THE USE OF SUPERCAPACITORS FOR WIDENING THE SCOPE OF APPLICATION OF PHOTOVOLTAIC CELLS

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Introduction

There are a lot of known untraditional energy sources: energy of water in rivers, waves in oceans, wind, geothermal energy and energy of the sun. The sun is one of the most perspective. Solar radiation continuously incoming to the Earth and has an enormous energy potential. Even ten times bigger energy demand than today may be covered by the sun. In order to use solar energy it is necessary to solve few tasks: to convert the solar radiation into acceptable type of energy; to store it and transmit it to its consumers.

Popular kinds of the solar energy's transformation are: direct conversion into electricity or to heat. The conversion into the electricity is often done by means of photovoltaic (PV) cells. Nowadays they are quite widely spread and used in many applications. However, this kind of the solar energy utilization is not so wide, as it could be. There are several reasons for that:

1) low efficiency of such transformation;
2) high cost of PV batteries;
3) instability of the solar light (night or cloudy weather);
4) problems with high volume electricity accumulation;
5) additional conversion equipment is necessary.

At the same time the cost of the PV elements, energy storages and semiconductor switches are getting lower, but their parameters – better. This especially regards efficiency of the solar cells that is only 30% at the given time. Therefore the only factor that really limits the solar energy utilization is instability of light. That is why there is a need to combine solar cells with some more reliable source of electricity, for example with electrical network.

An example of such system is being elaborated and tested at the given time in Riga Technical University for the purpose to explore possibilities and efficiency of the solar energetics in Latvia. An array of the solar panels and tracker are being mounted on the roof of Faculty of Power and Electrical Engineering.

In order to attach the panels to electrical network or/and to a standard (220V, 50Hz) consumer of electrical energy it is also planned to build an electronic converter. One of the ideas is to use topology of a half-bridge on-line uninterruptible power supply with solar batteries attached instead of (or together with) the usual energy storage – battery or supercapacitor. In order to check the idea a PSPICE model of the converter was built as close as possible to the real converter. Investigation of the model demonstrated difficulties of its implementation. Flow of the investigation is given below.

Photovoltaic systems and On-line converter

There are three basic groups of PV systems [1]: autonomous, hybrid and grid-connected. The autonomous systems contain only PV itself, some load and an additional regulator. Such systems are often used when some work should be completed during day time and there is no necessity in electricity at night. The autonomous system equipped with a battery can provide electrical power also at night or in cloudy weather. Hybrid systems are similar to autonomous, but contain some additional energy source, for example, reserve diesel generator.

The grid-connected systems, in most cases, are large arrays of PV panels - solar power stations. Such stations are often a part of the decentralized system of energy generation/consumption. Grid-connected systems have no need in energy storages, because an excess of the generated energy is accepted by the grid, but some lack of energy is supplied from the grid. Such solar systems may give some profit if correct measurements of the energy flow are done. Described PV systems are usually of high power and located in sunny regions.

As it was mentioned above the aim of the work is to build a complete low power photovoltaic system. At the initial stage a series connection of 4 solar panels of 90W is being mounted and attached to their tracker. Another part of the system is an electronic converter that must ensure energy flow to the consumer and return of the solar energy excess into the grid.

It was found that functionality of such converter is close to the functionality of an uninterruptible power supply: as long as the main energy source is available it feeds the load, but as soon as it became inactive – another one supplies the energy. Since the mentioned institution has a laboratory prototype of an on-line half-bridge uninterruptible power supply (UPS) it was decided to prove this converter suitability for PV system.

The mentioned converter is a power supply with double conversion. Its functional diagram is given in figure 1-a. It contains a half-bridge inverter and rectifier, as well as DC/DC converters for battery/supercapacitor recharging. The converter is symmetrical – the rectifier can be used as inverter for energy recuperation.

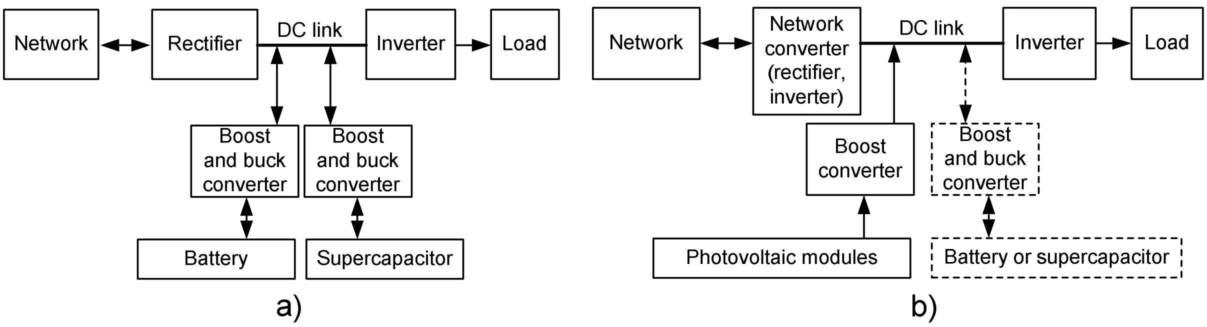


Figure 1.a) On-line uninterruptible power supply, b) On-line converter with photovoltaic array

It was decided to substitute the battery with the PV's and entitle this system «On-line converter with PV batteries». Operation mode of the DC/DC converter in such system is close to that in UPS. Series connection of 4 PV modules ensures voltage of 70V and can supply power of 360W at full light. This is close to 72V of 6 series connected accumulators.

The main functions of the on-line converter are: a) utilization of PV array if it can produce enough energy; b) connection of the load to the grid if energy of the solar panels is not sufficient. There are 6 basic directions of energy flow: from the grid to the load, from the grid to the energy storage (if installed), from the PV array to the load, from the PV array to the grid, from the PV array to the energy storage and from the energy storage to the load.

Various combinations of the flows can take place. For example, photovoltaic array can supply load, charge batteries, but excess energy can be recuperated to the grid.

PSpice model

The main question, however, is – is boost capability of the DC/DC converter is big enough to keep voltage of the DC-link at the high level. In order to answer this question a PSpice model of the converter was build and simulation was done. Since the aim of the simulation is very practical it was decided to use accurate models of elements. At the same time limited calculation capacity does not allow exact simulation of the complete system. That is why only boost converter with PV array was simulated [2,3] in order to estimate voltage of DC-link.
The model (figure 2-a) incorporates PV modules (E_T1…4), the boost converter (diode D1 – DSEP29-12, IGBT X1 – IRGP30B120, coil L1), DC-link C_DC and load R_Load, as well as optional input capacitor Cin.

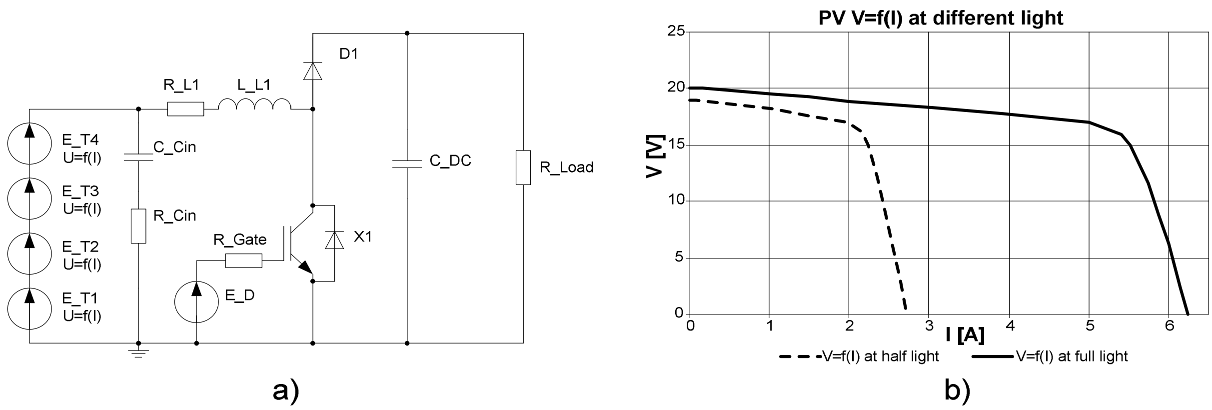
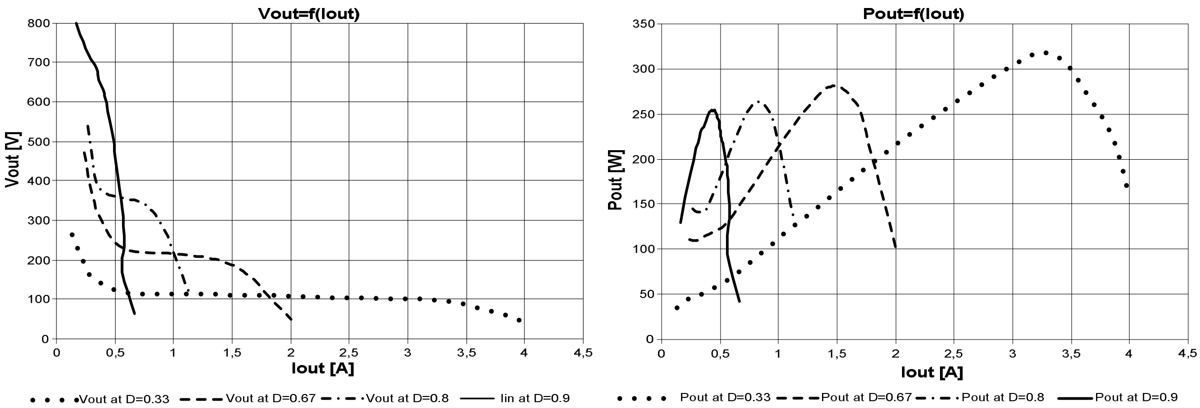


Figure 2. a) PSpice model of PV batteries and DC/DC boost converter, b) I-V characteristic of a solar cell

PV modules are represented as voltage sources E_T1…4 with real current-voltage curve of the solar battery. Current influence is taken into account in an indirect way – as control formula element. Experiments were made to get the I-V characteristics of PV module at two irradiation levels (Figure 2-b). I-V curve at full light was used during the simulation.
Adjusted internal PSpice model is used for D1, but X1 is a Darlington-like sub-circuit with a bipolar and field effect transistor. Control circuit of the transistor is formed as an error amplifier that compares sawtooth and reference signals, limits the difference and send it to IGBT. This circuit is made as controllable voltage source E_D.
Passive components – coil L1, output capacitor C_DC and input capacitor Cin – are less practical. However, resistances R_C_{in} and R_L1 are included in the model to evaluate their impact on voltage of DC-link. R_Load replaces all energy consumers (grid rectifier-inverter, battery charger and inverter with the load). The presented model is not very complex, but it was found suitable for PV estimation.

PSpice simulation

The main problem that was investigated was ability of the PV array to ensure rated voltage over the DC-link. Since the inverter and rectifier of the on-line converter are half-bridge circuits, voltage of the DC-link must be doubled amplitude of the grid voltage or 800V [4]. Voltage of 4 series connected PV batteries is up to 70V. Then gain of the boost converter must be about 12 that correspond to the duty cycle 0.92.
In the beginning the converter was simulated as it is - with small inductance (24mH) and no input capacitance. Results of this simulation are given in figure 3.



a) the output voltage b) the output power

Figure 3. Results of simulation at standard configuration

Diagram a) shows output voltage of the boost converter as a function of the output current. As it can be seen, even at D=0.8 that gives 400V on the output, zone of stable voltage is very narrow and is not enough for successful regulation. Besides that, the maximal output power decreases significantly (from 360 to 260W) at higher values of duty cycle (figure3-b).
The explanation of such behavior is given in figure 4. PV gives maximal power if it is kept in operation at the maximum power point (point A) that may happen if it operates at the constant current. If PV current (that is equal to inductor's current) have pulsations ΔI and they are small then the real operation points during a switching cycle do not go far from the point A, the output power is close to maximal, but the voltage does not drop significantly (figure 4-a).
However, if the current pulsations ΔI are big then the operation point may be far from the optimal and most of the time is located at the short circuit part (close to I_{SC}) of the I-V curve (figure 4-b). While PV array operates at the short circuit part its voltage and, hence, power is low. That is why the average voltage and power of the solar battery are also lower, as well as average power and voltage on the output (in the given occasion – in the DC-link). Higher current pulsations in the boost converts take place at higher D. So there is a contradiction between higher D for higher voltage, and lower D for smaller pulsations.

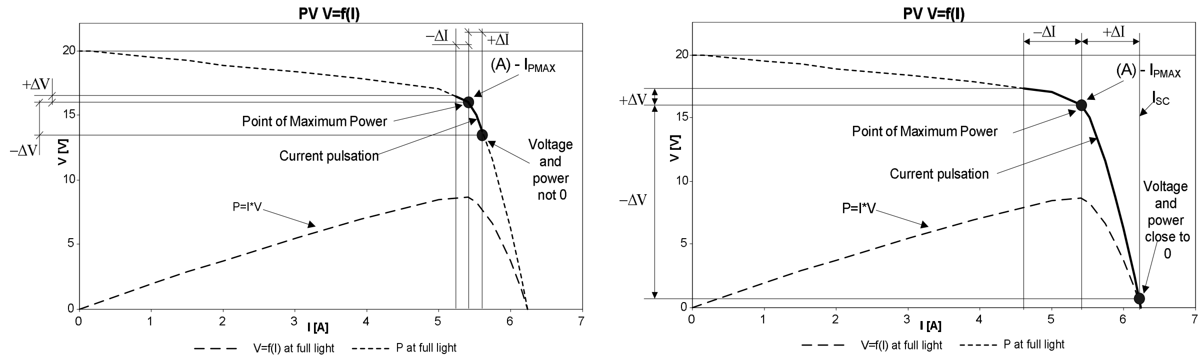
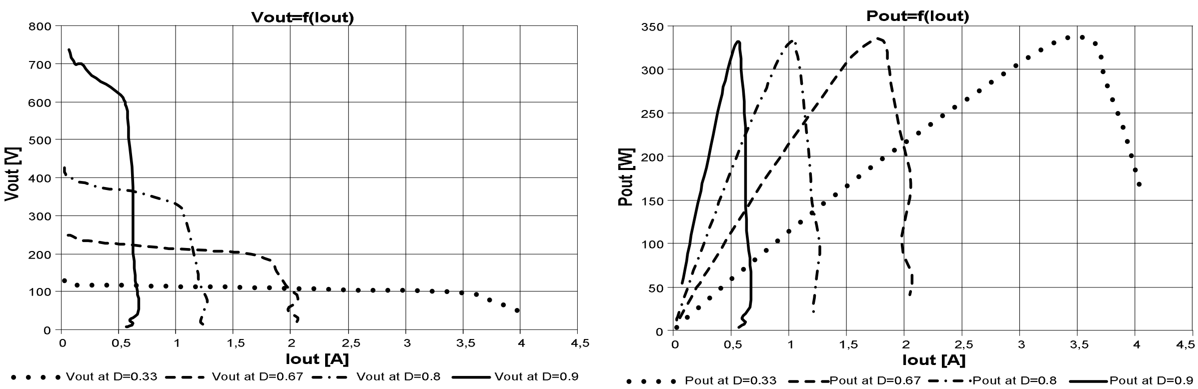


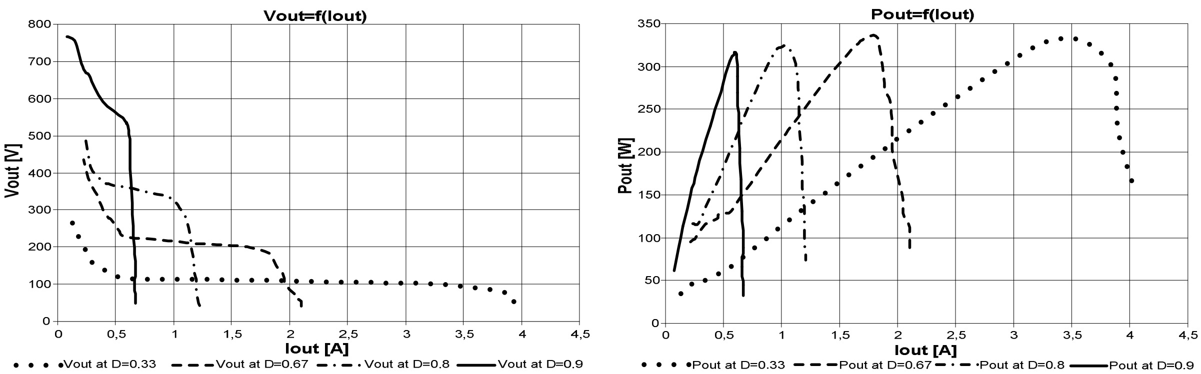
Figure 4. PV operation in the boost converter

Two kinds of modification of the system to achieve continuous operation at the maximum power point are obvious: increase of inductance of coil of the boost converter and/or adding some capacitance on the input.



a) the output voltage b) the output power

Figure 5. Simulation results at higher inductance



a) the output voltage b) the output power

Figure 6. Simulation results at 150uF input capacitance

Increase of inductance reduces pulsations of its current (and, hence, current of PV battery) in a direct way. This, of course, leads to operation near the optimal point.

The parallel capacitor does not reduce pulsations of current of the coil, but shunts most of them thus making current of PV battery more constant. Therefore operation points move closer to the optimal. The overall effect is similar to increase of the inductance, but less strong.
As it can be found from the simulation both methods diminish pulsations of the current consumed from PV array and increase maximum power point at higher values of the duty cycle (figure 5 and 6). Utilization of the capacitor is preferable, because it is much cheaper.
Supercapacitor usage with high capacitance and low internal resistance instead of capacitor can overcame two problems: PV current pulsations and PV power loss during short time shading by clouds, but it do not solve the problem with boost converter.
Although these methods significantly improve operation of the converter they do not ensure DC-bus voltage 800V. Therefore fluent regulation is not possible. Further simulations discovered also very little effect of the series parasitic resistances that may explained by the dominance of dynamic resistance of PV array (600 mOhm – from figure 2-b). This is reason for further significant modification of the hardware.

Conclusions

The above described simulation of boost stage of the on-line converter with PV array shows that the proposed topology is not completely suitable for interfacing the PV elements to grid or consumer.
This could be possible with the given topology if input voltage was higher (6…8 PV modules instead of 4). Other solutions assume other constructions of the boost converter (for example, double-stage) or alternative approach to the whole design (full-bridge schematics).
Therefore further work may be concentrated on elaboration and testing (including simulation) of new hardware solutions for the boost converter and the whole system. Some other efforts may be focused on PV tracker improvement to make it able managing more weight.

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Bisenieks L., Galkins I., Stepanovs A. Saules bateriju izmantošanas iespēju paplašināšana, izmantojot superkondensatorus.
Šajā rakstā ar modelēšanas palīdzību tiek apskatīta iespēja izmantot nepārtrauktas barošanas bloku ar pustilta spēka shēmu saules bateriju pieslēgšanai elektroapgādes tīklam vai patērētājam. Ir aprakstīts izmantotais programmas PSpice modelis. Ir veikta paaugstinošā pārveidotāja shēmas ar reāliem parametriem modelēšana, kā arī modelēti divi uzlaboti pārveidotāja varianti. Vienā variantā ir apskatīta superkondensatoru izmantošana, bet otrā - induktivitātes krasa palielināšana. Ir analizēti modelēšanas rezultāti, norādot iemeslus, kas traucē sasniegt vēlamos rezultātus. Balstoties uz iegūtajiem rezultātiem, ir izstrādātas rekomendācijas pārveidotāja uzlabošanai.

Bisenieks L., Galkin I., Stepanov A., The use of supercapacitors for widening the scope of application of photovoltaic cells.
The paper presents the simulation-based research into the uninterruptible power supply with a half-bridge topology for connection of the photovoltaic arrays to the grid or to a local consumer. The PSpice model is described and the results of analysis are given. Simulation was performed for a boost converter with real parameters and two improved converter configurations, one of them having 15 times higher input inductance, while another – a supercapacitor connected parallel to PVs and a real inductance. The recommendations for improvement of the converter have been worked out.

Бисениекс Л., Галкин И., Степанов А., Расширение возможности использования солнечных батарей применяя суперконденсатор.
В данной работе при помощи моделирования исследуется возможность применения силовой части источника резервного электропитания с полумостовой схемой для присоединения фотоэлектрических элементов к стандартной сети или к потребителю. Приводится описание модели и анализ результатов моделирования. На основании результатов сделаны рекомендации для развития системы.