Computer Simulation of the PV – Boost Converter System Working at MPPT Mode of Operation

Georgi Kunov[1], Elissaveta Gadjeva[2] and Deyan Zhelev[3]

Abstract – **A PV – Boost converter system working at hysteresis MPPT mode of operation is proposed in the present paper. A computer model of the system is developed and simulated. Behavioral parameterized *PSpice* macromodels are developed for the single photovoltaic element and for series connection of single cells. The PV model is used to simulate a concrete electrical circuit, which optimizes the mode of operation of the Boost converter in order to achieve maximum transmitted power from the photovoltaic element (maximum power point tracking - MPPT). The computer models are realized in the *Cadence Capture* and *Cadence PSpice* environment.**

Keywords – **Photovoltaic element, Boost converter, Maximum power point tracking, PSpice model.**

I. Introduction

Recently, the problem for non-polluting energy production using renewable energy sources is of significant importance. In this respect, the direct converting of the solar energy in electrical energy takes an important place. At present, the cost of the photovoltaic (PV) panels is a determining factor to the cost of the produced using this method electricity. Therefore, the obtaining of maximum amount of energy from PV is of significant importance, despite of climate working conditions. The PV panel has a highly nonlinear I-V characteristic, which in turn, varies depending on the intensity of solar irradiation and the temperature. The maximum power point tracking (MPPT) control of the PV system is therefore critical for the PV system efficiency. A number of methods are developed for MPPT control [1-4] such as:

– Perturb and Observe (P&O) (hill climbing) method;
– Modified Perturb and Observe (MP&O) method;
– Estimate Perturb-Perturb (EPP) method;
– Constant Voltage Method (CV);
– Increment Conductance (Inc Cond) method;
– Fuzzy Logic or Artificial Neural Network Control method.

The disadvantage of these control methods is the high cost of implementation as a result of complex algorithms that usually need a DSP as their computing platform. In the work [1], for instance, the microcontroller TMS320F2812 of TI is used. A relatively simple method for MPPT control is proposed in [5], [6]. Later, other researchers are involved in the investigations based on this method and develop the Ripple Correlation Control technique [4], [7]. The adequate computer modeling of the photovoltaic (PV) element is of significant importance for the computer simulation of MPPT control systems. *PSpice* models of the photovoltaic element are developed in [8], [9].

A PV – Boost converter system working at hysteresis MPPT mode of operation is proposed in the present paper. A computer model of the system is developed and simulated. Behavioral parameterized *PSpice* macromodels are created for the single photovoltaic element and for series connection of single cells. Two variants of PV models are developed – in schematic view, as well as in the form of a subcircuit in accordance to the input language of the *PSpice* simulator. The models are used to simulate a concrete electrical circuit, which optimizes the mode of operation of the Boost converter in order to achieve maximum transmitted power from the photovoltaic element. The computer models are realized in the *Cadence Capture* and *Cadence PSpice* environment.

II. PSpice Model of PV – Boost Converter System

PSpice simulation model of the system consisting of photovoltaic source, Boost converter, together with the proposed control system, is shown in Fig. 1. The power and I-V characteristics of the solar cell are presented in Fig. 2a and Fig. 2b correspondingly. The waveforms illustrating the principle of the hysteresis MPPT are shown in Fig. 3. The following waveforms are presented in Fig. 3a: Vpv_fb – voltage feedback from the PV output, Ipv_fb – current feedback from the PV output, as well as Ppv – resulting power, obtained by multiplication of Vpv_fb and Ipv_fb. The following waveforms are presented in Fig. 3b: Ppv_fb – scaled power, Ppv_max – upper threshold of the power hysteresis, obtained by a peak detector realized by the capacitor C1 and the switch S1, Ppv_min – lower threshold of the power hysteresis at the output of the scaling amplifier GAIN4. In the moment when Ppv_fb goes to the left of the power maximum, (Fig. 2a), hold by capacitor C1 (Ppv_max), the comparator E1 changes its state and the pulse Reset is produced for the R-S trigger U3A_U4A (Fig. 3c). The transistor Qsw is turned off and the power decreases to the right of the maximum (Fig. 2a). In the moment, when Ppv_fb becomes less than Ppv_min, the comparator E2 changes its state and the pulse Set is produced for the R-S trigger (Fig. 3c).

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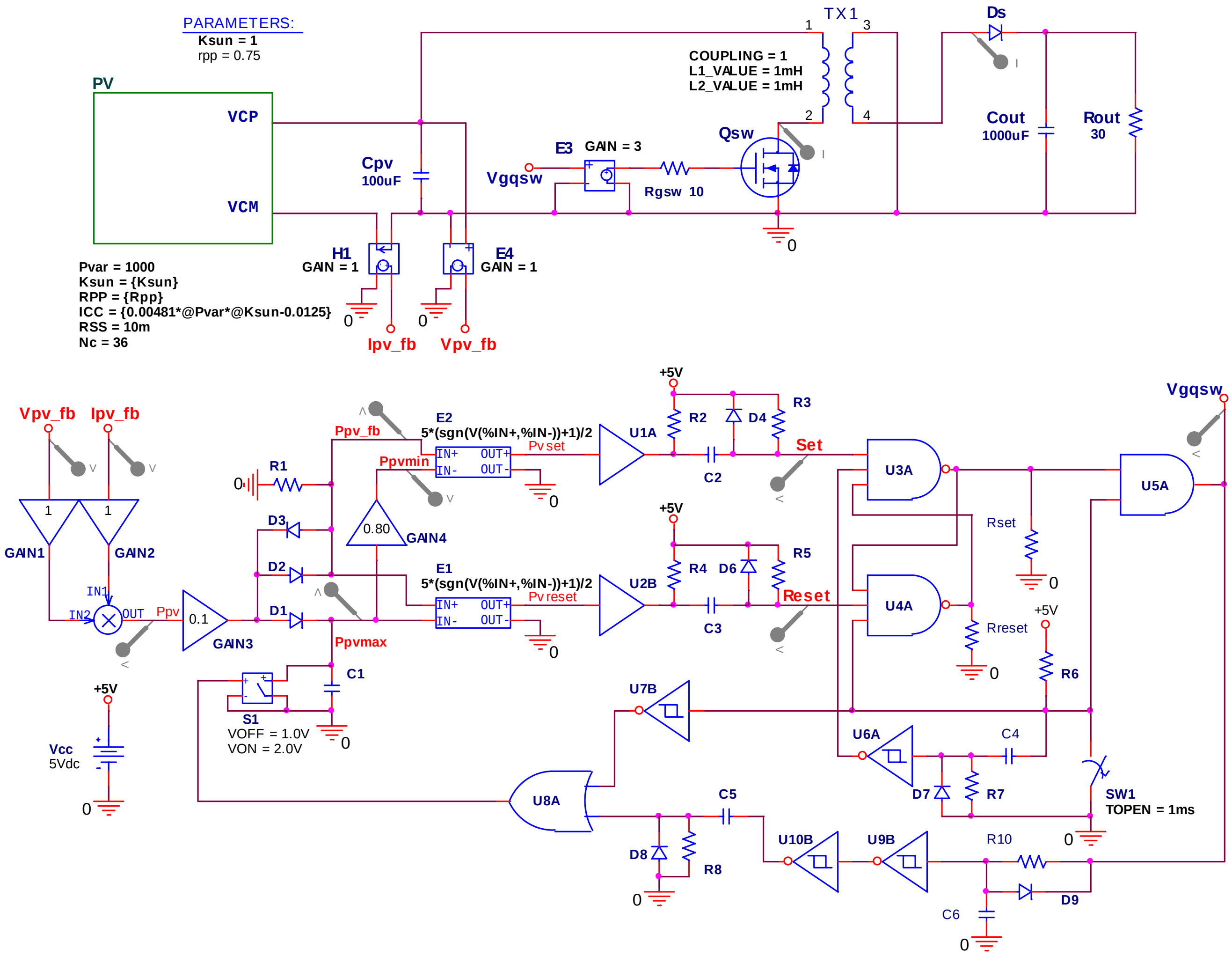

Fig. 1. *PSpice* simulation model of the system consisting of photovoltaic source, Boost converter, together with its control system

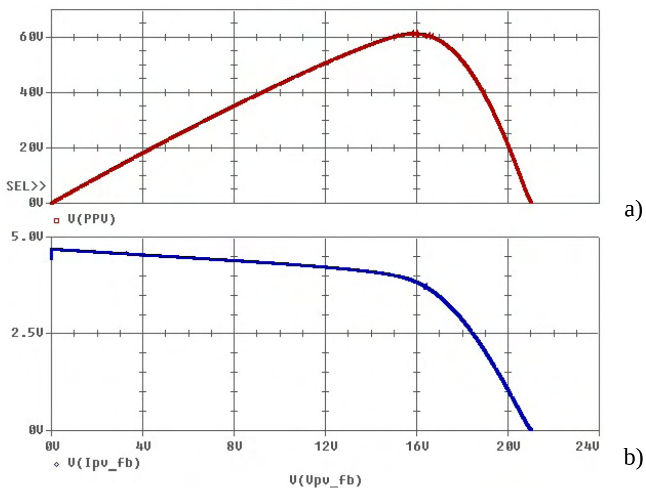

Fig. 2. The power and I-V characteristics of the solar cell

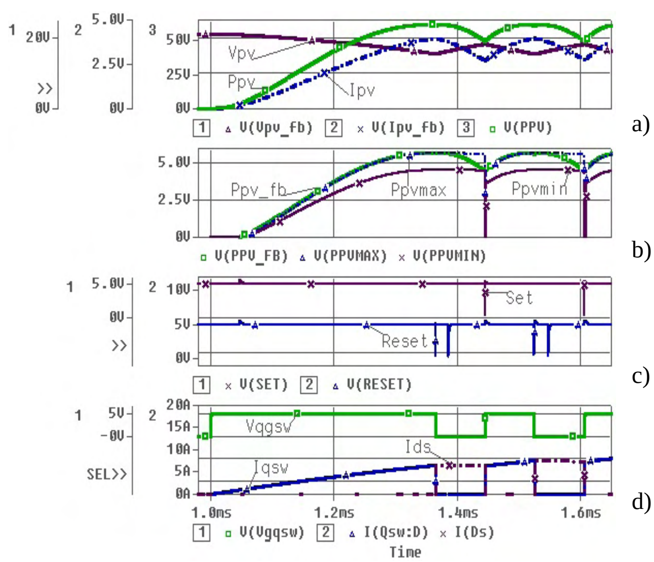

Fig. 3. Waveforms illustrating the principle of the hysteresis MPPT

The transistor Qsw is turned on again. The peak detector is reset and the MPPT process starts again.

The following waveforms are presented in Fig. 3d: Vgqsw – pulses applied to the gate of the transistor Qsw, Iqsw – current through the transistor Qsw, as well as Ids – current through the diode in the secondary winding of the transformer.

III. Computer Model of the Solar Cell

A. PSpice Model of a Single Solar Cell

The macromodel of single solar cell is created in the form of a hierarchical block as shown in Fig. 4. *Icc* is a DC current source which is a function of the solar irradiation P_{var} according to the equation [8] :

$$I_{CC} = aP_{var}K_{sun} + b \tag{1}$$

where *a* and *b* are constants depending on the PV cell.

The behavior of the cell under reduced light conditions is simulated using the shading coefficient K_{sun} . It is defined in the range [0,1], where K_{sun} = 1 for unshaded cell. D1 is a diode with parameters given for the solar cell. R_s and R_p model the corresponding series and shunt resistance losses. The parameters (Icc, Rss and Rpp) are preceded by “@” in the hierarchical block. The symbol and the block properties of the single cell are presented in Fig. 5.

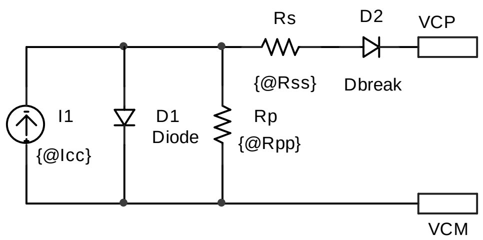

Fig. 4. Macromodel of the single solar cell

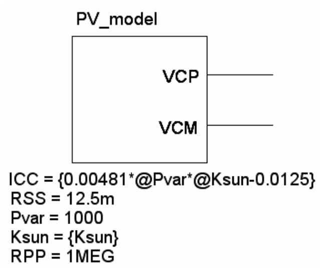

Fig. 5. Symbol representation of the single cell

B. PSpice Model of Series Connected Solar Cells

Based on the single cell model, the series connection of N_C cells is represented using the macromodel shown in Fig. 6. Using the voltage controlled voltage source (VCVS) E1 the voltage $V_{VCP,VCM}/N_C$ is applied to the single cell model consisting of the elements I_1, D_1, R_{P1} and R_{S1}. The voltage controlled current source (VCCS) G1 defines the current through the series connection of the cells, equal to the current of the single cell. The source E1 is of EVALUE type and the source G1 is of GVALUE type in order to ensure parameterization of the block elements.

The block properties of the of series connection of N_C cells are presented in Fig.7. The corresponding symbol is shown in Fig. 8.

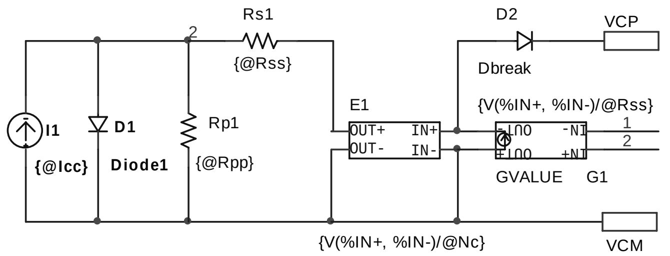

Fig. 6. Macromodel of series connection of *Nc* cells

	A
ICC	{0.00481*@Pvar*@Ksun-0.0125}
Ksun	{Ksun}
Name	PV
Nc	36
Pvar	1000
RPP	{Rpp}
RSS	10m

Fig. 7. Block properties of series connection of N_C cells

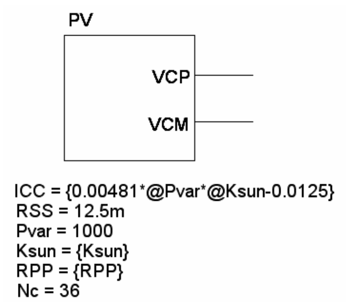

Fig. 8. Symbol representation of series connection of *Nc* cells

The parameterized library PV model of series connection of N_C cells is developed in accordance to the input language of the *PSpice* simulator [10] in the form:

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.subckt PV VCP VCM PARAMS: Rss={Rss}, Rpp={Rpp},
+ Nc={Nc}, Pvar={Pvar} Ksun={Ksun}
I1 VCM 2 DC {0.00481*Pvar*Ksun-0.0125}
D2  3  VCP  Dbreak
D1  2  VCM  diode
Rp1 VCM  2  {Rpp}
Rs1 1  2  {Rss}
E1  1  VCM  VALUE {V(3, VCM)/Nc}
G1  VCM  3  VALUE { V(2, 1)/Rss}
.model diode D (Is=100pA, Rs=3m, Ikf=.3227, N=1, Xti=0,
+ Eg=1.11, Cjo=302.5p, M=.7206, Vj=.50, Fc=.5, Isr=1.2u,
+ Nr=1.426)
.ends PV
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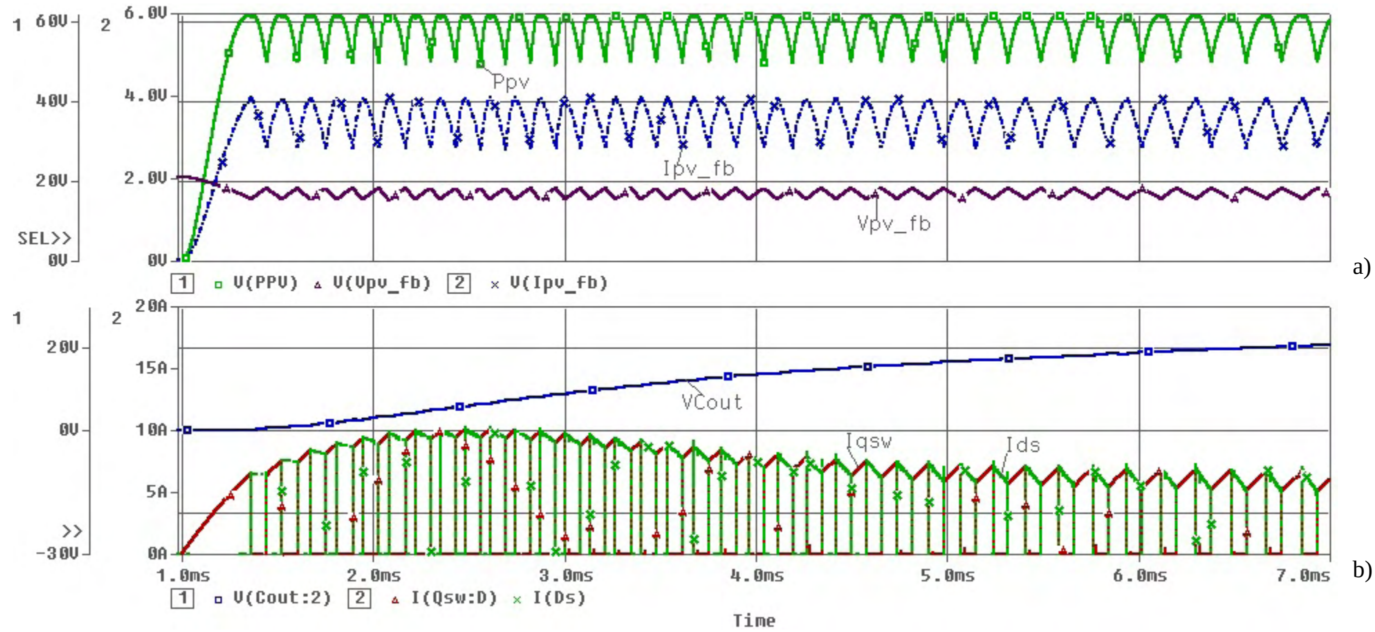

Fig. 9. Simulation in the time domain of the system

IV. Simulation in the Time Domain of the System

The waveforms presented in Fig. 9a show that the quantities Ppv, Vpv_fb and Ipv_fb have constant average value with pulsations defined by the MPPT hysteresis. The results for the currents Iqsw and Ids, as well as for the voltage VCout are shown in Fig. 9b. As the voltage on Cout during the transients increases from 0 to the nominal value, the values of the currents Iqsw and Ids in this interval are greater than the nominal ones.

V. Conclusion

A PV – Boost Converter System Working at hysteresis MPPT mode of operation has been proposed. The system optimizes the mode of operation of the Boost converter in order to achieve maximum transmitted power from the photovoltaic element. A computer model of the system is constructed and simulated. Behavioral parameterized *PSpice* macromodels are created for the single photovoltaic element and for series connection of single cells in schematic view, as well as using subcircuit definition in the form of *PSpice* model. The computer models are realized in the *Cadence Capture* and *Cadence PSpice* environment.

Acknowledgement

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