IOP Conf. Series: Materials Science and Engineering **81** (2015) 012112 doi:10.1088/1757-899X/81/1/012112

Power supply of autonomous systems using solar modules

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Abstract. The article shows the methods of constructing autonomous decentralized energy systems from solar modules. It shows the operation of up DC inverter. It demonstrates the effectiveness of DC inverters with varying structure. The system has high efficiency and low level of conductive impulse noise and at the same time the system is practically feasible. Electrical processes have been analyzed to determine the characteristics of operating modes of the main circuit elements. Recommendations on using the converters have been given.

1.Introduction

Basic requirements for the development of autonomous power supply (APS) systems are compact size, high efficiency and low level of impulse noise. Efficiency of modern electrical energy converting devices such as classic high frequency pulse-width inverters and DC-DC converters for autonomous energy supply systems is close to reaching its maximum limit. A further increase in the efficiency by a few percentages can be achieved by reducing the switching power losses in power keys by using methods of resonance, providing them with a mode of soft switching, as well as with the reduction in dynamic voltage drops when switching from cut off to saturation. Reduction of impulse noise level is achieved by a reasonable decentralization combined with multi-stroke mode of operation of used converters.

2. Studying of push-pull-push resonant down DC-DC converter with $cf = \frac{1}{2}$

Schematic diagram of the three-stroke resonant down DC-DC converter power circuit used in the APS for the lighting system is shown in Figure 1 and Figure 2 where timing diagrams explaining its operation [1].

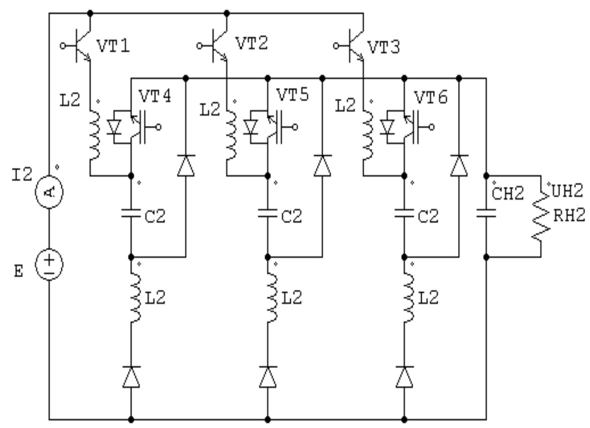

Figure 1. Three-stroke resonant down DC-DC converter with $cf = \frac{1}{2}$.

Converter is composed of k_2 down ECVs and each of them is composed of n_2 CDC. The operating principle of down ECV is periodic recharging of series-connected capacitors in its circuit from AB with voltage E by means of charging keys $VT1 - VT3$ which then have parallel discharge to the load though charging keys $VT4 - VT6$. As the source E recharges capacitors through series-connected load the ECV power circuit is simplified by the decrease of the number of CDCs by one. As a result the convertor output voltage is equal to $U_{H2} = \frac{E}{(n2+1)}$. Increasing of the number of ECV - k_2 also leads to a proportional increase of the maximum load current and a reduce of conductive impulse noise level.

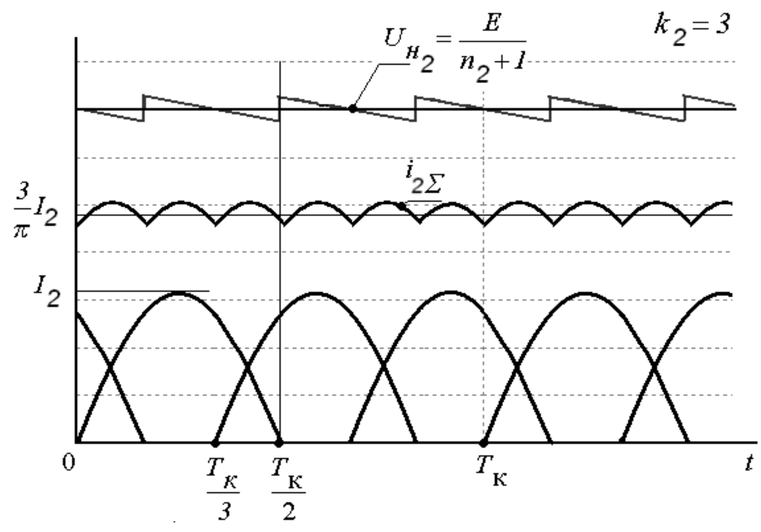

Figure 2. Timing diagrams explaining the operation of push-pull-push resonant down CP.

Charging current of the down CP is determined by the following expression (1)

$$i_2(t, \tau_2) = I_2 \cdot \sum_{i=0}^{k_2-1} [\sin\omega_K \cdot (t - i \cdot \frac{T_K}{k_2} - \tau_2)] \cdot 1[i \cdot \frac{T_K}{k_2} + \tau_2, \frac{T_K}{2} + i\frac{T_K}{k_2} + \tau_2] \quad (1)$$

where τ_2 - time offset of charging current impulse sequence related to the central point, $I_2 = \frac{\pi}{k_2} \cdot \frac{I_{H2}}{(n_2+1)}$ – the amplitude of the down CP charging current, $I_{H2} \approx \frac{E}{(n_2+1) \cdot R_{H2}}$ – average load current, [2–4]

The number of ECVs in k_2 groups (3), capacitance C and inductance L of modules (4) are determined from maximum required current $I_{нjср}$, voltage ripple on capacitors ΔU_C and switching frequency of keys $\omega_к$.

$$k_2 \cdot C_2 = \frac{2 \cdot \pi \cdot I_{H2}}{\omega_K \cdot (n_2+1) \cdot \Delta U_C} \tag{2}$$

$$L_2 = \frac{1}{\omega_к^2 \cdot C_2} \tag{3}$$

$\omega_K = (2\pi / T_к) = (1/\sqrt{L_2 \cdot C_2})$ – resonant frequency of charging circuit, L_2, C_2 – CDC inductance and capacitance of down CP. A further decrease of the impulse noise level on AB clamps during simultaneous operation of up and down CP in APS is achieved by optimal time offset choice - τ_1, τ_2 of charging currents $i_1(t,\tau_1)$ and $i_2(t,\tau_2)$. Generalized optimization criterion is formulated as follows: at the same frequency of commutation of keys $\omega_K = (2\pi / T_K)$, operating with a duty ratio equal to two, to determine time offsets $\tau_1, \tau_2, ..., \tau_к$, delivering minimum to the square of the real value of the variable component of the total charging current, consumed by K converters from AB (4)

$$i^2_{\partial\Sigma\sim}(\tau_j) = \frac{k_{min}}{T_K} \cdot \int_0^{\frac{T_K}{k_{min}}} [\sum_{j=1}^{K} i_j(t,\tau_j) - i_{0\Sigma}]^2 \cdot dt - min \tag{4}$$

Here k_{min} is minimum CP strokes, which consumes current from AB, $i_{0\Sigma} = \frac{1}{T_K} \cdot \int_0^{T_K} i_\Sigma(t,\tau_j) \cdot dt = \sum_{j=1}^{K} I_j \cdot \frac{k_j}{\pi}$ - constant component of the total charge current which is independent from τ_j. If k_{max} - is maximum CP strokes, then for APS made of two capacitors ($K = 2$) analysis gives the following expression for the optimal time offsets $\tau_1 = 0, \tau_2 = \frac{T_K}{2 \cdot k_{max}}$, $\tau_2 = \frac{T_K}{4 \cdot k_{max}}$ – respectively for even and odd values of k_{max}. If APS is made of 2 push-pull-push capacitors, i.e. $k_1 = k_2 =$, then the optimal offset on $\tau_2 = (T_K / 12)$, and respectively (5):

$$i^2_{min\partial\Sigma\sim}(\tau_2 = \frac{T_K}{12}) = \frac{1}{2} \cdot (1 + \frac{3\sqrt{3}}{2\pi}) \cdot (I_1^2 + I_2^2) + (\frac{\sqrt{3}}{2} + \frac{3}{\pi}) \cdot I_1 \cdot I_2 - [\frac{3}{\pi} \cdot (I_1 + I_2)]^2 \tag{5}$$

Its maximum (6) is achieved when $\tau_1 = \tau_2 = 0$:

$$i^2_{max\partial\Sigma\sim}(\tau_2 = 0) = \frac{1}{2}\cdot(1+\frac{3\sqrt{3}}{2\pi})\cdot(I_1^2 + I_2^2) - [\frac{3}{\pi}\cdot(I_1 + I_2)]^2 \quad (6)$$

It is important to note that for typical values $k_j = 2,3$ effectiveness of conducted. It is sufficient to compare the maximum and minimum values of $i^2_{\partial\Sigma\sim}$ to estimate it. If current impulse amplitudes are equal then the value of winning (7) is 15.46 times:

$$B = (\tau_2 = \frac{T_\kappa}{4\cdot k_{max}}) = \frac{i^2_{max\partial\Sigma\sim}}{i^2_{min\partial\Sigma\sim}} = 15.46 \quad (7)$$

Calculations based on the formulas given in the article show that for the APS with an output power in the AC circuit Pout~=10 kW and in the DC circuit (lighting) Pout=1 kW t is required to used 2 capacitors with capacity $C = 6$ mfd and voltage U=130 V and 6 capacitors with capacity $C = 1$ mfd and voltage U=260 V. For the lighting system 2 capacitors with capacity $C = 13$ mfd and voltage U=60 V are required.
The basic layout of a single-phase bridge voltage inverter based on up CP with varying structure is shown in Figure 3, and time diagrams of voltages and currents for explaining its operation are shown in Figure 4.

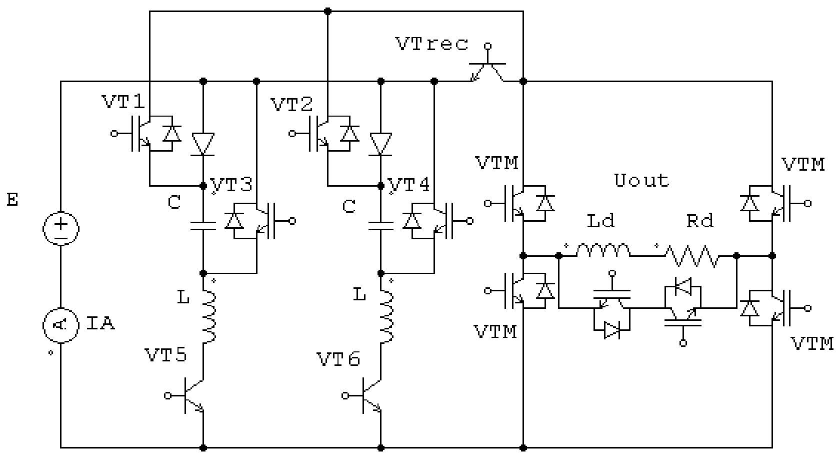

Figure 3. The basic layout of a single-phase bridge voltage inverter based on the up CP with varying structure.

The operating principle of the inverter is based on the change in the structure of the up DC-DC capacitor converter by alternate switching the transistor switches VT3,VT4 with frequency of 50 hz. Thus there is an abrupt change in conversion coefficient $K_n = 0,1,2$, which lead to the change of output voltage U_{out} , as shown in Figure 4. By the influence of harmonic PWM on VTM bridge transistors one can obtain a sinusoidal current in the load I(Ld). An important advantage of the inverter under consideration is the reduced dynamic voltage drop on bridge transistors which does not exceed 224 V in the considered APS.

As shown in the Bibliography [4] this can further increase the efficiency of the inverter by 1.5-2% due to the reduction of power loss on switching losses on VTM bridge transistors. The disadvantage of the inverter under consideration is the pulsating current, consumed by AB.

The Figure 4 shows that the value of current ripple I A is twice the current ripple on the load which has a negative effect on AB operation.

A significant reduction in consumed current ripple is achieved by the construction of the APS according to a decentralized scheme Figure 5.

The effect is achieved by a uniform distribution of current consumed by decentralized load I (Ld) for the half or the whole period of their frequency. Timing diagrams of input and output currents of decentralized APS, confirming a sharp decline in the value of the ripple current AB are shown in Figure 6.

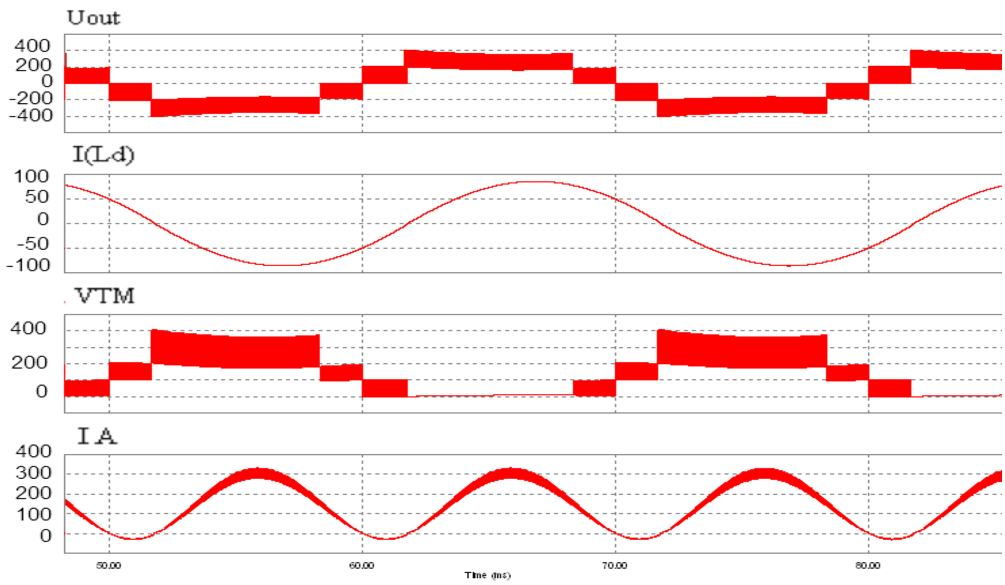

Figure 4. Timing diagrams explaining the operation of single-phase bridge voltage inverter based on up CP.

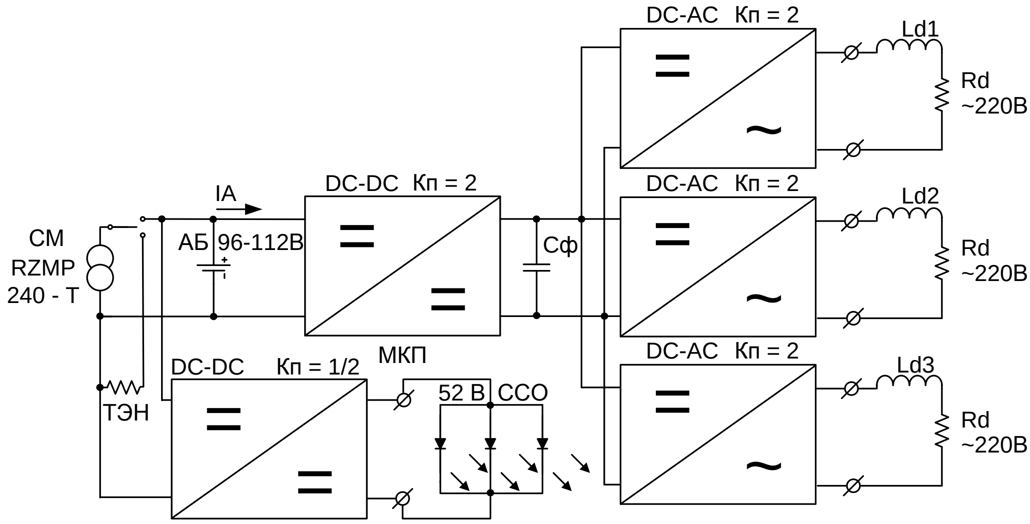

Figure 5. Structural diagram of decentralized APS.

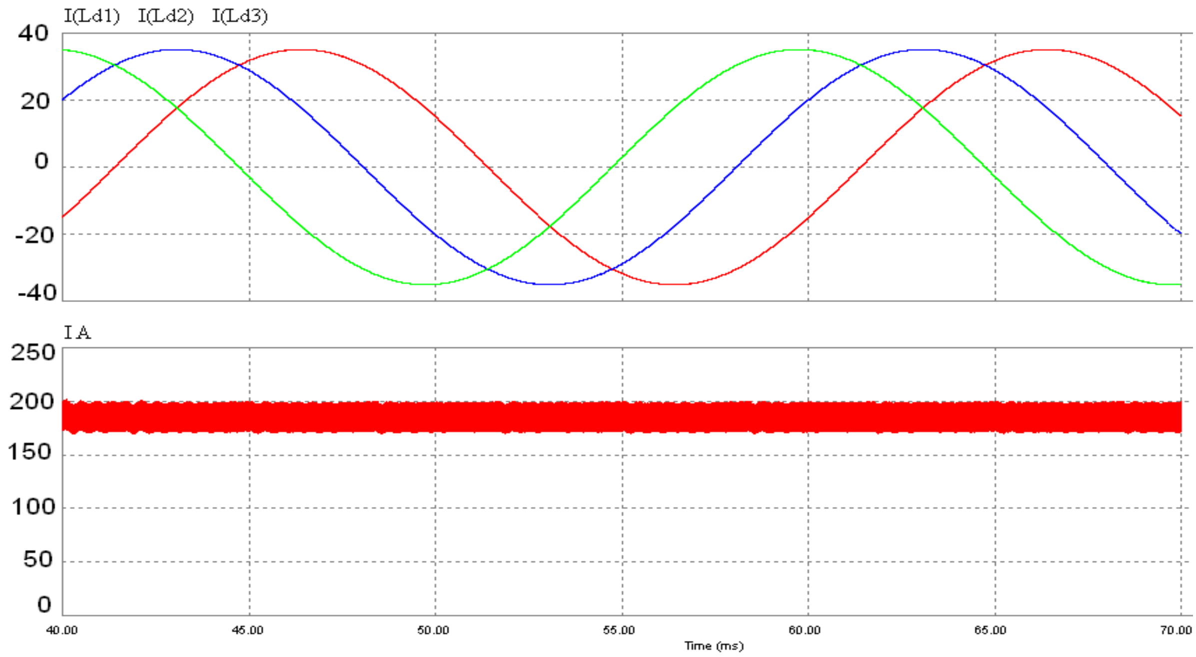

Figure 6. Timing diagrams explaining the operation of a single-phase bridge voltage inverter based on the control panel.

3. Studying of stroke capacitor resonant up DC/DC with $cp = 2$.

The importance of APS is that its power supply is performed from groups of 4 consecutive solar modules (SM) RZMP 240-T, which are parallel-connected (Figure 7). Such a solution allows applying the input battery (AB) with a sufficiently high output voltage 96-112 V and thereby reducing the cross section and the power losses in leading-in cables. Later on this voltage is doubled twice – firstly by DC-DC, and then by DC-AC converters. For the purpose of energy saving LED lighting system (LLS) is applied combined with double down DC-DC converter powering it [5].

Another distinctive feature of the APS is that in case of an increase in charge voltage above 112 volts SM disconnect from the battery and switch to heat the heating element, performing, for example, water heating.

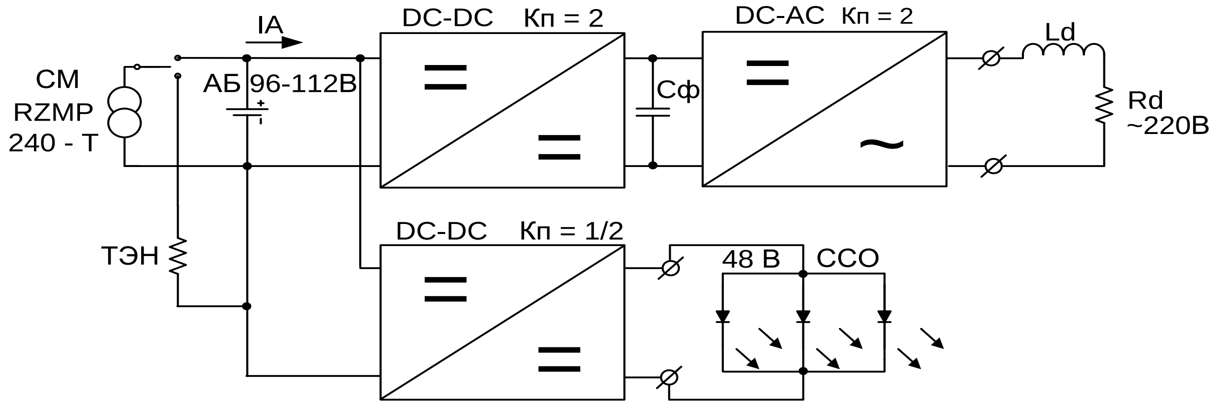

Figure 7. Structural layout of APS.

Schematic diagram of the power circuit 3-stroke capacitor resonant up DC-DC converters used in the APS is shown in Figure 8, and Figure 9 shows timing diagrams explaining its operation.

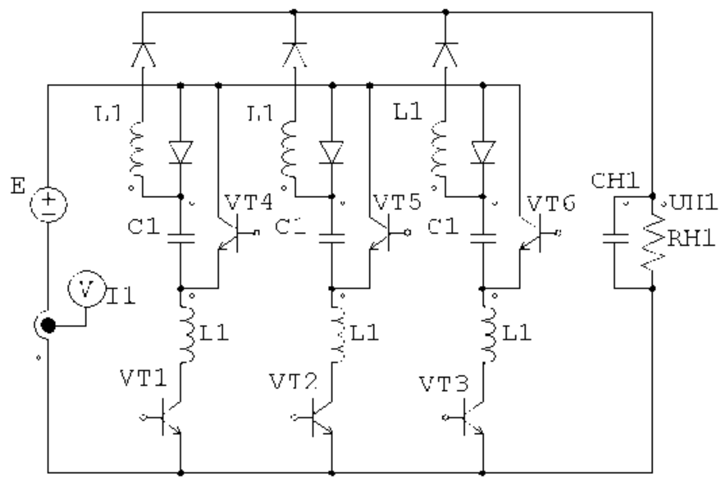

Figure 8. 3-stroke capacitor resonant up DC/DC cp = 2.

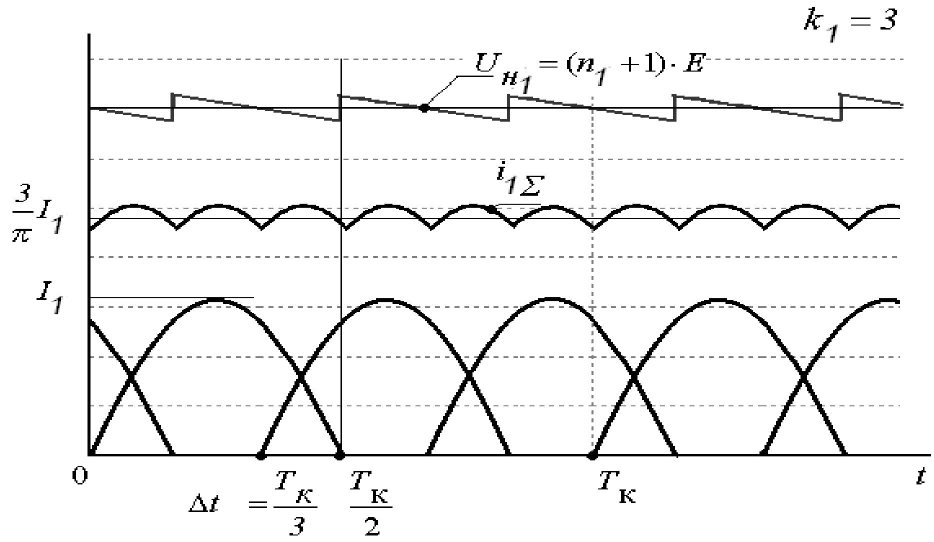

Figure 9. Timing diagrams explaining the operation of 3-stroke capacitor resonant up CP.

Downsizing and increase of efficiency is achieved correspondingly due to the increased frequency of conversion up to the magnitude of about 500 kHz or higher and due to a reduction in switching losses in high-frequency charging keys $VT1-VT6$ of the power circuit of series reactors L1, providing them with a soft switching mode.

Initially, the converter consists of k1 (strokes) similar up converters (PVC), each containing n1 capacitor-diode circuit (CDC), operating on the load.

The operating principle of the up OCP consists in periodic parallel recharge of capacitors its circuits from constant voltage E on input source through charge keys $(VT1-VT3)$ followed by their successive discharges to the load through the discharging keys ($VT4-VT6$) corresponding to this condition. Since the discharge of the capacitor to the load goes through a serial connection AB with voltage E, then the power circuit OKP simplifies by decrease in the number of CDC by one. As a result, the converter output voltage is equal to $U_{H1} = (n1+1)\cdot E$. Increase of strokes converter - k1 results in a proportional increase in the maximum load current and reduce impulse noise on the conductive terminals AB [6]. In order to minimize it recharging of capacitors ECV is made by positive impulses sinusoidal current with duration of $0{,}5\cdot T_{\kappa}$ which are universally distributed along the period T_k of switching frequency of charging keys with time offset related to each other equal to $(\Delta t)_1 = (T_{\kappa} / k_1)$. Charging current ECV is determined as follows (8):

$$i_1(t,\tau_1) = I_1 \cdot \sum_{i=0}^{k_1-1} [\sin\omega_{\text{к}} \cdot (t - i\frac{T_{\text{к}}}{k_1} - \tau_1)] \cdot 1[i\frac{T_{\text{к}}}{k_1} + \tau_1, \frac{T_{\text{к}}}{2} + i\frac{T_{\text{к}}}{k_1} + \tau_1] \quad (8)$$

Where τ_1 is time offset of sequence of charging current impulses from the central point, $I_1 = \frac{\Delta E}{\rho} = \frac{\pi}{k_1} \cdot n_1 \cdot I_{H1}$ – is the amplitude of ECV charging current, $\Delta E-$ is voltage ripple on ECV capacitors, $\rho = \frac{1}{n_1} \cdot \sqrt{\frac{L1}{C1}}$ – characteristic independence of ECV charging circuit, $I_{H1} = (U_{H1}/R_{H1})$ - average load current

$$i_{1\partial\sim} = \sqrt{(i_{1\partial}^2 - i_{10}^2)} = \sqrt{\frac{1}{T_K} \cdot \int_0^{T_K} i_1^2(t) \cdot dt - [\frac{1}{T_K} \int_0^{T_K} i_1(t) \cdot dt]^2} \tag{9}$$

where $i_{10} = \frac{1}{T_K} \cdot \int_0^{T_K} i_1(t) \cdot dt = I_1 \cdot \frac{k_1}{\pi}$ – average charging current $i_1(t)$. By increasing the number of converter strokes k_1 there is a decrease of $i_{1\partial\sim}(k_1)$.

The active power of load is determined by average value. Thus comparing values $i_{1\partial\sim}$ for same average values i_{10}, one comes to conclusion that the decrease of real value of interference current $i_{1\partial\sim}$ for odd k_1 happens on a sufficiently lowered level [7].

For instance, level of interference for k_1 equal to three and six correspond. Therefore one can make a conclusion about appropriateness of using only odd number of ECVs in groups. From the law of conservation of charge, it follows that the average currents of all ECV keys are same and equal to $I_{\text{Кср}} = \frac{1}{k_1} \cdot I_{H1}$. The amplitude of current going through charging and discharging ECV keys VT1-VT6 is determined by following expression (10):

$$I_{\text{К}1} = \frac{1}{n_1} \cdot I_1 = \frac{\pi}{k_1 \cdot (n_1 + 1)} \cdot I_{H1}. \tag{10}$$

The number of ECVs $-k_1$, capacity C1 and inductance L1 of circuits are determined from the maximum required current I_{Hmax}, ripple ratio on the first harmonic load voltage $K_{n1} = \frac{U_{H1}}{U_{H0}}$ and the frequency of key switching $\omega_\text{К}$ (11):

$$k_1 \cdot C1 = \frac{2 \cdot n_1 \cdot I_{H1max}}{K_{n1} \cdot \omega_\text{К} \cdot (n_1 + 1) \cdot E}, \; L1 = \frac{1}{\omega_\text{К}^2 \cdot C1}. \tag{11}$$

4. Conclusions
- It is shown that by reducing the switching losses in the power keys of DC-DC converters and capacitor inverters with a variable structure and by application of multi-stroked operation mode APS has a higher efficiency and significantly lower level of impulse noise.
- The analysis of the electrical processes was conducted and it allows calculating the characteristics of operation modes of the main circuit elements and making recommendations on the use of converters only an odd number of ECV.
- The principle of construction of autonomous decentralized energy systems from solar modules was suggested. It is based on the capacitor, up and down, multi-stroked, resonant DC-DC converters, and up capacitor inverters with varying structure as well.

- It is shown that due to reducing the switching losses in the power keys of DC-DC converters and capacitor inverters with varying structure and due to application of multi-stroked mode of operation APS has a higher efficiency and significantly lower level of impulse noise.
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References

[1] Weiss H H, Ince K and Zinovyev G S *Multi-Input Small-Power Renewable Energy Supply System Realized By Special Power Electronics* p.617-622
[2] Zotov L G 2006 *Adjustable DC down converter* (Patent RU №2284633: БИ №27)
[3] Zubritsky A 2002 *ScriptaPeriodica* **5(1)**, p. 46-52
[4] Nunez C and Visairo J N 2010 *EPE Journal* **20** p. 5-11
[5] Zotov L G 2005 *Scientific Vestnik* **1(19**) p. 83-88
[6] Smirnov D 2008 *Proceedings of the Institute of Engineering Physic*s **2(8)** p. 10-13
[7] Nunez C, Lira J and Visario N 2010 *EPE journal* **4** p. 5-11