Study of the elements of the photovoltaic system

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In this paperwork has been made a study of the elements of an off-grid photovoltaic system for power supplying of telecommunication systems and telecommunication modules. The laboratory model is described. The bi-directional converter provides mutual work between a supercapacitor and a battery in the system. The stage of charge and discharge of the battery is managed by BMS. The working algorithms of the converters in the system are studied. The information-measuring system of the stand is realized by the software LabView.

Изследване на елементи от фотоволтаична система (Димитър Д. Арнаудов, Николай Л. Хинов, Иван И. Недялков). *В работата са изследвани елементи от автономна фотоволтаична система за захранване на телекомуникационни системи и устройства. Опиисан е стенд за изследване на системата. Двупосочен преобразувател осигурява съвместната работа на суперкондензатор и акумулаторна батерия в системата. Процесът на заряд и разряд на батерията се управлява от BMS. Изследвани са алгоритми на работа на преобразувателите в системата. Информационно измервателната система на стенда е реализирана със софтуера LabView.*

Introduction

From conducted analysis for power supply needs of telecommunication equipment in places where such power cannot be provided from the grid, the best way to deliver power is by using the power of the sun. The photovoltaic systems, for power supply of telecommunication equipment, which are not connected to the grid and are intended to supply constant current loads, are made of the following blocks: photovoltaic, photovoltaic controller, battery and load. For improving the lifecycle of the battery, a supercapacitor can be added to the system [1], [2], [3].

The battery in the system mostly is lead-acid. It can be replaced with lithium battery. The photovoltaic controllers are designed to work with lead-acid batteries, which output voltages are 12V, 24V and 48V. To obtain a battery with these voltages and needed capacity, it is necessary to connect some lithium cells together (in series and/or in parallel). If we don’t want to overcharge the single cells of the lithium battery, it is strongly recommended to use a device, which provides charging equalization (BMS) and also provides correct and even charging of the separated cells [4], [5], [6].

The main functions which this kind of devices should perform are:

- Stop charging of the cell when the cell voltage reach its maximum;
- Prevent temperature rising over a certain limit, by ending the charging current;
- Prevent the discharge of the cell under a certain limit;
- Restrict the charging and discharging current in allowed limits.

1. Photovoltaic off-grid system

On Figure 1 the block diagram of studied system is shown. The system is made by the following blocks:

- PV Panel – photovoltaic panel, which is the main power source in the system;
- PV Controller – the controller is used to provide the working modes of the battery, and MPPT;
- DC-DC – bi–directional converter which provides the mutual work between the supercapacitor and the battery;
- Battery – made of lithium cells connected in series;
- BMS – this device provides the charging equalization of the battery;

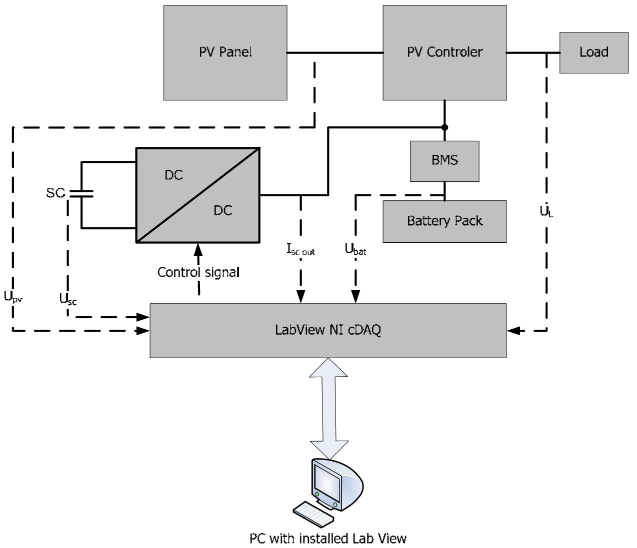

Fig.1. Block diagram of the laboratory model.

- Load;
- Information-measuring system – this system is used for control and measuring of parameters in the studied PV system. It is made of device for data acquisition and generation of control pulses (chassis NIcDAQ with programmable TTL input/output modules for managing converters and analog to digital converter for measuring);
- Virtual instruments created in LabView environment for managing the hardware.

The measured parameters in the system are:

- Usc – voltage over the supercapacitor;
- Upv – voltage in the output of the photovoltaic;
- Uab – voltage over the battery;
- UL – voltage over the load;
- Icharge – charging current;
- Isc out – discharging current across the supecapacitor.

With the help of the developed laboratory model all elements of the studied system can be tested [7]. The elements which are tested and described in this paperwork are: the working modes of the battery with and without BMS; working regimes of the bi-directional converter and working algorithms of the Control System.

2. Control System

For testing different kind of working modes of the system, a virtual instrument is developed by the software LabView [8], [9]. The virtual instrument contains two main modules – Front Panel and Block Diagram. The Front Panel of the developed Virtual Instrument is shown on Figure 2.

The scales are shown on the front panel. The parameters which are measured by these meters are described above. The indicator named LED1 shows when the supercapacitor is charged to one predefined value and LED2 shows when the voltage in the output of the PV module is lower than a predefined value (for example 14V).

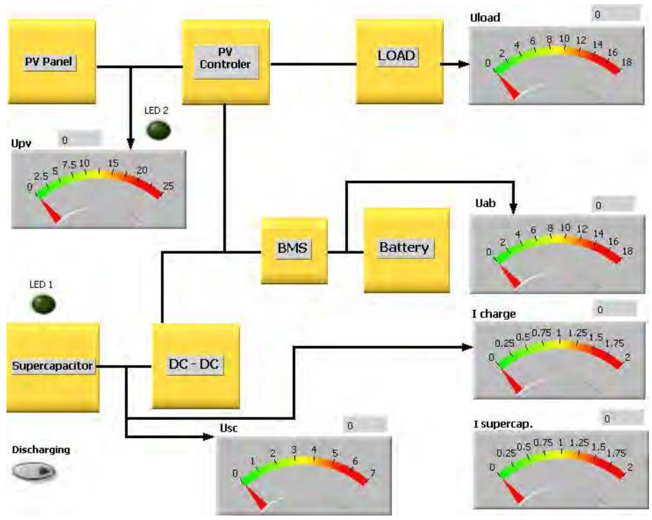

Fig.2. Front Panel of the Virtual Instrument.

The discharge button in the Front Panel is used for manual starting the discharging of the supercapacitor. This is made for imitating different kinds of working modes of the system.

Part of the Block Diagram of the Virtual Instrument is shown on Figure 3.

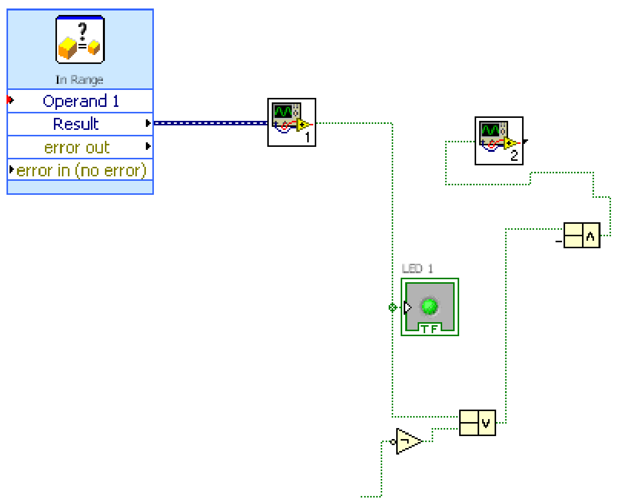

Fig.3. Part of the block diagram of the virtual instrument.

During the development of system's working algorithm and the creation of the block diagram of the virtual instrument, some subprograms are used (sub virtual instruments) – SubVI. The graphic presentations of these subprograms are shown on Figure 3, named as block number 1 and block number 2.

The comparator "InRange" compares the measured instantaneous value of voltage over the supercapacitor with one predetermined value. If the measured value is bigger than the predetermined one, in the output of the comparator we have logical 1. If the measured value is lower than the predetermined one, in the output we have logical 0.

SubVI 1 is subvirtual instrument, made of several elements, which are used to convert the output signal from the comparator in a suitable signal for further treatments.

SubVI 2 is another subvirtual instrument, which is used to convert the signal from SubVI1 in signals, suitable for generation of control pulses, for managing the bi-directional converter. These pulses are generated in the TTL outputs of the chassis cDAQ for managing the bi-directional converter.

Part of the working algorithm of the system is: the charging of the supercapacitor is made only when the output voltage of the PV panel is over a predetermined value. The charge stops when the supercapacitor is charged.

Another main block is the Control System of the battery.

3. Studying of BMS for lithium–ion battery.

The circuit of the connected cells to the tested BMS is shown on Figure 4.

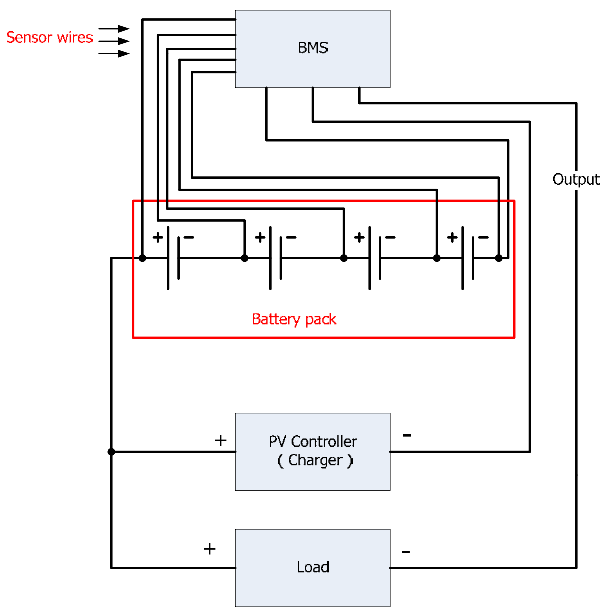

Fig.4. Block diagram of the tested BMS.

The tested BMS is used to control the charge of four lithium battery cells, which are connected in series.

One wire sensor is connected to the positive electrode of each of the separate cells for measuring each single cell. To the negative electrode of the first cell a wire sensor is also connected. This is done because this is the point to which the BMS makes all measurements of the other cells.

Charging and discharging of the battery has been made with and without using BMS.

The results of charging the battery with BMS are shown on Figure 5. The voltages over the four cells are shown. From the waveforms we can see that during charge the difference between the voltages over the different cells are insignificant.

On Figure 6 are shown the results of charging the battery without using BMS. The voltages over the four cells are shown. As we can see from the waveforms during the charge, the difference between the voltages over the four cells are significant. And if we track the cell with the biggest capacity, we will overcharge the other cells.

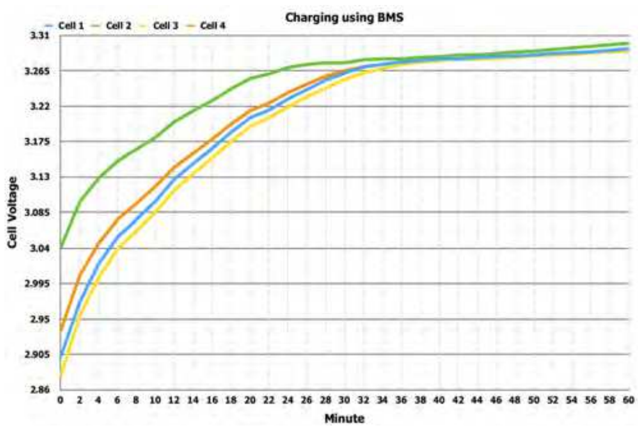

Fig.5. Charging characteristics with BMS.

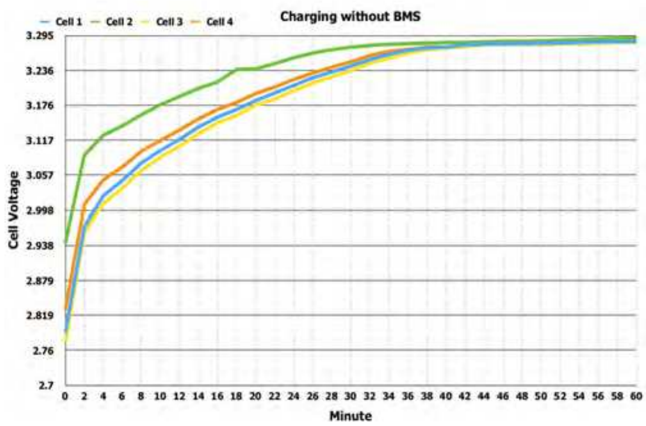

Fig.6. Charging characteristics without BMS.

The following two figures represent the results from discharging the battery, by using or not the BMS.

Figure 7 shows the measured parameters of the separate cells in discharging mode, without using the BMS.

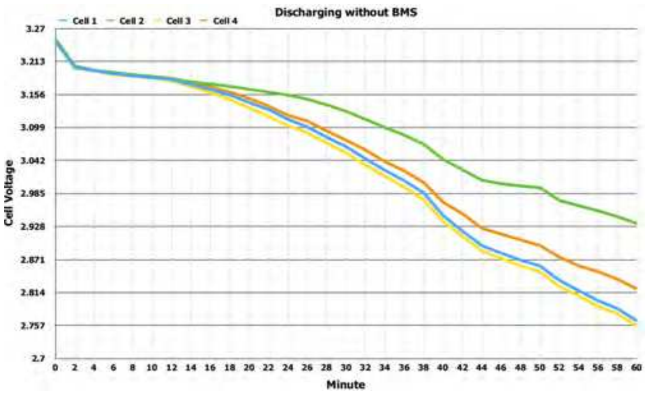

Fig.7. Discharging characteristics without BMS.

As we can see from the results, the discharge of the separate cells is not even – one of the cells discharges faster, than the other. This is unwanted, because it will lead to faster drop of the voltage level over this cell, triggering irreversible processes in it.

Figure 8 shows the results of discharging mode of the cells, by using the BMS.

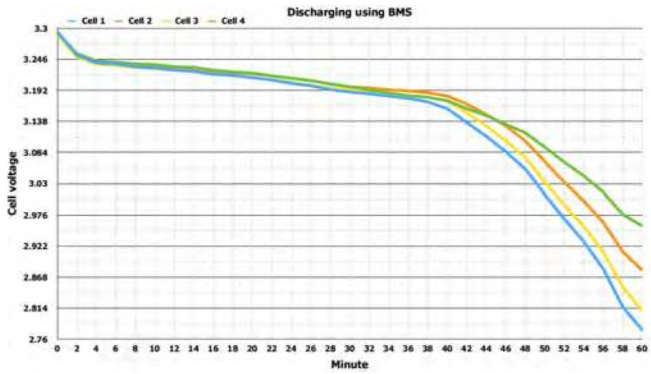

Fig.8. Discharging characteristics using BMS.

From the presented results on Figure 8, it is obvious that using BMS, during discharge, leads to more evenly discharging of the separate cells, which extends their lifecycle.

The analysis of the experimental results, shows that the tested BMS provides mainly protective functions – protects the battery pack from overcharging and deep discharge.

4. Bidirectional converter

The circuit of the tested bi-directional converter is shown on Figure 9 [7].

The converter is made of two specialized integral circuits of switching DC-DC converters - U_1 and U_2.

The converter is connected to the system and it is tested in charging and discharging mode of the supercapacitor.

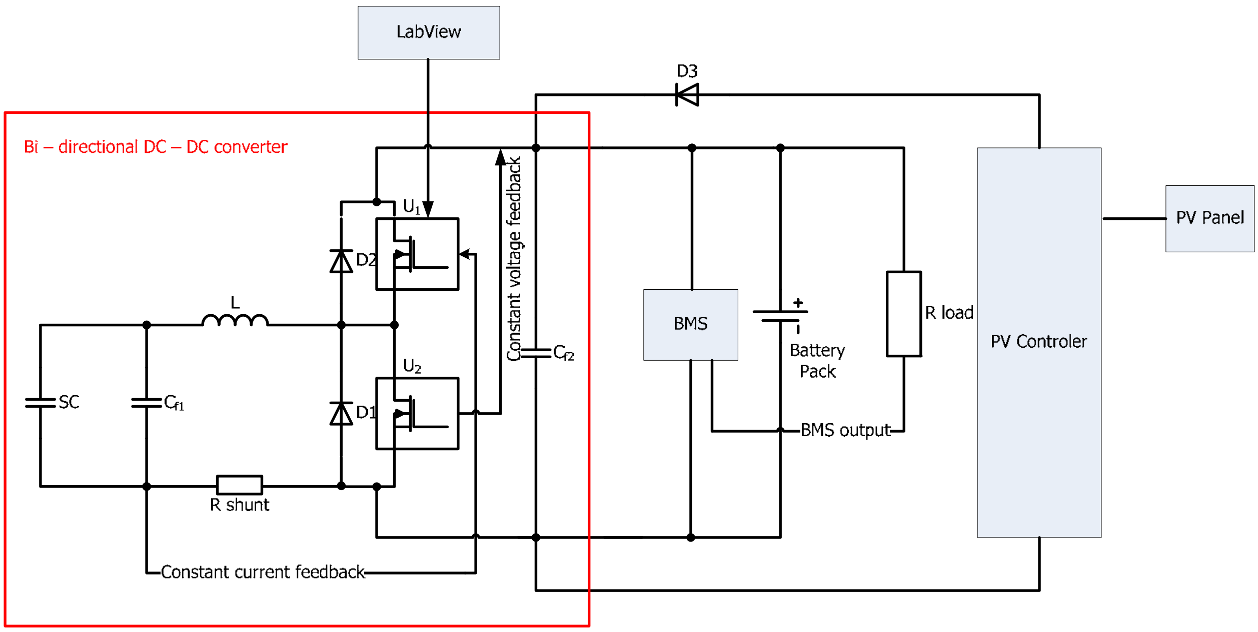

Fig.9. Circuit of the examined Bi – directional DC – DC converter.

Experimental testing of the bi-directional converter in charging mode.

On Figures 10, 11 and 12 are shown the results of the experimental testing in charging mode. The presented results are: voltage over transistor, integrated in IC U1; voltage over the supercapacitor; current across the inductor.

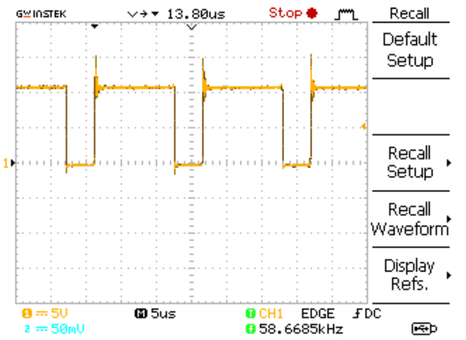

Fig. 10. Voltage over the switch during charging of the supercapacitor.

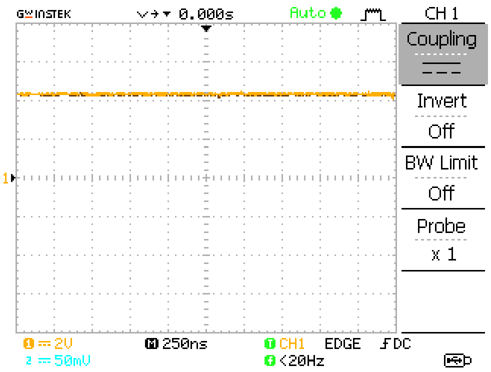

Fig. 11. Voltage over the supercapacitor.

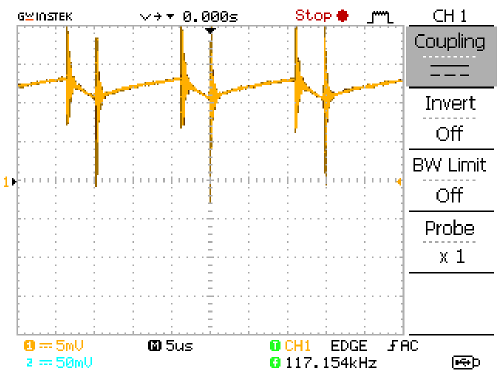

Fig. 12. Current across the inductor.

5. Modeling of the bi-directional converter

For a more detailed study of the bi-directional converter in a power supplying system, a MatLab Simulink model is developed. The MatLab Simulink model is shown on figure 13.

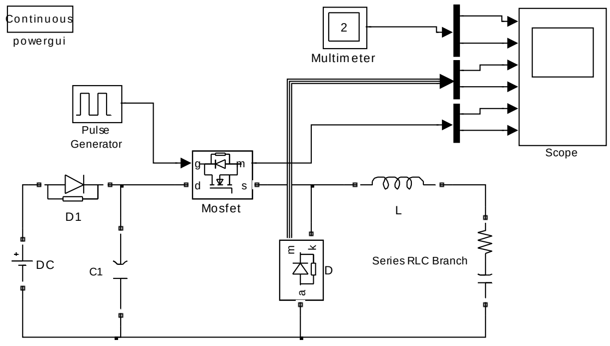

Fig. 13. Matlab Simulink model.

The results of the modeling are shown on Figure 14. From top to bottom are shown: voltage over the supercapacitor; current through the supercapacitor; current through the diode D (which corresponds to diode D1 from figure 7); voltage over the diode D; current through the transistor (which corresponds to the transistor integrated in IC U1); voltage over the transistor. These results are confirmed by the experimental results.

By the developed MatLab Simulink model optimal working regimes of the control system can be searched. Likewise the transients in the converter can be explored by different disturbance. By using a system for designing of converters, it is very easy to get the values of the elements, by different output conditions [10].

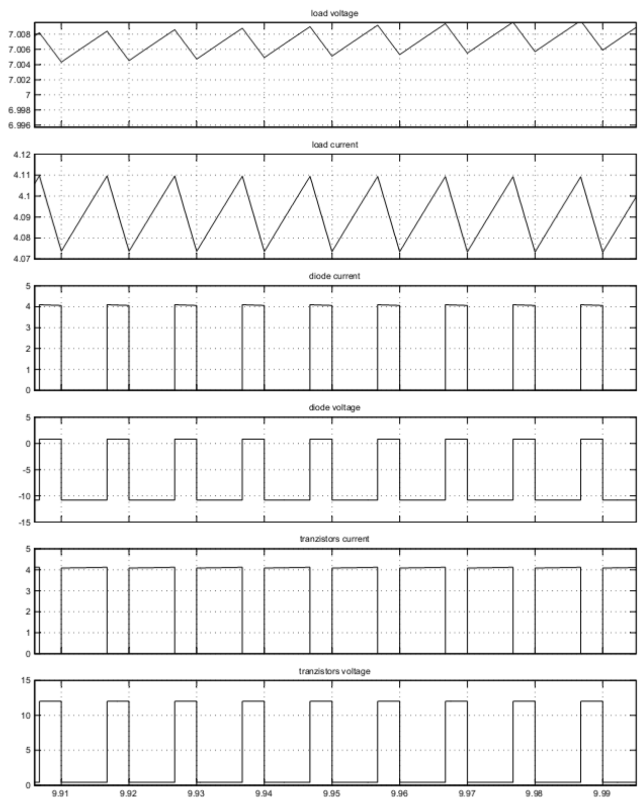

Fig. 14. Simulation results.

6. Simulation studies of circuit for charging of supercapacitor allowing voltage equalization

Simulation studies have been made of a circuit for charging of supercapacitor made of three series connected cells. The simulation model, made by the software LTSpiceIV, is shown on Figure 15. The three series connected cells are: C_{SC1}, C_{SC2} and C_{SC3}. They are shown with their equivalent series connected resistors. The power source is realized by a half-bridge resonant inverter, with voltage limitation over the switching capacitor. The results of the simulation are shown on Figure 16, Figure 17 and Figure 18. On Figure 16 and Figure 17 are shown: the voltage across the first cell- V(n014); the voltage over the second cell- V(N016,N014), the voltage over the third cell- V(N018,N016) and the current through the inductor Lk.

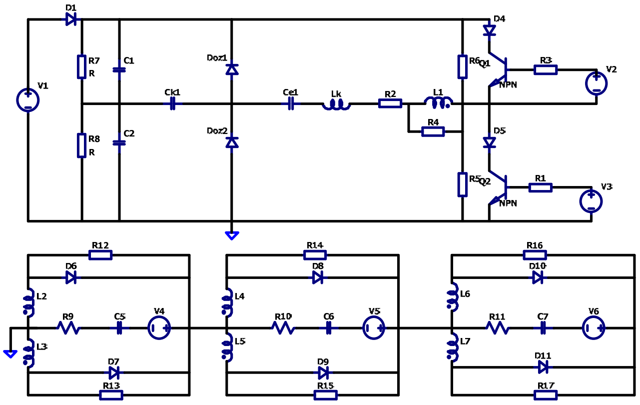

Fig.15. Simulation model of tested circuit.

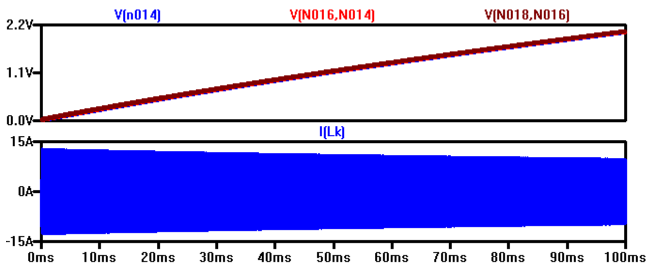

Fig.16. Simulation results.

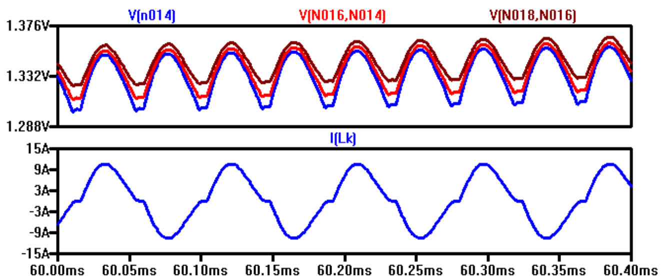

Fig.17. Simulation results.

On Figure 18 are shown: the current through the transistor Q1 – Ic(Q1) and the current through the inductor Lk.

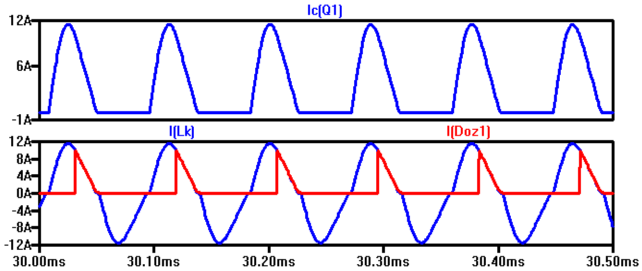

Fig.18. Simulation results.

From the waveforms shown on Figure 16, we can see that the difference between the voltages over the separate cells is insignificant.

Conclusion

1. For the realization of the mutual work, it is appropriate using the proposed circuit topography.
2. The tested circuit provides distribution of the energy between the energy storage elements and their effective use.
3. A flexible information – measurement system based on different specifically designed virtual instruments, allowing studying of different working algorithms of the converters is proposed. By using it, the optimal working regimes and optimal parameters of the elements in the system, can be searched.
4. In order to enhance the efficiency and reliability of energy storage systems, it is necessary to search for solutions of converters, on the one hand for charging and achieving voltage equalization of series connected battery cells or supercapacitor cells, on the other hand.

Acknowledgements

This research was funded from the scientific and research sector of the Technical University of Sofia under contract №142ПД0012-03 “Study of dc – dc electric energy converters with applications in telecommunication systems”.

REFERENCES

[1] Glavin, M., W. Hurley. Optimisation of a Photovoltaic Battery Ultracapacitor Hybrid Energy Storage System. Solar Energy 86 (2012) 3009–3020.

[2] Miller, Dr. J., M. Prummer and Dr. A. Schneuwly. Power Electronic Interface for an Ultracapacitor as the Power Buffer in a Hybrid Electric Energy Storage System. WHITE PAPER, Maxwell Technologies.

[3] Smith, I.C. Benefits of Battery – Ultracapacitor Hybrid Energy Storage System. Fulfillment of the requirements for the degree of Master of Science in Electrical Engineering at the Massachusetts Institute of Technology, June 2012.

[4] Chalczuk, M., L. Rzesiak, B. Ufnalski. A Lithium Battery and Ultracapacitor Hybrid Energy Source for an Urban Electric Vehicle. Maszyny Elektryczne:zeszyty problemowe, Vol.95, 2012, pp.13-20.

[5] Andrea, D. Battery Management Systems for Large Lithium-Ion Battery Packs. ARTECH HOUSE 2010.

[6] Daowd, M., N. Omar, P. Van Den Bossche, J. Van Mierlo. Passive and Active Battery Balancing comparison based on MATLAB Simulation. Vehicle Power and Propulsion Conference (VPPC), 2011 IEEE.

[7] Nedyalkov, I., D. Arnaudov, N. Hinov. Stand for testing of bi - directional converters in photovoltaic systems. Annual Journal of Electronics, Volume 8, Sofia 2014. pp. 223 – 226.

[8] http://www.ni.com

[9] http://www.metrisys.bg

[10] Vakovski, D. BUCK DC-DC converter. Сборник конкурсни теми по проект BG051PO001-3.1.09-0006. ТУ-София, 2014.

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Received on: 25.02.2015