About use of supercapacitors in autonomous power supplies

M I Ganiev, A I Dyomko and O Yu Semenov

Surgut State University, Surgut, Russia

E-mail: ous.tutor.phinma@mail.ru

Abstract. The article describes the use of supercapacitors in power supplies designed for a long time of unattended operation in difficult meteorological conditions. A comparison is made of the energy efficiency factor of energy storage devices - batteries and supercapacitors when using solar panels. The optimization of the power supply circuit is considered, taking into account the provision of the maximum battery life with a limited number of charge / discharge cycles.

Key words: power source, storage battery, supercapacitor, solar battery, energy efficiency factor.

1. Introduction

Wireless technologies confidently take positions in many areas of our lives. In most cases this involves self-powered with different scenarios ensure efficiency: using network chargers stationary power sources or alternative power sources (wind generators, solar cells, tidal power, etc.). A necessary element of autonomous devices is an autonomous power supply (APS), which can use non-renewable energy sources (disposable chemical power sources - batteries) and renewable (ionistors, batteries, etc.) [1].

The weight, size and duration of autonomous operation of APSs are determined not only by their structure, but also by the requirements for power parameters and climatic conditions of work. In addition, the weight and size parameters of the APS depend on the fraction of the energy of the primary sources, which can be used during operation. The energy efficiency of consumers is characterized by a coefficient of performance, however, this parameter is not directly related to the energy parameters of the source.

2. Theory

For primary energy sources can introduce energy efficiency coefficient $K_e$ characterizing the fraction (in relative units or percentage) of energy, which energy is used when data conditions (time, temperature, load, etc.). [2]:

$$K_e = \frac{E_1}{E},$$

where $E_1$ - available for use the energy of one primary source; $E$ is the total energy that the source can give to the consumer under optimal conditions (for a battery, this value is related to the electric capacity, measured in A*h or W*h); $N$ is the number of primary energy sources used.

Consider the energy efficiency ratio for lithium cells are widely used to supply stand-alone devices. They are characterized by optimal current consumption of only 2 - 6 mA [3], and with a larger current.
consumption, the electric capacity of the battery is significantly reduced. As an example in Fig. 1 shows the values of the energy efficiency coefficient calculated on the basis of [3] for the lithium cell SL2880 with a nominal capacity of 19 A*h.

As follows from calculation, only 50 will be used in non-optimal load - 80% of the battery power (9 - 15 A*h).

There is a method of increasing the energy efficiency coefficient of a battery with a pulsed nature of the load by using an intermediate controlled DC / DC converter, a ballast resistor and a buffer storage capacitor [3]. Controlled DC / DC converter boosts the output voltage of 100 mV increments to an external command. Thus the amount of current consumed by the battery does not exceed the set value, while the buffer capacitor current discharge may be substantially greater magnitude. The block diagram of the device is shown in Fig. 2, and the diagrams of the current consumption from the battery and the capacitor voltage in Fig. 3.
Another example of improving power efficiency coefficient battery refers to autonomous devices, for a long time at low temperatures at which capacitance battery, its output voltage and the maximum load current are reduced [4].

The increase of the load current (say when the radio auxiliary device) can result in an unacceptable reduction in the output voltage, causing a standalone device stops working. To prevent such an emergency, it is necessary to use either the above method of dosed current extraction from the battery or its heating [5-8].

For autonomous APSs operating in a wide temperature range, it is advisable to use capacitors of large capacity (ionistors) that are charged from solar panels. Features of supercapacitors are low internal resistance, the possibility of working at low negative temperatures and a large number of charge / discharge cycles, which advantageously distinguishes them from batteries [9-12].

We calculate the energy efficiency coefficient of the ionistor. The ionistor is discharged from the initial voltage of 2.7 V to the final $E_{\text{fin}}$, determined by the capabilities of the energy consumer. There are three options for taking energy from the ionistor:

1) with a constant load resistance $R_{\text{load}}$,
2) with constant current consumption,
3) with a varying load current resistance (load in the form of a DC / DC converter).

3. Experimental Results
For example, we determine the energy efficiency coefficient of the ionistor for constant load resistance $R_{\text{load}}$. The voltage on the supercapacitor is determined by solving the problem on the transition process and has the form shown in Fig. 4. In this case, the current through the resistor will change in proportion to the voltage on the ionistor according to the exponential law.
Figure 4. The dependence of the voltage of the ionistor on time with a resistive load

Full energy stored in supercapacitors:

\[ E = \frac{1}{R_n} \int_0^\infty \frac{U_c^2(t)}{R_c} dt = \frac{R_n C}{2} U_{c0}^2 e^{-\frac{2t}{R_c}} \int_0^\infty dt = \frac{C U_{c0}^2}{2} = C \frac{27^2}{2} = 3.645C \]  

(2)

\[ K_{el} = \frac{E_{fin}}{E_{fin}} = \frac{2.7^2 - E_{fin}^2}{2.7^2} = 1 - \left[ \frac{E_{fin}}{2.7} \right]^2. \]  

(3)

When series connection supercapacitors energy efficiency ratio increases:

\[ K_{eN} = \frac{E_{fin}}{E_{fin}} = \left( \frac{N \cdot 2.7}{(N \cdot 2.7)^2} \right)^2 = 1 - \left[ \frac{E_{fin}}{(N \cdot 2.7)} \right] = 1 - \left[ \frac{E_{fin}}{2.7} \right]^2. \]  

(4)

4. Results Discussion

Figure 5 shows the dependences of the energy efficiency coefficient of ionistors during its discharge on a voltage of 2.7 V to the final \( E_{fin} \) for one and two series-connected ionistors.
In most cases, a stable voltage is required to power the equipment, while the power is supplied not directly from the ionistor, but through a stabilizing DC / DC pulse converter.

As an example, consider a DC / DC boost converter LTC3525-3.3 with an output voltage of 3.3 V when the input voltage changes from 0.8 to 2.7 V. In Fig. 6 and Fig. 7 shows the experimentally measured parameters of the converter at a constant load (current 3.14 mA, load resistance 1050 Ohms).

**Figure 5.** The energy efficiency coefficient of one (1) and two (2) series-connected supercapacitors

**Figure 6.** The dependence of the current consumption of the Converter LTC3525-3.3 from the input voltage
As follows from fig. 6, the current consumed from the ionistor does not decrease, but increases with decreasing voltage on the ionistor. To determine the energy efficiency coefficient (by analogy with (2)) in this case, approximations of the experimental current dependences and efficiency were preliminarily performed:

\[ i = (4.015u^2 - 20.7u + 29.991), \text{ } \text{mA}, \]

\[ \eta = 0.76 + 0.045u. \]  

(5)  

(6)

Results of calculation of the energy efficiency coefficient supercapacitors during its connection to the stabilizing DC / DC converter is pulsed with 3.3 LTC3525-3.3 The output voltage shown in Fig. 8.
The final discharge voltage supercapacitors $E_{\text{fin}}$ ranged from 0.8 V (corresponds to the lower boundary of input voltages for which the operating DC-DC converters) to 1.8 V (corresponds to the lower boundary of the supply voltages, at which employ microcontrollers and wireless modems) [13-fifteen]. Similar calculations can be made for the battery.

5. Conclusions
1. The use of supercapacitors in conjunction with solar panels it is advisable to stand-alone power supply with long-time operation in a wide temperature range.
2. The electric double layer capacitors have a high value (0.95) Energy efficiency factor that helps to minimize weight and size independent power supply.
3. The use of supercapacitors together with a stabilizing DC / DC switching converter slightly (1.2-fold) reduces the ratio of energy efficiency supercapacitors.
4. The above results may be useful in the design of autonomous power supplies.

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References
[1] Dyomko I, Petrov B A and Radomsky S A 2016 Autonomous intelligent power supply Patent No 2615985 for an invention.
[2] Dyomko I and Semenov O Yu 2019 [“Power supply of autonomous devices,”] in Oil and Gas Engineering-2019 AIP Conference Proceedings, edited by Myslijavev A V et al. (OSTU Omsk) pp 193. Russian.
[3] Lithium batteries "Tadiran". Catalog. http://www.platan.ru/docs/pdf/ tadiran_2014.pdf.
[4] Pushkarev O 2015 How to achieve maximum operating time of a wireless node with autonomous power “Electronics News” vol 2. Russian.
[5] Alferov Zh I, Andreev V M and Rumjancev V D 2004 Semiconductors vol 38 (8) pp 937–948. Russian.
[6] Nikitin M 2012 [Electronics: Science Technology Business] vol 4 pp 50–56. Russian.
[7] Odeim F, Roes J and Heinzel A 2015 Energies vol 8 pp 6302–6327.
[8] Ganiev M I, Dyomko A I and Semenov O Yu 2019 [“The use of supercapacitors in the autonomous power supplies”] in Problems of Improving Energy Efficiency in the Northern Regions of the Russian Oil and Gas Industry International Scientific and Practical Seminar, edited by Salnikov V G et al. (NSU, Nizhnevartovsk) pp 59–64. Russian.
[9] Jaysree K S, Ezhilarasan G, Monish K, Arundhilipan V and Sumalatha G 2014 Int. J. Sci. Eng. Res. vol 5 pp 214–218.
[10] Kyriakarakos G, Piromalis D, Dounis A I, Arvanitis K and Papadakis G 2013 Appl. Energ vol 103 pp 39–51.
[11] Dyomko A I, Radomskij S A and Petrov B A 2017 RF Patent No 20161028/01 (17 January 2017). Russian.
[12] Kollimalla S K, Mishra M K and Narasamma N L 2014 IEEE Trans Sustain Energy vol 5 pp 1137–1144.
[13] Ye Y and Cheng K W E 2015 IEEE J EM SEL TOP P vol 3 pp 977–983.
[14] Dyomko A I, Dyomko I A and Semenov O Yu 2019 [Embedded program of power source microprocessor intelligent device operation] Software Registration Certificate No 2019662143/69 (02 December 2019). Russian.
[15] Rana M M et al 2017 Int. J Elec. Power vol 84 pp 225–231.