} & -\frac{1}{2}L_{sm} & L_{srm}\cos(\gamma) & -L_{srm}\sin(\gamma) \\ -\frac{1}{2}L_{sm} & L_{\sigma s} + L_{sm} & -\frac{1}{2}L_{sm} & L_{srm}\cos\left(\gamma+\frac{4\pi}{3}\right) & -L_{srm}\sin\left(\gamma+\frac{4\pi}{3}\right) \\ -\frac{1}{2}L_{sm} & -\frac{1}{2}L_{sm} & L_{\sigma s} + L_{sm} & L_{srm}\cos\left(\gamma+\frac{2\pi}{3}\right) & -L_{srm}\sin\left(\gamma+\frac{2\pi}{3}\right) \\ L_{srm}\cos(\gamma) & L_{srm}\cos\left(\gamma+\frac{4\pi}{3}\right) & L_{srm}\cos\left(\gamma+\frac{2\pi}{3}\right) & L_{\sigma r}^{*} + L_m & 0 \\ -L_{srm}\sin(\gamma) & -L_{srm}\sin\left(\gamma+\frac{4\pi}{3}\right) & -L_{srm}\sin\left(\gamma+\frac{2\pi}{3}\right) & 0 & L_{\sigma r}^{*} + L_m \end{bmatrix} \begin{bmatrix} i_{sA} \\ i_{sB} \\ i_{sC} \\ I_{r\alpha} \\ I_{r\beta} \end{bmatrix} \quad (5)$$

And maximum values of inductances are defined as:

$$L_{sm} = \frac{2}{3} L_m$$
$$L_{srm} = \sqrt{\frac{2}{3}} L_m \quad (6)$$

IV. SIMULATION MODEL AND RESULTS OF SIMULATION

The simulation model of the inductive motor supplied from three-phase ac chopper at multiple conducting of the power switches (Fig.1) in the form of Simulink block diagram is presented in Fig.4. In such model the equations of machine (4)... (6) and the motion equation are used. The motion equation is defined as:

$$\frac{dw}{dt} = \frac{p}{j}(T_e - T_m) \quad (7)$$

The torque equation of a monoharmonic inductive machine can be written as [2]:

$$T_e = pL_m R_e\left\{ j\underline{I}_s^{*}\underline{I}_r \right\} \quad (8)$$

The stator current space vector *Is* can calculate basing the instantaneous stator phase currents while the rotor current space vector *Ir* can calculate basing the axis components of the rotor current:

$$\underline{I}_s^{*} = \sqrt{\frac{2}{3}}(i_{sA} + \underline{a}^2 i_{sB} + \underline{a} i_{sC}) \quad (9)$$

$$\underline{I}_r = I_{r\alpha} + jI_{r\beta} \quad (10)$$

The paper presented results of simulations for inductive machine:

$P_n\, 4kw$ $U_{sn} = 380$, $I_{sn}\, 6.7A$
$n_n = 1450 rpm/\min$, $\cos\varphi_n = 0.82$

And parameters:

$R_s = 2.1$, $R_r^{*} = 1.25\Omega$, $L_{\sigma s} = L_{\sigma r}^{*} = 0.00652\ H$
$L_m = 0.225$, $j = 0.35 kg.m^2$
$T_m = 0 N.m$

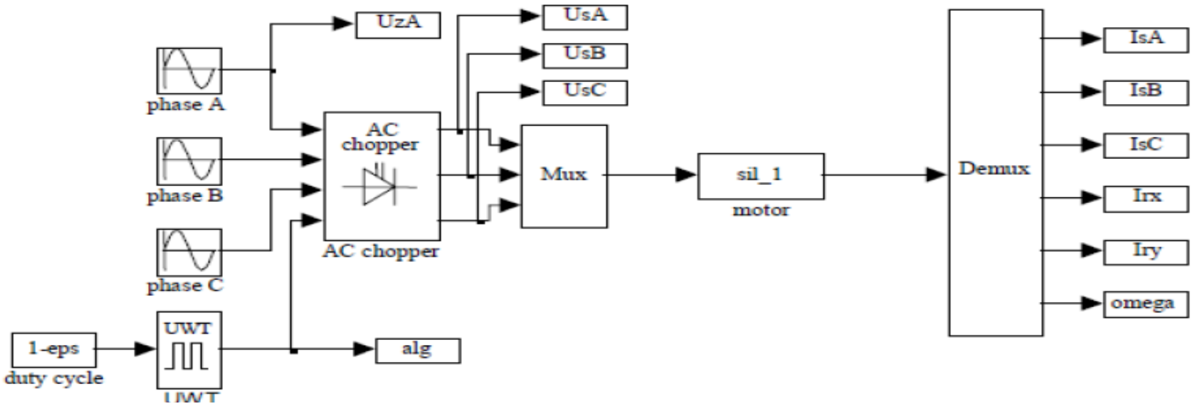

Fig.4 Simulation model in the form of Simulink block diagram.

In the simulation model (Fig.4), the inductive motor represents the Mat lab s-function (name *sil_1*) basing the equations (4) and (7) for angle $\gamma = 0$ (Fig.3). The power switches of three-phase ac chopper are turn on and off by the transistor firing system (UWT) depending on chopper duty cycle ε. The power switches represent element Switch of the Mat lab library Nonlinear [1]. Such solution permits to obtain waveform output voltage as Fig.2. The simulation researches carried out for range of duty cycle changing, i.e. for range $\varepsilon = 0 \div 1$. The waveforms of the stator current i_{sA} and the torque T_e during motor start up at duty cycle $\varepsilon = 1$ are shown in Fig.5a. The waveforms of the stator current i_{sA}, the torque T_e and the motor speed as well as the torque-speed characteristic during motor start up at switching frequency $f_p = 500Hz$ and duty cycle $\varepsilon = 0.75$ are shown in Fig.5b.

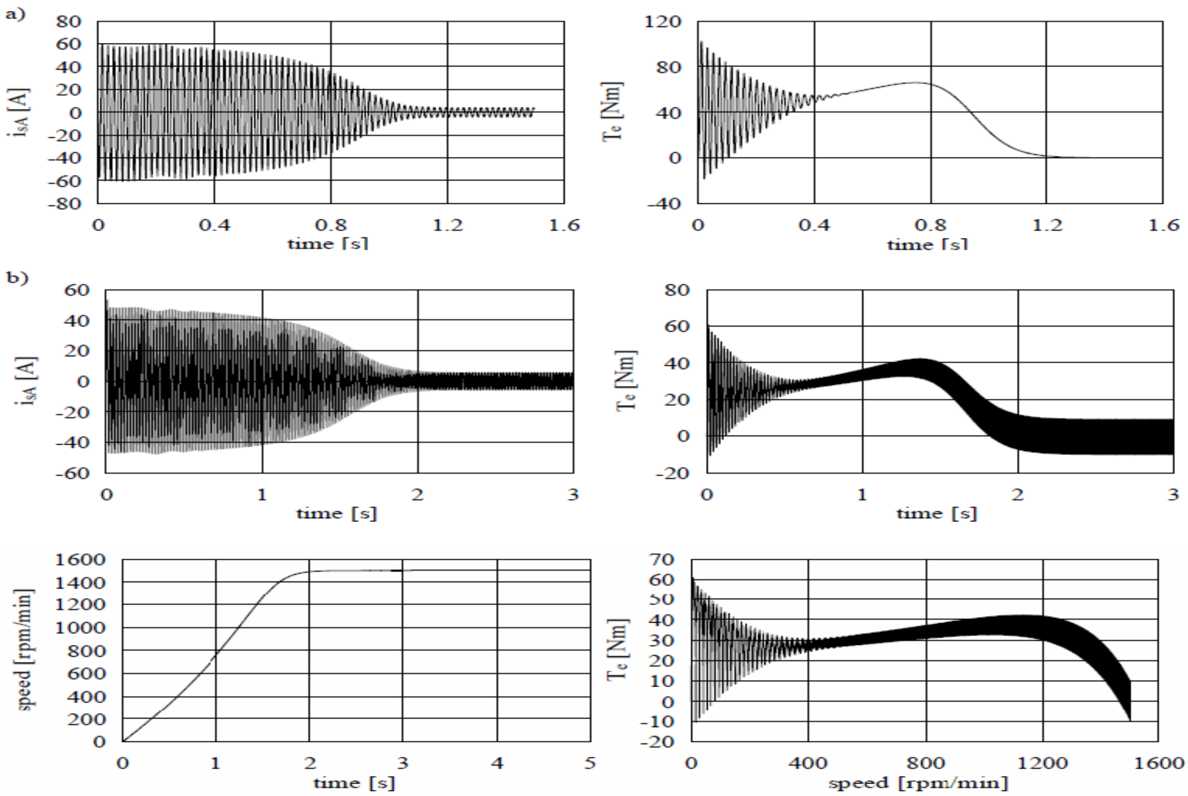

Fig.5 Simulation results: a) waveforms of the stator current *sA i* and the electromagnetic torque *e T* during motor start up at duty cycle $\varepsilon = 1$) b) Waveforms of the stator current *sA i*, the electromagnetic torque *e T*, the motor rotational speed during motor start up at switching frequency $f_p = 500Hz$, and duty cycle $\varepsilon = 0.75$.

The stator current beside first harmonic contents high harmonic. In Fig.6 the instantaneous steady state stator current and the results of FFT (Fast Fourier Transformation) carried out with the use of Mathcad program are shown. In waveform of the stator current occurs only some of harmonic. By right selection the switching frequency *fop* can eliminate a number of high harmonic [1], because harmonic about number appears ν = 1, n ± }1,2n ± }1 }1,… In Fig.7 the torque-speed characteristic for a few values of duty cycle ε is shown. This characteristic is calculated by average electromagnetic torque receiving from simulation.

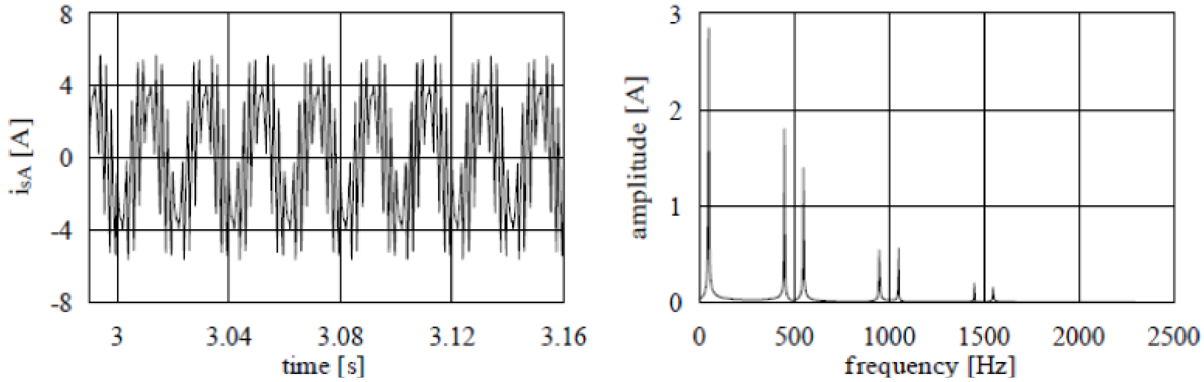

Fig.6 Results of harmonic analysis FFT of the stator current at switching frequency *fp=500 Hz* and duty cycle *ε =0, 75.*

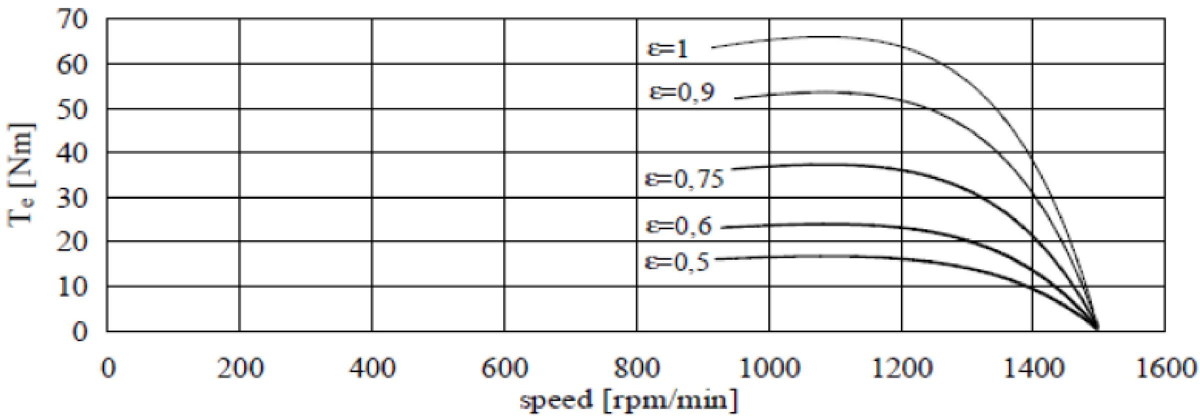

Fig.7 Torque-speed characteristic at a few duty cycle

V. CONCLUSION

The three-phase ac chopper at multiple conducting of the power switches makes possible setting the rms output voltage as well as limitation of harmonic contents in output voltage and current. By right selection of switching frequency *fp* and duty cycle ε lower harmonic contents of the stator current is obtained. In the three-phase ac chopper the power switches full controlling are used so it need using a microprocessor controller, which can generate complex transistors firing sequences. In the future, thanks own advantages, such circuit can take place of ac chopper using thyristors SCR in such circuit.

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