Semester Project

P0

Group INTRO-760

Autumn Semester 2018

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1 Introduction

To this date, sustainable energy sources have become an area in focus worldwide in an attempt to reduce the environmental impact due to emissions of CO2 and other greenhouse gasses. The development of competitive systems to exploit renewable energy sources is the best alternative to reduce the use of fossil fuels for the production of electricity. Over the last years there have been a considerable increase in electricity production from renewable energy sources being the fastest growing sector wind and solar energy. In 2017, solar photovoltaic was the renewable energy source which experienced the highest increased in newly installed capacity amounting a total installed capacity of approximately 402 GW.[ref]

Photovoltaic (PV) is referred to the production of electricity in the form of direct current (DC) directly from sunlight shining on solar cells. Solar cells are semiconductor devices which typically can produce around 0.5 V DC so they are series connected to form a PV module/panel which can also be connected to other PV panels resulting in a PV array. This way, according to the system´s requirements, the PV panels can be interconnected in series or parallel in order to get at the output a higher voltage or current, respectively. Connecting PV panels either in series or parallel will result in an increase of the system´s overall electricity production.

Nevertheless, it is essential to keep into consideration the mismatches that may appear between the power generated by the different PV panels, which will result in losses in the PV system and thus in a lower efficiency. Mismatches occur when the PV modules operate in a different operating point than its maximum power point (MPP) due to partial shading, manufacturing tolerances, defects in the PV modules due to weather conditions and aging, among others. Even a small mismatch in one of the PV modules can result in a very high reduction of the power production from the entire PV array. Mismatch losses in a PV system can be reduced by forcing every PV module to work at its MPP by using a technique known as Maximum Power Point Tracking (MPPT). This can be reached by using electronic devices called Module Integrated Converters (MICs) which basically consist on DC-AC micro inverters or DC-DC converters that incorporate a MPPT unit to ensure that the output power of the MIC is the one corresponding to the MPP of the PV module.

This project focuses on the design and test of a MIC based on a non-inverting buck-boost DC/DC converter for integration with a PV module in order to operate at its MPP and thus harvest maximum energy from the sunlight.

1.1 PV generation

The phenomenon on which the transformation of solar energy to electrical energy is based is known as the *Photovoltaic effect*. This phenomenon was first discovered by a French physicist named Edmond Becquerel in 1839 and is based on the emission, from the sunlight or light, of massless photons which collate on two superimposed layers of semiconductor material causing some of the electrons to flow and, hence, allowing the generation of voltage and electric current. Solar PV cells are made of a negative charged layer (n-layer) and a positive charged layer (p-layer) of a semiconductor material, usually crystalline silicon, joined establishing a pn-junction. If photons emitted by the light, when they collide with the n-layer, have enough energy to excite the electrons an electric field will be formed in the p-n junction due to the attraction of electrons and holes. This electric field will work as a diode permitting the separation of the positive and negative charge carriers. This way electric current will flow across the pn-junction allowing the generation of electric energy. The greater the intensity of the light (irradiance) that is absorbed by the PV panel the higher the amount of electric power generated. On the other hand, the efficiency of the panel will decrease with the temperature. Usually, PV panels are tested under standard test conditions (STC) which is at 25°C and 1000 W/m^2. Some of the most important characteristics associated with a PV panel's datasheet are the following: maximum power point (Pmax), open-circuit voltage (Voc), short-circuit current (Isc), MPP voltage (Vmpp), MPP current (Impp) and efficiency (η). These features are important to define the I-V curves of the PV panel in order to develop the MPPT controller.

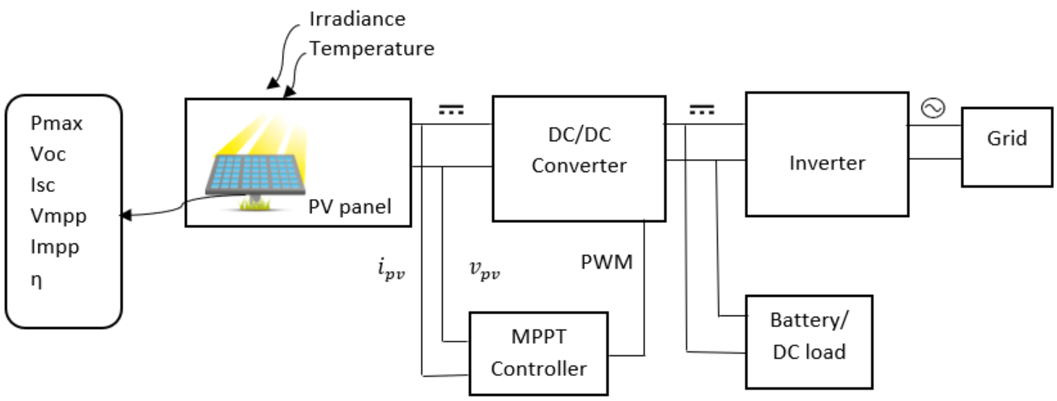

Figure 1.1. Basic diagram of a PV system.

1.2 State of The Art

1.3 Buck-converter

The task of a buck converter is to be changing the input voltage to a lower output voltage. The components, which are needed, are a DC-source for input voltage, a switch contained of a diode and a MOSFET, an inductor, a capacitor and a resistor for the load. The equivalent diagram in figure 1.1 illustrated a buck-converter with an ideal switch.

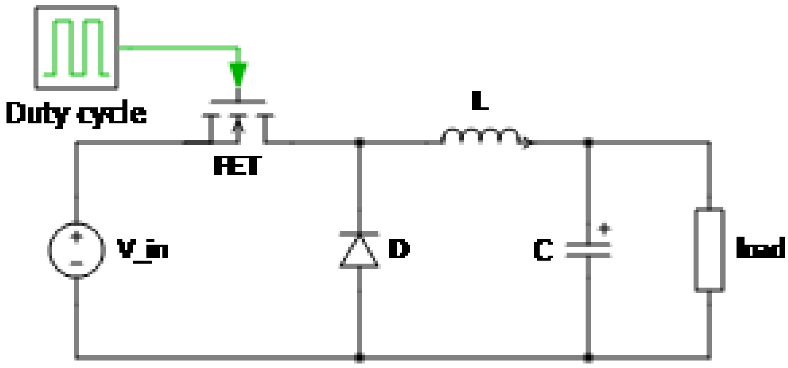

Figure 1.2. Buck-converter.

A buck-converter perform in two operating modes. In both operating modes have been approach that the converter is in steady state and the average of a value is constant. Therefore, we can assume a DC-voltage at the load. At the case, that the MOSFET conducts current (position 1), the diode will be gesperrt. During the switch is in position 1 the voltage dropes at the inductor and you can measure a lower voltage at the load. Furthermore, the capacitor is charging voltage and the inductor is stored current. For the position 2 the inductor works as a current source and feeds the closed circuit with current. The capacitor enstored is energy from the electrical field. The advantage for using a buck converter is that the structure is very simple and you need one power switch. The size for the component is small and the cost for this are low. Furthermore, the buck converter has a high effiency over 90

So we come to the disadvantgages eines buck converters. The transient response is slow for changes. The input has got a filter. Thus, could a buck converter no signal, where you need a unfilter signal,can used.

1.4 Flyback

The flyback converter is another option for a DC-DC converter. It comes with galvanic isolation between the input and outputs. The flyback converter is basically a buck-boost converter, but here the inductor is split to form a transformer. The windings of the transformer can have different turns ratio and in that way it is possible to step the voltage and current both up or down.

The basic circuit of the topology can be seen in figure 1.3. It uses a switch, a diode and a single control device.

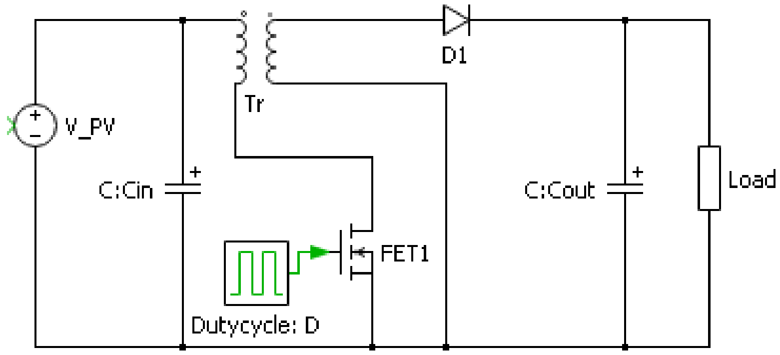

Figure 1.3. Flyback converter

When the MOSFET is on, the energy is transferred from the input voltage source to the transformer. In this state the output capacitor will supply the load with the output voltage. In the off-state the transformer will supply the output load with energy while it charges the capacitor as well.

"Wiki"

Because of the single control device another advantage of the flyback converter is a wide choice of controllers. For example it is possible to directly connect a PWM controlled IC to control the FET, and by that the converter.

The drawbacks are primary the current and voltage waveforms. The stress on the switch and diode can be high and comes as a function of the turns ratio of the transformer. Furthermore the leakage inductance from the transformer will result in a big voltage spike at the rising edge of the FET. This needs to be reduced by a snubber circuit. This will increase the power loss and efficiency though. The leakage inductance will also produce transients which will make the voltage stress at the FET bigger and give high-frequency ringing at the input. Lastly there will be increased noise at both terminals due to the fact that the input and output currents are discontinous.

"Non inverting buckboost texasConverter"

1.5 Non-inverting buck-boost converter

The Non-inverting Buck-Boost converter is a DC to DC converter that allows the voltage at its output to be higher or lower than the voltage at its input. The topology can be seen in figure 1.4. It uses 4 switches, of which 2 are controlled devices.

The controller can force the system to work in any of the following modes:

1. Buck $\rightarrow D \subset [0,1]; D' = 0$
2. Boost $\rightarrow D = 1; D' \subset [0,1]$
3. Buck-Boost $\rightarrow D \subset [0,1]; D' \subset [0,1]$

One of the main drawbacks of the topology is the control's complexity, which must calculate the appropriate duty cycle D and D' in any of the modes and also the transition between

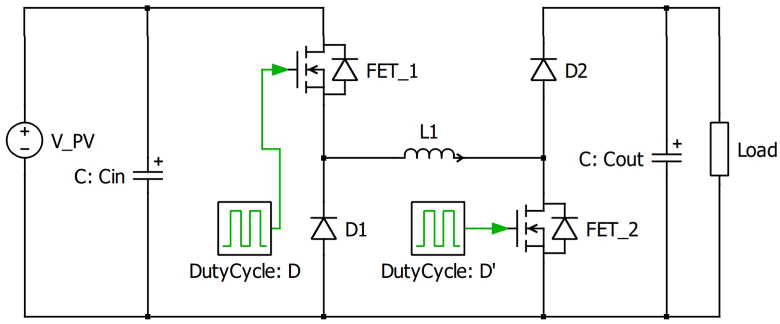

Figure 1.4. Non-inverting buck-boost converter.

these modes.

Usually the inverter's input voltage is fixed to some value higher than the grid's voltage. The possibility of higher and lower voltages at the converter's output allows different ways of associating photovoltaic modules. Then the user is able to arbitrarily decide how many PV modules to link in series. Differently of what would happen in the case of Buck or Boost converters where the constraints regarding the number of panels are tighter.

Compared with other topologies that can have both higher and lower voltages at the output, such as the SEPIC or ZETA converters, this converter features a single inductor and no intermediate capacitor. With such reduction in passive components the price, efficiency and power density rises significantly [Under the hood of a noninverting buck-boost converter].

Although this topology exhibits appropriate features, it can be further improved by replacing the diodes by MOSFETs. The circuit may be seen in figure 1.5, it's called Bidirectional Non-Inverting Buck-Boost converter. With this variation, the following changes occur:

1. The system becomes bidirectional.
2. The conduction losses are decreased. −> **Discuss with supervisor**

If the system is bidirectional it can be used in different MIC strategies, such as ++**reference to the introduction figure with the MICs outputting power to the PV**++. Or even implement diagnosis features with the panels' electroluminescence, whenever these are fed enough power.

As seen in figure 1.5, notice that duty cycles of the switches that replace the diodes are $\overline{D}$ and $\overline{D'}$.

The main drawback is the increased difficulty of the driver circuitry. And the requirement of a dead time in order to avoid the short circuit of FET_1 and FET_3 or FET_2 and FET_4 which could damage the system. When using diodes, the system is intrinsically protected against a shoot-through event.

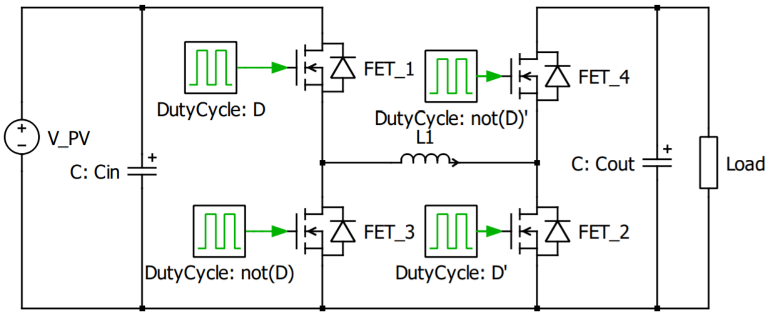

Figure 1.5. Bidirectional Non-inverting buck-boost converter.

1.6 Selection of topology

The selection of converter topology will be made from the research discovered earlier in this chapter. The converter should be able to allow both a higher and a lower output than the input. This requirement will stress the buck and boost converters, which only converts either up or down. This means that before the requirement is meet, both a buck and boost converter must be a part the implementation. This is not desirable, because it will introduce unnecessary work.

The next requirement states that the converter should have as high an efficiency as possible. The flyback converter will have a lower efficiency than the buck-boost, because of the transformer. This will introduce a loss in the extra inductor winding, and a larger loss in the FET because of the turns ratio in the transformer. Using a 4-switch buck-boost converter, in stead of a 2-switch, it is possible to further optimizing the power loss because of the use of FET's instead of diodes.

The 4-switch buck-boost converter does also has the advantage of being bidirectional. This means that it's possible to either extract a current from the PV-module to the inverter at the output, or to inject a current from the inverter to the PV-module. Because that the PV-modules acts like photodiodes, they will radiate an infrared light if current are injected. If the PV-modules are damaged in some way, i.e. having cracks, the radiation will be affected. This means that it is possible to discover faulty modules before efficiency drops. This will increase the overall efficiency of the system, and ease the maintenance sequence significantly.

The Bidirectional Non-Inverting Buck-Boost converter is chosen because of these arguments. How ever the bidirectional functionality will not be addressed in this project, but could be a part of further development of the converter.

2 Problem Analysis

2.1 Specifications

2.2 Research Question

Objectives 3

4 Future Work

The following list contains the subjects which will be addressed after the hand-in of the P0 report.

1. Non-inverting Buck-Boost converter design
2. Design of control system
3. Hardware implementation
4. Test & validation of converter
5. Further development
6. Conclusion

Appendix 5