

Shape and Measurement Monitoring of Inrush Current Characteristics of a Battery-Capacitive Energy Storage Device with Two-Channel Digital Oscilloscope

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Abstract

The main reason of voltage instability in stand-alone power supply systems is the electric drive motors inrush current, which are usually higher than their nominal value. The most reasonable way to solve this problem is using capacitive energy storage. The purpose of research is shape and measurement monitoring of battery-capacitive energy storage device inrush current characteristics. Parameters comparative analysis for lithium-ion battery (LIB) part and capacitive part of the energy storage device was holding with the two-channel digital oscilloscope.

Measuring testing bench included parallel connected LIB part and capacitive part of the storage device and connected to the power source. The LIB part of the storage device is made on the basis of the ATOM 10 multifunctional motor drive device of the new generation, which contains 15 V lithium-ion battery and 9.4 A·h capacity. The capacitive part of the storage device is the INSPECTOR Booster supercapacitor with an 80 F electrostatic capacitance and 15.5 V voltage. A 12 V AC/DC step-down converter was used as a power source. An electric air automobile compressor M-14001 was used as a current drain. The testing bench measuring part consisted of a two-channel digital oscilloscope and two standard measuring shunts with 15000 μOm resistance serial attached to LIB part and capacitive part of the storage device. Shape and measurement monitoring of inrush current characteristics of LIB part and capacitive part of the energy storage device was held synchronously using a two-channel digital oscilloscope with recording data to FAT32 file system USB flash drive. Obtained data was transferred to a personal computer and analyzed.

The measurement results showed that 82.3 % of the energy losses compensation of the motor start is taken over by the capacitive part of the energy storage device, what makes longer LIB's life. By adjusting the oscilloscope sweep trace index you can analyze more detailed time response shape and its duration. The values of the inrush current amplitudes were calculated in proportion to the voltage drop on the shunts and their resistances.

The developed method for monitoring shape and measurement inrush current characteristics can be used in various technical applications: smart stand-alone photovoltaic system, uninterruptible power supply devices, electric drive control systems, etc.

Keywords: charging and discharging characteristics, Li-ion battery and supercapacitor energy storage device, standalone photovoltaic system, supercapacitor.

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Регистрация формы и измерение пусковых разрядных характеристик аккумуляторно-ёмкостного накопителя электроэнергии с применением двухканального цифрового осциллографа

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Одной из основных причин нестабильности напряжения в автономных системах энергообеспечения являются пусковые токи двигателей электроприводов, многократно превышающие их номинальное значение. Наиболее рациональным путем решения этой проблемы признано использование ёмкостных накопителей энергии. Целью данной работы являлась регистрация формы и измерение пусковых разрядных характеристик аккумуляторно-ёмкостного накопителя электроэнергии с применением двухканального цифрового осциллографа для сравнительного анализа параметров аккумуляторной и ёмкостной частей накопителя.

Разработан измерительный стенд, в котором аккумуляторная и ёмкостная части накопителя соединены параллельно и подключены к источнику электроэнергии. Аккумуляторная часть накопителя выполнена на базе многофункционального пускового устройства нового поколения АТОМ 10, имеющего в составе литий-ионную аккумуляторную батарею напряжением 15 В, ёмкостью 9,4 А·ч. Ёмкостная часть накопителя представляла собой пусковое устройство суперконденсаторного типа INSPECTOR Booster с электростатической ёмкостью 80 Ф при напряжении 15,5 В. В качестве источника энергии использовался понижающий AC/DC-преобразователь напряжением 12 В. В качестве нагрузки использовался электродвигатель привода воздушного автомобильного компрессора М-14001. Измерительная часть разработанного стенда состояла из двухканального цифрового осциллографа типа С8-46/1 и двух стандартных измерительных шунтов типа 75ШСМ 3-5-0,5 сопротивлением 15000 мкОм, последовательно подключенных к аккумуляторной и ёмкостной частям накопителя соответственно. Исследование формы и измерения величин пусковых разрядных токов аккумуляторной и ёмкостной частей накопителя проводились синхронно с использованием двухканального цифрового осциллографа с записью на электронный носитель в файловой системе FAT32. Полученная информация переносилась на персональный компьютер и анализировалась.

Результаты измерений показали, что 82,3 % компенсаций потерь энергии на пуск электродвигателя принимает на себя ёмкостная часть накопителя, что продлевает срок эксплуатации аккумуляторной батареи. Регулируя коэффициент развёртки осциллографа, можно детально исследовать форму переходного процесса и его продолжительность. Значения амплитуд пусковых токов рассчитывались пропорционально падению напряжения на шунтах и их сопротивлениям.

Разработанный метод регистрации формы и измерения пусковых характеристик может найти применения в различных технических приложениях: автономных интеллектуальных фотоэлектрических системах электроснабжения, устройствах бесперебойного электропитания, системах управления электроприводом и др.

Ключевые слова: зарядно-разрядные характеристики, аккумуляторно-ёмкостный накопитель электроэнергии, автономная фотоэлектрическая система, суперконденсатор.

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Introduction

One of the reasons of unstable electricity oscillation by stand-alone renewable energy systems hides in energy consumption structure. Nowadays more than 50 % of world generated electricity is consumed by electric drives. Energy consumption start-up modes is are typical for AC and DC electric drives and can lead to in electric networks voltage drop and failures in their work. Currently, a significant result in voltage stabilization is achieved by using batteries as energy storage devices [1].

First of all, ground-based and space-based stand-alone photovoltaic (PV) power supply systems are equipped with battery energy storage devices [2]. However, using of electrochemical energy sources to amend start-up modes in power supply system isn't an optimal solution. Electrochemical energy sources are quite expensive, have a short-live and unable to deliver high power to the current drain without degradation. They are charging and discharging slowly [3].

Currently, supercapacitors are being intensively researched for being used as a storage of electrical energy. They have noticeable advantages over batteries in terms of charge and discharge cycles num-

ber, charging and discharging speed, power amount delivery and the durability [4–9]. A full replacement of batteries with supercapacitors in energy storage is still impossible due to their low storage density. Although there is a publication about the samples of a graphene supercapacitor, which energy capacity reaches the lithium-ion battery's energy capacity [3].

The use of hybrid battery-capacitive storage devices is being intensively studied and seems to be relevant and promising direction in stand-alone PV system and grid power supply systems development [10–12]. The industrial use of such storage device requires a non-standard approach in the field of control and monitoring circuitry, because two parts of the storage device operate on different physical principles. The research task was to make a comparative analysis of the battery-capacitive energy storage device parameters.

Main body

Stand-alone photovoltaic system (SAPS) is successful and cost-effective solar energy project. The block diagram of an SAPS is in Figure 1.

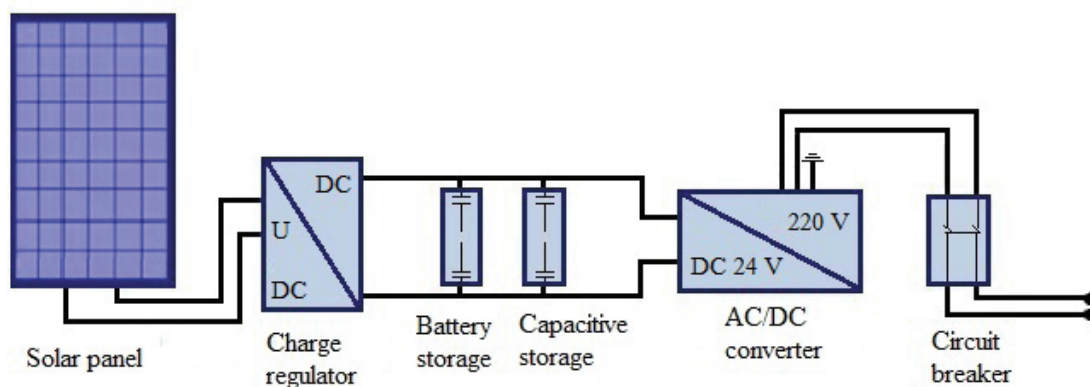


Figure 1 – The block diagram of an stand-alone photovoltaic system with the battery-capacitive energy storage

The SAPS power ranges from 0.1 kW if it's used as a power supply of security systems up to 256 kW if it's used as a life support of the international space station. It is expected that if SAPS is equipped with hybrid battery-capacitive storage device it will significantly increase its applicability and improve its capacity for inrush current drain compensation. Figure 2 shows the block diagram of the developed testing bench for the shape and measurement monitoring of inrush current characteristics of a hybrid battery-capacitive energy storage.

The lithium-ion battery (LIB) part of the storage device is the "ATOM 10" multifunctional motor drive device of the new generation, manufactured in RF, which contains lithium-ion battery with 9.4 A·h capacity, 15 V peak voltage and 300 A inrush current.

The capacitive part of the storage device is the INSPECTOR Booster supercapacitor manufactured in ROK. The main feature of this type of devices is the absence of built-in batteries. Instead of batteries in this device is used a block of supercapacitors with

80 F electrostatic capacitance, 15.5 V voltage capability and 800 A inrush current. The application of such capacitive storage allows to guarantee its work if the open circuit voltage of the power sources is not above 15.5 V.

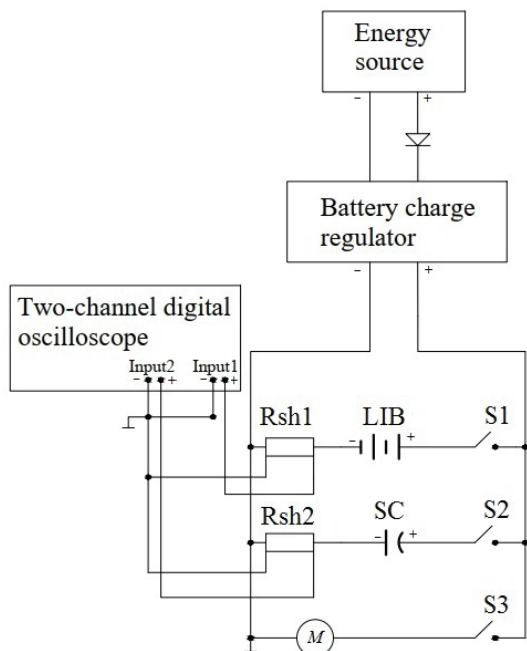


Figure 2 – Block diagram of the developed testing bench for the shape and measurement monitoring of inrush current characteristics of a hybrid energy storage

In developed testing bench battery and capacitive energy storage parts are joined-up in parallel and connected to the power source with the built-in charge adjustment device of the “ATOM 10” and the blocking diode. Adjustment device is used as maximum voltage limiting of storage device at 15 V. The blocking diode prevents the backstreaming of electrical current from the storage device into the energy source.

Testing bench allows to work with different power suppliers such as electrical grid with a step-down AC/DC converter (220 V, 50 Hz/12 V), or a 12 V solar battery or a 12 V DC car power grid, etc. In this research was used a step-down AC/DC converter which is turns off after full charging of the hybrid battery-capacitive energy storage and during the study of inrush charging currents.

As the current drain was used a DC electric air automobile compressor M-14001M manufactured by Mega Power, PRC. It is capable to simulate the charging current instability of the battery and capacitive parts of the energy storage.

The recommended supply voltage of electric air automobile compressor is (12–13.5) V. The maximum current consumption is 14 A. The current consumption value can be adjusted by increasing or decreasing pressure in the airline and controlled with the built-in manometer.

The testing bench measuring part consisted of a two-channel digital oscilloscope and two standard measuring shunts Rsh1 and Rsh2 with 15000 μOhm resistance which serial attached to LIB part and capacitive part of the energy storage device. Oscilloscope was used for monitoring shape and measurement parameters of single and periodic electrical signals in the frequency range up to 60 MHz with a maximum sampling rate of 1 GS/s and an equivalent frequency of 25 GS/s. The oscilloscope has two synchronous channels equipped with A/D converter and attenuators.

Analyzed signals are fed to the inputs of the attenuators, where the synchronization signals are generated, which are fed to the synchronization circuit. As well as the signals fed to the inputs of two A/D converters, which convert the analog signals into a digital code processed in the conversion device. The oscilloscope provides digital measurements of voltages, time intervals impulse front and fall time and amplitudes of periodic signals.

Measuring electrical shunt is a conductor with ultra-low resistance, or a low-resistance resistor. The shunts can be used for DC current measurements in the range of 5–15000 A. Shunt resistance ranges from 5 $\mu\Omega$ to 15000 $\mu\Omega$. The rated voltage drop of the shunt is 75 mV. The maximum permissible basic error of shunts δ_0 at any current drain not more than $\pm 0.5\%$ or $\pm 1.0\%$ of the rated resistance. Accordingly, the accuracy class of shunts for 5 A is 0.5 and for 15000 A shunts – 1.0.

The current is measured in following manner (Figure 3): the voltmeter is connected to the shunt with potential fan. The moment the current flows through the current shunt, a voltage drop measured by the voltmeter occurs at the potential fan. The current strength is determined by dividing measured voltage by the electrical resistance of the shunt – 15000 μOhm .

Shape and measurement monitoring of inrush current characteristics of a LIB part and capacitive part of the energy storage was carried out according to the block diagram of the testing bench on real time basis synchronously with using a two-channel digital oscilloscope and recording on FAT32 file system

USB flash drive. Obtained data was transferred to a personal computer and analyzed.

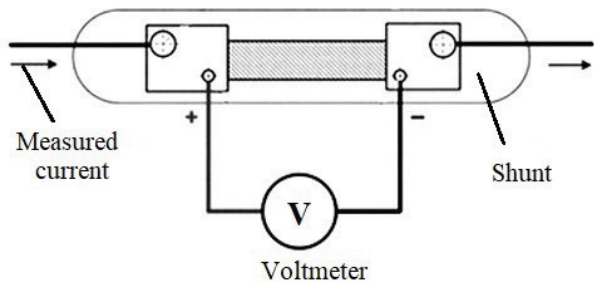
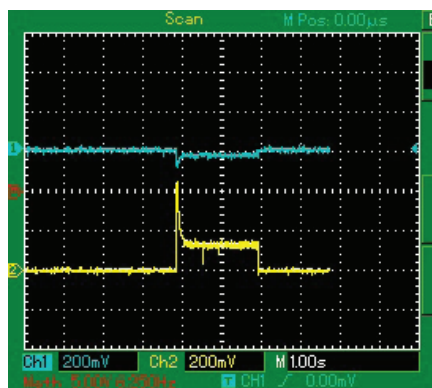
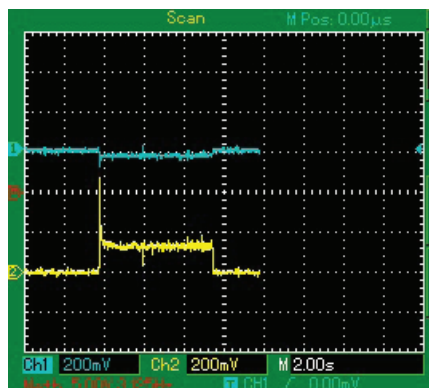


Figure 3 – Shunt connection to voltmeter

It is convenient to monitor the shape of the discharge current triggering pulses by changing the index of the sweep trace (Figure 4).



a



b

Figure 4 – Triggering pulses oscillograms which were recorded at sweep traces of 1 s/div (a) and 2 s/div (b)

Table

The results of measuring the inrush discharge characteristics of the hybrid LIB-capacitive energy storage

Type of energy storage device	Shunt voltage, mV	Shunt resistance, μOm	Inrush current amplitude, A
LIB part	80	15000	5.3
Capacitive part	440	15000	29.3

Data in the table shows that 82.3 % of the compensation for electric motor start energy losses is taken over by the capacitive part of the energy storage device, what prolongs life of expensive LIB storage devices.

Conclusion

On the basis of modern charging and motor drive devices was developed a hybrid lithium-ion

The input of channel 1 (Ch1) from the shunt Rsh1 is supplied with a signal from the LIB part of the energy storage device (blue color trace of the oscillogram), the input of channel 2 (Ch2) from the shunt Rsh2 is supplied with a signal from the capacitive part of the energy storage device (yellow color trace of the oscillogram). As you can see from the oscillograms, a decrease in the sweep trace allows to analyze the shape and duration of the trigger pulses more detailed.

From the oscillograms we know the scale of the measured voltage and counting the divisions' number from the zero to maximum of steps height, we also know the resistance of each shunt (15000 μOm), and so we can determine the voltage and calculate the values of the inrush currents amplitudes.

Measured data from oscillograms (Figure 4a) are in the table.

battery-capacitive energy storage device. A measuring unit was based on a two-channel digital oscilloscope and method of synchronous registration and measurements of stationary and mutual characteristics of lithium-ion battery part and capacitive part of the energy storage device. Experimental research have been carried out inrush current parameters consumed by an electric air compressor. This research clearly demonstrate the advantages of a hybrid storage device.

The developed method for monitoring shape and measurement inrush current characteristics can be used in various technical applications: smart stand-alone photovoltaic system, uninterruptible power supply devices, electric drive control systems, etc.

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