ENERGY STORAGE CHARGING MODULE WITH DIGITAL CONTROL

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Abstract

The paper considers a module for charging energy storage cells - supercapacitors or rechargeable batteries. The module is controlled via a digital interface to achieve constant current, constant voltage or constant power modes of operation. The control of the module is through an Arduino based system. This allows the construction of a control system for the charging processes of the individual cells, including a virtual instrument.

В статията е разгледан модул за зареждане на клетки за съхранение на енергия – суперкондензатори или акумулаторни батерии. Модулът е управляван, чрез цифров интерфейс и може да работи в режими на константен ток, константно напрежение и константна мощност. Управлението на модулът се осъществява посредством Arduino базирана система. Това позволява изработването на система за управление на зареждането на всяка клетка включваща виртуален инструмент.

Keywords: DC-DC, digital control, energy storage, charging.

INTRODUCTION

The energy storage systems are conprised of series-connected cells which voltages must be equalized. The equalization is accomplished through additional charging current or discharging of the cell. The paper considers a variant in which current is added to the cell with the help of an additional DC-DC converter. In the experimental part a converter with digital control capabilities based on InnoSwitch 3 Pro was investigated.

InnoSwitch 3 Pro is a series of digital controllers for DC-DC converters operation in constant voltage, constant current and constant power modes and has built-in synchronous rectifier control. The controllers have I²C interface through which the digital communication is carried out for setting the operating mode and its parameters. For the purposes of the study an RDK-641 development board containing an INN3377C based converter and a PIC16F18325 MCU was used to demonstrate the digital control capabilities. It's possible to disconnect the built-in MCU from the I²C bus and connect an external controller instead as was done with Arduino board for the experiments. The

aim of the study of a digitally controlled converter is its use in active voltage balancing systems to equalize the voltages of energy storage elements by supplying an additional charging current to each element ina a series-connected cell pack as shown in Fig. 1.
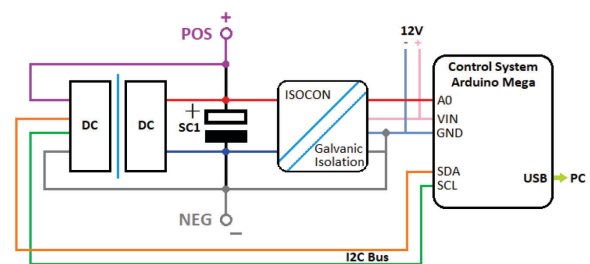

***Fig. 1** – One element charging circuit*

EXPOSITION

A) Control via I²C

The control of the converter is carried out by setting the mode and its parameters via writing the corresponding values in the registers of the InnoSwitch controller through the I²C interface. Fig. 2 shows the connection of the development board with the converter to the Arduino control board.
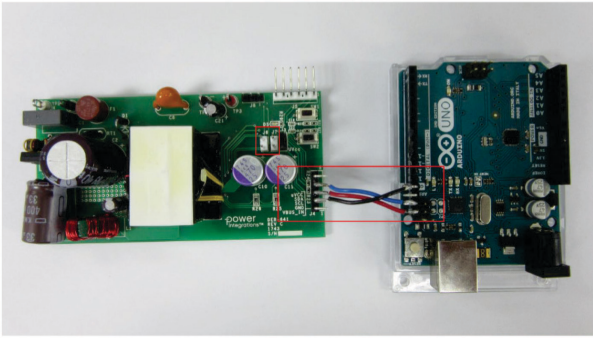
Fig. 2 – RDK-641 connection to the Arduino

B) Commands for setting voltage and current

For the study one of the provided examples with the manufacturer software library was modified and used to provide the desired voltage and current for the various experiments and to output data to the control system so that it could be logged and used to plot the collected data.

Management is done by using the parameter setting library functions provided by the manufacturer library. Fig. 3 shows block diagram of the library structure and its levels of abstraction. The library provides the hardware drivers, the communication drivers for the InnoSwitch controller - frame formation and compliance with the timing parameters of the communication and an API providing the functions for parameter setting and calculation of the registers values with the required parity checks.
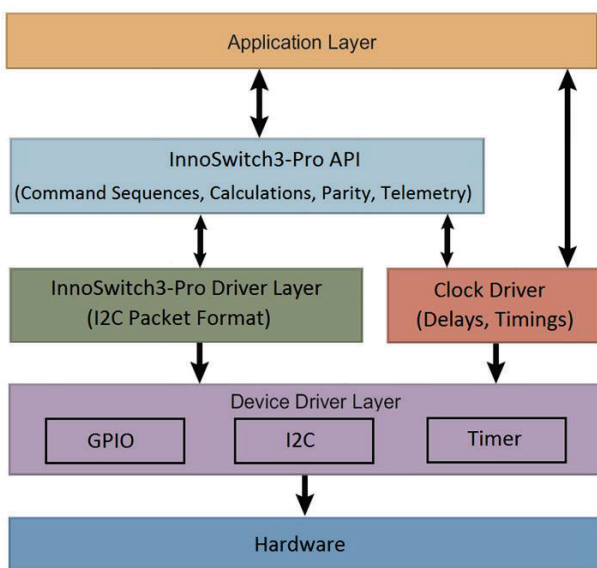

Fig. 3 – InnoSwitch control library structure block diagram

Communication with the controller requires the creation of control objects and the initialization of the library, as shown in Fig. 4.

```
42.  //Step  1  :  Add the Header Files
43.  #include <Drv_Rtc.h>
44.  #include <Drv_i2c.h>
45.  #include <Inno3Pro.h>
46.  #include <Inno3ProConfig.h>
47.
48.  //Step  2  :  Create the class instance
49.  Inno3Pro_Rtc Inno3ProClk;
50.  Inno3Pro_Application Inno3ProApp;
51.
52.  //Step 3 :  Write Initial Commands to Inno Pro
53.  void setup()
54.  {
55.    // initialize the serial communication:
56.    Serial.begin(9600);
57.    Inno3ProApp.Inno3Pro_Initialization();
58.  }
```

Fig. 1.4 – Library initialization

Output voltage and current are meeasured by the feedbacks of the InnoSwitch controller and their values are read from its registers using the code shown in Fig. 5.

```
72.    //Timer Routine For Automatic Activation of  Requests
73.    if (Inno3ProClk.clock_HasTimeElapsedMs(u16_Request_Timer, 100))
74.    {
75.
76.      Inno3ProApp.b_Request_Enable = true;
77.
78.      fReadVolt = Inno3ProApp.Inno3Pro_Read_Volts();
79.      Serial.print(fReadVolt);
80.
81.      Serial.print("\t");
82.
83.      fReadAmps = Inno3ProApp.Inno3Pro_Read_Amps();
84.      Serial.println(fReadAmps);
85.
86.      u16_Request_Timer = Inno3ProClk.clock_GetTimeStampMs();
87.    }
```

Fig. 5 – Measurement of voltage and current

The desired output voltage setting for the constant voltage mode and the current limit for the constant current mode are set by the command at line 89 shown in Fig 6. Line 90 shows a command to set an additional voltage to compensate for the voltage drop across the connecting cable to the load, setting the voltage in [mV]. On line 91 is the command to set the threshold voltage (in [V]), after which the converter goes into constant output power mode (power limitation). Line 92 shows the output switch control command, which turns power on and off at the board's output terminals, with 1 turning the output on and 0 turning it off. When power is initially applied to the converter the output is turned off and the power-on command must be executed at least once atfer the converter is powered on. By setting the voltage and

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current before turning on the output, time is provided for the converter to reach the desired output voltage before it is applied to the output terminals.

```
88.    //Set Voltage and current
89.    Inno3ProApp.Inno3Pro_Write_VI(10, 2.0);
90.    Inno3ProApp.Inno3Pro_Write_Cable_Drop_Comp(300);
91.    Inno3ProApp.Inno3Pro_Write_Volt_Peak(7);
92.    Inno3ProApp.Inno3Pro_Vbus_Switch_Control(1);
```

Fig. 6 – Setting of voltage and current

With the use of this program experimental studies of the behavior of the converter at different set parameters were made at different active load resistances which have been simulated using a programmable electronic load operating in the constant resistance mode in order to observe the different operating modes of the converter and the transitions between them. In a real voltage balancing system, the load will be an energy storage element such as battery or supercapacitor.
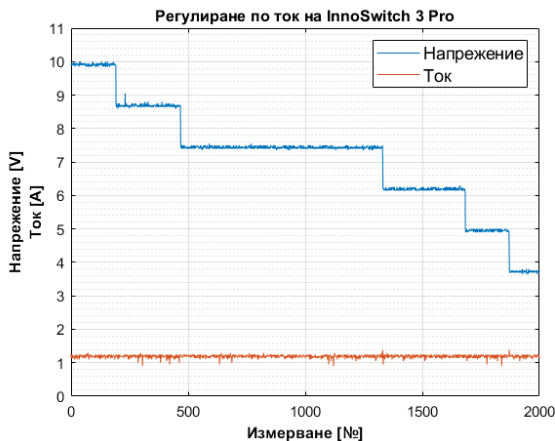
EXPERIMENTAL RESULTS

Fig. 7 – Output voltage and current in constant current mode of operation at 1 A and different load resistance

Fig. 7 shows the change of the output voltage (blue) when the active load resistance changes with the programmable load, thus the output current (orange) remains constant, which means that the converter works in constant current mode. It can also be seen that the minimum current in this mode is ~1.2 A which is determined by the shunt resistance which is 5mΩ and a 32 mV drop across it at a maximum current of 6.4 A and the minimum current is 20% of the maximum which makes 1.28 A. When charging a battery the

maximum voltage must be reduced to the desired maximum charging voltage for the cell.

In Fig. 8 to 12 show the output voltage and current at different load resistances, in constant voltage mode set to 10 V and current limit from 1 A to 5 A. On each graph the moment of transition from constant voltage to constant current mode is indicated by an arrow. In each figure, the values of the software-set voltage and current are shown with dashed gray horizontal lines, and the load at which the converter is expected to switch from constant voltage mode to constant current mode is shown with a purple vertical line. The actual transition between the two modes is indicated by an arrow. The difference between the expected and the actual transition moment is due to the resistance of the connecting wires.
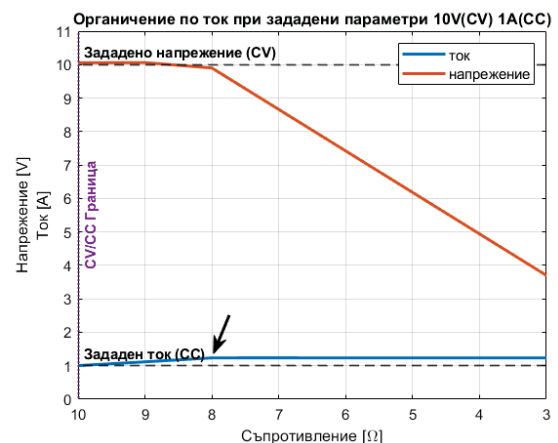
Fig. 8 – 10 V CV / 1 A CC Mode

In Fig. 8 the transition occurs when the minimum current for the constant current mode is reached at ~1.2 A.
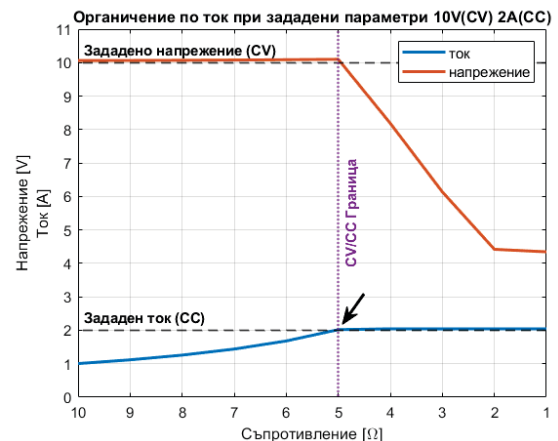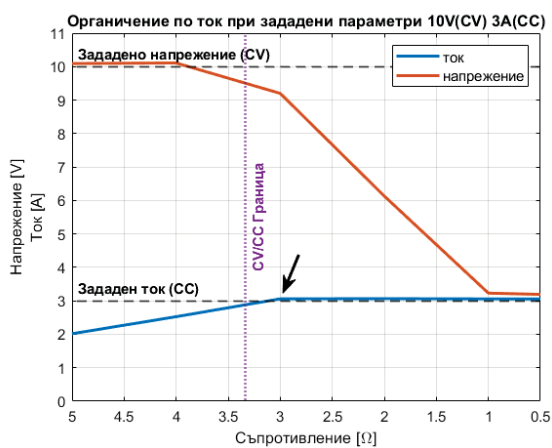
Fig. 9 – 10 V CV / 2 A CC Mode

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Fig. 10 – *10 V CV / 3 A CC Mode*

In Fig. 9 and 10 the voltage almost does not change towards the end because of the resistance of the connecting wires and because of the set compensation of the voltage drop on them, which is set with the same value for all the experiments. In Fig. 11 and 12, a slight increase in voltage is also observed at very low load resistance, which is also due to the cable voltage drop compensation.
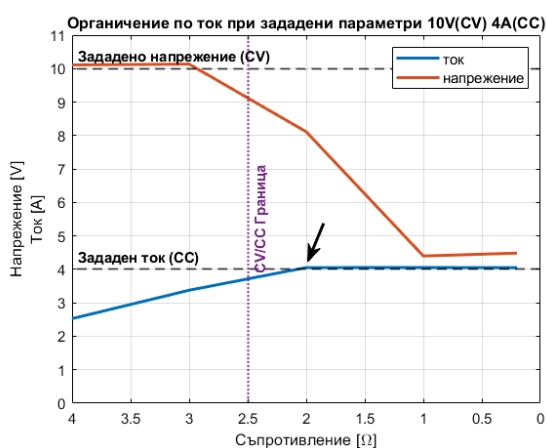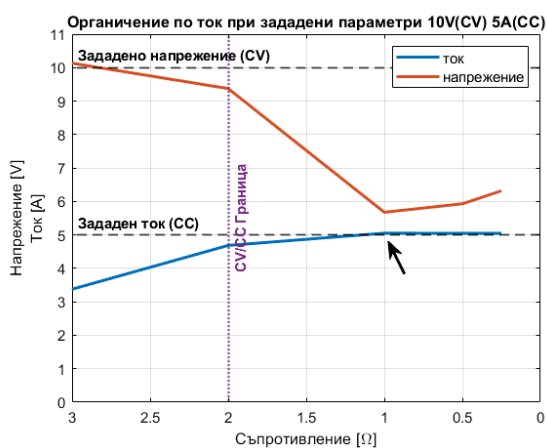

Fig. 11 – *10 V CV / 4 A CC Mode*

Fig. 12 - *10 V CV / 5 A CC Mode*

Tab. 1 and 2 give the output voltage and current values measured with a digital multimeter and the ones read from the InnoSwitch feedbacks through the I²C interface. Voltage is measured at no-load(idle).

Зададено	11V	12V	13V	14V	15V
Мултимер	10,998V	11,998V	12,998V	13,998V	14,998V
InnoSwitch	11,86V	11,84V	12,8V	13,75V	14,72V

Tab. 1 – *Voltage feedback evaluation*

The current was measured with a programmable load connected to the output in constant current mode with the corresponding current magnitude.

Зададено	1A	2A	3A	4A	5A
Мултимер	0,998A	1,999A	3A	4,002A	5,002A
InnoSwitch	1A	1,98A	2,96A	3,94A	4,905A

Tab. 2 – *Current feedback evaluation*

CONCLUSION

From the experiments and the data from them, it can be said that this type of converters can be successfully used in active voltage balancing systems. The converter supports all necessary operating modes – constant current, constant power and constant voltage. The digital control capabilities make this type of converter very convenient for working with a large number of cells where the battery management system can directly set the required additional equalizing current of each converter.

The maximum difference in the current and voltage measured by the feedback loops compared to the actual values measured with a digital multimeter is less than 2%, which is accurate enough for this type of converter to be used in voltage balancing systems.

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