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CALCULATION AND SIMULATION OF THE MAIN DC-DC CONVERTERS USED IN PHOTOVOLTAIC SYSTEMS

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Abstract- Energy harvesting with a photovoltaic cell requires efficient elements for better use of the sun's irradiance, due to the randomness inherent in this type of energy. One of the important elements that exist in PV systems is the DC/DC converters. These items, mainly, they convert a certain voltage to another dc voltage (of greater or lesser value) with less ripple voltage. The three basic configurations are Buck, Boost and Buck-Boost. The first two types of converters are most commonly used in photovoltaic energy conversion. The objective of this paper is the analysis and modeling of these types of converters in Matlab-Simulink with two of their toolbox, SimPower System and Simscape. The two type of converters will be analyzed mathematically, calculating their elements and then will be showed the models used in these calculations with these simulation tools.

Keywords: Photovoltaic (PV), DC-DC Converters, Buck, Boost, Modeling, Simulation, Matlab/Simulink.

I. INTRODUCTION

Due the fast development of society and economy, traditional fossil energy demand is increasing, and the environmental polltuion and greenhouse effect are increasingly serious, sustainable development of people is seriously threatened.

The solar energy photovoltaic is very interesting alternative on supplement the electric system generation, due to the persistent cost reduction of the overall system and cleaner power generation.

Basic advantage of this energy source is the abundance of solar radiation in nature and environmental friendly way of electricity production. Besides being inexhaustible and not pollute. This makes it an interesting source of energy.

One of the main uses of solar photovoltaic is electricity production. Either small scale (stand alone) or high-power facilities generally are operating at medium or high voltage (grid connected PV array). Although the high cost of PV panels and their low efficiency, big PV parks have been installed in recent years around the world. Distributed generation and, it microgrids are increasingly common in power systems. Is mainly due to increased electricity production facilities based on renewable energy technologies, such as photovoltaic (PV). The output power of the photovoltaic systems can vary dramatically in seconds. High levels of penetration of PV, this intermittent can cause problems in the supply operations as well as the equipments due to these voltage fluctuations. This requires equipments for regulating the output voltage of these facilities. These will be the DC/DC converters.

All the photovoltaic installation engaged in the production of electricity will use this component, either stand alone (Buck) or connected to the grid (Boost), as shown in Figure 1. This paper will study a basic design and simulation.

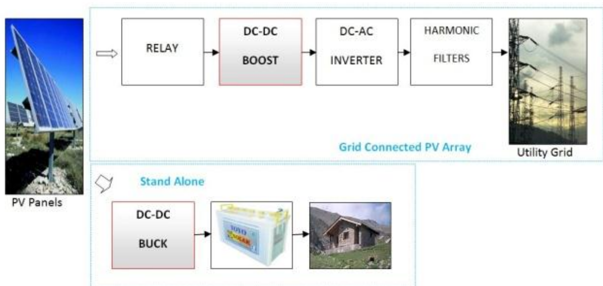

Figure 1. Schematic of the elements of a photovoltaic system

II. DESIGN OF THE CONVERTER DC/DC

The DC-DC converters are circuits that control the charging and discharging of energy in their passive energy storage elements, obtaining a change in the value of a DC voltage.

The operation principle is the same for these two types of converters: the principle of storage and transfer of energy by switching cycles. During the first part of the duty cycle, the converter stores energy in the inductor, transferring this energy to the capacitor in the second part of the work cycle.

An ideal (or working with maximum efficiency) converter will be composed of components that do not have losses or that do not consume power.

- Reactive components: These elements store energy, as capacitors and inductors. These components absorb energy from the circuit, store it and finally return it to the circuit.
- Switch Components: These devices behave as ideal switches, i.e., without switching losses.

The different ways of connecting components will result in a converter or other. However, both converters can be divided into three parts:

- Switch: These are responsible for chopping the incoming signal from the frequency and duty cycle.
- Accumulator: Switch rules on stored energy and decides when it is released to the load.
- Filter: It is a LC filter that performs the filtering of the signal switched.

These converters have two driving modes. These modes are due to the relationship between the time when the switch is closed, and the time required by the inductor to fully discharge the energy previously stored. Possible driving modes are:

- Continuous conduction mode (CCM): The current flowing through the load will vary between maximum and minimum values, but is never annulled. This is because the switch must be blocked a time interval allowing the current in the load does not become zero. In this way, at the beginning of the following period the current may start from an initial value.
- Discontinuous conduction mode (DCM): The intensity in the load becomes zero at a given time over a time interval during which the switch is open. The time that remains open the switch is greater than the time that can be the inductor giving energy, so at the beginning of the following period the intensity in the load will be zero.

A. Buck Converter

A *Buck Converter* is a DC-to-DC power converter with an output voltage lower than its input voltage. This type of converter is used in stand-alone installations, in which the supply electricity is expensive or difficult to access. It will be placed between the PV generator and battery (Figure 1).

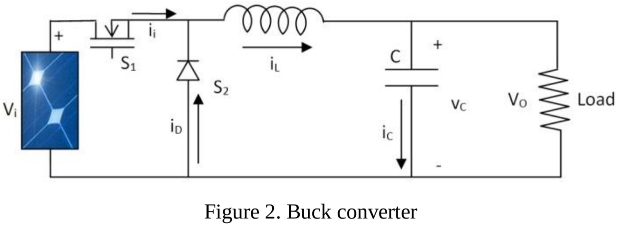

Figure 2. Buck converter

As seen in Figure 2, the operation is as follows: when the switch S_2 is opened, the photovoltaic generator supplies power to the circuit, giving as a result an output voltage (V_0) through the load or battery. When the switch changes position and closes the circuit, the energy stored in the inductor and the capacitor is discharged through the load. It allows transforming an unregulated input voltage in a regulated output voltage lower than the input voltage.

The converter, attached to a control algorithm, will allow extracting the maximum power that can supply the photovoltaic generator. Power transfer through the converter is controlled by the duty cycle (D). This duty cycle is based on a fixed working frequency, with a pulse width modulation (PWM). It is defined as:

$$D = \frac{T_{ON}}{T} \quad (1)$$

The design of the converter, under ideal assumptions, involves the calculation of three elements, the value of the duty cycle (D), the inductor and the capacitor:

1. Calculation of Duty Cycle, D

The value of the duty cycle will depend on the voltage you want to get at the output. The voltage across an inductor during a full period of time is zero. From this statement, the transfer function in conditions of steady state is equal to:

$$(V_i - V_0)T_{ON} - V_0(T - T_{ON}) = 0 \quad (2)$$

$$(V_i - V_0)DT - V_0(T - DT) = 0 \quad (3)$$

$$D = \frac{V_0}{V_i} \quad (4)$$

Calculating the value of D for a (V_0) output voltage of 12 volts and an input voltage (V_i) of 24 volts, yields a value of the duty cycle (D) equal to 0.5.

2. Calculation of Inductor, L

The calculation of the inductor is to be performed according to the ripple of the current in the inductor and considering that it is working in continuous conduction mode during all the charging rate.

Its value is found by applying the following equation.

$$L \geq \frac{(V_i - V_0)\, D\, R_{Load}}{2V_0 f} \quad (5)$$

with values of R_{Load} = 1Ω, V_i = 24 V, V_0 = 12 V, D = 0.5 and a frequency, f = 100 kHz, yields a value for the inductor of 2.5 μH. It will be needed to use a value equal to or greater than that obtained.

3. Calculation of Capacitor, C

Its value will depend on the ripple of the maximum allowable voltage on the load. Its value will be found using the following equation.

$$C \geq \frac{(V_i - V_0)\, D}{8 L f^2 k} \quad (6)$$

with values of V_0 = 12 V, V_i = 24 V, D = 0.5, a frequency, f = 100 kHz, a inductor of 2.5 μH and a ripple voltage k = 25×10^{-3} mV, yields a value for the capacitor of 1.2 mF. It will be needed to use a value equal to or greater than that obtained.

B. Boost Converter

A *Boost Converter* is a DC-to-DC power converter with an output voltage greater than its input voltage. This type of converter is used in grid-connected systems. It will place before the inverter DC/AC (Figure 1). It will allow an output voltage higher than the voltage of the panels, but output current is lower than the input.

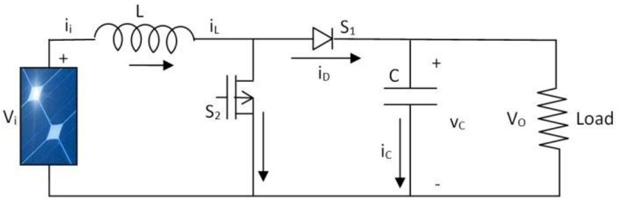

Figure 3. Boost converter

As shown in Figure 3, when the switch S2 is closed, the circuit is separated into two parts: on the left, photovoltaic panels will load the inductor, while on the right, the capacitor will maintain the output voltage using the previously stored energy. When the switch changes its position and opens, both the panels and the energy stored in the inductor will supply energy to the circuit of the right and therefore increases the output voltage. The output voltage can be maintained at the desired level by controlling the switching sequence.

The design of the converter, under ideal assumptions, involves the calculation of three elements, the value of the duty cycle (D), the inductor and capacitor:

1. Calculation of Duty Cycle, D

The voltage across an inductor during a full period of time is zero. From this statement, the transfer function in conditions of steady state is equal to:

$$V_i D + (V_i - V_0)(1-D) = 0 \tag{7}$$

$$V_0 = \frac{V_i}{1-D} \tag{8}$$

Calculating the value of D for a (V_0) output voltage of 24 volts and an input voltage (V_i) of 12 volts, yields a value of the duty cycle (D) equal to 0.5.

2. Calculation of Inductor, L

The calculation of the inductor is to be performed according to the ripple of the current in the inductor and considering that it is working in continuous conduction mode during the charging rate. Its value will be found using the following equation.

$$L \ge \frac{V_i\, DT}{2R_{Load}\, dI} \tag{9}$$

$$dI = \frac{\%dI\, I_{Load}}{100} \tag{10}$$

with values of R_{Load} = 10Ω, V_0 = 24 V, V_i = 12 V, D = 0.5, a percentage ripple of the current of $\%dI$ = 15 and a frequency, f = 100 kHz, yields a value for the inductor of 41.66 μH. It will be needed to use a value equal to or greater than that obtained.

3. Calculation of Capacitor, C

Its value will depend on the ripple of the maximum voltage on the allowable load. Its value will be found using the following equation.

$$C \ge \frac{V_0\, DT}{2\, R_L\, dV} \tag{11}$$

$$dV = \frac{\%dV\, V_0}{100} \tag{12}$$

with values of R_{Load} = 10Ω, V_0 = 24 V, D = 0.5, a frequency, f = 100 kHz and a percentage ripple of the voltage of $\%dV$ = 0.35, yields a value for the capacitor of 71.43 μF. It will be needed to use a value equal to or greater than that obtained.

III. MODELING OF CONVERTERS

After calculating the values of the elements of the converters, the next step is to simulate them computationally to validate their operation. It will be used the toolbox of Matlab-Simulink SimPowerSystems and Simecape. It is making a model with each one of them but with the same values of the elements.

A. Buck Converter

According to the scheme shown in Figure 2 the model is made in SimPowerSystems obtaining as a result the scheme showed the Figure 4.

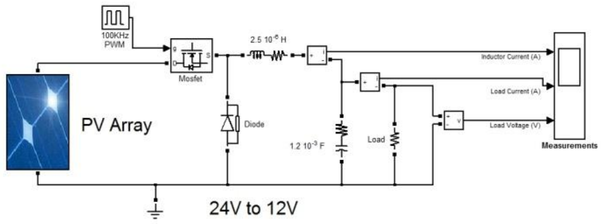

Figure 4. Buck converter, with SimPowerSystems

Figure 5 shows the Measurements scope after simulating the model. You can see that the value of the voltage on the load is 12 V, value to be sought with the simulation. Now the same scheme of Figure 2, is made but with the toolbox Simscape.

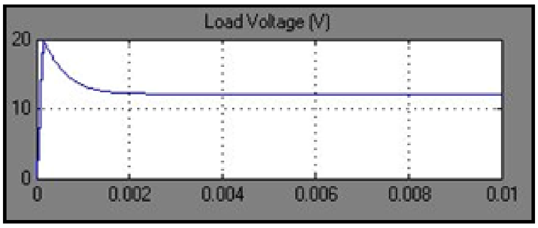

Figure 5. Result simulation buck converter

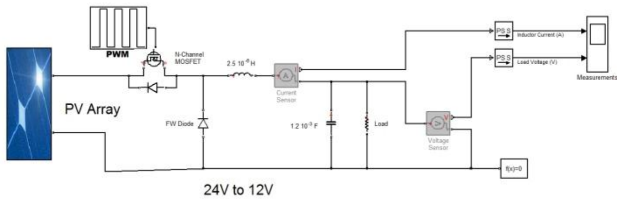

Figure 6. Buck converter, with Simscape

Figure 7 shows the Measurements scope after simulating the model. It is observed that the value of the load voltage is greater than 12 V, value to be sought with the simulation.

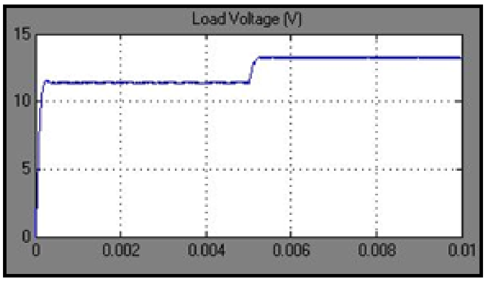

Figure 7. Result simulation buck converter

B. Boost Converter

According to the scheme shown in Figure 3 the model is made in SimPowerSystems obtaining as a result the scheme showing the Figure 6. Figure 7 shows the Measurements scope after simulating the model. It notes that the value of the voltage on the load is 24 V, value to be sought with the simulation.

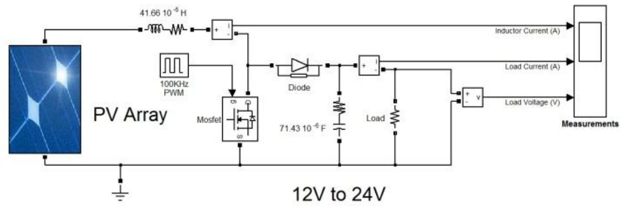

Figure 8. Boost converter, with SimPowerSystems

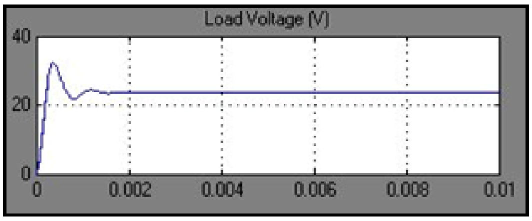

Figure 9. Result simulation boost converter

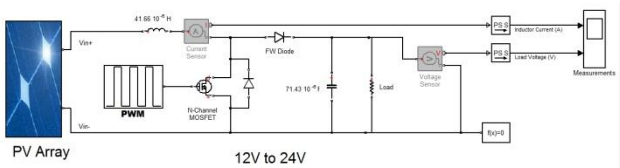

Figure 10. Boost converter, with Simscape

Now the same scheme of Figure 3 but is made with the toolbox Simscape. Figure 11 shows the Measurements scope after simulating the model. It is observed that the value of the load voltage is lower 12 V, value to be sought with the simulation.

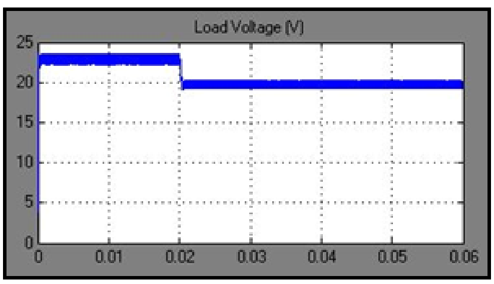

Figure 11. Result simulation boost converter

IV. CONCLUSIONS

In this paper, we have modeled two types of converters DC/DC using two similar but different simulation tools. There are different ways to perform the calculation of the values of the elements of both converters. It has been found that the chosen are those which are closest to the desired values during the simulation.

Simscape toolbox is much slower and the results don't fit so good to the results desired as SimPowerSystems, although the starting values are the same. With the models developed, although they are simple models, it is possible to study the behavior of DC/DC converters in the time domain in a photovoltaic system.

NOMENCLATURES

D: Duty cycle
T: Switching period
T_{ON}: Time that the switch remains closed
V_0: Converter output voltage
V_i: Converter input voltage
V_C: Capacitor voltage
I_L: Current through the inductor
I_{Load}: Current through the load
R_{Load}: Load resistance

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REFERENCES

[1] D.Y. Lee, H.J. Noh, D.S. Hyun, I. Choy, "An Improved MPPT Converter Using Current Compensation Method for Small Scaled PV-Applications", Eighteenth Annual IEEE Applied Power Electronics Conference and Exposition, APEC'03, Vol. 1, pp. 540-545, 9-13 February 2003.
[2] J.M. Enrique, E. Duran, M. Sidrach de-Cardona, J.M. Andujar, "Theoretical Assessment of the Maximum Power Point Tracking Efficiency of Photovoltaic Facilities with Different Converter Topologies", Solar Energy, Vol. 81, Issue 1, pp. 31-38, January 2007.
[3] A. Coronado Mendoza, J. Bernal Agustín, J. Domínguez Navarro, "Photovoltaic Boost Converter System with Dynamic Phasors Modelling", Electric Power Systems Research, Vol. 81, Issue 9, pp. 1840-1848, September 2011.
[4] C. Osorio, "Matlab/Simulink Models", Mathworks.
[5] http://ecee.colorado.edu/~ecen2060/matlab.html .
[6] N. Bizon, M. Oprescu, "Control Performances of the Bi-Buck Interface Used for Inverter Current Ripple Compensation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 2, Vol. 2, No. 1, pp. 5-10, March 2010.
[7] N. Bizon, M. Oprescu, "Modelling the Bi-Buck Interface for Inverter Current Ripple Compensation", International Journal on Technical and Physical Problems of Engineering (IJTPE), Issue 1, Vol. 1, No. 1, pp. 32-37, December 2009.

[8] Y. Du, D.D.C. Lu, "Battery Integrated Boost Converter Utilizing Distributed MPPT Configuration for Photovoltaic Systems", Solar Energy, Vol. 85, Issue 9, pp. 1992-2002, September 2011.
[9] M. Gradella, J.R. Gazoli, E.R. Filho, "Analysis and Simulation of the P&O MPPT Algorithm Using a Linearized PV Array Model", Industrial Electronics, IECON '09, 35th Annual Conference of IEEE, pp. 231-236, 3-5 November 2009.

BIOGRAPHIES

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