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POWER SUPPLY WITH DISCRETE ELECTRICITY CONSUMPTION

We propose a discrete power supply with power consumption and relay—controlled electromagnetically compatible with the circuit, which is invariant to the action of the perturbation and reduced losses in the power supply line. The analytical expressions to calculate the frequency relay modes, power losses and simulation results are given.

Key words: *electromagnetic compatibility, relay control, invariance, power loss, power supply*

At the present time the solution of electromagnetic compatibility and energy saving problem is at the first place during the development of any converters of electric energy parameters. The most effective means of integrated solutions of this problem (inactive component of the total compensation of power and the power distortion) are the power active filters (PAF) with Pulse Width or vector control. Algorithms implementing these controls are based on a large amount of measurement, conversion and computing operations, which lead to complication control system and deterrence of their introduction [1].

Another way to solve the EMC problem is proposed in this article: using tracker system with forced formation circuit consumed currents close to sinusoidal shape in the absence of a phase shift between voltage and current (the problem of EMC is solved) and relay control (the problem of speed, accuracy, low sensitivity of the perturbation to the action is solved). Such a solution can dramatically simplify both power section and control system [2].

At the expense of power factor close to unit, a reduction of the quantity current consumed by the circuit and hence reduction of the power loss in the supply lines is reached.

The proposed control power supply algorithm allows additionally reducing the power loss in the line due to the discrete electricity consumption of the circuit.

Figure 1 shows a functional block diagram of the power supply, made on the basis of a single-phase module (SPM).

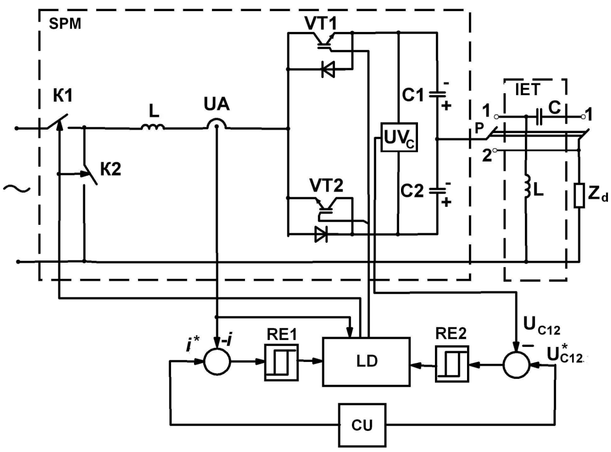


Figure 1 — Functional diagram of the power supply

The module consists of two keys K1 and K2 with bilateral conductive, input throttle L , current sensor UA, two IGBT transistors shunted by bypass diodes, two capacitors C1 and C2 and the voltage sensor UV_C on the capacitors.

The control system consists of coefficient unit (CU) of capacitor voltages U^*_{C12} and current consumption of the circuit $i = I_m \sin \omega t$, two adders, two relay elements RE1 and RE2 and logic device (LD) providing work of the keys K1, K2 and transistors VT1, VT2.

Before working it is necessary the capacitors C1 and C2 to be charged to a voltage exceeding the peak value of the phase voltage (it is a necessary condition of the module efficiency) $U_{C1} = U_{C2} > U_m$. When applied to a summing input of the first adder the signal $i = I_m \sin \omega t$, and the countdown input from the UA voltage output sensor, the unit impulse or zero signal, depending on the sign of the error $\Delta i = i^* - i$ unit appears on the output element of the relay RE1.

The transistors VT1 and VT2 are connected to the capacitors C1 and C2 according to the phase voltage or counter, keeping current in the current corridor, which is set by the width of the hysteresis loop relay element RE1.

The equations describing the behavior of the current in the load, depending on the magnitude and sign of the error is of the form (we neglect throttle active resistance)

$$\begin{aligned} & L\frac{di}{dt} + u_d = U_m \sin \omega t + U_{C1} \\ & -a \le \Delta i \le a, \frac{di}{dt} > 0 \\ & L\frac{di}{dt} + u_d = U_m \sin \omega t - U_{C2} \\ & -a \le \Delta i \le a, \frac{di}{dt} < 0, \end{aligned} \qquad (1)$$

where $U_m \sin \omega t$ is the instantaneous voltage circuit, i is the instantaneous current in the load, L is throttle inductivity, 2a is hysteresis width relay element RE1, u_d — the instantaneous load voltage.

The current fragment formation consumed by the circuit is shown in Figure 2, according to which the expressions describing the behavior of the current have the form

$$\begin{aligned} & i = I_m \sin \omega t + \frac{2a}{\tau_1} t \quad -a \le \Delta i \le a, \frac{di}{dt} > 0 \\ & i = I_m \sin \omega t + \frac{2a}{\tau_2} t \quad -a \le \Delta i \le a, \frac{di}{dt} < 0, \end{aligned} \qquad (2)$$

where τ_1 is the current increase time from $(i^* - a)$ to $(i^* + a)$, τ_2 is current reduction time from $(i^* + a)$ to $(i^* - a)$.

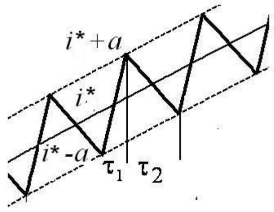


Figure 2 — Determination of the time τ_1 and τ_2

In general, the active load comprises an active resistance R_d, inductivity L_d and capacitance C_d. Then the voltage on the load will be

$$u_d = u_R + u_L + u_C, \qquad (3)$$

where u_R is the voltage on R_d, u_L is the voltage on L_d, u_C is the voltage on C_d.

Taking into consideration (2) the voltage

$$u_R = I_m^* R_d \sin \omega t \qquad (4)$$

is determined

By $-a \le \Delta i \le a, \frac{di}{dt} > 0$

$$u_L = \omega L_d I_m^* \cos \omega t + \frac{2aL_d}{\tau_1}; \qquad (5)$$

$$u_C = -\frac{1}{\omega C_d} I_m^* \cos \omega t + \frac{1}{C}\int \frac{2a}{\tau_1} t dt + A; \qquad (6)$$

By $-a \le \Delta i \le a, \frac{di}{dt} < 0$

$$u_L = \omega L_d I_m^* \cos \omega t - \frac{2aL_d}{\tau_2}; \qquad (7)$$

$$u_C = -\frac{1}{\omega C_d} I_m^* \cos \omega t - \frac{1}{C}\int \frac{2a}{\tau_2} t dt + A; \qquad (8)$$

$$\frac{1}{C_d}\int \frac{2a}{\tau_1} t dt \approx 0, \quad \frac{1}{C_d}\int \frac{2a}{\tau_2} t dt \approx 0. \qquad (9)$$

Since switching keys K1 and K2 is carried out by $\omega t = 0$ and $\omega t = \pi$, so from (6) and (8) with (9), the constant of integration is

$$A = \frac{1}{\omega C_d} I_m^* \quad при \quad \omega t = 0$$
$$A = -\frac{1}{\omega C_н} I_m^* \quad при \quad \omega t = \pi \qquad (10)$$

Solving (1), subject to (2-10) with respect to τ_1 and τ_2, we obtain

$$\tau_1 = \frac{2a(L+L_d)}{U_1 - U_2 + U_{C1} \pm \frac{1}{\omega C_н} I_m^*}$$
$$\tau_2 = \frac{2a(L+L_d)}{-(U_1 - U_2) + U_{C2} \pm \frac{1}{\omega C_d} I_m^*}, \qquad (11)$$

where $U_1 = (U_m - I_m^* R_d)\sin \omega t$

$$U_2 = \left[\omega(L+L_d) - \frac{1}{\omega C_d}\right] I_m^* \cos \omega t$$

Then the frequency of the relay mode in the formation of the current i^*

$$\nu_1 = \frac{U_C^2 + (U_1 - U_2)^2 \pm \frac{1}{\omega C_d} I_m^*}{4a(L+L_d)}. \qquad (12)$$

The stable operation of the source will be subject to the power balance, i.e. equality of power consumption of the network and load power. Control of the balance of power conservation is carried out by controlling the keys K1 and K2.

If the power consumed from the circuit $P_c = \frac{U_m I_m^*}{2}$ (the key K1 is closed) is more than the power of the load, the capacitors C1 and C2 are charged from the voltage $(U_{C12}^* - b)$ to $(U_{C12}^* + b)$ (Fig. 3). Upon reaching the voltage values $(U_{C12}^* + b)$ key K1 opens and K2 closes and capacitors start discharging from the voltage $(U_{C12}^* + b)$ to $(U_{C12}^* - b)$, then processes are repeated .

When the capacitors are being charged the energy balance equation has the form

$$\left(\frac{U_m I_m^*}{2} - \frac{I_m^{*2} R_d}{2}\right) t_1 = \frac{C_{12}}{2}\left((U_{C12}^* + b)^2 - (U_{C12}^* - b)^2\right), \qquad (13)$$

where t_1 is time to increase the voltage on the capacitors, $C_{12} = \frac{C_1 C_2}{C_1 + C_2}$, 2b - hysteresis width relay element PE2, $U_{C12}^* = U_{C1} + U_{C2}$.

We determine the time from (13)

$$t_1 = \frac{4bC_{12}U_{C12}^*}{U_m I_m^* - I_m^{*2} R_d} = \frac{2bC_{12}U_{C12}^*}{P - P_d}. \qquad (14)$$

The energy balance equation at the capacitor voltage reduction stage will be

$$-\frac{I_m^{*2} R_d}{2} t_2 = \frac{C_{12}}{2}\left((U_{C12}^* - b)^2 - (U_{C12}^* + b)^2\right), \qquad (15)$$

where t_2 voltage reducing time.

We determine t_2 from (15)

$$t_2 = \frac{4bC_{12}U_{C12}^*}{I_m^{*2} R_d} = \frac{2bC_{12}U_{C12}^*}{P_d}. \qquad (16)$$

We determine the frequency shift keys K1 and K2 as

$$\nu_2 = \frac{1}{t_1 + t_2} = \frac{P_d (P - P_d)}{2bC_{12}U_{C12}^* P}. \qquad (17)$$

Relative duration of the power source is in the circuit will be

$$\gamma = \frac{t_1}{t_1 + t_2} = \frac{I_m^{*2} R_d}{U_m I_m^*} = \frac{P_d}{P}. \qquad (18)$$

The expression (18) allows to determine the range of current control at a given rated load resistance and the range of variation of the load resistance at a given current.

$$0 \le I_m^* \le \frac{U_m}{R_н}, \qquad R_d = const$$
$$0 \le R_d \le \frac{U_m}{I_m^*}, \qquad I_m^* = const \qquad (19)$$

The control algorithm keys K1 and K2 allows to reduce power loss input line in accordance to

$$\Delta P = \frac{\gamma^2 I_m^{*2} R_l}{2}. \qquad (20)$$

Figure 3 shows the processes in the power source in the current source. Figure 3a shows the response of the source to the reduction of the current task. Sinusoidal current and current coincidences in the phase with the circuit voltage are saved and electromagnetic compatibility is not broken. Figure 3b shows the response of the source to the reduction of the supply voltage. The load current is not changed, i.e. source is not sensitive to the effects of such perturbations, sinusoidal current and cosφ = 1 are saved.

Figure 4 shows the process when the load is fed through inductive capacitive transducer (P switch in position 2). Figure 4a –shows the response source to the reduction to the voltage, figure 4b shows the response to the reduction in the supply voltage. As in the case of a current source, electromagnetic compatibility is not broken, the source is not sensitive to changes in voltage.

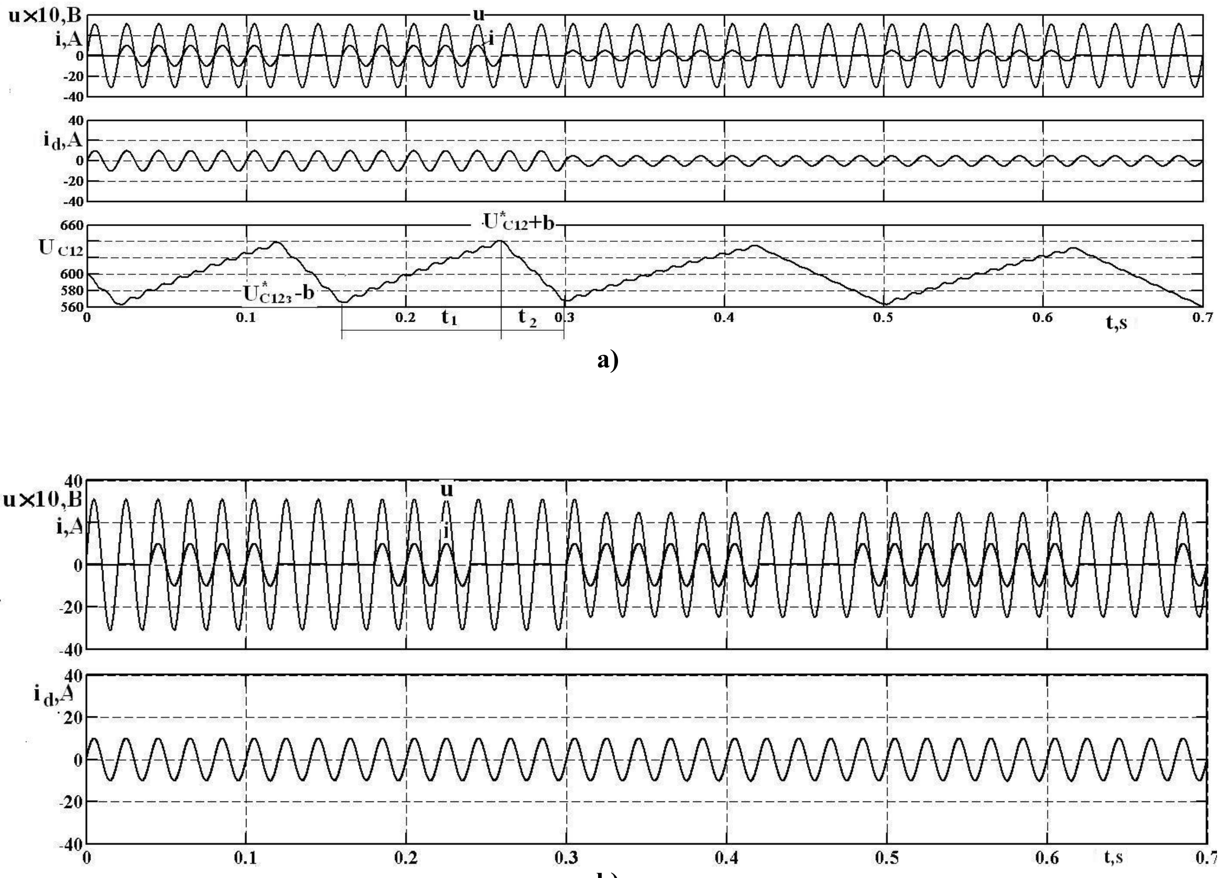
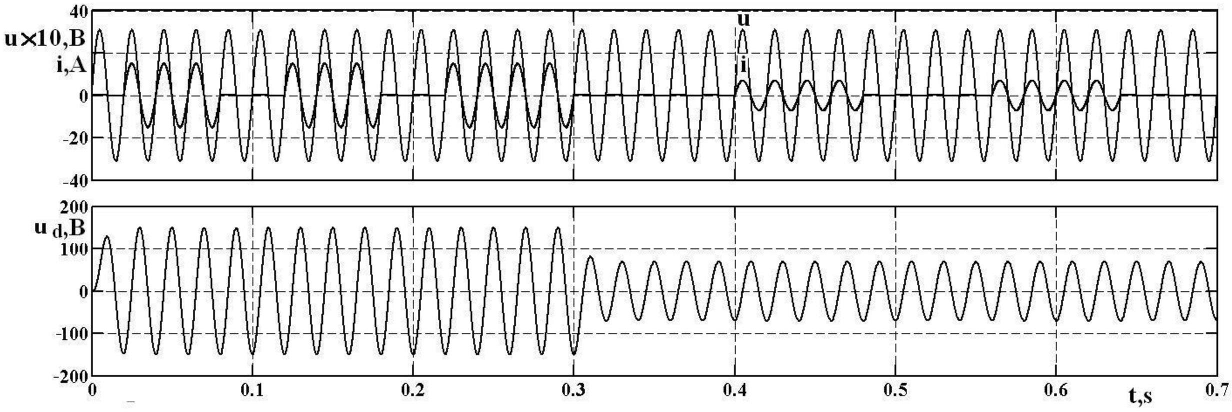
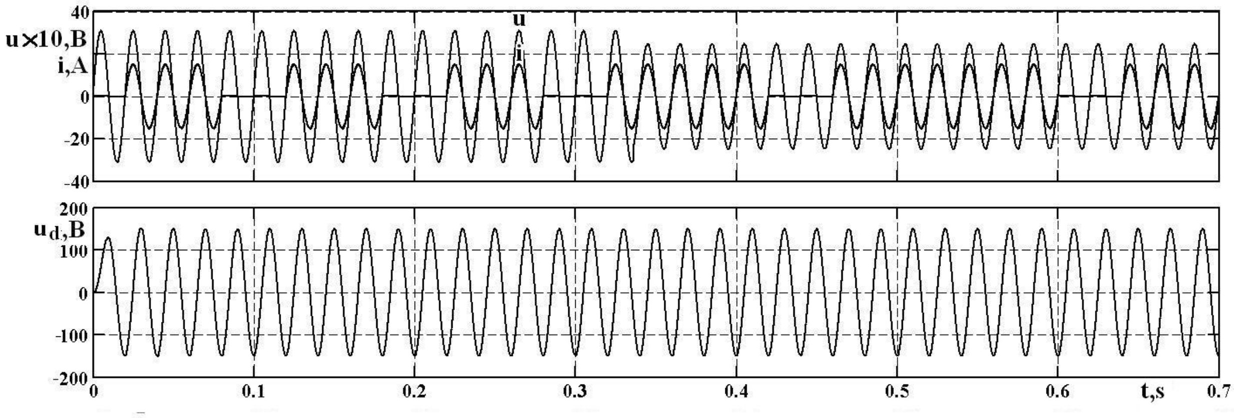


Figure 3 shows the processes in the power supply in the current source
a) reaction to the change in the current job, b) response to changes in voltage



a)



b)

Figure 4 shows the processes in the power source voltage source mode
a) response to changes in voltage reference, b) response to changes in circuit voltage

Thus, the proposed source of supply is the electromagnetic compatibility with the network, an invariant to the action on it of disturbances at power loss reduction in the supply line.

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ИСТОЧНИК ПИТАНИЯ С ДИСКРЕТНЫМ ПОТРЕБЛЕНИЕМ ЭЛЕКТРОЭНЕРГИИ

Предложен источник питания с дискретным потреблением электроэнергии и релейным *управлением, электромагнитно совместимый с сетью, инвариантный к действию возмущений и с уменьшенными потерями мощности в подводящей линии. Приведены аналитические выражения для расчета частот релейных режимов, потерь мощности и результаты моделирования.*

Ключевые слова: *электромагнитная совместимость, релейное управление, инвариантность, потери мощности, источник питания.*

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ДЖЕРЕЛО ЖИВЛЕННЯ З ДИСКРЕТНИМ СПОЖИВАННЯМ ЕЛЕКТРОЕНЕРГІЇ

Запропоновано джерело живлення з дискретним споживанням електроенергії та релейним керуванням, електромагнітно сумісне з мережею, інваріантне до дії збурень і з зменшеними втратами потужності в лінії підведення. Наведено аналітичні висловлювання для розрахунку частот релейних режимів і втрат потужності та результати моделювання.

Ключові слова: *електромагнітна сумісність, релейне керування, інваріантність, втрати потужності, джерело живлення.*