Ben-Gurion University of the Negev

Faculty of Engineering Science
Dept. of Electrical and Computer Engineering

Fourth Year Engineering Project

Optimal converter for solar cells

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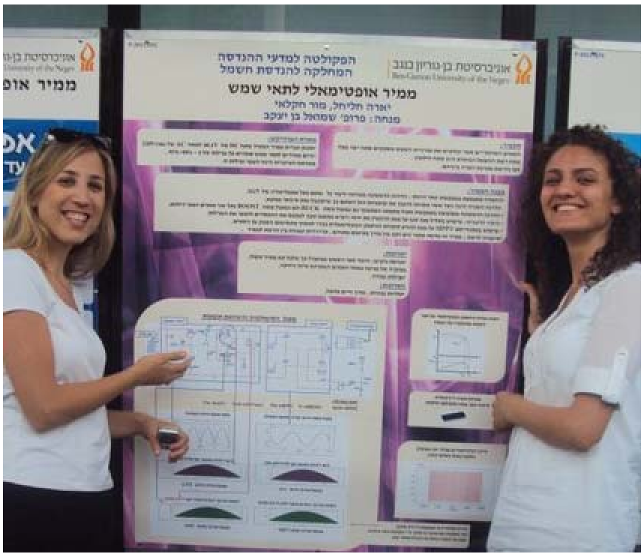

Abstract:

Due higher demand and the cost of resources such as oil, gas and coal, the cost of electricity has risen in recent years.

In times like these, where environmental issues are taken very seriously, there is more motivation to move away from conventional and nuclear power stations. Therefore, the use of alternative energy sources such as solar cells has become an essential next step in the energy industry.

There are several different topological arrangements for connecting solar panels.

One of the popular topologies for harvesting solar energy is to use several photovoltaic panels connected in series that share a centralized inverter to transfer the energy to the grid. A downside of this topology is that a low output current production of a single panel will affect the production of the whole series.

The topology to be developed in this project will apply a modular approach of integrated converters which will allow each of the panels to operate at the optimum power point. Each module will use a micro inverter which can invert the solar energy (DC) to the grid (AC).

This use of module integrated inverters is relatively expensive and for this reason it is only a partial solution for this problem. Furthermore, there is a problem of efficiency.

As for now, the solar cell energy is not exploited to its maximum possibility.
The solar cells' output power is only 20% of the sun's energy while the efficiency of conventional micro inverter stands between 92-98%.

The micro inverter developed in this study applies a new circuit concept, the tapped inductor converter, which may help improve the efficiency by lowering the losses.

The idea and goals:

(1) This micro inverter was designed and built based on two levels.
The first level input is about 30.1[V] DC from the solar cells. And he first level output is pulsating wave with amplitude of 331[V] (220V_{rms}).
The second level input is the first level output. The second level output is sine wave of 220V_{rms} and grid frequency (50 Hz) and is derived by changing the polarity of the input.
(2) Improving the inverters efficiency – up to 95%.
(3) Using digital system control - dsPIC30F2020 microcontroller- which is responsible for switching the transistors, so we will be able to get the right output.
(4) Long lifetime (avoid using electrolytic capacitor).
(5) Low cost micro inverter.
(6) Designing appropriate MPPT algorithm.

Schedule changes:

Because of lack of time we could only finish building of the first level. So the experimental results will include only the first level. And for this reason we couldn't examine the MPPT algorithm.

Solution principle:

The solution principle is based on using micro inverter based on switching circuit's model.
The switching is controlled by digital controller, which is using varying duty-cycle to control the switching. This way we will get the right output.

The first level is a circuit which is behaving as a buck inverter part of the time and the other part as a boost inverter.

This micro inverter is naturally synchronized to the grid.

Requirements Specifications:

Input values (DC):

Requirement's number	Requirement's definition	Requirement's solar-cells value
1	Recommended input power	180W
2	Maximum input voltage (DC)	30V
3	Maximum input current	6A

Output values (AC):

Requirement's number	Requirement's definition	Requirement's system value
1	Nominal output voltage	220Vrms
2	Nominal output current	840mA
3	Frequency range	47.5-52.5Hz
4	THD	<5%
5	Inverter's efficiency in maximum points	92.5%-98%

Simulation first level scheme and results:

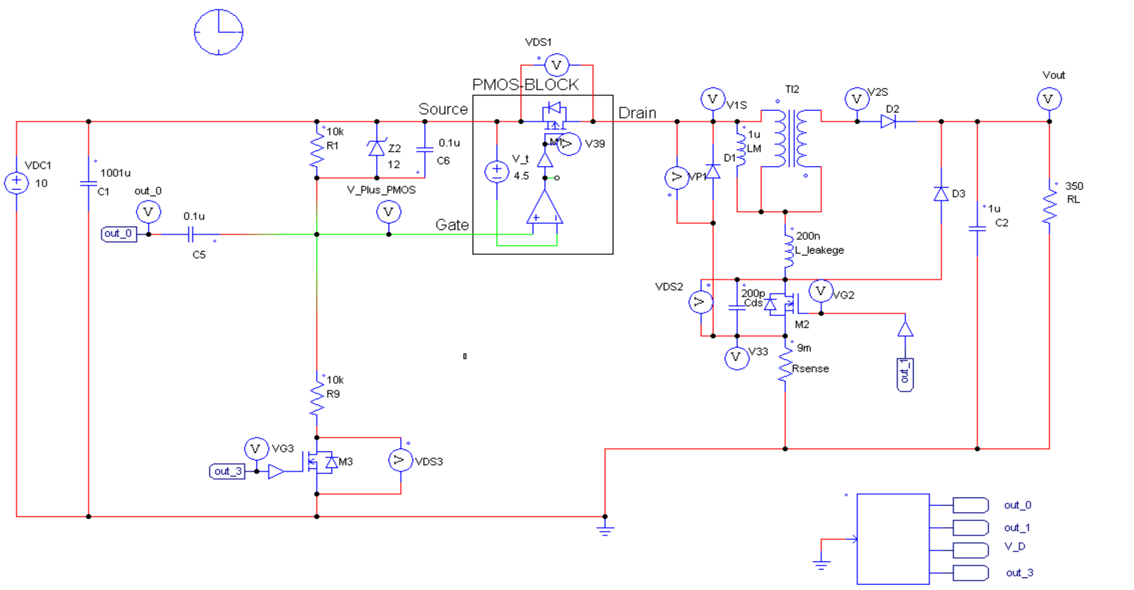

Fig. First level simulation circuit (PSIM)

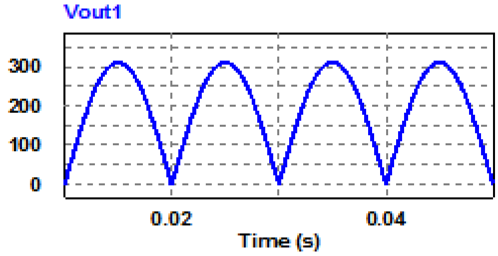

Fig. Simulation circuit (PSIM) output voltage of the first level

As we can see from the simulation results, the first level output is pulsating wave with amplitude of 311[V] and with 50Hz frequency.

Simulation second level scheme and results:

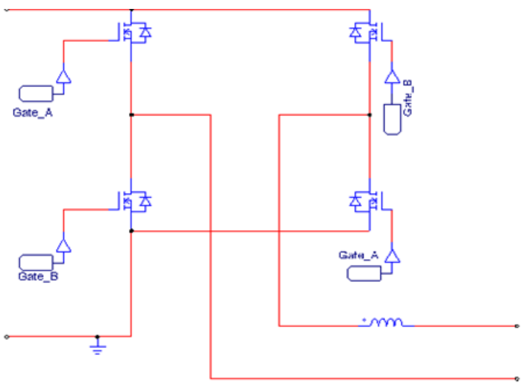

Fig. Second level simulation circuit (PSIM)

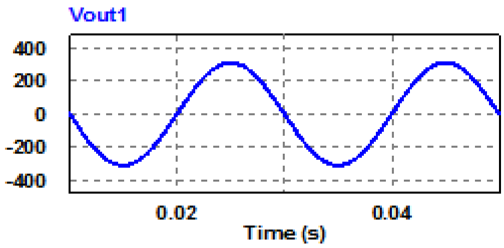

Fig. Simulation circuit (PSIM) output voltage of the second level

As we can see from the simulation results, the second level output is sine wave with amplitude of 311[V] and with 50Hz frequency (grid's requirements).

Evaluation board scheme of the first level:

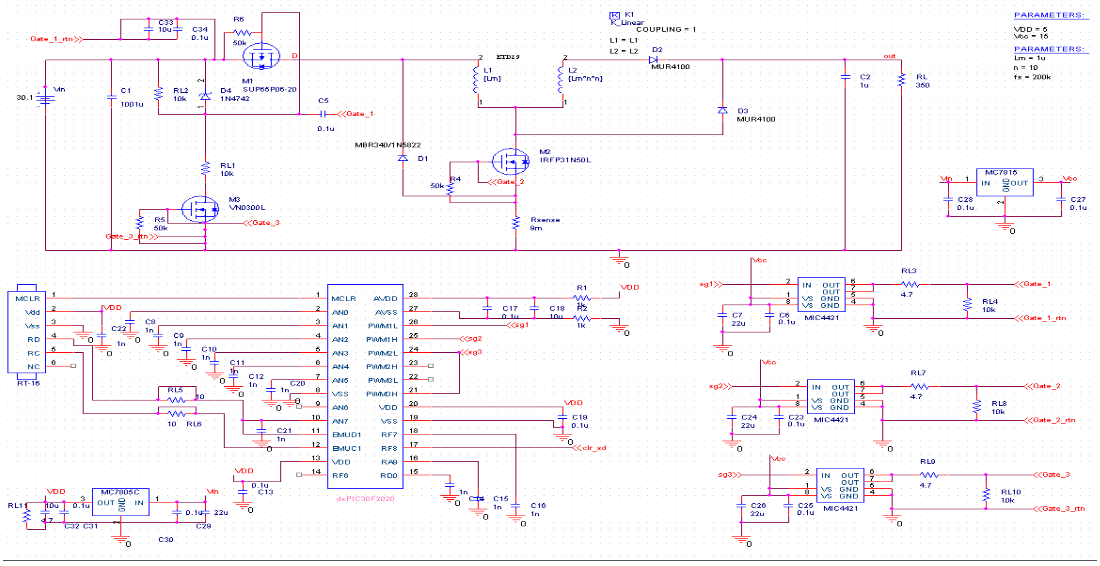

Fig. First level simulation circuit (SPICE) – Evaluation board

Problems and their solution:

(1) Leakage inductance currents because of using the tapped inductor.

$L_{leckage}$ is loaded during the period the transistor is in "on" state, and then, during the "off" period, the transistor is open and the gate capacitance of the transistor is loaded. This is realized by rising the voltage over the transistor, and causes that not all the energy is gating to the output, large part of it is wasted.

The solution for this problem is returning the wasted energy to the output by adding a bypass diode which will create a current path to the output. The solution is examined by checking the voltage over the transistor under the tapped inductor.

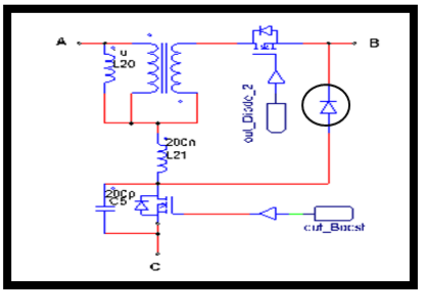

Fig. bypass diode (marked) in the first level circuit

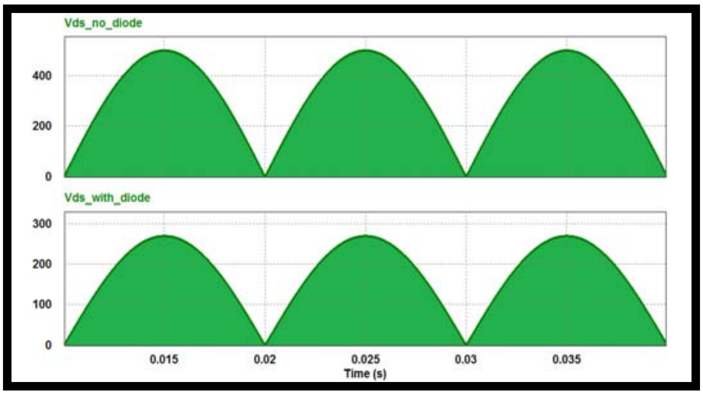

Fig. upper: Simulation circuit (PSIM) transistor voltage before diode
lower: Simulation circuit (PSIM) transistor voltage after diode

Note: in Fig. we can see that the transistor voltage decreased from about 500[V] to about 270[V].

(3) The transistors are turned "on" and "off" by using drivers.
The transistor M1 doesn't have a direct connection to the ground, so it means that it should have a floating driver which should also be capable of holding the transistor in conducting state. These requirements are causing a problem in finding a suitable driver.
The solution for this problem is adding a new unit which is connected to the transistor M1 and her purpose is creating a path to the ground during the time the transistor is in continuous "on" state, when it's connected in BOOST configuration.

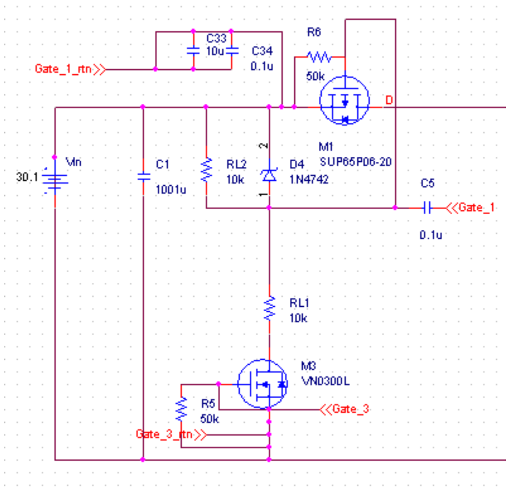

Fig. first level circuit (SPICE) after the floating driver solution

Evaluation board picture of the first level:

DC-AC, BUCK,BOOST circuit

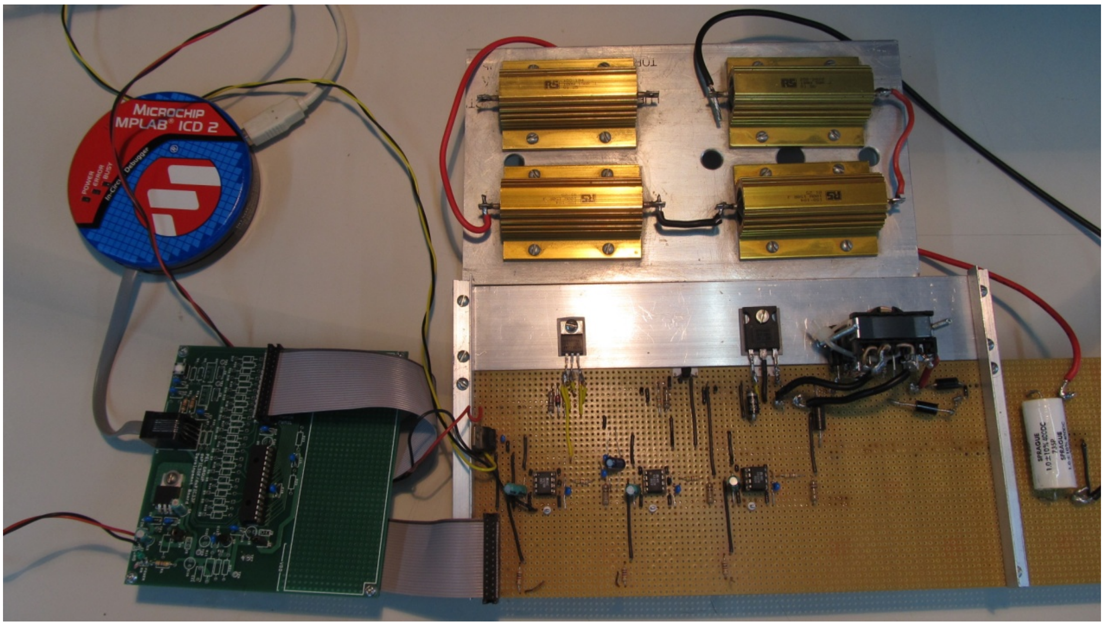

Fig: the experimental first level circuit

Comparing between simulation and experimental results:

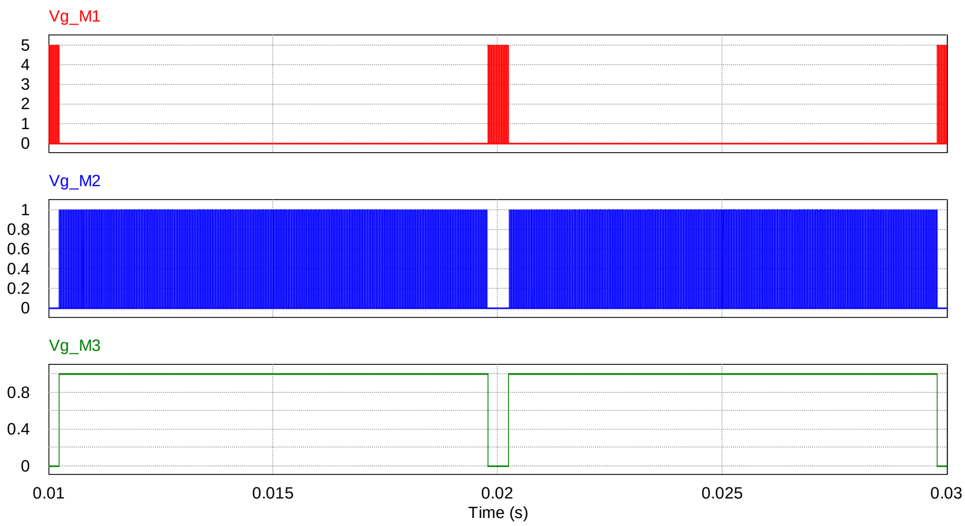

Fig. : Simulation (PSIM) results for:
First Fig: the Gate voltage of M1
Second Fig: the Gate voltage of M2
Third Fig: the Gate voltage of M3

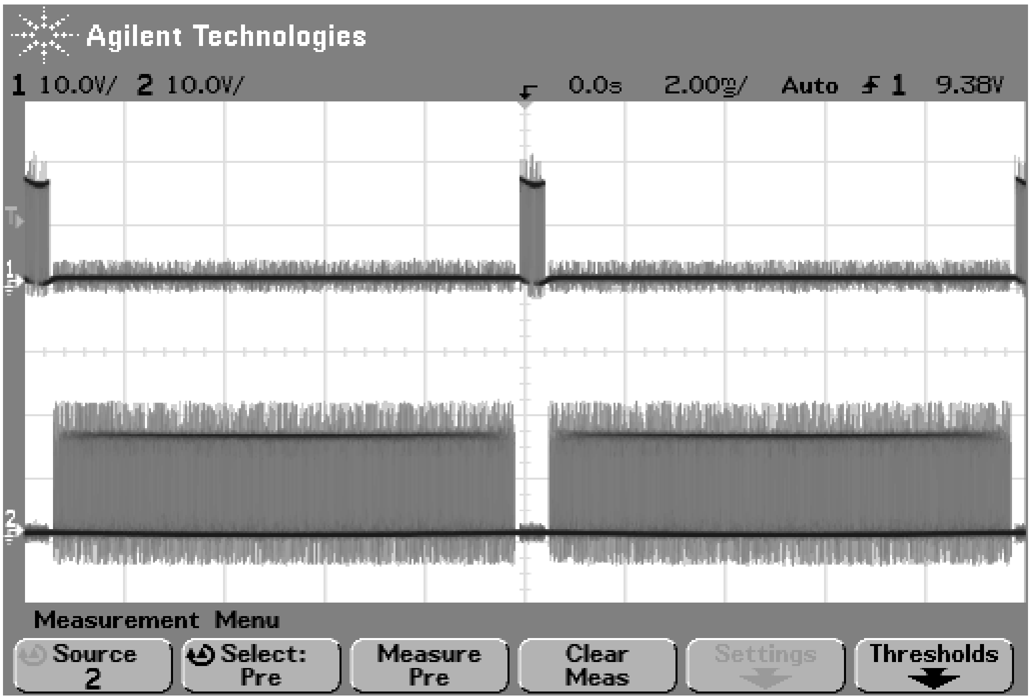

Fig. experimental results for:
First Fig: the Gate voltage of M1
Second Fig: the Gate voltage of M2

From the results we can see that there is a matching between the simulation results and the experimental results. So the transistors are switching as required.

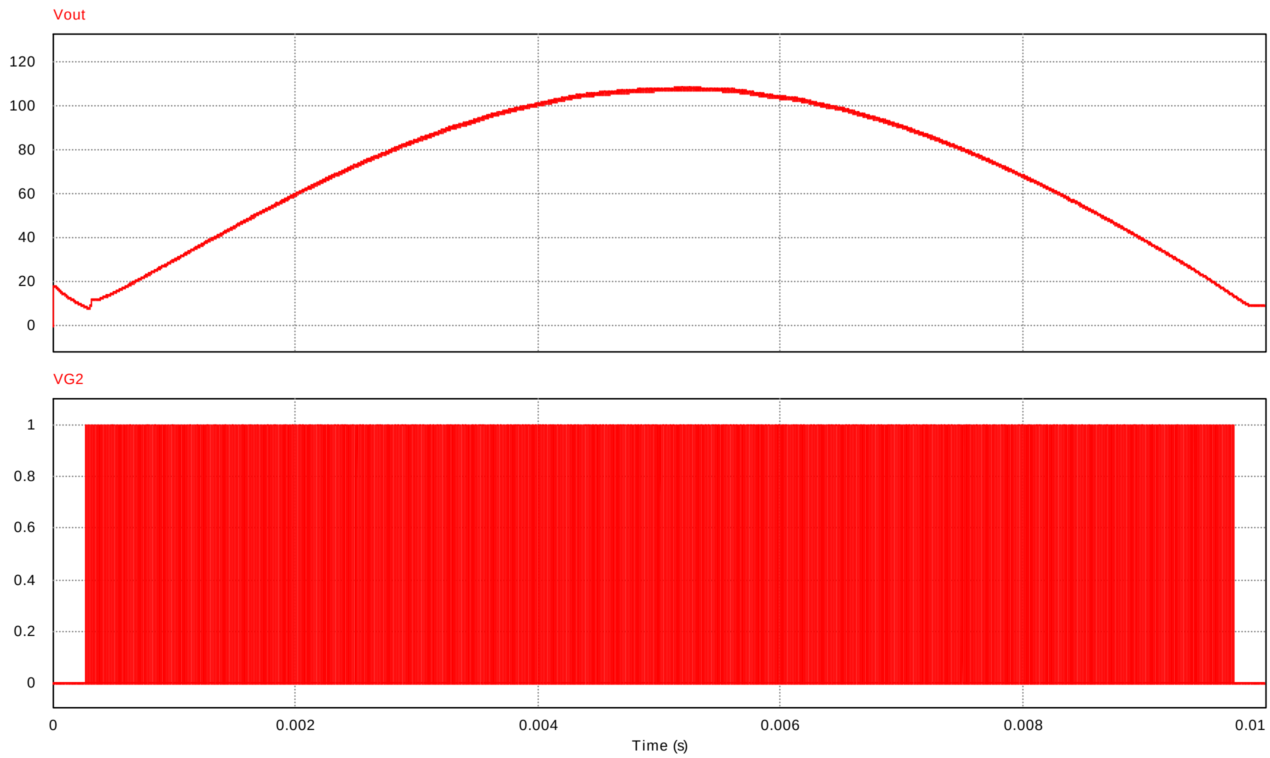

Fig. upper: Simulation circuit (PSIM) output voltage
lower: Simulation circuit (PSIM) transistor M2 gate voltage

BUCK,BOOST ; DC-AC

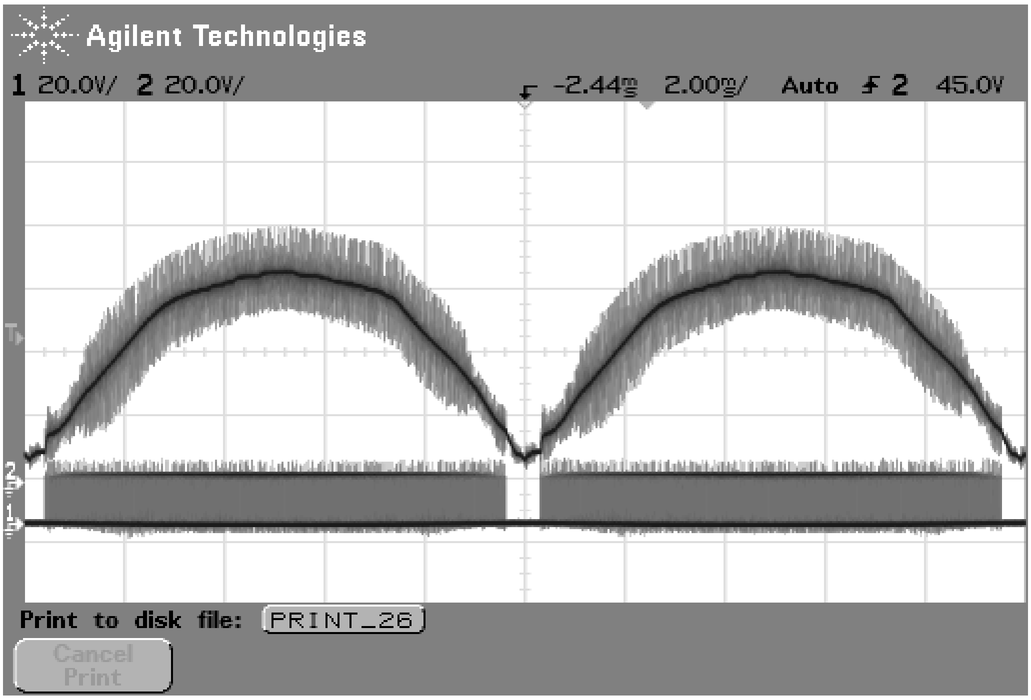

Fig. upper: experimental output voltage
lower: experimental gate voltage of transistor M2
BUCK,BOOST , DC-AC

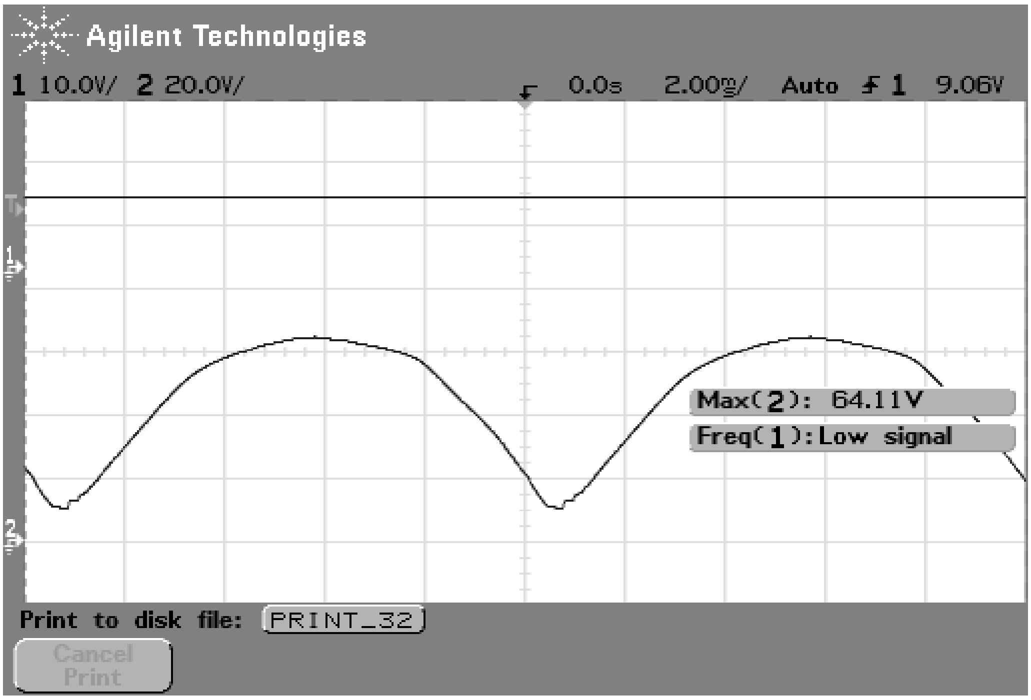

Fig. upper: experimental input voltage
lower: experimental output voltage after averaging
BUCK,BOOST , DC-AC

Comparing between simulation and experimental results shows as significant difference in the amplification result, the experimental is lower than the simulation (theoretical requirements).

And also there is a difference in the efficiency result; the experimental is 70% while the simulation is 100%.

<u>The circuit amplification:</u>

Experimental DC-AC circuit which behave as BOOST and also as BUCK circuit

Based on the theoretical output and input voltages calculations,
for 10V input voltage we will expect the amplitude of the output voltage to be:

$$V_{out} = V_{in} \cdot (1+n)^2 = V_{in} \cdot (1+10)^2 = 110V$$

The experimental results where: RMS output voltage of 48.581V for 10V input voltage.
By comparing between these results we conclude that the experimental circuit couldn't amplify as well as we wanted.
A possible reason for the low amplification is that there are voltage falls upon the transistors and lines in the circuit that causes power losses, and there affection is much more significant when we are taking about low input voltages. Because the system should work on photovoltaic cells, the input voltage should be about 30.1[V], so the problem will be less drastic.
This problem causes losses in the circuit efficiency:

$$P_{out} = \frac{V_{out,rms}^2}{R_{out}} = \frac{(48.581)^2}{350} \cong 7W$$

$$P_{in} = |V_{in}| \cdot |I_{in}| = 10[V] \cdot 1[A] \cong 10W$$

$$\eta = \frac{P_{out}}{P_{in}} \cdot 100\% \cong \frac{7}{10} \cdot 100\% = 70\%$$

We should note that the input current is: $I_{in} = 1A$.

Parameter's index	Parameter	Simulation results	Experimental results
1	Inverting DC input voltage to AC output voltage	succeeded	succeeded
2	Output amplitude as required at the theoretical operation	succeeded	The circuit didn't amplified the output voltage as requestd
3	Efficiency above 95%	succeeded	Lower efficiency
4	The output of the second level is have the same amplitude as in the output of the first level and the shape of the absolute of it	succeeded	There wasn't experimental second level
5	MPPT Algorithm	succeeded	There wasn't experimental second level, so we couldn't use the algorithm
6	Digital control system responsible of the transistors switching so it results the right output	succeeded	succeeded

Input values (DC):

Requirement's number	Requirement's definition	Requirement's solar-cells value	Experimental results
1	Input recomended power	10W	10W
2	Maximal input DC voltage	10V	10V
3	Maximal input current	1A	1A

Output values (AC):

Requirement's number	Requirement's definition	Requirement's system value	Experimental results
1	Nominal output voltage	$\approx 78V_{rms}$	$\approx 49V_{rms}$
2	Nominal output current	222mA	$\approx 141mA$
3	Frequency range	47.5-52.5Hz	50Hz
4	THD	<5%	-
5	Inverter's efficiency in maximum points	92.5%-98%	$\approx 70\%$

Note: The output current was measured at the output of the second level where there is a resistor of $R_{out} = 350\Omega$, so the output power might be measured by:

$$P_{out} = I_{out,rms}^2 \cdot R_{out} \quad \text{-ו-} \quad P_{out} = \frac{V_{out,rms}^2}{R_{out}}$$