AALBORG UNIVERSITET

DC-DC Converter for PV Module Integration

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Synopsis:
PV modules must work at their maximum power point in order to achieve the highest overall efficiency. Several environmental conditions can affect the output power of the PV modules.
This project will address these problems, by implementing a MIC including a MPPT algorithm. The MIC will minimize the power losses and therefore increase the efficiency.
The purpose of this report is to define the boundaries of the project. This includes the main objectives and the initial research. Furthermore there have been included a gantt chart of the entire project.

By signing the document, members of the group accepts that the entire group have participated in the work of the report. Therefore, all members vouch for the content of the report, and confirms that it doesn't include plagiarism.

Contents

Preface

This paper describes the "P0" report of the group project "DC-DC converter for PV module integration." It has been developed from the 10^{th} of September to the 9^{th} of October 2018, at Aalborg University, Institute of Energy, by the group INTRO-760.

The "P0" is an initial report which discusses research about maximizing the electrical power generated by PV modules. Furthermore, a theoretical comparison between different converter's topologies has been carried out in order to decide which MIC is going to be used in this project. After the "P0" report there will be a "P1" report which will include the entire development of the project.

The literature references are shown in square brackets, with a number referring to a specific document which can be found in the bibliography. Pictures and tables will be denoted in the X,Y format, with X representing the chapter and Y the figure or table number.

The process and development of "P0" has been based on the Problem Based Learning (PBL) method. This method is explained in the appendix 5.1. This method will also be applied for the "P1" report.

The source of the picture at the front page is:
Solar Panel Disposal: Exploring Your Options and Knowing the Risks. Oct. 2, 2018.
URL: http://www.safegardgroup.com/blog/2017/07/27/solar-panel-disposal

Summary

A DC-DC converter is designed to maximize the power generation of PV modules under mismatch conditions. These mismatches might appear due to partial shading, uneven dirt distribution, manufacturing tolerances and ageing among others. The DC-DC converter is connected to each PV panel becoming a module integrated converter (MIC).

An overview of the different DC-DC topologies has been performed, the bidirectional buck-boost converter has been selected because it best fulfills the requirements of high efficiency, bidirectional energy flow and input voltage increase and decrease capability. An analysis of the input and output conditions has been done in order to define the system requirements for the project. For this, commercial grid inverters, MICs and PV modules' figures of merit have been evaluated.

The future work of this project will cover the design and implementation of a MIC valid for generic PV modules. Design, simulation, implementation and testing will be performed and conclusions on the project will be drawn.

Nomenclature

Abreviations:

AC	Alternating Current
DC	Direct Current
FET	Field-Effect Transistor
IC	Integrated Circuit
MIC	Module Integrated Converter
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
PBL	Problem Based Learning
PV	Photovoltaic
PWM	Pulse Width Modulation
SEPIC	Single Ended Primary Inductance Converter
STC	Standard Test Conditions

Symbols:

η	Efficiency
°C	Degree Celsius
D	Duty Cycle
E	Energy
I	Current
I_{mpp}	MPP Current
I_{sc}	Short Circuit Current
N	Number of PV Panels
P	Power
P_{max}	Maximum Power
t	Time
V	Voltage
V_{ds}	Drain Source Voltage
V_{mpp}	MPP Voltage
V_{oc}	Open Circuit Voltage
W	Watt
W/m^2	Irradiance

1 Introduction

To this date, sustainable energy sources have become an area of worldwide focus in an attempt to reduce the environmental impact due to emissions of CO_2 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 has been a considerable increase in electricity production from renewable energy sources being the fastest growing sectors wind and solar energy. In 2017, photovoltaic generation was the renewable energy source which experienced the highest increase in newly installed capacity. The total installed capacity reached approximately 402 GW[1].

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 panel which can also be connected to other PV panels resulting in a PV array [2]. 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 on the power generated by the different PV panels. This will result in losses in the PV system and thus in a lower efficiency. Mismatches may lead to uneven power generation. These can be caused to partial shading, manufacturing tolerances, defects in the PV modules due to weather conditions and ageing 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 [3]. Mismatch losses in a PV system can be reduced by forcing every PV module to work at its Maximum Power Point (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). MICs consist on DC-AC micro inverters or DC-DC converters that incorporate a MPPT controller unit to ensure that the output power of the MIC is the one corresponding to the MPP of the PV module [3].

1.1 Photovoltaic generation

The generation of direct current electricity from solar energy is a phenomenom known as *Photovoltaic effect* which was first discovered by a French physicist named Edmond Becquerel in 1839 [4]. This process allows the generation of electrical energy in a solar cell, which is composed of two layers of semiconductor material (usually silicon), when it is exposed to the sunlight [4]. 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 decreases with increasing temperature [2]. Usually, PV panels are tested under standard test conditions (STC) to indicate the performance of the PV modules. The STC test is carried out at a solar cell's temperature of 25°C and at a solar irradiance of 1000 W/m^2 [2]. When the temperature of the PV cell is higher than 25°C, the PV panel generates less power and at a lower temperature the electricity generation is improved [2].

Some of the most important characteristics associated with a PV panel's datasheet are the following: maximum power (P_{max}), open-circuit voltage (V_{oc}), short-circuit current (I_{sc}), MPP voltage (V_{mpp}), MPP current (I_{mpp}) and efficiency (η) [2]. These features are important to define the I-V curves of the PV panel in order to develop the MPPT controller unit. PV panel's I-V curves are a graphical representation of the relationship between the voltage and current of the solar panel for different temperatures and levels of irradiance [5]. Therefore, I-V curves provide all the necessary information required to perform the MPPT. Figure 1.1 shows the I-V curve for a given PV cell's temperature and solar irradiance. As it is well known, the power generated by a PV cell is the product of current and voltage at each point, hence, the P-V curve can be obtained and it is displayed in purple in Figure 1.1.

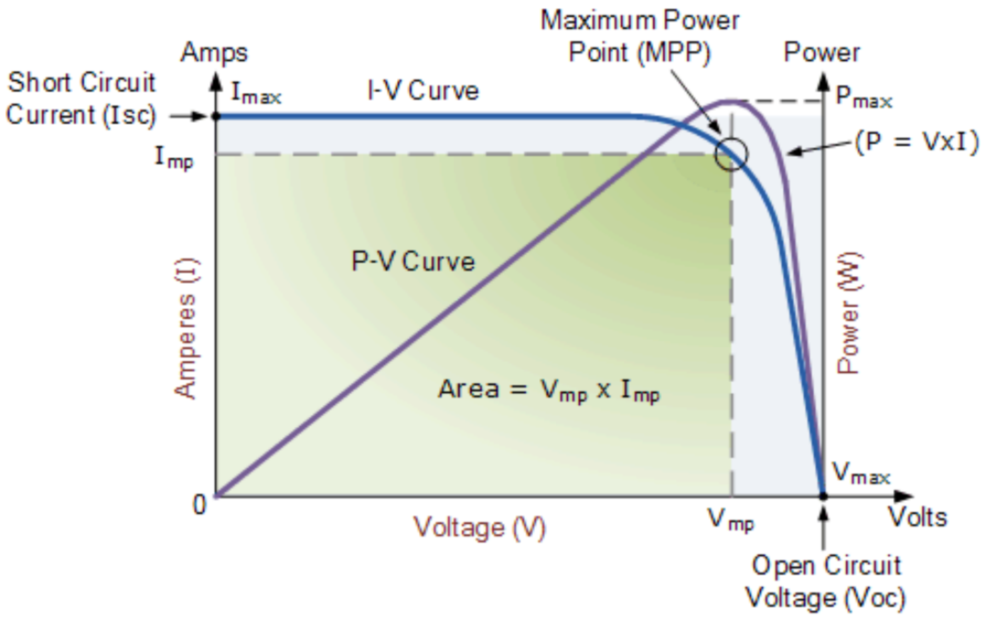

Figure 1.1. I-V characteristics of a generic solar panel [5].

From the P-V curve, the maximum power generated by the solar panel (P_{max}) is obtained. This maximum power corresponds to the MPP and takes place for a specific combination of voltage (V_{mpp}) and current (I_{mpp}). Therefore, the ideal operating point of a PV panel corresponds to the MPP which varies according to the level of solar radiation and the temperature [2].

There are different types of photovoltaic systems, however, the most common PV systems implemented nowadays are grid-connected [2]. This type of PV system is mainly composed of a solar array, a DC-DC converter with an MPPT controller unit and an inverter, as shown in Figure 1.2.

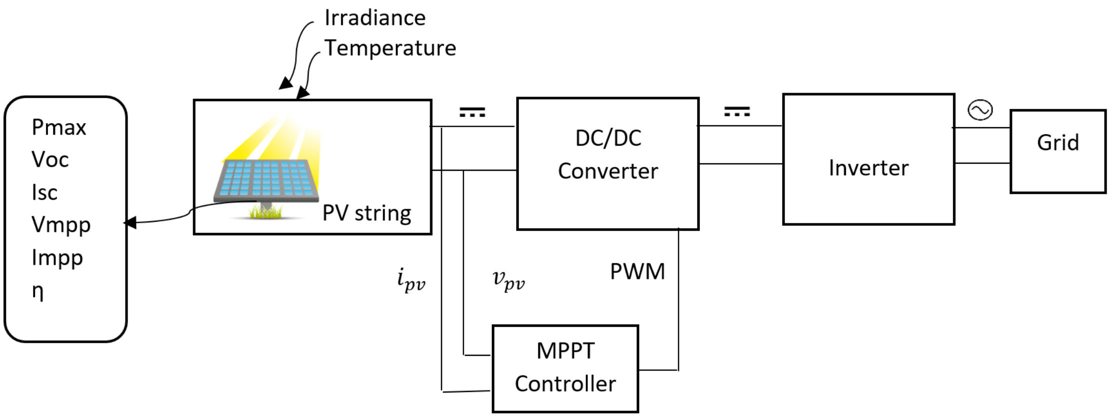

Figure 1.2. Basic block diagram of a PV system.

As mentioned at the begining of the chapter, PV modules can be connected to each other resulting in a PV array/string which generates electrical energy in the form of direct current. The MPPT controller unit takes the PV array's output voltage and current as input variables in order to calculate the ideal duty cycle. This duty cycle is used to vary the Pulse Width Modulation (PWM) signal of the DC-DC converter in order to get the PV string to work continuously at its MPP. The output of the DC-DC converter is connected to an inverter to convert the DC electric energy in an AC electrical signal compatible with the grid.

1.2 MIC implementation

One of the most important factors to take into consideration when implementing PV modules is to constantly obtain the maximum energy possible out of these PV panels. If this is not done, the amount of energy that should have been obtained will instead be lost. Since energy is equal to power over time, power must be maximized when the energy is being extracted. To achieve such goal a MPPT needs to be implemented. This is an electrical system that is always on the search of the location of the MPP where the power generated by the PV module is maximum. MPPTs mostly consist of a power circuit that regulates either voltage drop or current flow across the PV terminals. There are different kinds of circuits that can be used to follow the MPP of the PV, this topic will be further introduced in chapter 3.

Solar plants and domestic installations are composed of several modules connected to each other in series or parallel configurations. To simplify the PV system's structure, one MPPT is commonly used for many modules as shown in figure 1.2. This approach may lead to unoptimal efficiency of the system since the uneven power generated by the PV modules might lead to have a system with a local MPP in addition to a global MPP [6]. In figure 1.3 a system exhibiting two MPP, due to partial shading, is shown. In order to ensure that the system is working in the global MPP and not in the local MPP, the controller will have to perform a voltage sweep in order to find the global MPP. This voltage sweep is a higher level of complexity in the MPPT control system [6]. In any case, the system will not be able to get the maximum power generation, as one panel is bypassed by a diode.

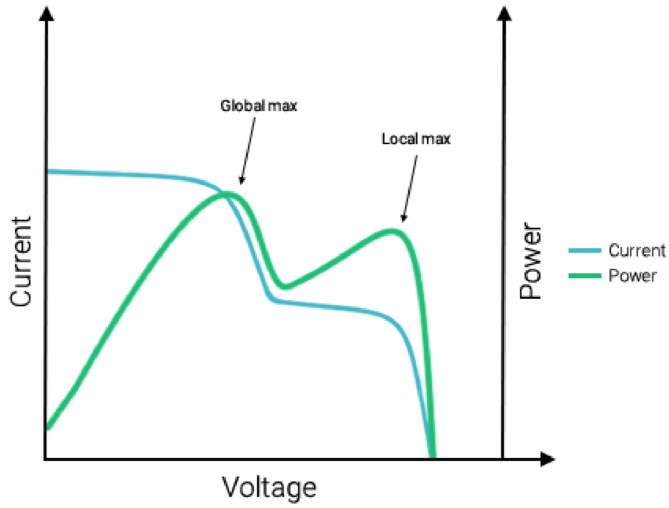

Figure 1.3. I-V curve of a system with more than one MPP [7].

Another possible configuration is using MICs for each PV module which will result in higher overall efficiencies [8]. With this configuration, events like partial shading, uneven dirt, wear distribution or imperfections produced during the assembly line are reduced and do not affect the rest of the PV modules in the array. Also, a more detailed control of the plant is achieved since separate data from each individual panel is obtained [8]. As seen so far, different implementation options for MIC devices are possible but the most important objective of these devices is to individually control each PV module, resulting in an overall improved efficiency as well as a more robust system against any kind of disturbance [8]. Each PV module will then be connected directly to a MIC allowing the output voltage and current to be defined by the load, either an inverter or a battery. This way the system is able to operate at different voltage and current levels whilst maintaining the MPP at all time [8].

MICs can be either microinverters or DC-DC converters. In figure 1.4 a PV system using MICs to perform the voltage reduction or increase is used. Notice that N panels might be used. Series or parallel connections can be used to link MICs' outputs and then connect this output to the inverter input through a DC link. The power rating of this inverter will have to be higher than the maximum power that can be delivered by MICs. Then the size of the inverter must consider the amount of PV panels installed.

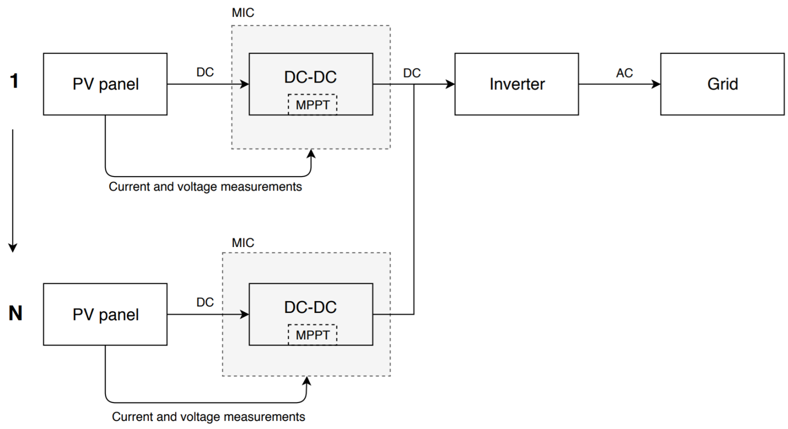

Figure 1.4. PV generation with DC-DC MIC system structure.

The panels with a MIC consisting on a microinverter, include a DC-DC converter with MPPT together with an inverter and are directly tied to grid. In figure 1.5 a microinverter system structure can be seen. For the user, this system is simpler, as only the PV must be purchased. The user doesn't have to worry about selecting and installing an inverter.

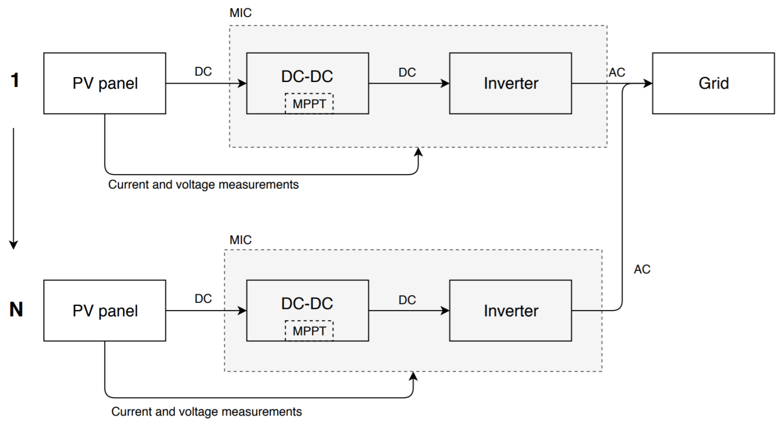

Figure 1.5. PV generation with microinverter MIC system structure.

The main advantage of the microinverter system is that it is simpler for the user, however, it implies an increase in costs and are usually less efficient than a DC-DC system with a higher power general inverter [8]. Therefore, for the development of this project a DC-DC MIC will be employed.

Problem Analysis 2

As discussed in chapter 1, uneven module power generation due to mismatches may lead to inefficient overall power generation. If one of the modules of the PV array is generating below average, it will affect the overall power generation. This situation can be addressed by placing a bypass diode in parallel with every PV panel as shown in figure 2.1. This way the current can flow through the diode, maintaining a higher current in the string [8]. However this solution will drive the power generation in the bypassed module to 0 and will cause a small power loss in the diode. Notice that the total power generated in the string is 120 W instead of 150 W.

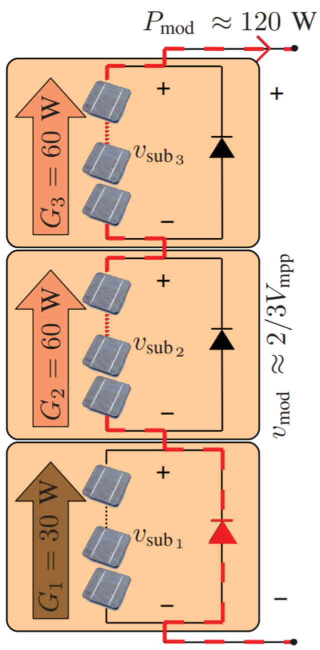

Figure 2.1. PV module being bypassed by a diode[8].

For avoiding the loss of the power generated by the bypassed PV module, a MIC may be used [8]. These MICs are usually micro-inverters or DC-DC converters which incorporate a MPPT algorithm in order to maximize the power generated by the module. Microinverters are composed of a DC-DC converter with MPPT and an inverter to convert the DC current from the PV directly to AC current to be connected to the grid. DC-DC converters need an inverter at their output if the desired load is the grid. As the micro-inverters have reported higher cost and slightly lower efficiency [8] the project will be focused in developing a DC-DC MIC for integrating it with a single PV panel.

2.1 System requirements

For the design and test of the MIC it is of great importance to have the requirements of the system defined. The input requirements of the MIC will be based on the specifications of the PV panel *STP300S-20/Wfb* from Suntech Power. The specifications are shown in table 2.1.

Maximum power (P_{max})	300 [W]
Optimum Operating Voltage (V_{mpp})	32.6 [V]
Optimum Operating Current (I_{mpp})	9.21 [A]
Open Circuit Voltage (V_{oc})	39.9 [V]
Short Circuit Current (I_{sc})	9.65 [A]
Module Efficiency (η)	18.3 %

Table 2.1. Electrical characteristics *STP300S-20/Wfb* [9].

The values from the previous table will be the input for the DC-DC converter. The specifications of the load of the MIC will be based on the commercial inverter *"Power-one STGU-105"*[10] in order to have the output voltage defined. From the inverter's datasheet it is found that the nominal voltage in the DC-link is 360 V, with a maximum input power of 5500 W.
The development of this project will be based on these requirements because they are based on real commercial products that the user can purchase.

Table 2.2 shows the requirements of the MIC, extracted from the specifications of the PV panel and the inverter. It defines both the requirements regarding input, output and of the length of PV panel strings.

Input	
Maximum input power (P_{max})	300 [W]
Maximum input Voltage (V_{oc})	40 [V]
Maximum input current (I_{sc})	10 [A]
Minimum efficiency (η_{min})	98 %
Output	
Maximum output voltage (V_{out})	90 [V]
Maximum output current (I_{out})	15 [A]
Control	
Gain margin (GM)	To be defined
Phase margin (PM)	To be defined
Rise time (t_r)	To be defined
Overshoot (OS)	To be defined
PV system specification	
Minimum string length	4
Maximum string length	15
Others	
Maximum dimensions	To be defined
Operating Temperature	-40 to 85 [°C]

Table 2.2. MIC requirements.

2.2 Problem statement

The problem statement for this project can be formulated as the following question:

How can a module integrated converter be designed to maximize the PV power generation under real conditions?

The problem statement will be answered by fulfilling the following objectives:

- Design an efficient DC-DC converter for integration with a PV panel.
- Analyze different implementations of MPPT techniques and implement the selected control system.
- Hardware implementation of the MIC components including PCB layout.
- Test of the system using a PV simulator and validation of the results.

Background of converter topologies 3

3.1 Buck converter

A buck converter is one of the simplest DC-DC converters with the task of decreasing the input voltage. The required components are a DC-source for the input voltage, two switches (a diode and a transistor), an inductor, a capacitor and a load. The equivalent diagram in figure 3.1 illustrates a buck-converter.

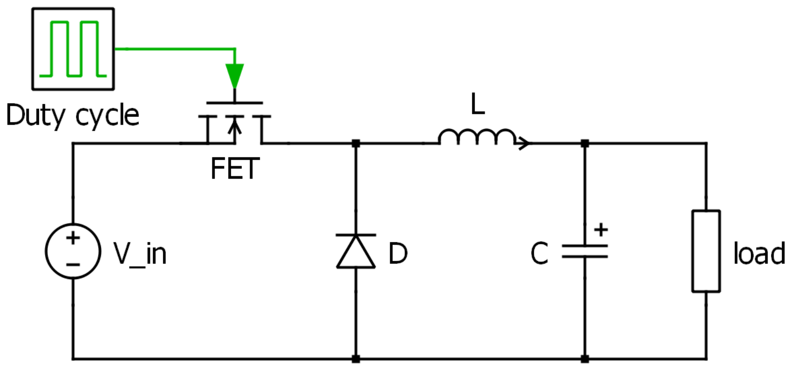

Figure 3.1. Buck-converter.

A buck-converter performs in two operating states. During the first state, the MOSFET is conducting and the diode is working as an open-circuit, the voltage drop then is divided between the inductor and load. Since the voltage is split, the voltage drop on the load is lower than the one of the input source. In addition, both the capacitor and the inductor are being charged. In the second state, the MOSFET is switched off and the current flows through the diode. During this state, the inductor works as a current source and the capacitor stabilizes the voltage [11].

The main advantage for using the buck converter is that the structure is very simple and only one controlled switch is needed. Also, the component count and thus cost of components is low. Furthermore, the buck converter can reach efficiencies up to 99% [12].

However, this topology is not very versatile since it does not allow the increase of output voltage with respect to the input. Another drawback is the lack of galvanic isolation between the input and the output [13].

3.2 Boost converter

A boost converter is another type of DC-DC converter, it is similar to the buck but instead of lowering the output voltage, it produces a higher electrical potential at the output with respect to that at the input.

The circuit consists of two switches (a transistor and a diode), an inductor, a capacitor, a load and a DC-source for the input voltage. Figure 3.2 shows an equivalent circuit diagram with the aforementioned components.

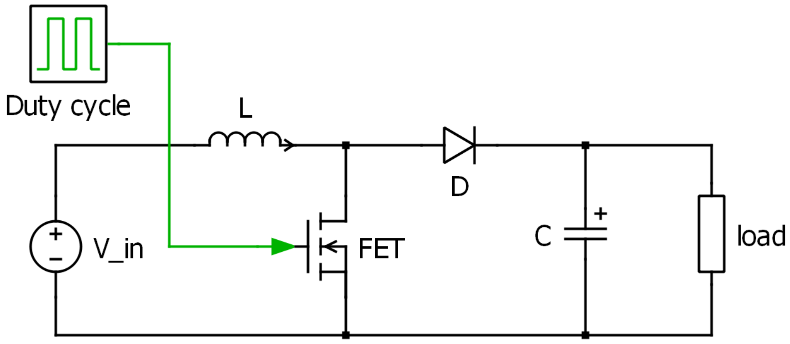

Figure 3.2. Boost-converter.

Similarly to the buck converter, this topology has two states, when the MOSFET is on, the current flows only trough the inductor because the diode is working as an open-circuit. Energy is then stored in the inductor, which voltage is equal to the input voltage, and current increases. Meanwhile, the capacitor releases the previously stored energy to the load. During the second state, the MOSFET is turned off, the current then loops trough the inductor, diode, capacitor and the load. Since the inductor had been previously charged, it now works as a current source in series with the voltage source of the circuit. The voltage across the load is then risen with respect to that at the input. Furthermore, the capacitor is charging [11].

An advantage for a boost converter is that it can raise the output voltage without using a transformer. It is also a cheap converter easy to control [14].

However, as it happened with the buck, the boost converter is also limited to rising the voltage and lowering it cannot be achieved. Also, if an error happens in the control of the MOSFET and it is left in ON-mode for a long time, a short-circuit is created and the current will increase until a component fails. Finally, this converter does not have galvanic isolation either.

3.3 Flyback converter

The flyback converter is another option for a DC-DC converter. It has galvanic isolation between the input and the 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 [15].

The basic circuit of the Flyback topology can be seen in figure 3.3. It consists of a DC-source, two switches (a transistor and a diode), two capacitors, a transformer and a load.

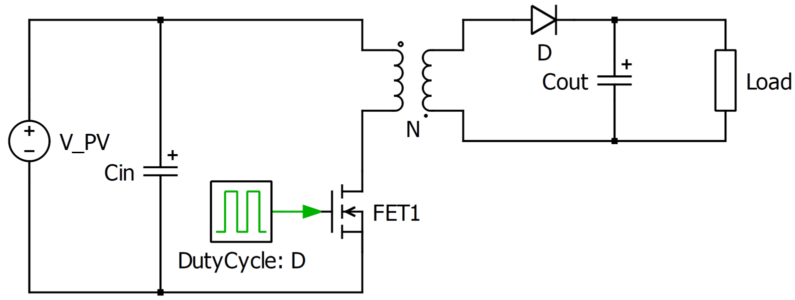

Figure 3.3. Flyback converter

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 also charges the capacitor[15]. The transformer makes it possible to have multiple secondary windings, and therefore different output voltages. This can be used when designing the supply voltage for the control system[15].

The transformer makes it possible to have multiple secondary windings, and therefore output voltages. This can be used when designing the supply voltage for the control system[15].

The drawbacks are primarily the current and voltage waveforms. The voltage-drop across the two switches in their respective off periods, is decided by the input- and output voltages and the transfer ratio of the transformer. Furthermore the leakage inductance from the transformer will result in a big voltage spike at the rising edge of the drain source voltage (V_{ds}) of the MOSFET. These needs to be reduced by a snubber circuit, like a RCD-circuit placed in parallel with the MOSFET[15]. This will increase the power loss and therefore decreasing the efficiency. The leakage inductance will also produce transients which will make the voltage stress at the MOSFET bigger and give high-frequency ringing at the input[16]. The V_{ds} is showed at figure 3.4 as V_{SW}.

Even though the transformer is be driven in continuous conduction mode (CCM), the currents in the windings will be discontinuous. This means that the RMS currents in both the primary and the secondary windings becomes higher[15]. The primary and secondary currents are shown at figure 3.4 as i_{pri} and i_{sec} respectively.

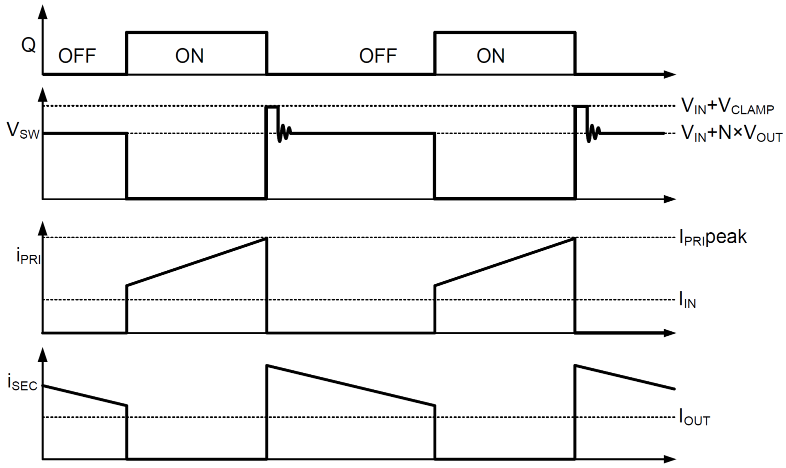

Figure 3.4. Flyback voltage and current waveforms[17]

3.4 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 3.5. It uses 4 switches, of which 2 are controlled devices.

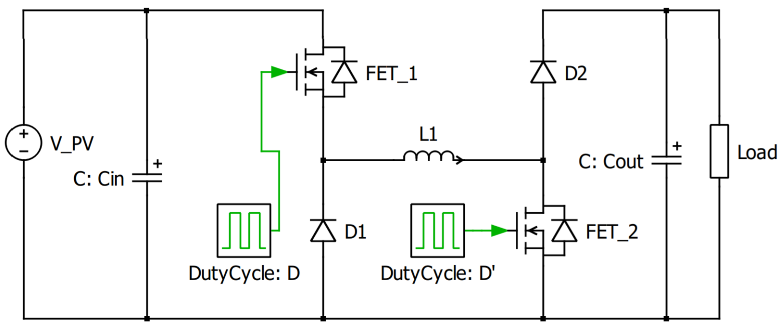

Figure 3.5. Non-inverting buck-boost converter.

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 $\rightarrow D \subset [0,1]; D' \subset [0,1]$

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 converter, this DC-DC features a single inductor and no intermediate capacitor. See SEPIC schematic in figure 3.6, notice the additional inductor and capacitor. With such reduction in passive components the price, efficiency and power density improves significantly [16].

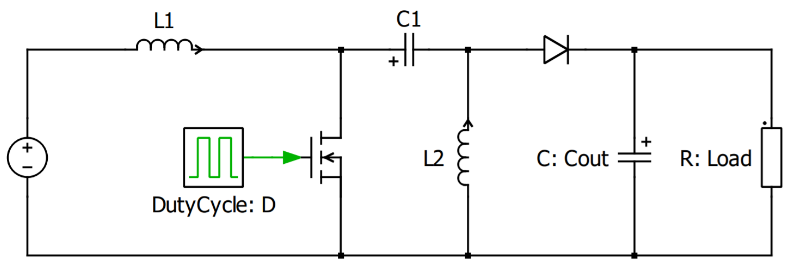

Figure 3.6. SEPIC converter.

One of the main drawbacks of the non-inverting buck-boost 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 these modes. The buck-boost mode is specially complicated as there are two duty cycles to calculate. This problem might be addressed by setting a constant duty cycle in one of the bridge's legs and then the control will calculate the other leg's duty cycle [18].

Although this topology exhibits appropriate features, it can be further improved by replacing the diodes by MOSFETs. The circuit may be seen in figure 3.8, 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 smaller.

If the system is bidirectional it can be used in different MIC strategies, as the topology seen in figure 3.7, which features an isolated dc link. This topology needs a bidirectional MIC as energy flow in both directions is needed. It also allows diagnosis of PV modules, as described in section 3.5.

As seen in figure 3.8, notice that duty cycles of the switches that replace the diodes are $\overline{D}$ and $\overline{D'}$. This line over the variables means that it is the negated value of the original variable. The duty cycle is the boolean variable that indicates the conduction state of a switch. In the case of an enhancement switch, the switch is conducting whenever its driving duty cycle is equal to '1' and it is closed when its driving duty cycle is equal to '0'.

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.

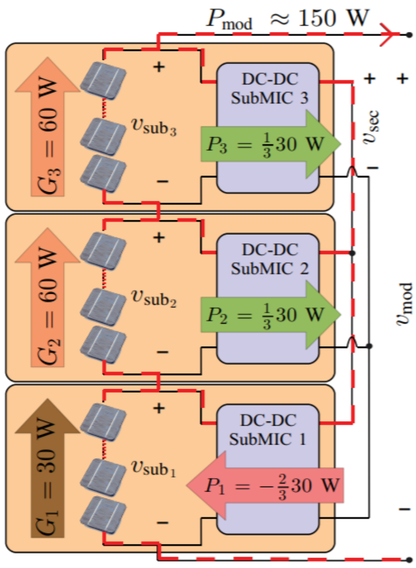

Figure 3.7. Bidirectional MIC use [8].

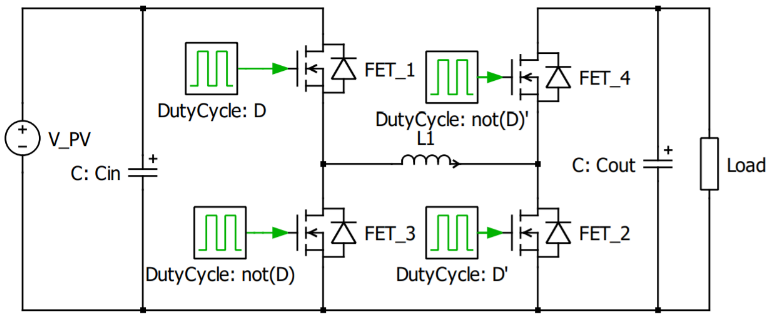

Figure 3.8. Bidirectional Non-inverting buck-boost converter.

3.5 Selection of topology

The selection of converter topology will be made based on the research made earlier in this chapter. The converter should be able to allow both a higher and a lower output than the input. This requirement will limit the buck and boost converters, which converts either up or down. This means that before the requirement is met, both a buck and boost converter must be a part of 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 transistor buck-boost converter, instead of a 2 transistor, it is possible to further optimizing the power loss because of the use of FET's instead of diodes.

The 4 transistor buck-boost converter does also have the advantage of being bidirectional. This means that it's possible to either extract current from the PV-module to the inverter at the output, or to inject current from the inverter to the PV-module. Due to that the PV-modules acts like LEDs, they will radiate an infrared light if current is 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. However the bidirectional functionality will not be addressed in this project, but could be a part of further development of the converter.

Future Work 4

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

4. **Non-inverting Buck-Boost converter design**
    1 Circuit analysis
    2 Component sizing
    3 Open-loop simulation and results
5. **Design of control system**
    1 Small-signal model
    2 Evaluation of main MPPT techniques
    3 Selection of MPPT
    4 Simulation and result
6. **Hardware implementation**
    1 Selection of components
    2 PCB layout
    3 PCB assembling
7. **Test & validation of the MIC**
8. **Conclusion & further development**

Appendix 5

5.1 Problem Based Learning

Problem Based Learning (PBL) is a method to organize the group work which will help to approach the project's objectives. Collaboration in the group is a very important factor to get the project working as efficient and fluent as possible. Therefore there has initially been put some work into a way to work and organize the project. By doing that in the beginning we will save important time later on. First of all this is a group of 6 people so it is important to give different tasks to different people to keep it efficient.

To make sure everyone know what is going on there will be a group meeting at least once a week but usually there will be more. Here the group members present their progress for each other, share the knowledge acquired and, if there has been any problems, it will be discussed here. In these meetings there will be one chair-person who needs to make sure that all the topics of the agenda are being discussed in detail. Besides the chair-person there will be a responsible for writing the minutes-of-meeting.

A supervisor meeting will be held at least once every two weeks. Again with a chair-person and a responsible for writing. Before the meeting, the agenda and questions to be discussed are sent to the supervisors and afterwards the group will sent the minutes-of-meeting. The goal here is to show the supervisors that the project is moving in the right direction and to get the questions answered. Furthermore, the group sends the documentation progress to get feedback regularly.

To organize the tasks between the group members the web page *Trello* is used as a taskboard. All the tasks that should be done are written here and divided in sections: "To do", "Doing" and "Done". This makes sure that everybody can see which tasks are in progress and who is working on them. A time-plan has been develop for the "P0" and the "P1" report using a Gantt chart (Figure 5.1), so there is a common agreement on which tasks should be done at first and the milestones of the project report.

5.2 Gantt chart

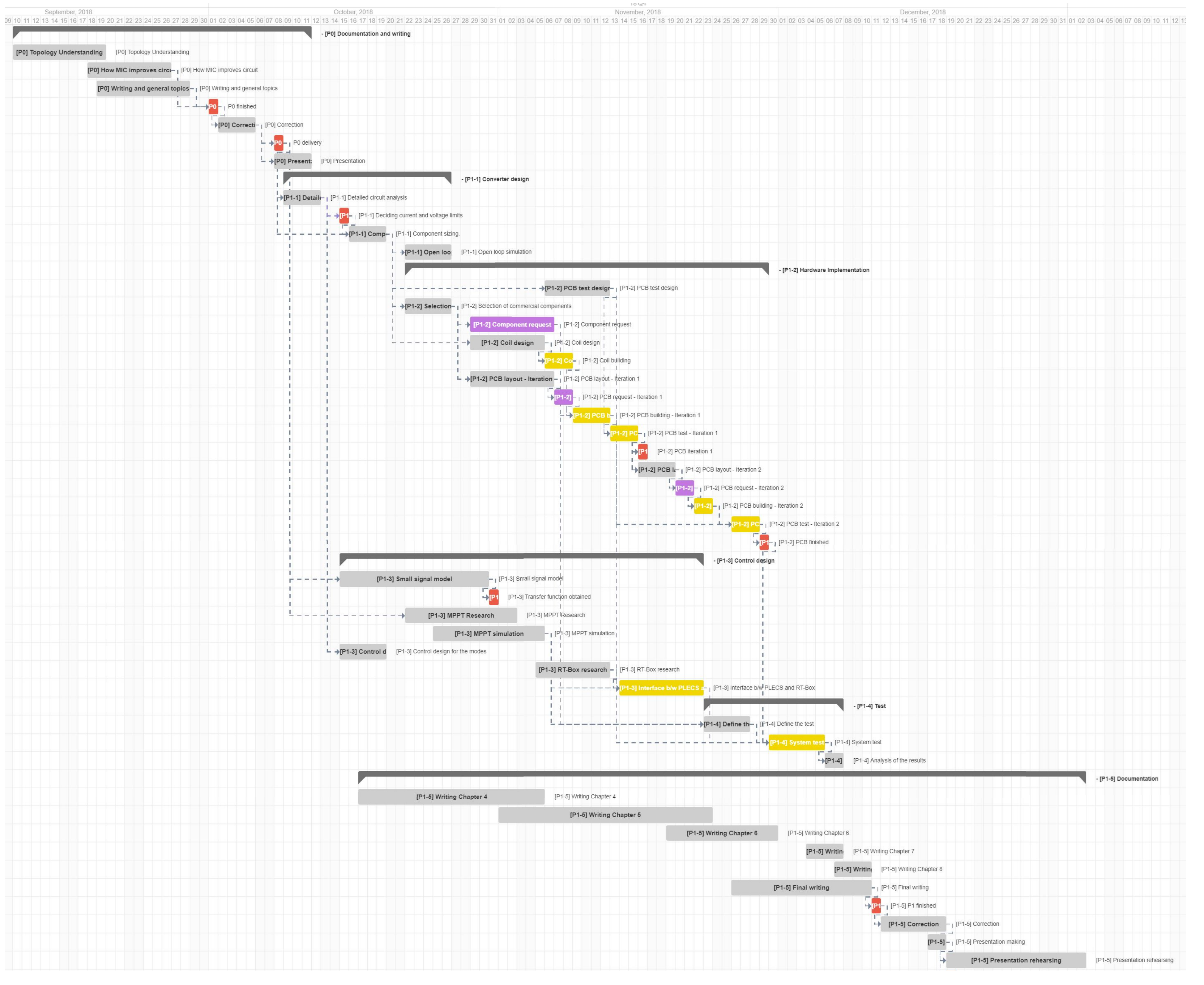

Figure 5.1. Project Gantt chart

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