Study of Regular Output Power with Converters

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ABSTRACT: *In this paper we have addressed the power supply with regular output power which is the converters with energy dosing. It provides energy dosing in the load with operation principle. The power is related to the output voltage received that is equivalent to the load parameters. We in this research have introduced a few converters with the required changes. We have also highlighted the design of converters. We have presented the design and mathematical interpretation of the processes.*

Keywords: Energy Dosing, Converter, Harmonic Analysis, Load Matching, Self-harmonization

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1. Introduction

Although modern power supply sources constitute a greatly electronized and highly intelligent system, they still contain complex controllable power elements, such as transformers, autotransformers, capacitor banks, chokes [1-6]. Along with their undoubted advantages, they have certain disadvantages relating to the methods, the hardware and the quality of their matching with the variable load. The same is true about the regulation and the assigning of a specific value for their output power.

CED are sources of a new type [7-9] and they successfully solve some of the problems in this area. What distinguishes them from the sources we have been familiar with so far is the fact that their output power is assigned in a definite way, and in the process of operation it does not depend on the load parameters, remaining equal to the assigned value.

Figure 1 presents the schematic diagram of the CED. It is shown schematically that between the source of DC voltage (the rectifier) and the HF converter another block is connected - a doser. By means of this block the energy is transmitted to the load in definite portions (doses).

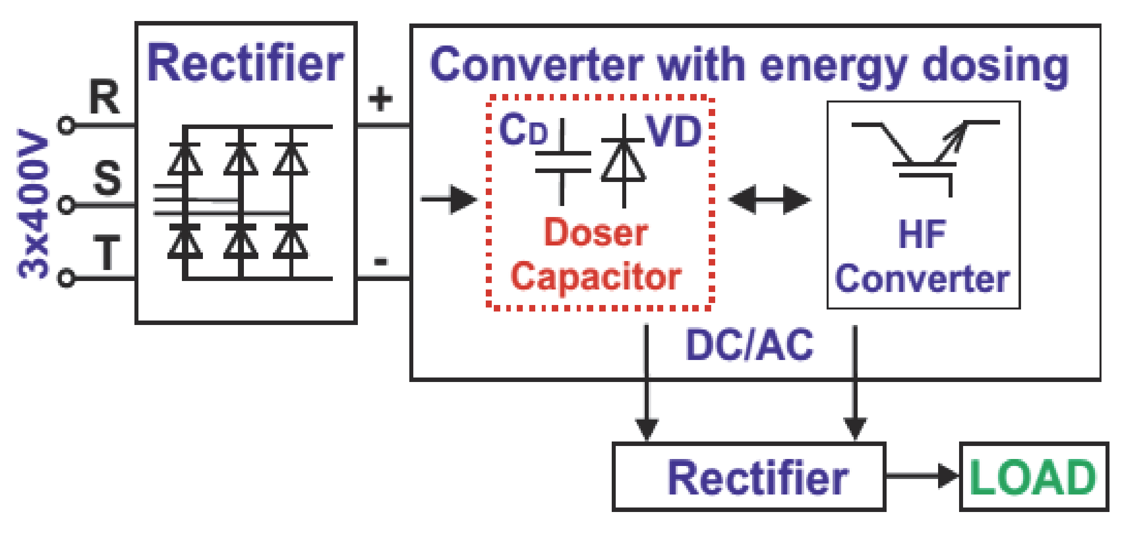


Figure 1. The schematic diagram of CED

The doser consists of a reactive element, normally a capacitor (an inductor is also possible) and a diode connected in anti-parallel to it. The capacitor charged up to voltage $+E$ of the supply source is either discharged completely or recharged up to voltage $-E$ in the course of one half-period, its energy being transformed into the converter and transmitted to the load.

The dose of energy W and the power P are equal, respectively

$$W = kE^2C_d \tag{1}$$

$$P = kE^2C_df = U_L^2/Z_L = const \tag{2}$$

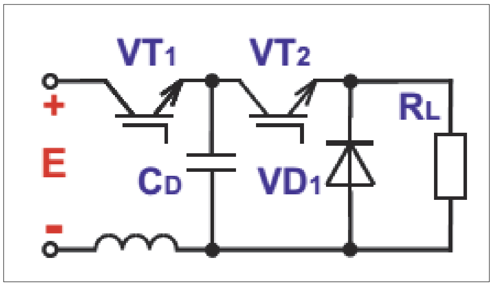
where C_d is the capacitance of the dosing capacitor; f -converter switching frequency; k - a coefficient dependent on the circuit of the doser and the converter; U_L - effective value of the output voltage, Z_L - load resistance. According to (2) when the values of E, C_d and f do not vary, the power P has a constant value independent of the load parameters and its changes. In practice, this means that the output voltage of the CED (voltage U_L) changes in strict accordance with the concrete load parameters, i.e. self-harmonization with the specific load is performed, naturally, without the influence of the control system.

A large proportion of the ideas in this field have been thoroughly investigated both theoretically and experimentally, and are being used in real practice [10-12].The main purpose of the present paper is in this direction - overview of circuits of CED and the investigations performed on them and common method for their analysis and design.

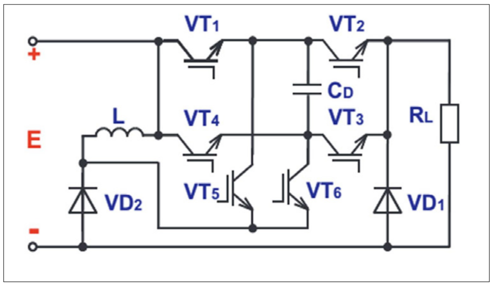
2. An Overview of Converters with Energy Dosing

A great number of circuits of CED are known [1-3], [8], [12]. Their distinctive feature is the presence of a dosing capacitor included in series in the load loop through the interval of energy consuming by the main. All of them provide dosing of the energy supplied to the load, reliable work of loads changing from idle running to short circuit and high commutation stability in the dynamic operating mode.

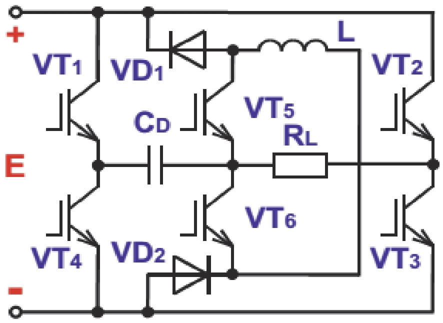
In Figure 2 are shown the basic circuit and their time intervals, illustrating the principle of energy dosing. It can be seen that the dosing capacitor voltage is fixed always to the value of the supplying DC voltage. Consequently, at constant work frequency the power given in the load will always be one and the same. For the circuits with combined recharge of the dosing capacitor, in the expression for the power takes part the coefficient ***k*** which is less than 1 and depend on the load parameters.



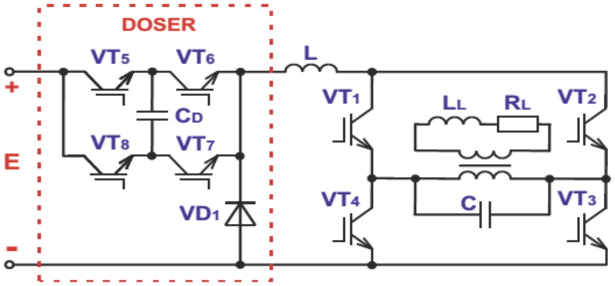
(a) CED with capacitor recharging by load current -time intervals and power: $0 \div t_1$- VT_1; $t_1 \div t_2$- $VT_2 t_2 \div \pi$ - VD_1 ; $\mathbf{P=E^2C_df}$.



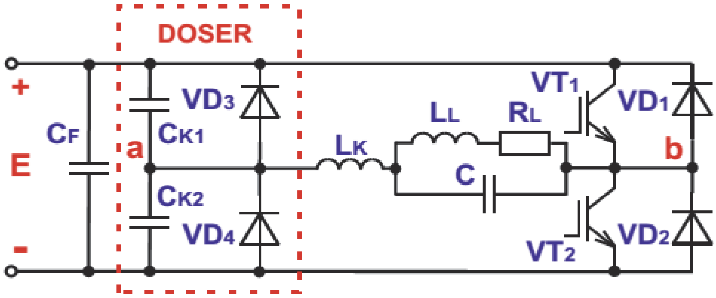
(b) CED with combined recharge of the dosing capacitor - time intervals and power: $0 \div t_1$-VT_1, VT_6; $t_1 \div t_2$- VT_1, VT_4, VT_6; $t_2 \div t_3$ - VD_1, VD_2; $t_3 \div t_4$- VT_3, VT_5; $t_4 \div t_5$ - VT_2, VT_3, VT_5; $t_5 \div \pi$ - VD_1, VD_2; $\boldsymbol{P = kE^2C_df}$



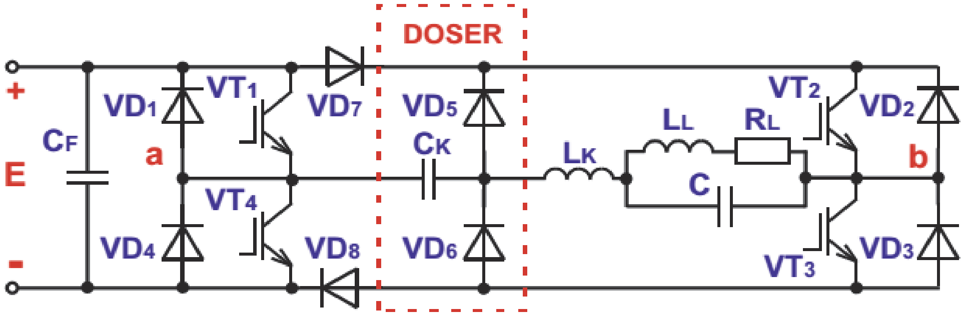
(c) CED combining energy converting and dosing - time intervals and power: $0 \div t_1$-VT_1, VT_6, VD_1; $t_1 \div t_2$–VT_1, VT_3; $t_2 \div t_3$ - VD_1, VD_2; $t_3 \div t_4$- VT_4, VT_5, VD_2; $t_4 \div t_5$ - VT_2, VT_4; $t_5 \div \pi$ - VD_1, VD_2; $\boldsymbol{P = kE^2C_df}$



d) CED with capacitor recharging by equivalent load of current fed invertor - time intervals and power:$0 \div t_1$- VT_1, VT_3, VT_5, VT_7; $t_1 \div \pi$-VD_1, VT_1, VT_3; $\boldsymbol{P = 4E^2C_Df}$



(e) half-bridge CED - time intervals and power: 0÷t_1 - VT_1; t_1÷π - VT_1, VD_3; $P = E^2C_Kf$



(f) full-bridge CED - time intervals and power: 0÷t_1-VT_1, VT_3, VD_8; t_1÷π - VT_3, VD_6; $P = 4E^2C_Kf$

Figure 2. Typical schematics of CED

The comparative analysis of the presented circuits and results from the examinations in previous works [2-5], [11] gives the main feature of CED:

- At the lack of requirements to the load current pulsations it is expedient to be used the circuit from Figure 2*a*;

- At the necessity of supporting small output current pulsations, at a wide regulation range are used the circuit from Figure 2*b*. Theoretically, it do not have limits in the regulation characteristics;

- For CED from Figure 2*b* and Figure 2*c* it is important to note that to keep the small output current pulsations at a range of regulation $k > 3$ it is necessary to install inductance L with high value;

- The output power of current fed inverter can be adjusted very accurately within a wide range by CED working frequency - Figure 2*d*;

- By changing the working frequency of CED from Figure 2*e* and Figure 2*f* the output voltage can be supported constantly when the load value and/or the input voltage are changed.

3. Study Method

A unified approach and methodology have been suggested for the analysis and design of CED. The basis of the generalization suggested is the harmonic analysis, the general parameters of fluctuation circuits comprising resonant converter and as well as the information that is contained in the time-chart of their alternating current [2]. With minor modifications, the method is applicable to any CED circuits.

From a great variety of presented circuits and ways of operational half-bridge CED (HBCED) with forced turn-off of the transistors before half-period has been chosen (Figure 2*e*) for analysis. According to the power levels and the load additional serial and/or parallel capacitors can be included in the load circuit. Current and voltage waveforms are shown in Figure 3. Because of earlier transistors turn-off before halfperiod end alternating current pulse “shrinking” is obtained.

In moments π, 2π, ..., *n*π it is equal to zero and its fall sector with the biggest damping is cut. This pulse is closer to sinusoidal wave shape than with other resonant converters. Therefore HBCED research and design procedure based on the harmonic analysis are used and AC voltage being accepted to a clear sinusoid.

The transistor current pulse has natural frequency ω_n (see curve 1 on figure 3)

$$\omega_n^I = 2\pi f_n^I = 2\pi / T_n^I < \omega_c \tag{3}$$

where ω_C is control frequency. Relation ω_n^I / ω_C is equal to

$$\omega_n^I / \omega_c = \pi / (\pi + t_0^I) < 1 \tag{4}$$

Proceeding from the obligatory ratio in resonant converters [2], [4]

$$tg\delta > (\omega_n / \omega_c);\ tg\delta = (1{,}2 \div 1{,}5)(\omega_n / \omega_c) \tag{5}$$

and assigning

$$t_0^I = (0{,}5 \div 0{,}8).to \tag{6}$$

(to is input datum) angle δ can be determined. δ is the phase angle at the resonant converter *AC* circuit after the inductor L_k.

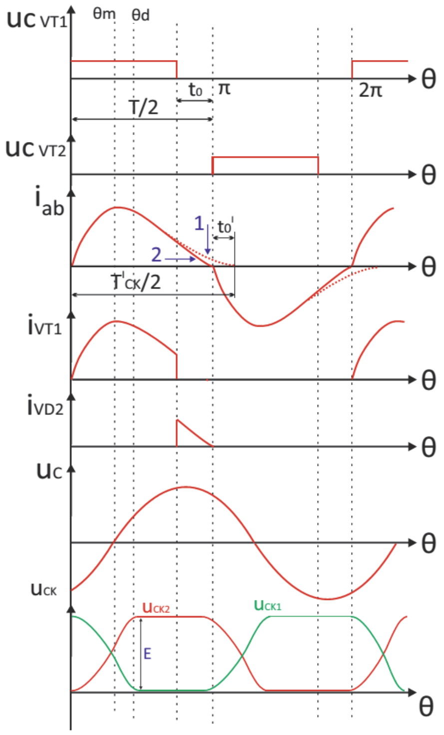


Figure 3. Time-charts of HBCED – $u_{CVT1\text{-}2}$ - control pulses; IAB- alternating current; i_{VT1}, i_{VD2} - current through transistor VT_1 and diode VD_2; u_C, u_{CK} - voltage over capacitors *C* and C_K

After that, the phase φ_1 of the alternating current first harmonic and the amplitude of the voltage across the load circuit $U_{cm} = U_{gm}$ are respectively calculate

$$\mathrm{tg}\varphi_1 = 0{,}406\mathrm{tg}\delta - (0{,}165\mathrm{tg}^2\delta - 0{,}188)^{(1/2)} \tag{7}$$

$$U_{cm} = U_{gm} = \pi.\mathrm{E}/[2.\cos(\delta - \varphi_1)] \tag{8}$$

It is easy to determine all converter quantities and elements:

- Staggering $\xi_0 = 1/\left[\omega(LC)^{(1/2)}\right]$ of the load circuit

$$\xi_0^2 = (tg\varphi + ctg\varphi)/(tg\varphi + tg\delta),\ (tg\varphi = \tfrac{\omega_L}{R}); \tag{9}$$

- Capacitor *C* value

$$C = 1/(\omega^2.\xi_0^2.L); \tag{10}$$

- Active *Re* and reactive *Xe* equivalent resistances of the load circuit

$$Re = (1/\omega C).\{\xi_0^2.ctg\varphi/[(1-\xi_0^2)^2 + ctg^2\varphi]\}; \tag{11}$$

$$Xe = Re.tg\delta; \tag{12}$$

choke L_k using the frequency ω_n

$$\omega_n = [1/(L_K C_e) - R_e^2/(4.L_K^2)]^{(1/2)}; \tag{13}$$

- **The moments:** ϑ_d- at which the energy consumption from the power supply stops, ϑ_m- at which the alternating current has maximum value:

$$\vartheta_D = \pi/(\omega_n/\omega_c) - (arctg2Q\omega_n/\omega_c)/(\omega_n/\omega_c) \tag{14}$$

$$\vartheta_m = (arctg2Q\omega_n/\omega_c)/(\omega_n/\omega_c) \tag{15}$$

- Dosing capacitor:

$$C_k = P/(E^2.f) \tag{16}$$

The converter current equation is formed:

$$i(\theta) = \frac{E\theta}{\omega L_k} - \frac{U_{gm}[\cos(\delta-\varphi_1) - \cos(\delta-\varphi_1-\theta)]}{\omega L_k} \tag{17}$$

The average and maximum values of the currents across the transistors and the reverse diodes are equal to:

$$I_{mVT_{1,2}} = \frac{E}{\frac{\omega_n}{\omega_c}\omega_c L_k} e^{-\frac{\vartheta_m}{2Q}} sin\frac{\omega_m}{\omega_c}\vartheta_m$$

$$I_{0VT_{1,2}} = \frac{EfC_k}{2} = \frac{I_0}{2},$$

$$I_{mVD_{3,4}} = i(\vartheta_d) = \frac{E}{\frac{\omega_n}{\omega_c}\omega_c L_k} e^{-\frac{\vartheta_d}{2Q}} sin\frac{\omega_n}{\omega_c}\vartheta_d,$$

$$I_{0VD_{3,4}} = EfC_k e^{-\frac{\pi-\vartheta_d}{2Q}},$$

$$I_0 = \frac{1}{\pi}\int_0^{\pi-\vartheta_d} i(\vartheta_d)d\vartheta = EfC_k \tag{18}$$

The approach suggested and the methodology for a unified analysis and design has been carried out for all CED and has been confirmed by computer and real experiments.

4. Computer Aided and Experimental Study

CED have been studied well both theoretically and in practice. In order to prove the properties and the characteristics of the presented circuits, experimental study has been carried out with the following input data: P = 5 kW; f = 30 kHz; E = 300 V. Table 1 presents the results of the investigations, with a change of the load parameters by ±25% of the following circuits:

-CED from Figure 2*b* - R_L= 0,15Ω; Lk = 1,06μH; Cd = 2μF;

-CED from Figure 2*c* - R_L= 0,15Ω; Lk = 1,06μH; Cd = 0,5μF.

Electrical parameters and elements values			
CED type	R_{Lnom}(-25%)	R_{Lnom}.	R_{Lnom}(+25%)
CED with combined recharge of the dosing capacitor	$U_{RL\ m}$ = 80V I_{in}= 10,4A I_{VTm} = 302A I_{VT} = 10,4A P = 5,2kW	$U_{RL\ m}$ = 95V I_{in}= 10A I_{VTm} = 242A I_{VT} = 10A P = 5kW	$U_{RL\ m}$ = 84V I_{in}= 10,6A I_{mVT} = 245,9A I_{VT} = 10,6A P = 5,3kW
CED combining energy converting and dosing	$U_{RL\ m}$ = 239V I_{in}= 10,7A I_{VTm} = 350A I_{VT} = 10,7A P = 5,35kW	$U_{RL\ m}$ = 93,8V I_{in}= 10,1A I_{VTm} = 290,2A I_{VT} = 10,1A P = 5 kW	$U_{RL\ m}$ = 258,55V I_{in}= 10,8A $I_{m\ VT}$= 255,3A I_{VT} = 10,8A P =5,4kW

Table 1. Test Results of the CED form Figure 2*b* and Figure 2*c*

The design of the half bridge CED converter (Figure 2*e*) is based on the expressions, obtained in paragraph III. The purpose is to be defined the values of all elements and phase correlations providing not only efficiency, but also guaranteeing the output parameters and characteristics. The obtained values of the elements and the quantities from the computer simulation calculations and from the practical experiment are presented in Figure 4 and Table 2. There is a good coincidence among the results on the three directions from the transformer examination.

P=5kW ; f=30kHz; E=300V; R=4,3Ω ; L_K=15 μH ; C_d=0,462μF						
quantity	U_{OUT} V	I_{IN} A	$I_{VT\,m}$ A	I_{VT} A	I_{VD} A	P_{OUT} kW
calculated	148	16,2	82,9	18,3	2,08	5,09
computer experiment	151,5	16,2	81,1	18,2	2	5,33
practical experiment	152	17	86,2	19,2	2,3	5,37

Table 2. Designing, Computer Experiment and Practical Examination Results

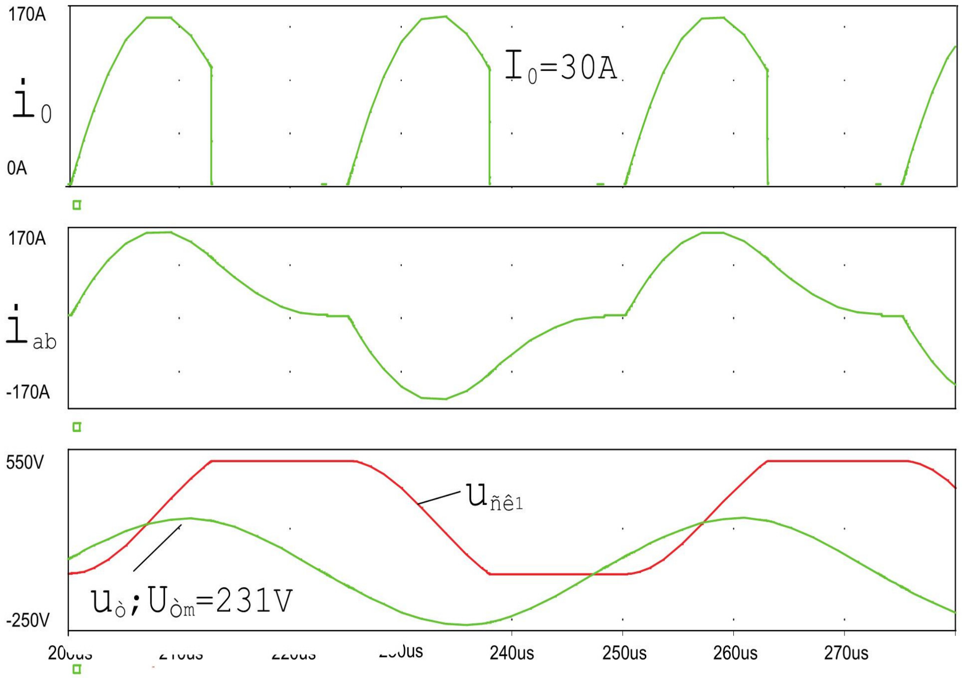


Figure 4. Test results of half-bridge CED at P=5 kW and f=30 kHz – input current, AC current and load and dosing capacitor voltages

From the information in Table II it can be drawn the conclusion that the output power is in correspondence with expression (2), i.e. there are dosing qualities. This is determined by the average value of the consumed current I_{in} and by the voltage on the load U_{out}. Obtaining the given power can be proven with a third result, as well. The difference between the capacitor and the diode current is equal to the input current and energetically it satisfies the processes of energy consuming in the interval $0 \div \vartheta_d$ and the short circuit of the alternating converter circuit of the interval $\vartheta_d \div \pi$ (see Figure 3).

5. Conclusion

This paper described an overview, design and experimental study of power supplies with constant output power, so called CED. A 5 kW converter was designed and implemented to verify the validity of the developed common analysis. The basis of the generalization suggested is the harmonic analysis and the information that is contained in the time-chart of the alternating current. The obtained expressions giving the law for operating mode with a purpose to keep the output power constant when the load parameters are changed. It can be concluded that the developed CED may contribute to higher system efficiency and good matching characteristics.

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