Studying of Converter for Charging and Management of Energy Flows in Photovoltaic System

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Abstract – **In the following article a converter, providing management of the energy flow from the photovoltaic system (PV) to the elements for energy storage – supercapacitors, has been studied. The proposed converter provides charging and voltage balancing across series connected elements (supercapacitor cells). Simulation and experimental studies of the proposed circuit, from the PV system, has been made. Characteristics of the tested converter were made**

Keywords – **Supercapacitor charging, Resonant converter, PV system**

I. Introduction

For extending the operational life of a battery, used in a photovoltaic system, a mutual work between battery and supercapacitor is applied [1, 2, 3, 4, 5, 6]. The purpose of the supercapacitor is to provide high power to the load, for a short period of time, without using the battery and so to reduce the discharging/charging cycles of the battery. A typical example for such kind of load, requiring a lot of power for short period of time, is the telecommunication equipment, transmitting data at certain intervals of time. For studying the management algorithms of energy flows, via PV, battery and supercapacitor, a test bench of a PV system has been created [1].

In the proposed system the bi – directional converter, providing the energy transfer to/from the supercapacitor, is made of two unidirectional converters. The block diagram of the proposed system is shown on figure 1.

II. Management Algorithm for Energy Flow

To create a converter for charging supercapacitors and reservation of the energy, a circuit, proposed from the authors, is used. The proposed circuit is based on Resonant Converter with Voltage Limitation Over the Commutating Capacitor (RIVLOCC). The circuit of the charging converter is shown on figure 2. Figure 1 shows the block diagram of the proposed system.

The management algorithm is the following: When the PV system generates instantaneous power, bigger than the consumed power in the load, the difference between generated and consumed power is priority accumulated in the supercapacitor. When load demands higher power, the DC/DC2 converter provides the desired power, by the control system.

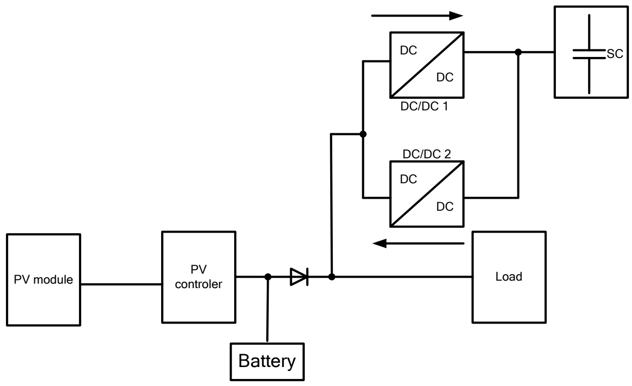

Fig.1. Block diagram of the proposed system

Because of the factory tolerances of the capacitors capacity, they discharges to a different voltage, since the consumed current, from the series connected capacitors, building the supercapacitor pack, is the same. When the voltage over one cell reaches zero, the consumptions must stop. In the following charge, it is necessary first to charge the cell, with the lowest voltage level. The circuit, providing these working regimes, is RIVLOCC. In the diagonal of it a double – phase, half – wave rectifiers are connected, by using an inverter transformers, which are used for charging of the supercapacitors.

There are other applications of supercapacitors in hybrid systems [7].

III. Studying of the Converter for Charging and Voltage Balancing over Series Connected Supercapacitors Cells

The working principal of the circuit from figure 2 is similar like the working principal of RIVLOCC. When the voltage across C_k reaches the value of $\pm U_d/2$, the limitation diodes (D_{d1} or D_{d2}) turns on and starts to conduct, where U_d is the power supplying voltage of the converter.

At the working process of the circuit, during charging of the supercapacitor cells, there is a moment when the limitation diodes D_{d1} and D_{d2} does not turn on. This is achieved when the voltage over C_k is always lower then $\pm U_d/2$. In this case the circuit works like Resonant Inverter with Reverse Diodes - RIRD.

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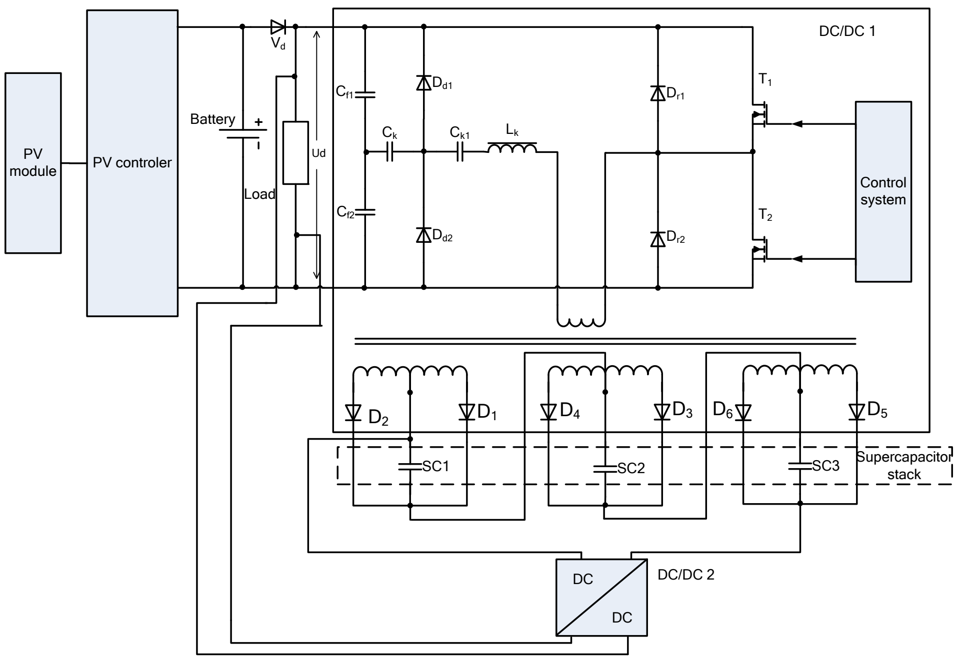

Fig.2. Proposed circuit for charging and balancing

Simulation and experimental studies of DC/DC 1 converter, from figure 2, has been made. The studies havebeen made on three supercapacitor cells. The capacity of cell 1 is 20% lower than cell 2. The capacity of cell 3 is 20% bigger than cell 2.

A simulation model, based on the circuit from figure 2 has been made, using LTSpice. The used transistors in the model are with low R_{DS}. The supercapacitors are presented with their equivalent model, made of series connected resistor and capacitor. For more precise simulation studies the supercapacitor models from [7] can be used.

For the simulation studies the capacity of the cells are significantly reduced, than the real, to assess the quality of the circuit, for less simulation time.

Figure 3 shows the waveforms of the charging currents through the supercapacitor cells – I(Csc1), I(Csc2), I(Csc3), and the voltage over the cells .

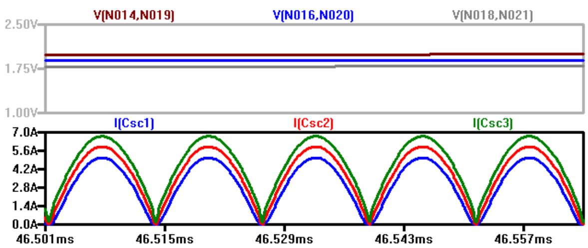

Fig.3. Charging currents and voltages over the cells

I(Csc1) is the charging current through cell 1, I(Csc2) is the charging current through cell 2 and I(Csc3) is the charging current through cell 3.

V(N014, N019) is the voltage over cell 1, V(N016, N020) is the voltage over cell 2 and V(N018, N021) is the voltage over cell 3.

As we can see from the waveforms, the difference in the voltages, between the cells is almost the same.

Figure 4 shows waveforms of the current through the transistor and its reverse diode – Id(T1), the current through the limitation diode – I(Dd1) and the voltage across the transistor – V(N002, N010). As we can see from the waveforms the transistor turns on, on zero current and turns off, on zero voltage (ZCS and ZVS).

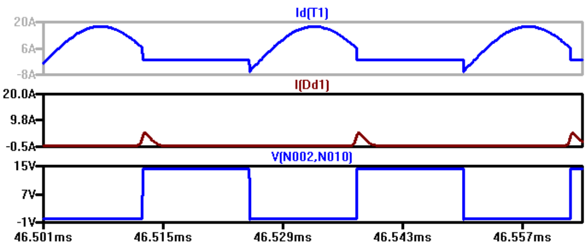

Fig.4. Current through transistor, reverse diode, limitation diode and voltage over the transistor

IV. Studying of Converter for Charging and Voltage Balancing over Series Connected Supercapacitor Cells, by Using CL – Filter on the Rectifiers

To charge the supercapacitor cells with constant current, instead charging with pulse current, the circuit on figure 5 is proposed. The outputs of the rectifiers are connected to CL – filters (Cff1 and Lff1).

Figure 6 shows the waveforms in the begging of the charging process. The shown waveforms are: current through one of the transistors and through its reverse diode – Id(T1), voltage over it – V(N002, N010), current through two of the rectifying diodes – I(Diz1), I(Diz2), current trough supercapacitor 1 – I(Csc1), and voltages over the three supercapacitor cells – V(N019, N021).

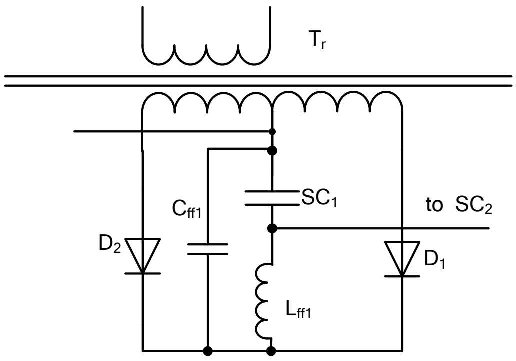

Fig.5. Using CL – filter on the rectifiers

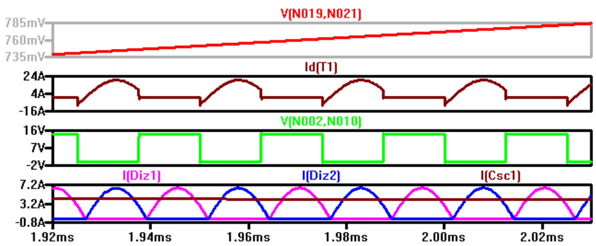

Fig.6. Currents and voltages in the begging of the charge

Figure 7 shows the following waveforms: current through one of the filter capacitors – I(Cff1), Currents through rectifying diodes – I(Diz1) and I(Diz2), voltage across diode D1 – V(N013,N014), the and current through one of the supercapacitors – I(Csc1).

As we can see, the maximum value of the charging current flows through the filter capacitor. Through the charged supercapacitors cell flows the average value of the charging current.

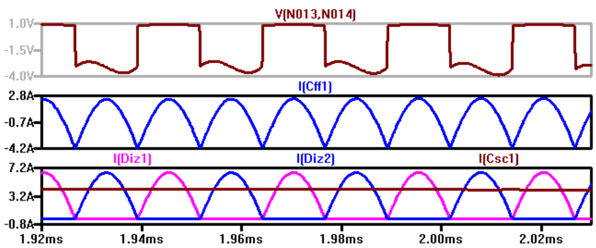

Fig.7. Currents and voltages in the load circuit

V. Experimental Studies

For conducting of the experimental studies of the circuit from figure 2, a test circuit has been developed. For management of the converters and testing different management algorithms of the energy flows, a virtual instrument has been developed, by using the software for graphical programming – LabView. The virtual instrument is described in [1]. Experimental studies for evaluation of the parameters of supercapacitors can be find in [8].

Figure 8 shows the current through one of the transistors and voltage over it, obtained from the experimental studies. As we can see the transistor turns at zero current and zero voltage, which confirms the simulation results.

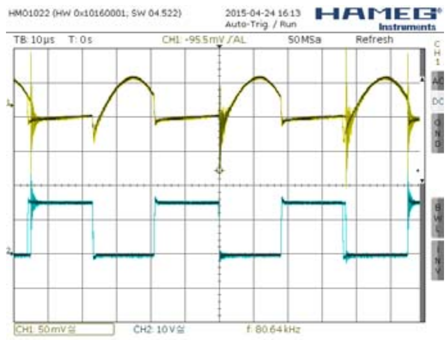

Fig.8. Current and voltage of one of the transistors

The characteristics from figures 9 to 13 are made from the carried out simulation studies. These characteristics show the change of the corresponding parameter, by changing the voltage across the charging supercapacitor cell – SC1. The characteristics are built up in relative units to the value of the corresponding parameter - beginning of the charge, when Usc = 0V

Figure 9 shows the change in the average value of the charging current through SC1.

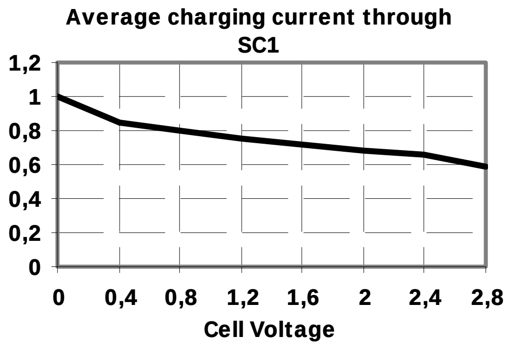

Fig.9. Average charging current characteristic

Figure 10 shows the consumed current by RIVLOCC in relative units. From the chart we can see that the consumed current is approximately constant.

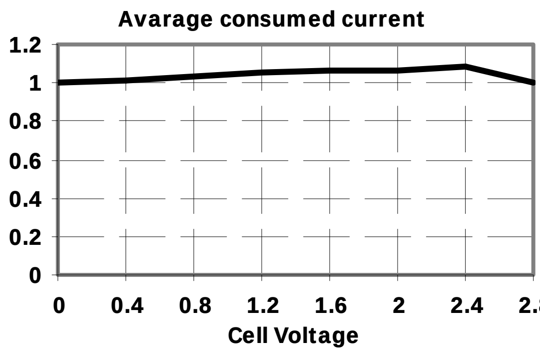

Fig.10. Average consumed current characteristic

The circuit is so designed that by reaching the value of 2,6V across the supercapacitor cell, the limitation diodes D_{d1} or D_{d2} stops working.

Figure 11 shows the change of the maximum value of the current through one of the transistors, during charging.

Figure 12 shows the characteristic of the maximum current through the reverse diode during the charging process.

Figure 13 shows the change in the maximum value of the current through the limitation diodes. From the chart we can see that, when the voltage across the supercapacitor cell is 2.6V, limitation diodes are turned off.

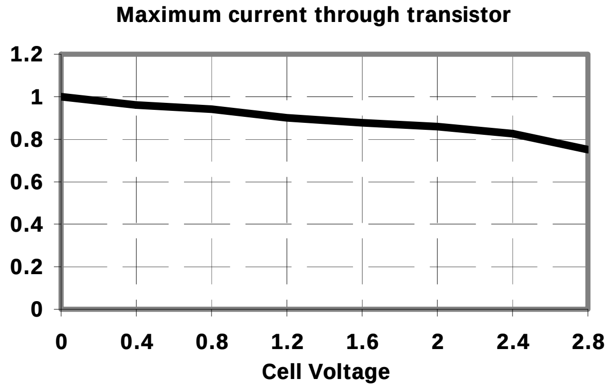

Fig.11. Maximum current through transistor characteristic

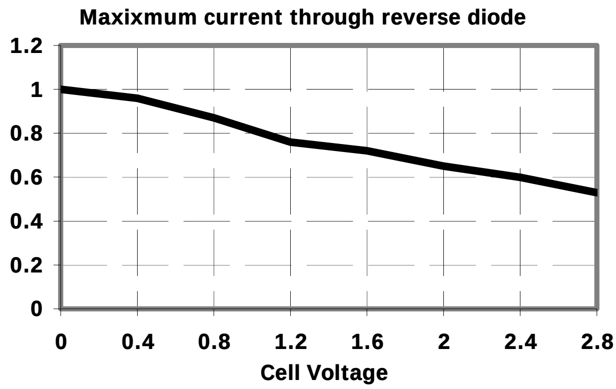

Fig.12. Maximum current through reverse diode characteristic

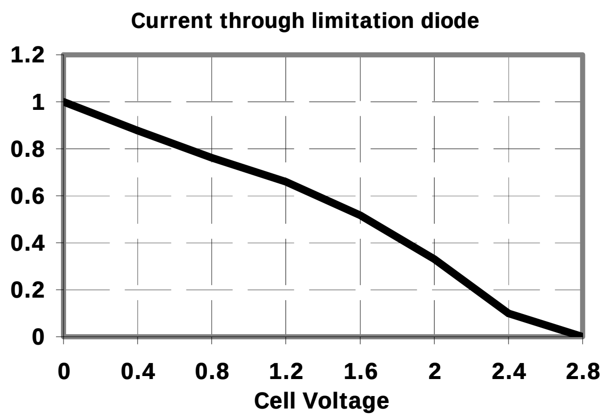

Fig.13. Maximum current through limitation diode characteristic

VI. CONCLUSION

1. Circuit of a converter for management of the energy flows at charging, of series connected supercapacitor cells, is developed. The circuit provides charge initially to the supercapacitor cell with the lowest voltage over it. The developed model allows examining the characteristics of the converter for management of the energy flows and charging of series connected elements for energy storage. By using the obtained characteristics, different algorithms for management of the energy flows in a PV system, can be developed.

2. Using a CL – filter (fig.6) in the circuit from figure 2, provides charging with constant current instead with pulse current.

3. The obtained characteristics of the maximum value of the currents through the elements, allows the capability of evaluating the qualities of the proposed circuit and selection of some basic rations at designing the circuit.

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