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PiL simulation of the P&O MPPT algorithm for PV systems on a DSP under two irradiation scenarios

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CHAPTER 1

Introduction

1.1 Overview of the PV system

A photovoltaic (PV) system, also known as a solar power system, converts sunlight into electricity using solar panels. Here's a detailed description of a typical PV system, along with a block diagram illustrating its components and their interconnections:

1. Solar Panels (Photovoltaic Modules): Solar panels, also called photovoltaic modules, are the primary component of a PV system. These panels consist of multiple solar cells that convert sunlight into direct current (DC) electricity through the photovoltaic effect.

2. Maximum Power Point Tracking (MPPT) Controller: The MPPT controller is responsible for optimizing the power output of the solar panels by tracking the maximum power point (MPP). It continuously monitors the voltage and current of the panels and adjusts the operating point to ensure maximum power generation.

3. DC-DC Converter: The DC-DC converter, also known as a power converter or charge controller, interfaces between the solar panels and the battery or inverter. It regulates the DC voltage output from the panels to match the requirements of the connected components. In off-grid systems, the DC-DC converter also charges the battery bank.

4. Battery Bank (Optional): In off-grid or hybrid PV systems, a battery bank is included to store excess energy generated by the solar panels. The battery bank provides backup power during periods of low sunlight or at night. The DC-DC converter charges the batteries when surplus energy is available and supplies power from the batteries when needed.

5. Inverter: The inverter is an essential component of grid-tied or hybrid PV systems. It converts the DC electricity generated by the solar panels or stored in the battery bank into alternating current (AC) electricity. The AC output from the inverter is synchronized with the utility grid's frequency and voltage, allowing the system to supply power to the grid or to power the connected loads.

6. Grid Connection: In grid-tied PV systems, the PV system is connected to the utility grid. The inverter synchronizes the PV system's AC output with the grid's electrical parameters and feeds the excess power generated by the system into the

grid. When the PV system generates less power than the load demand, it draws power from the grid.

7. Electrical Load: The electrical load represents the appliances, devices, or machinery that consume electrical power. It can include residential, commercial, or industrial loads. The load may be powered directly by the PV system during sunlight hours or by a combination of PV system and grid power in grid-tied systems.

The DC part of the system can be schematized as follows:

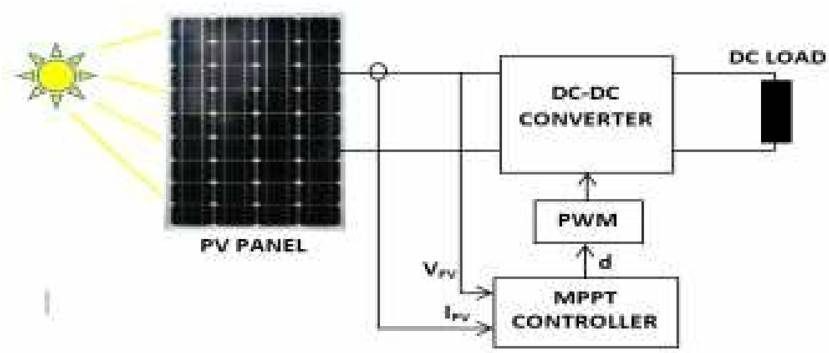

Figure 1.1: PV system scheme - DC part.

The AC instead, is represented in this figure:

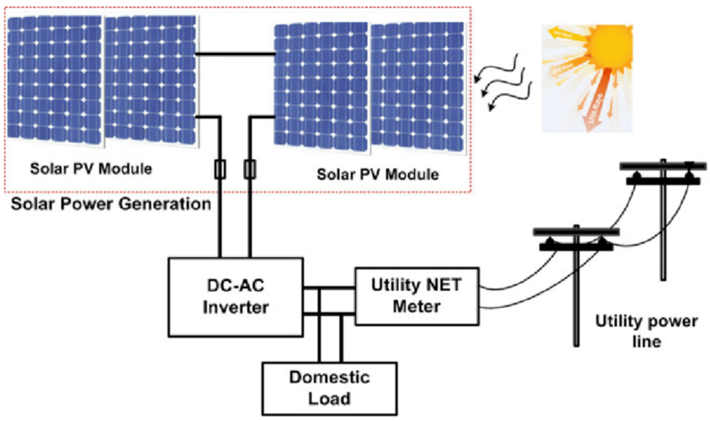

Figure 1.2: PV system scheme - AC part.

For the purpose of the project, the DC part is of interest.

1.2 P&O MTTP algorithm

The Perturb and Observe (P&O) algorithm is one of the most commonly used maximum power point tracking (MPPT) algorithms in photovoltaic (PV) systems. Its purpose is to continuously track and adjust the operating point of the PV array to its maximum power point (MPP), where the array can generate the most power. Here's a description of the P&O algorithm:

1. Initialization: The P&O algorithm starts by measuring the output power of the PV array at the initial operating point. This can be achieved by monitoring the voltage and current at the array's terminals and calculating the corresponding power.

2. Perturbation: The algorithm perturbs the operating point by making a small change to the voltage or current. Typically, a small increment or decrement in the voltage is applied. This change allows the algorithm to explore different operating points around the initial point.

3. Power Comparison: After the perturbation, the algorithm measures the new power output at the modified operating point. The power is calculated using the updated voltage and current measurements.

4. Power Comparison Analysis: The P&O algorithm compares the new power output with the previous power output. Based on this comparison, the algorithm determines whether the operating point has moved closer to or further away from the MPP.

5. Adjustment: If the power has increased, the algorithm continues to perturb in the same direction. This means that the perturbation is in the correct direction and the algorithm is approaching the MPP. On the other hand, if the power has decreased, the algorithm reverses the direction of the perturbation, aiming to move closer to the MPP.

6. Iteration: Steps 2 to 5 are repeated in a continuous loop, continuously perturbing the operating point and comparing the power output until the MPP is reached or a predefined termination condition is met.

The P&O algorithm is relatively simple and computationally efficient, making it popular for MPPT applications. However, it has some limitations. One major drawback is its susceptibility to oscillations around the MPP, especially under rapidly changing environmental conditions or in the presence of partial shading. Additionally, the P&O algorithm may not precisely converge to the true MPP in certain scenarios, leading to suboptimal performance.

To mitigate the limitations of the P&O algorithm, researchers have developed more advanced MPPT algorithms such as Incremental Conductance (IncCond), Fractional Open Circuit Voltage (FOCV), and Model Predictive Control (MPC). These algorithms aim to improve tracking accuracy and enhance the overall performance of the PV system in various operating conditions.

1.2.1 P&O and Variable step P&O

In our simulations we employed the perturb and observe algorithm for the MPPT. In the shading case an improved version based on a variable step duty cycle increment was employed to obtain less oscillations in duty cycle and power with respect to a fixed step P&O algorithm. The two algorithm flowcharts, [2], [5], are the following:

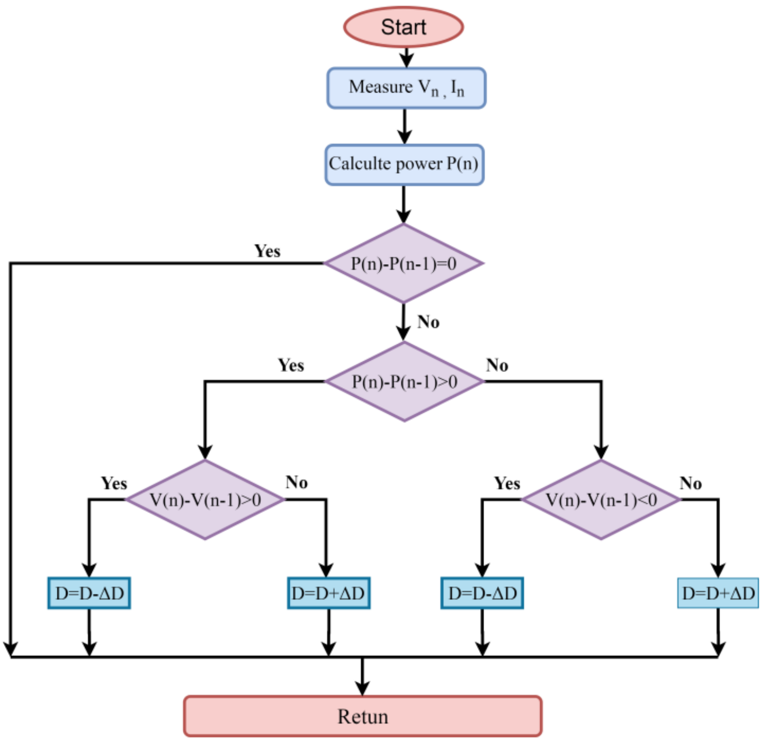

Figure 1.3: Standard P&O.

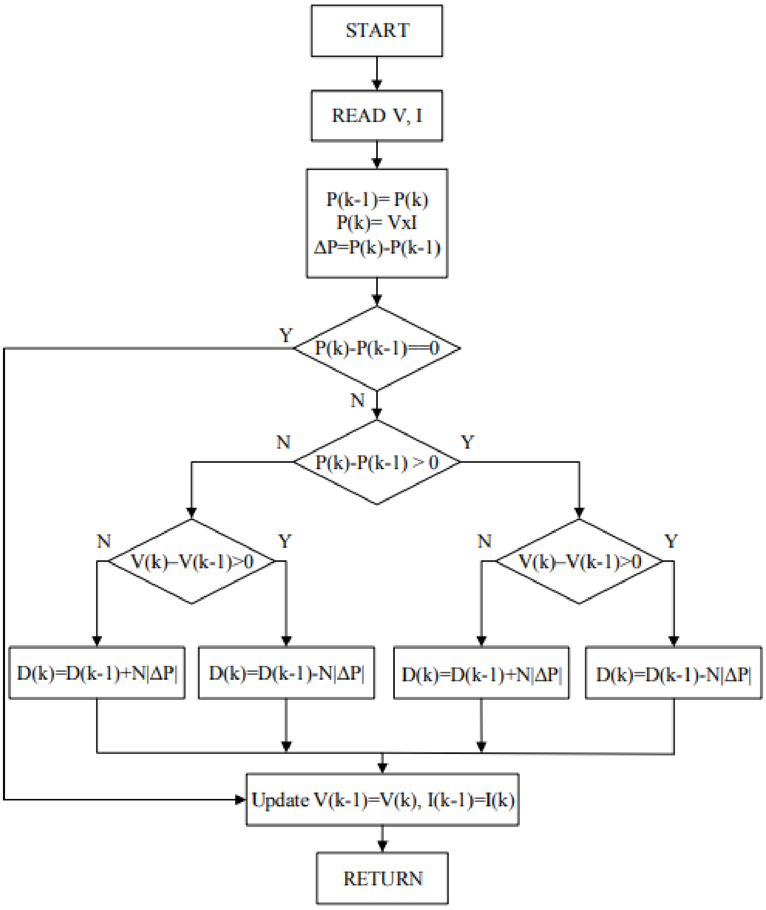

Figure 1.4: Variable step P&O.

All the above information has been extracted from the analysis of different papers of the matter: [3], [1], [6] and these slides [4].

1.3 Project description

This report presents a project aimed at simulating photovoltaic (PV) arrays and a boost converter in Simulink, and integrating the Perturb and Observe (P&O) algorithm for Maximum Power Point Tracking (MPPT) using a Texas Instruments board, in particular, the LAUNCHXL-F28379D development kit. The project focuses on the realization of serial communication between MATLAB and the Texas Instruments board for the purpose of achieving a Processor-in-the-Loop (PiL) simulation.
After that, even if the fixed objective has been already achieved, an enhanced version of the P&O algorithm has been implemented: the variable step version. The purpose here is to study how the algorithm performs under partial shading condition of the PV arrays.

Unlike the conventional P&O algorithm, which uses a fixed step size for perturbations, the variable step P&O algorithm dynamically adjusts the step size based on the PV array's behavior. This approach helps to reduce oscillations around the MPP and enhance the system's overall power generation capabilities. The final achieved PiL simulation can be schematized as shown

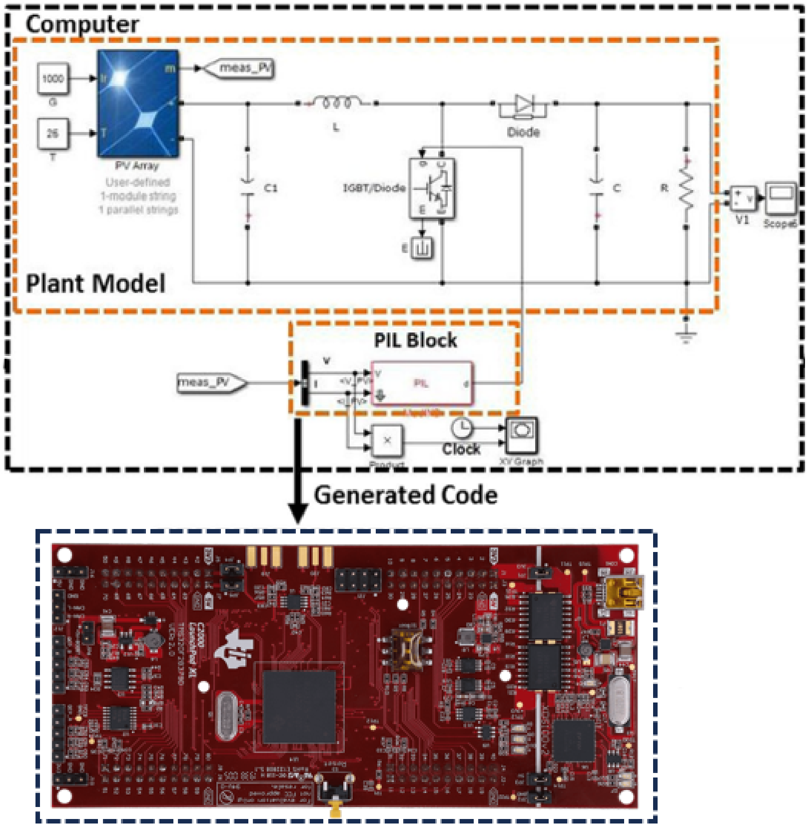

Figure 1.5: PiL scheme.

In the next chapter, all the realization details will be explained.

CHAPTER 2

Realization

Before going into the details, it is worth to remark the importance of PiL testing with this graph:

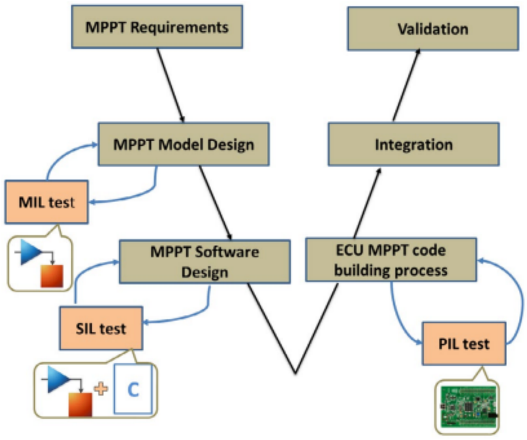

Figure 2.1: V-shape graph.

Now, moving to the realization description, two simulations have been built.

1. In the first one the setup includes the PV arrays under uniform irradiation and the basic P&O algorithm.
2. In the second one instead, the partial shading (not-uniform irradiation) condition has been combined with the variable-step P&O algorithm. In this case, the PV arrays are manually split and connected in series, in order to choose different irradiation values.

In the next section, the two scenarios are explained.

2.1 Simulink setup

In this sections the simulink models are presented

2.1.1 **Scenario 1**

In this single pv array simulation a SunPower SPR-315E-WHT-D is employed. The array is composed overall of 64 parrallel strings and 5 series connected modules per string

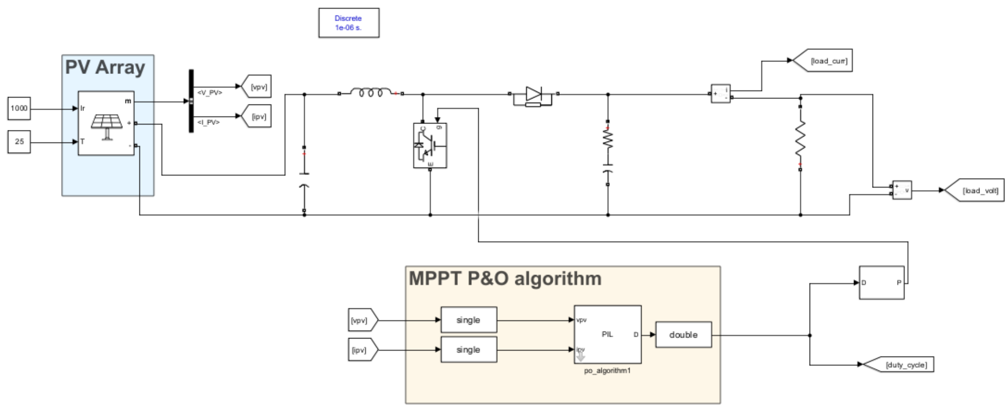

Figure 2.2: MPPT with po technique PiL scheme.

Following are its characteristic curves:

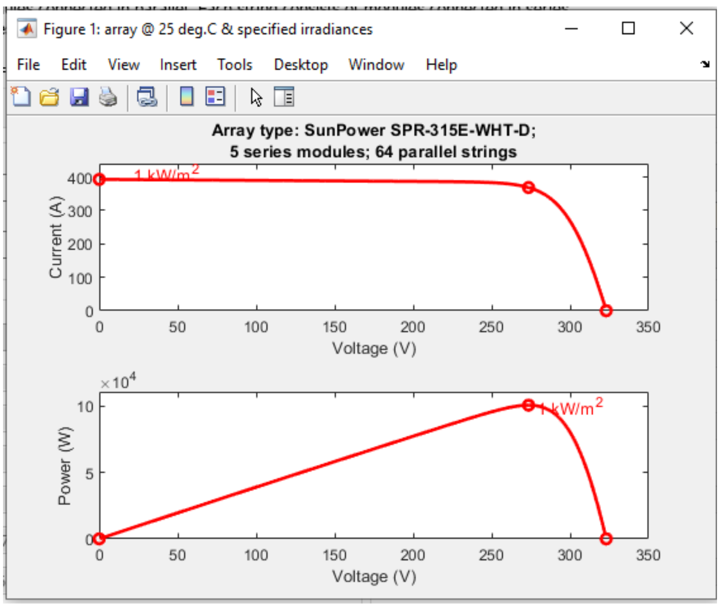

Figure 2.3: Single array curves.

2.1.2 **Scenario 2**

In this configuration, the pv arrays have been split. The model is the same, again with 64 parallel strings but now the first block has 2 series connected modules, same as the second and the third, instead, has only one module. In this way, the equivalent of the 5 series module has been recreated with the advantage of choosing different irradiation level in order to carry out a partial shading simulation.

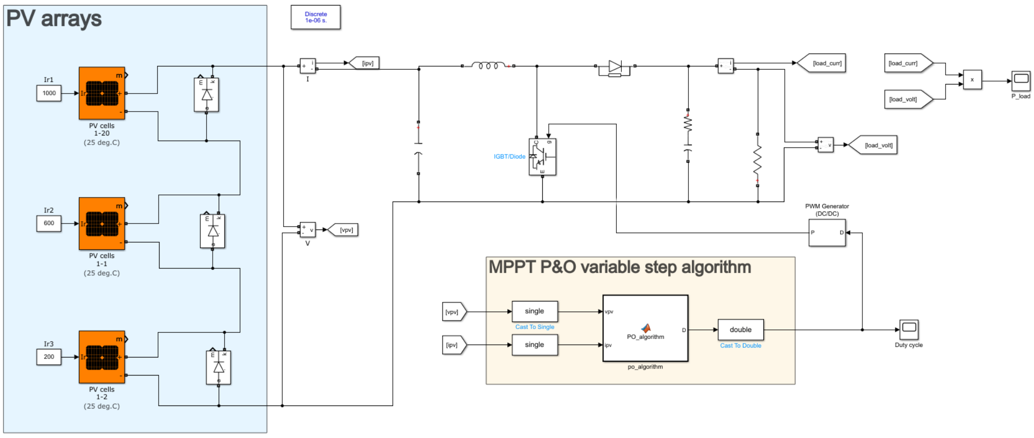

Figure 2.4: 2nd scenario.

The characteristic curve presents different maximum points:

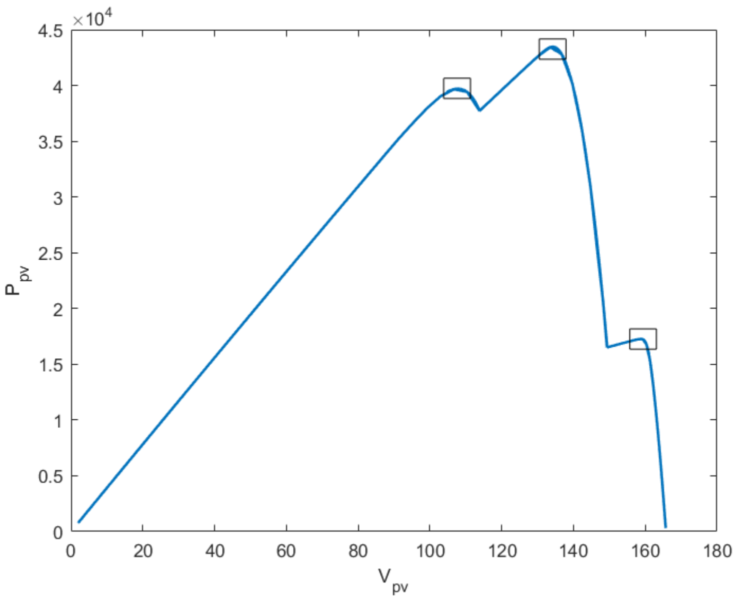

Figure 2.5: Multiple array curves.

2.1.3 Embedded Coder Support Package for TI Processors

Embedded Coder Support Package for Texas Instruments C2000 Processors enabled us to run Simulink models on LAUNCHXL-F28379. Embedded Coder automatically generates C code for your algorithms and device driver blocks that can run directly on the target hardware. This support package can be used for rapid prototyping and production workflows for different control applications including motor control and power conversion. Following are the steps to be followed in order to have compatibility with our board:

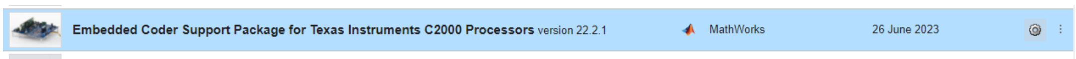

Figure 2.6: Add-on needed for the board support.

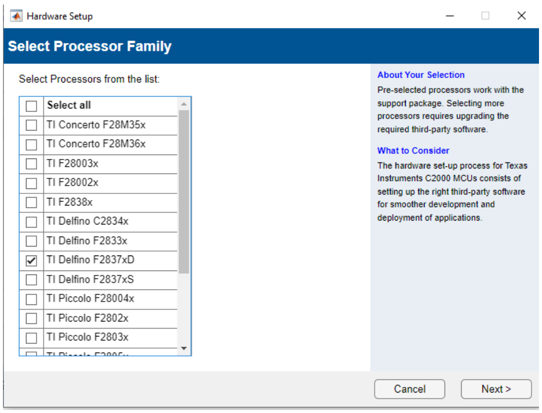

Figure 2.7: Target processor selection.

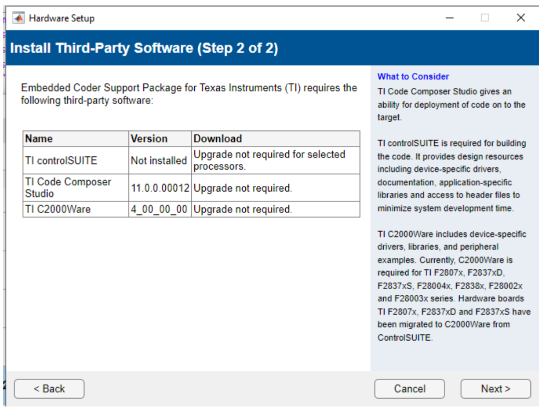

Figure 2.8: Software requirements.

Having done this setup we are ready to execute code on our target board LAUNCHXL-F28379.

2.2 Serial communication and C-code setup

Thanks to the above described package, it has been possible to setup a serial communication between the board and the laptop. After that, using Code Composer Studio, the target C-code has been generated and flashed on the DSP.
For the purpose of enabling the serial communication, some preferences have been set. Here are the commands:

```
setpref('Mathworks_Embedded_IDE_Link_PIL_Preferences', 'COMPort', 'COM10');
setpref('Mathworks_Embedded_IDE_Link_PIL_Preferences', 'BaudRate', 115200);
setpref('Mathworks_Embedded_IDE_Link_PIL_Preferences', 'enableserial', true);
```

.

Next step is to set the PiL mode:

```
set_param('pvarray_mttp_sim', 'CreateSILPILBlock', 'PIL')
```

.

and then finally, the build command:

```
rtwbuild(['pvarray_mttp_sim/po_algorithm'])
```

.

At this point, the process of building the code for the target board is started. The result, as one can see in Fig. 2.2, is an equivalent Simulink block which contains the C-code for the hardware.

2.3 Troubleshooting

During the realization of the project, several issues have been encountered:

1. Compilation issue
2. Error initializing flash programming: flash is not available on this device
3. Types compatibility
4. Long simulation time

For solving the first one, after carefully search on the web, the whole path of the file has been modified, eliminating the spaces.
The second one was an hardware related problem, a lot of time has been spent in understanding what the problem could be and then, a cable change was the trick to

solve it.
Moving to the third one, again an hardware problem related to compatibility. Simulink uses by default the ”double” data type that causes issues when calculus are executed directly on the TI board. In order to manage this, a ”single” conversion has been applied, this can be seen in Fig. 2.2.
Finally, last issue is the simulation time. This is the only problem that couldn’t be fixed because more than a problem, it looks like a real hardware limitation given by the serial nature of communication . For PIL, you have Simulink and Windows in the loop of every step of calculation. Simulink issues a serial send to the Windows COM port, waits for one step to be processed on the F28379 and waits to receive a message back from the F28379 on the COM port.

CHAPTER 3

Tests and results

3.1 Scenario 1 - P&O in MIL

Here the results of the first scenario are presented. No partial shading was considered in this simulation and in both Mil and Pil simulation convergence of the load power to the power generated by the PV array can be observed. The simple P&O algorithm is enough in the shadingless case. As we expect the load power is the same as the power produced from the solar array and is the maximum power point in figure 2.3.

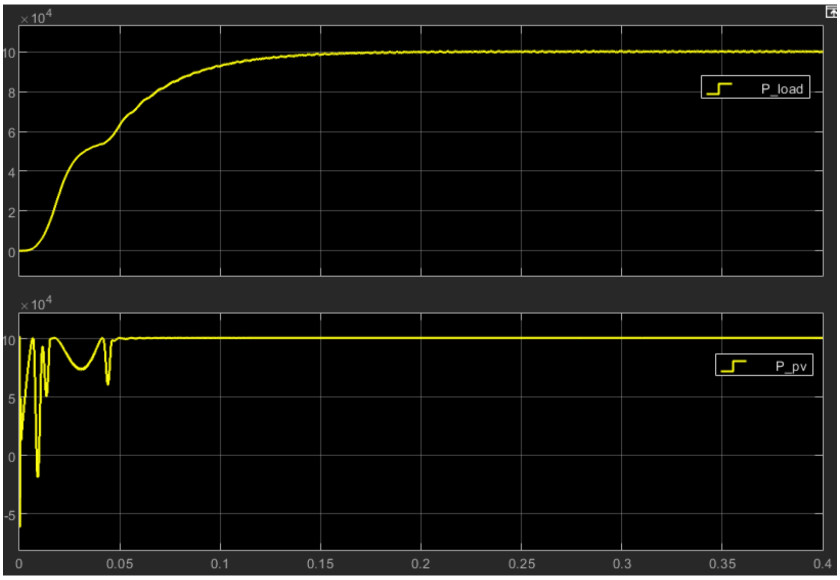

Figure 3.1: Power profile (scenario 1).

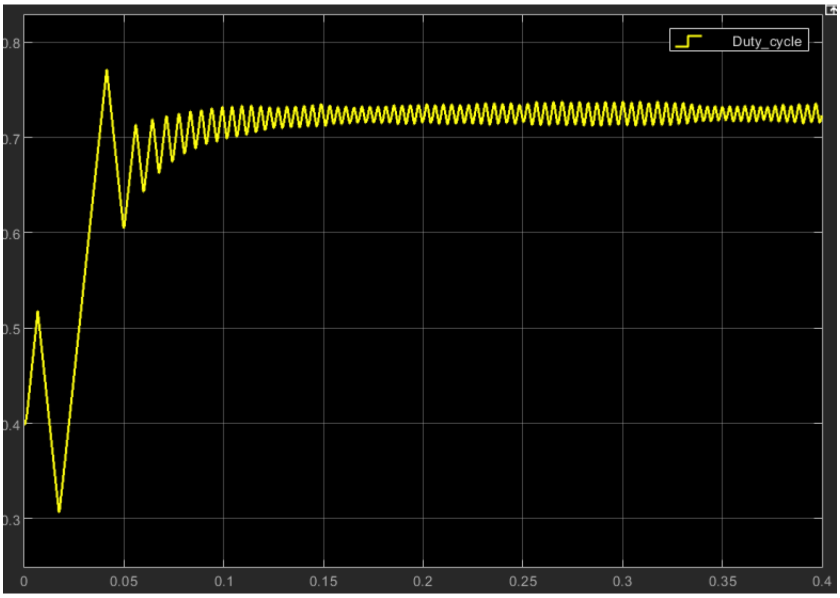

Figure 3.2: Duty cycle (scenario 1).

3.2 Scenario 1 - P&O in PIL

The following simulations are short because they took lots of time and we would need to run a simulation at least overnight for observing results. Communication with the DSP has been established as can be seen in the following:

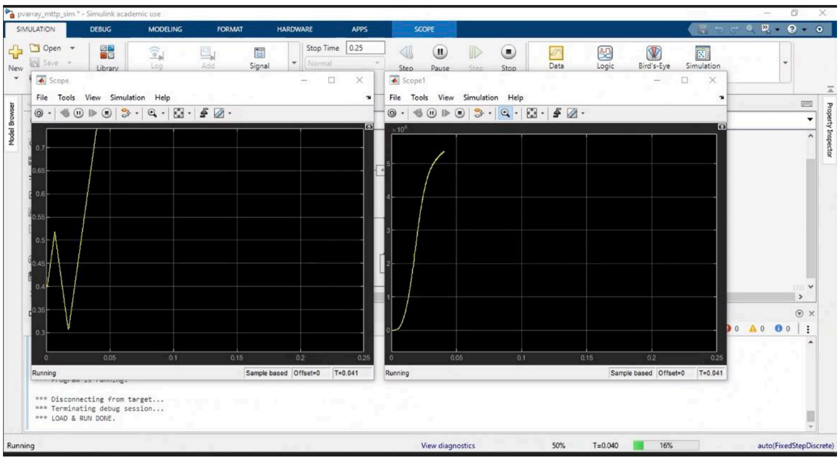

Figure 3.3: Power profile and duty cycle (PiL).

3.3 Scenario 2

These simulations represent a case where we have partial shading of the overall array. The P&O algorithm is only able to reach a local maximum that is of about 40kW while the Variable step P&O algorithm that we have employed is able to track the global mppt.2.5

3.3.1 Standard P&O

The standard P&O algorithm is not able to reach the MPPT because it gets stuck on a local maximum that is at about 40kW in Figure 2.5. In order to make the tracking possible with this kind of algorithm we would have to lower the duty cycle increment sensibility to the order of e^{-6} and this cannot be always obtained in real world applications.

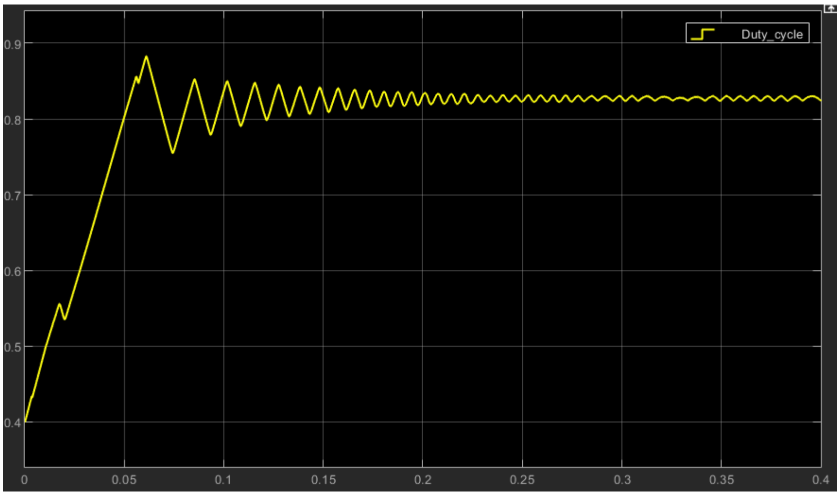

Figure 3.4: Duty cycle (scenario 2.1).

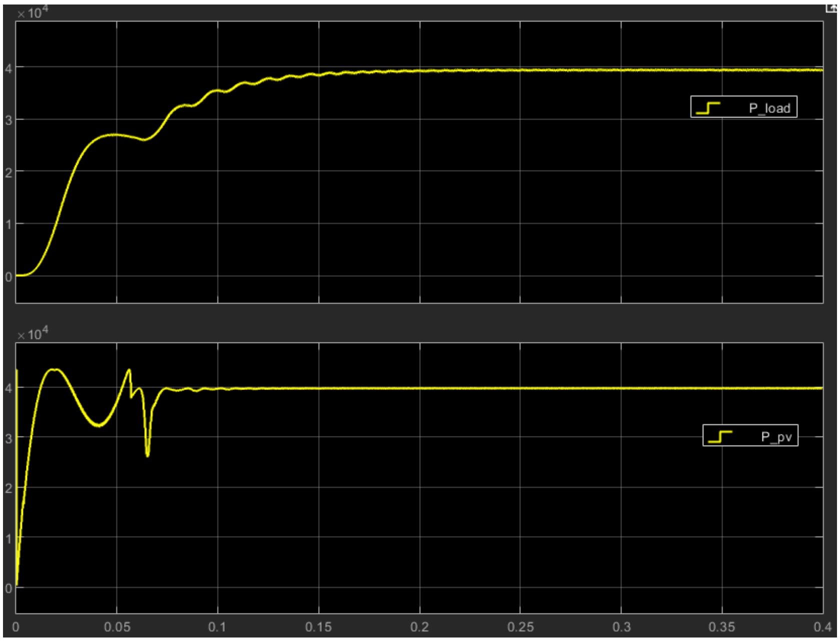

Figure 3.5: Power profile (scenario 2.1).

3.3.2 Variable step P&O

With this control technique we are not only able to reach the Global MPPT (43kW) but even with less overall oscillations and in a faster way. In a millisecond we are able to track the maximum power point and that is more than sufficient for real world applications since we do not have such fast dynamics in cloud movements.

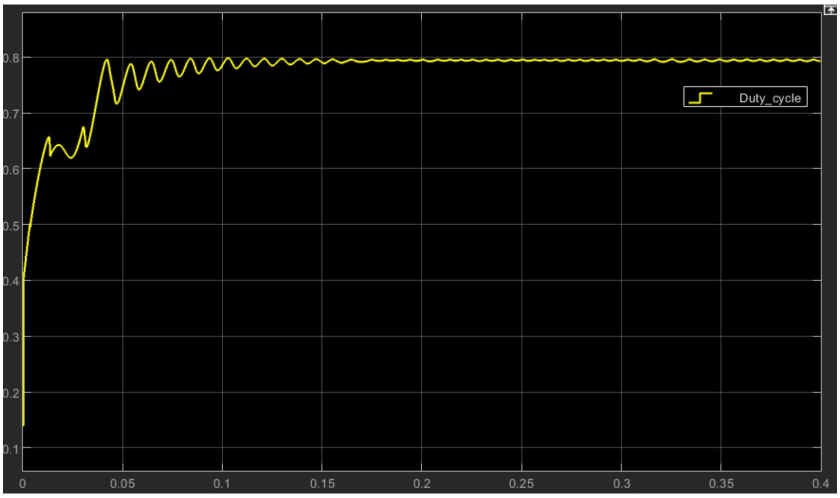

Figure 3.6: Duty cycle (scenario 2.2).

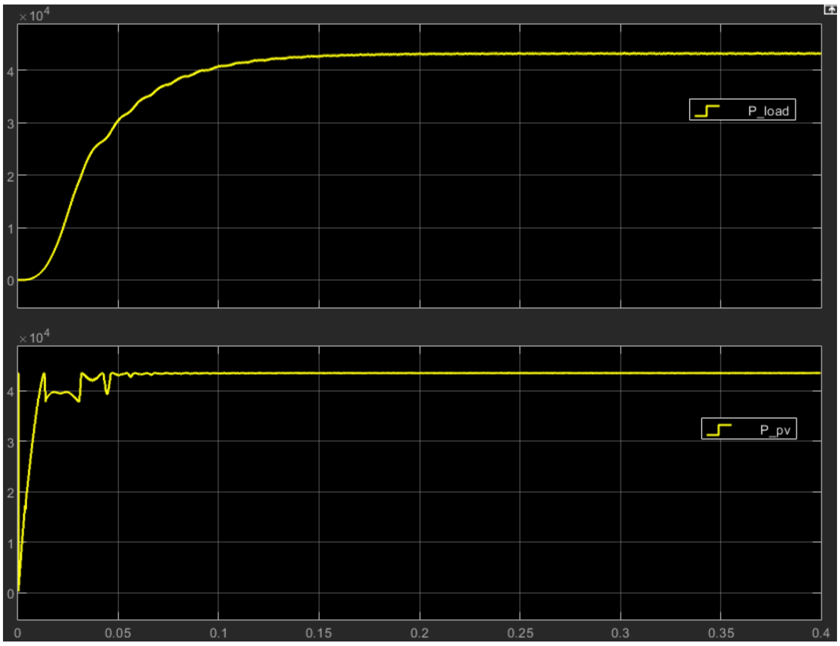

Figure 3.7: Power profile (scenario 2.2).

3.3.3 Variable step P&O - load variation

Another interesting situation is when the load changes. In all the previous showed graphs the load is a resistance of 10 Ohm. Dropping this value to the half, 5 Ohm, we get the following result:

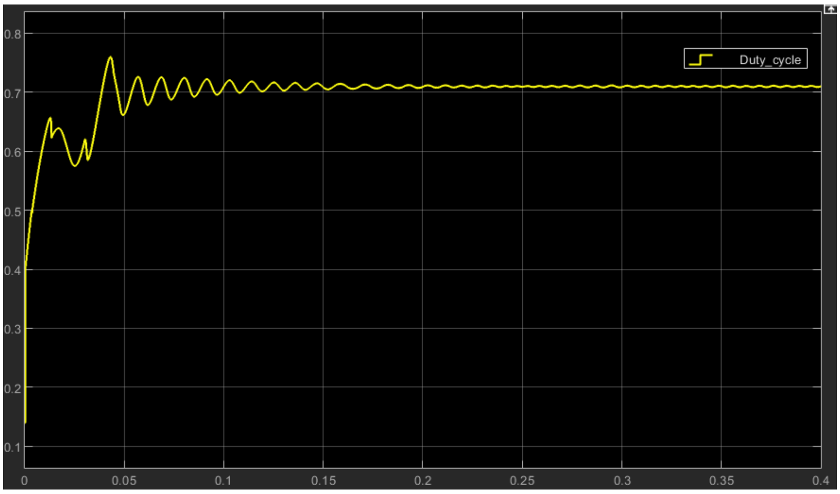

Figure 3.8: Duty cycle (scenario 2.3).

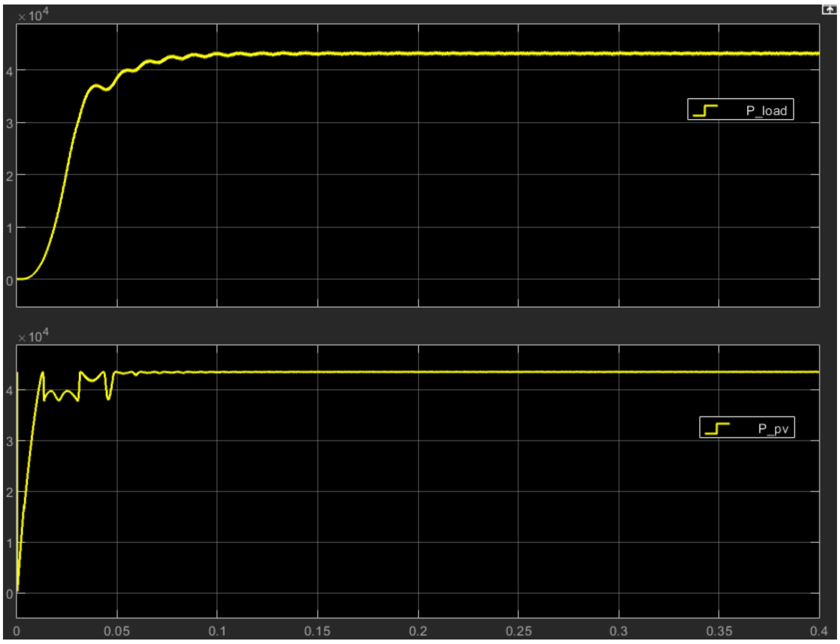

Figure 3.9: Power profile (scenario 2.3).

as one can see, the power is always the same but this time the duty cycle is 0.7, that is lower than in the other cases. This is exactly the purpose of the controller: adjust the duty cycle in order to keep the load power constant.

CHAPTER 4

Conclusions

In this report, we have addressed the analysis and simulation of a photovoltaic panel array by implementing various Maximum Power Point Tracking (MPPT) control configurations on a Digital Signal Processor (DSP) through Processor-in-the-Loop (PIL) simulations on Simulink. Through a series of experiments, we examined the behavior of the array under different operating conditions to evaluate the efficiency and adaptability of the system.

In the first case, we investigated the array's behavior without shading, assessing the effectiveness of both the standard MPPT Perturb and Observe (P&O) algorithm and the Variable Step MPPT P&O algorithm. The results demonstrated that both algorithms successfully tracked the maximum power point. However, the Variable Step algorithm showed greater adaptability to varying operating conditions, enhancing the system's efficiency.

Subsequently, we explored the impact of shading on the solar panel array. Our experiments revealed that shading can lead to significant power losses and reduced array efficiency. Furthermore, we compared the effectiveness of the standard MPPT P&O algorithm with the Variable Step MPPT P&O algorithm under these conditions. Once again, the Variable Step algorithm proved to be more effective in dealing with shading effects, recovering the maximum power point more rapidly and minimizing losses.

Lastly, we varied the load resistance to study the system's response to this variation. The results clearly demonstrated how the duty cycle adapted to different load conditions, ensuring efficient power regulation.

In conclusion, this project has allowed us to gain a comprehensive understanding of solar technologies, the implementation of MPPT algorithms on a DSP, and the performance analysis of the photovoltaic panel array. The PIL simulation on Simulink proved to be a valuable tool for testing and evaluating the system under various operating scenarios. The investigation carried out has strengthened our knowledge of renewable energies and power control. Overall, the project has been engaging and rewarding, opening new perspectives in the field of solar energy and MPPT.

These findings may be useful for future developments in the solar technology sector and for optimizing the efficiency of photovoltaic generation systems. The knowledge gained during this project has provided us with a solid foundation to tackle more complex challenges in the future and contribute to the advancement of renewable energies.

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