PV generation model (Assignment 2)

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Chapter 1

PV array model

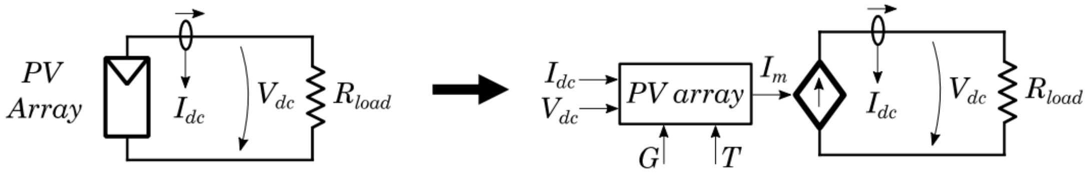

FIGURE 1.1: PV array model implementation

In this assignment, we integrated the grid model from previous assignment with a converter model. This converter is linked to a constant current source, which mimics a set of solar panels operating at a steady state. We adapted the VSC control from our previous work but tweaked it to regulate the DC voltage instead of managing active power. This regulation involves charging or discharging the DC capacitor. We also developed the VSC model, displayed both within the subsystem and separately, assuming no power losses during the AC/DC conversion process.

1.1 Model assumptions:

- From the data provided by manufacturer a decent PV array model can be build;
- Manufacturers also provide temperature coefficients that can be used to adapt the model for different conditions: K_v - voltage temperature coefficient, K_i - current temperature coefficient;
- The approximation $I_{pv} \approx I_{sc}$ is acceptable since the diode current in short-circuit conditions is very small;

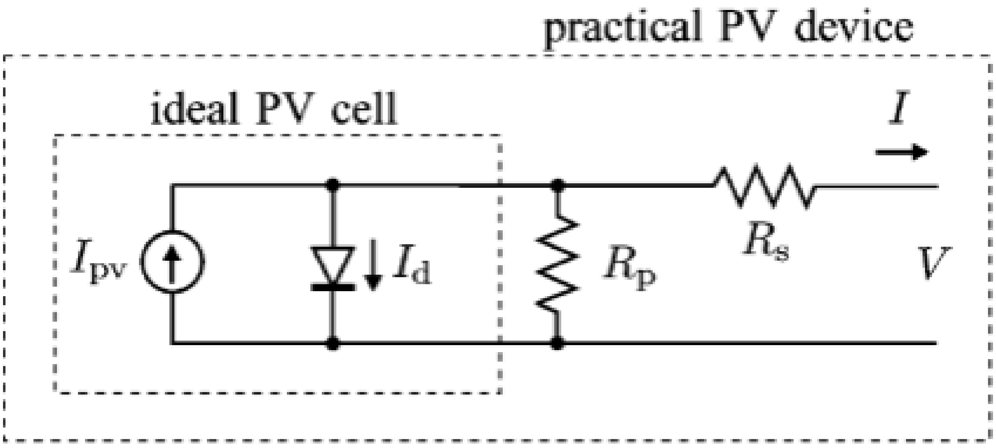

FIGURE 1.2: PV Array Model

- The I_{pv} variation for different temperatures and irradiances is expressed as:

$$I_{pv} = [I_{pv,n} + K_I(T - T_n)] \frac{G}{G_n} \tag{1.1}$$

- The I_0 can be obtained in nominal conditions from the open-circuit point. Then, if temperature dependency is included, this current is expressed as:

$$I_0 = \frac{I_{sc,n} + K_I(T - T_n)}{\exp\left[V_{oc,n} + \frac{K_V(T-T_n)}{V_{ta}}\right] - 1} \tag{1.2}$$

considering the quantities of photovoltaic cells and modules connected in series and parallel, the overall current output from the photovoltaic system is equal:

$$I = N_{\text{cellpar}} \left(I_{\text{pv}} - I_0(\exp\left(\frac{V/N_{\text{cellser}} + RsI/N_{\text{cellpar}}}{V_t}\right) - 1\right) - \frac{V/N_{\text{cellser}} + RsI/N_{\text{cellpar}}}{R_p} \tag{1.3}$$

where:

- I_{pv}: current generated by the incident light;
- I_0: reverse saturation or leakage current of the diode;
- V_t: thermal voltage of the diode;
- a: diode ideality constant;
- R_s: equivalent series resistance of the array (usually very small);

- R_p: equivalent parallel resistance of the array (usually very large).

Implementation of the solar panel is Simulink:

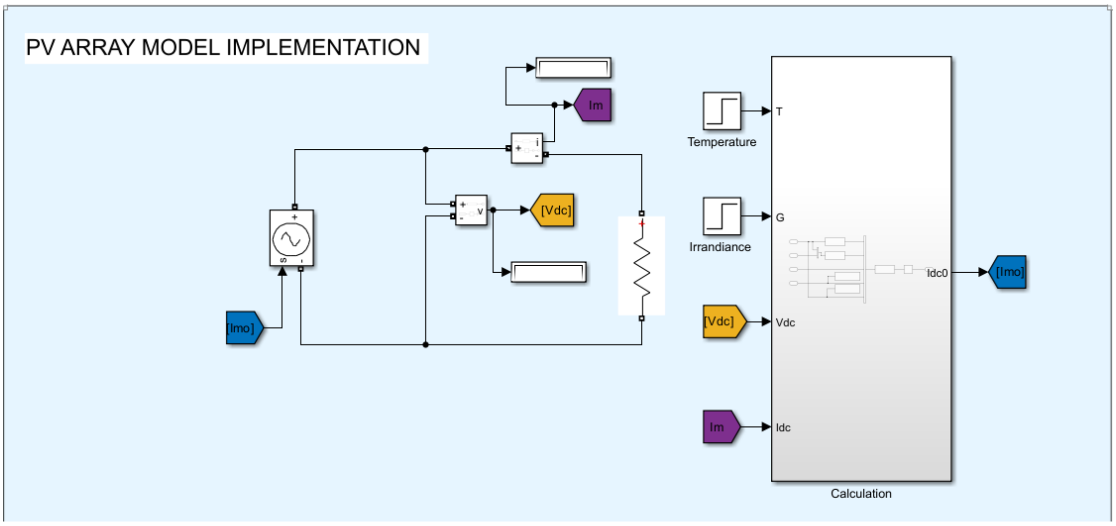

FIGURE 1.3: Simulink of PV array Model

The above equations (equation 1-3) that were explicitly stated were implemented in the PV array model block, which can be seen below in simulink:

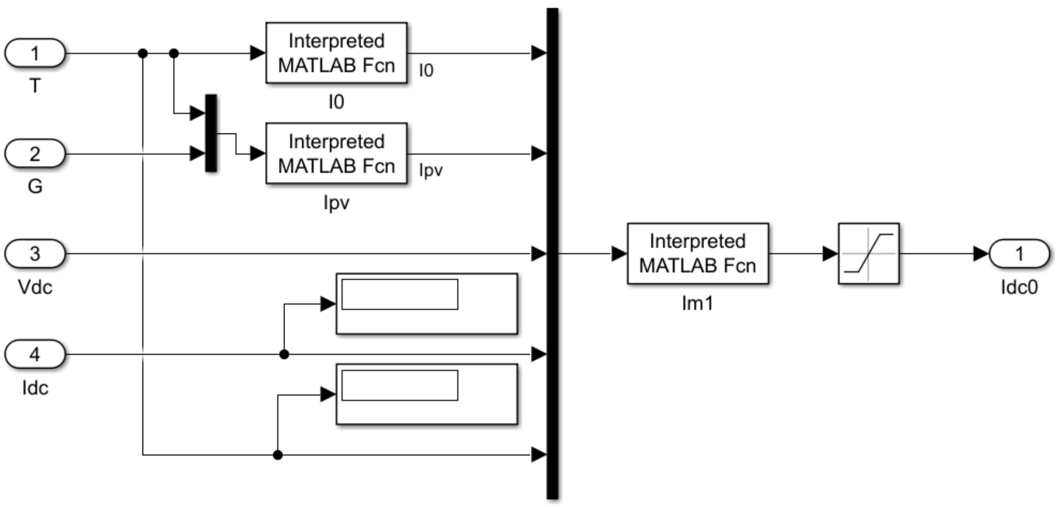

FIGURE 1.4: currents calculations related to the solar panels

Nominal value for temperature is 298 K, for irradiance is 1000 W/m^2. Table for different values of temperature and irradiance is represented below.

T	**I**	**V**
T_n, G_n	4327 A	1298 V
T_n, $0.8 \times G_n$	4048 A	1215 V
T_n, $1.2 \times G_n$	4473 A	1342 V
$0.8 \times T_n$, G_n	4290 A	1287 V
$1.2 \times T_n$, G_n	4017 A	1205 V

TABLE 1.1: Values of current and voltage of solar panels for different T and G

As observed, an increase in irradiance leads to a rise in both voltage and current. However, the effect of temperature change differs. Regardless of whether the temperature is below or above the nominal value, both current and voltage decrease.

Chapter 2

VSC model with DC voltage control

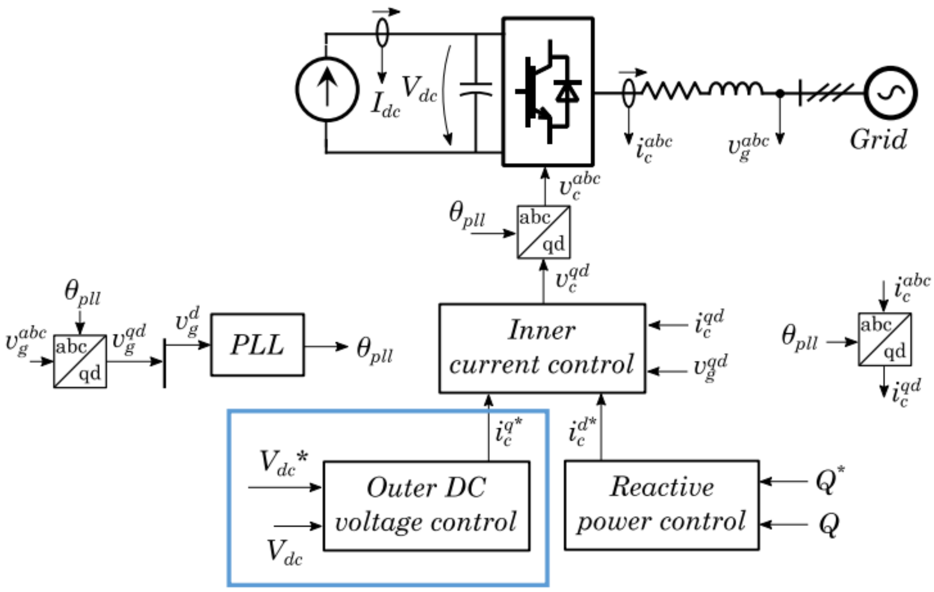

FIGURE 2.1: DC VOLTAGE IMPLEMENTATION IN THE BASIC VSC MODEL

Model assumptions: In this task the basic VSC model will be modified to include a DC voltage control

Figure 2.2 illustrates the implementation of DC control, which assumes that the dynamic response of the current loop is ignored, relying instead on disturbance rejection.

this graph depicts the constant voltage, indicating that the converter effectively maintains a consistent voltage under normal operating conditions.

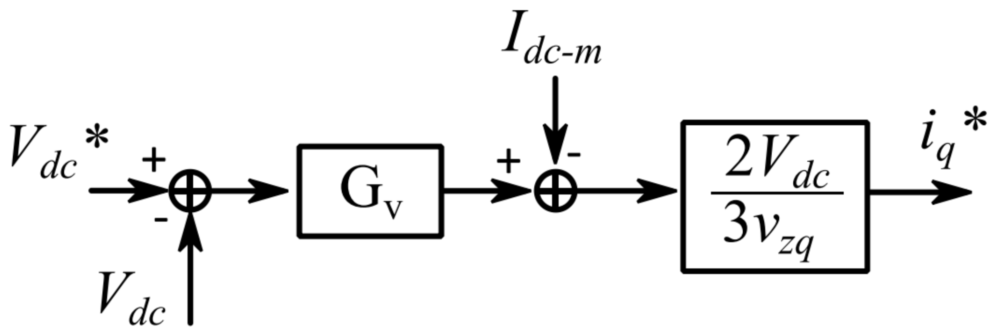

FIGURE 2.2: DC VOLTAGE CONTROL IMPLEMENTATION

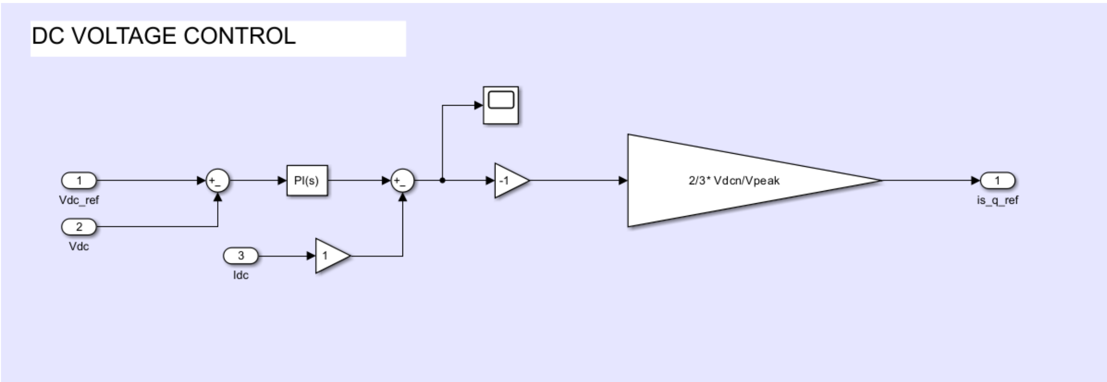

FIGURE 2.3: DC VOLTAGE CONTROL IMPLEMENTATION

From figure 2.3, we implemented the schematic in MATLAB, with gains for the PI controller given by:

$$k_{pv} = 2\xi\omega_n C_{dc}$$
$$k_{iv} = \omega_n^2 C_{dc}$$

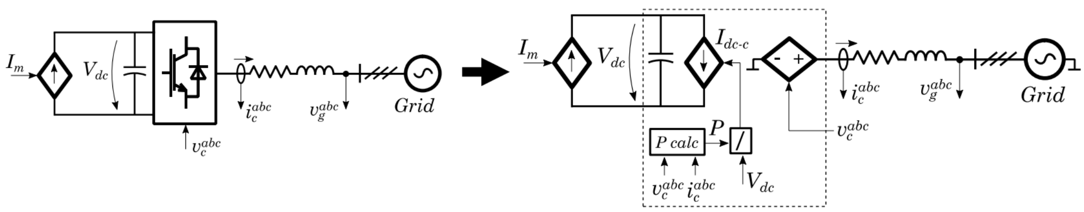

FIGURE 2.4: IMPLEMENTATION OF A DC VOLTAGE CONTROL OF VSC MODEL

Added the DC component of the VSC average model, including a DC capacitor and a regulated current source I_m that represent an external system (which will represent the PV array in subsequent tasks). Additionally, establish interconnection between the AC and DC sides of the VSC, taking power considerations into account.

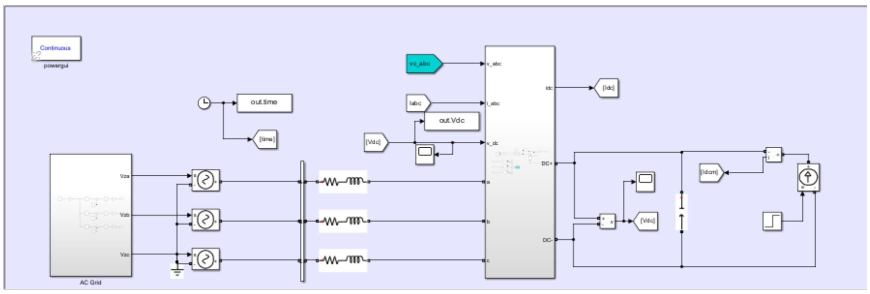

FIGURE 2.5: Implementation of a voltage control in the basic VSC model in Simulink

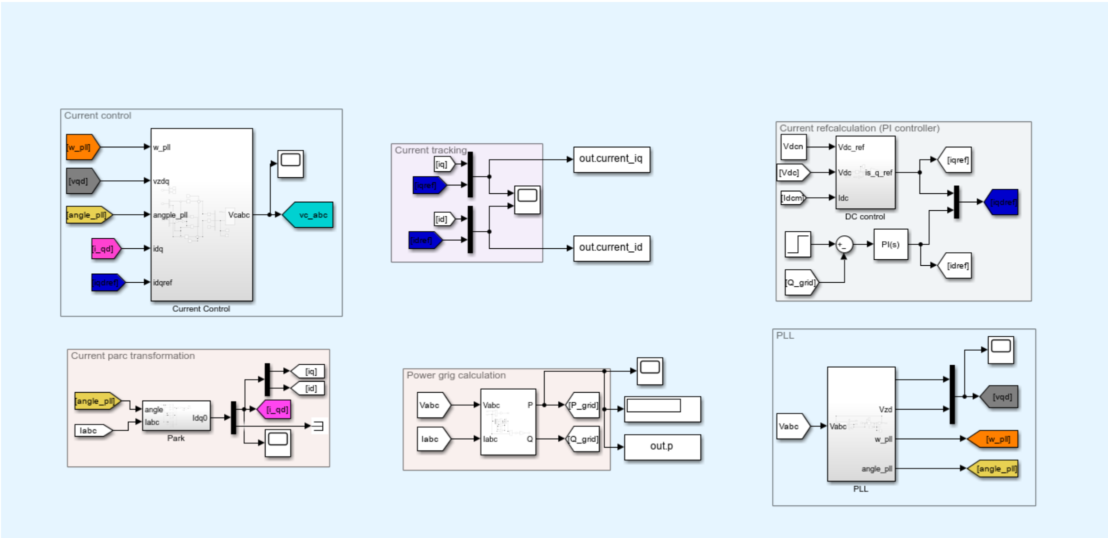

FIGURE 2.6: CONTROL STRUCTURE

GRAPH OF CURRENT AND VOLTAGE:

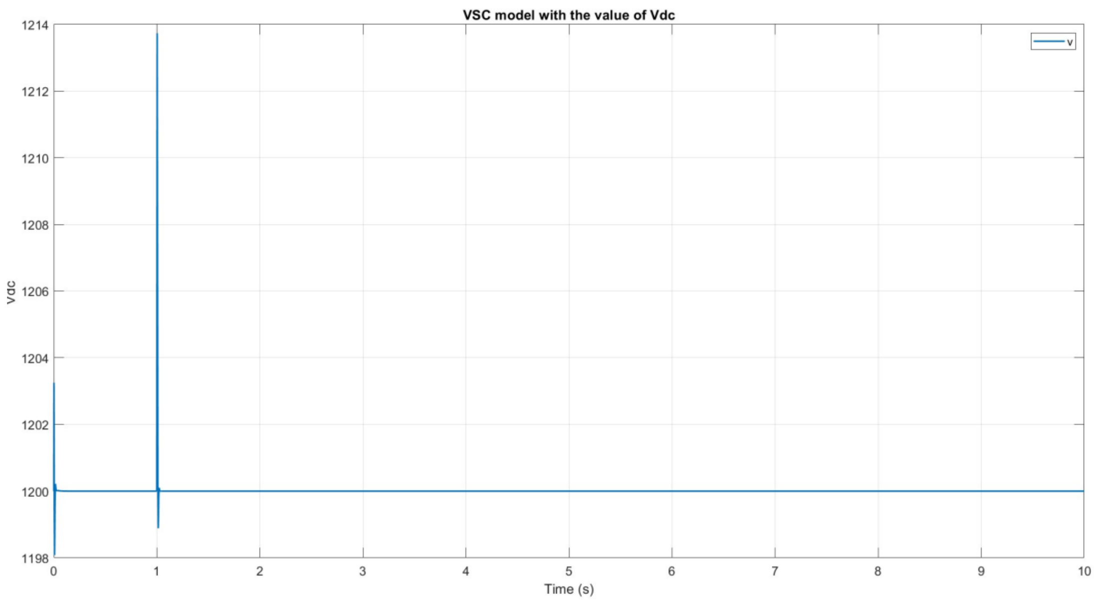

FIGURE 2.7: VSC model with the value of Vdc

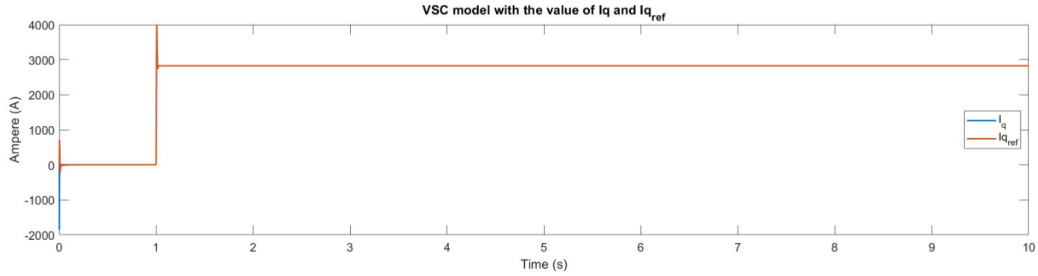

FIGURE 2.8: VSC model with the value of Iq illustrates the D-axis tracking current.

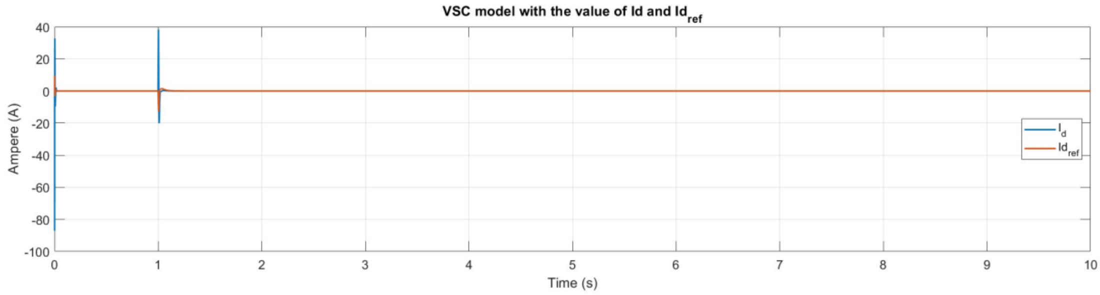

FIGURE 2.9: VSC model with the value of Id illustrates the q-axis tracking current.

DIFFERENT VALUES OF POWER:

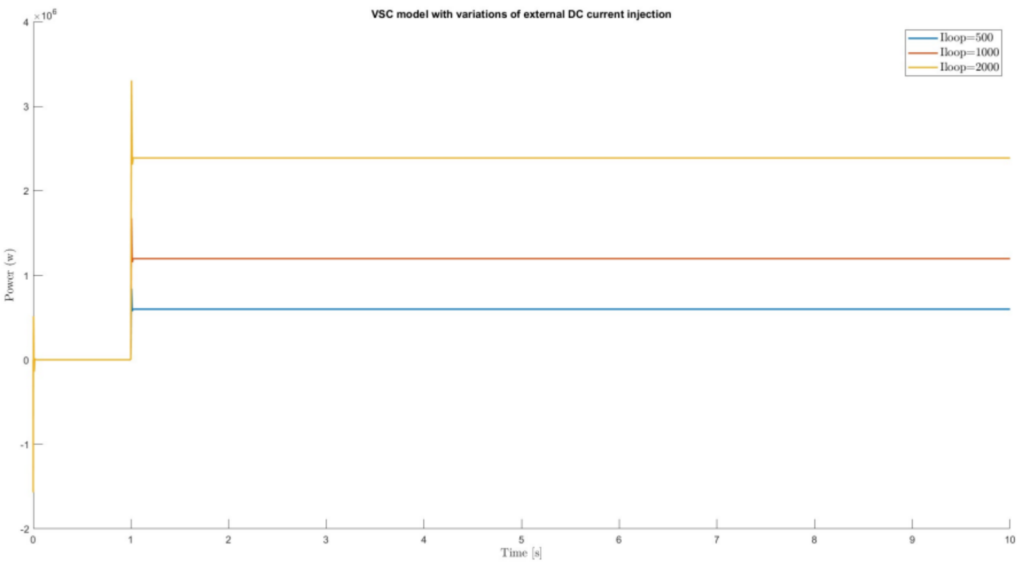

FIGURE 2.10: VSC model with variations of external DC current injection
"The three outcomes of injecting external DC current Iloop, depicted in Figure 2.10, show that as the current rises, the power also increases, which corresponds to the sustained voltage levels."

Chapter 3

PV GENERATION SYSTEM

Full model of PV generation system is represented below:

Here instead of step as input for controlled current source we get current from solar panels.

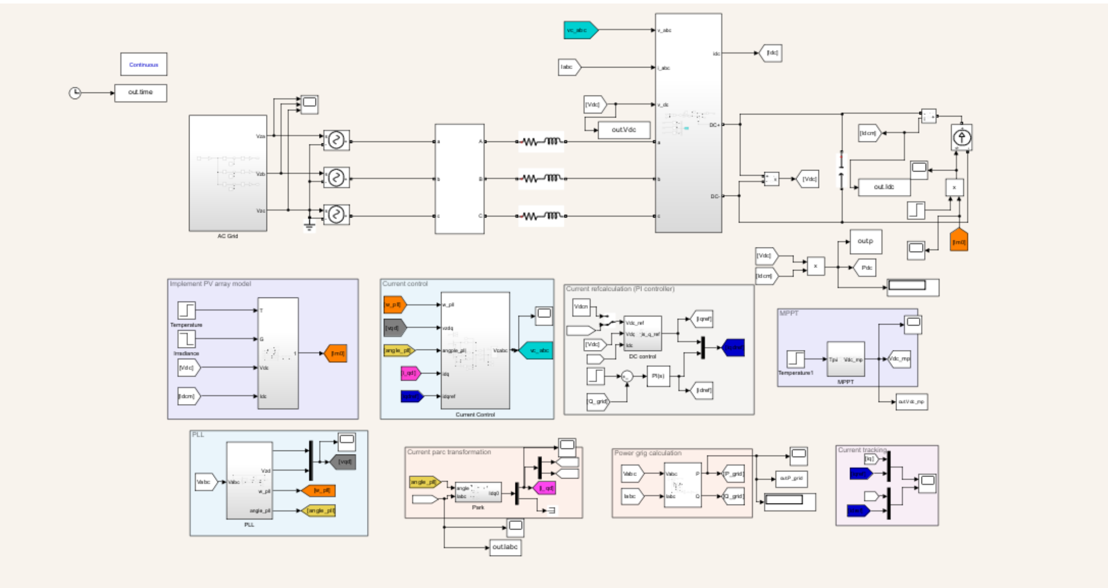

FIGURE 3.1: PV generation system with MPPT

-DIFFERENT TEMPERATURE

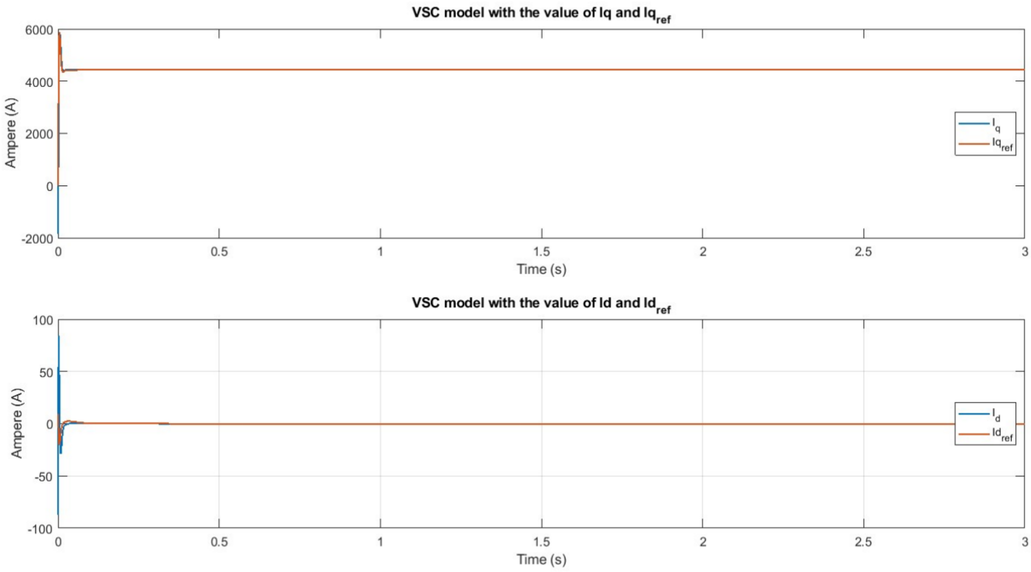

FIGURE 3.2: CURRENT TRACKING
Current loop works correctly. Iq reaches reference value, Id = 0.

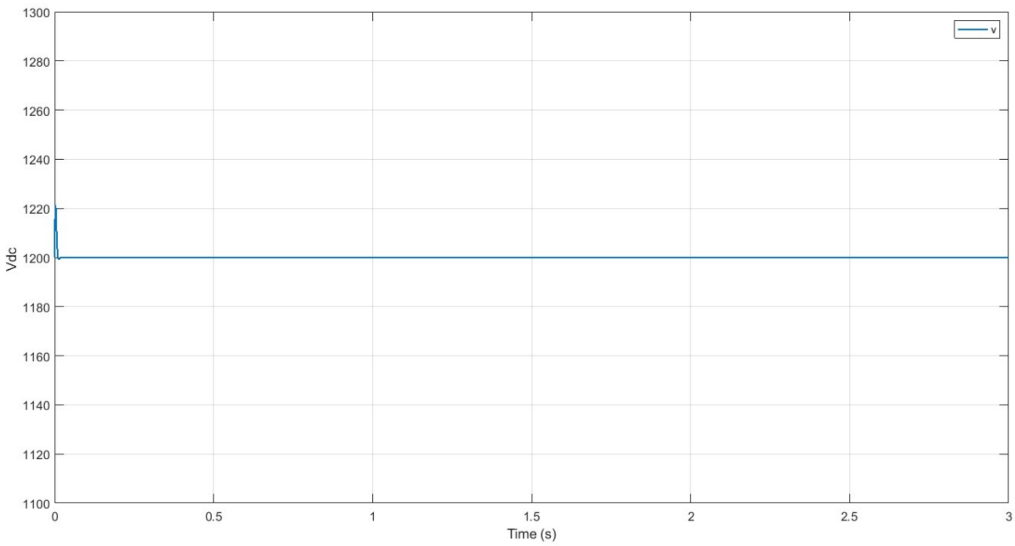

FIGURE 3.3: DC VOLTAGE TRACKING
Vdc voltage also reaches reference value.

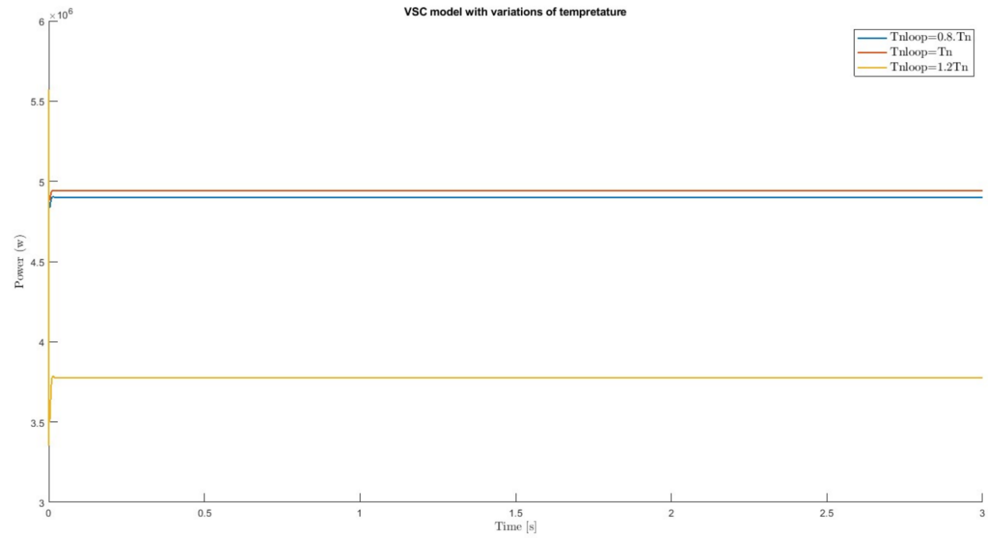

FIGURE 3.4: POWER FROM SOLAR SYSTEM

Analysis: It is evident that the nominal temperature, set at 25 degrees, yields the highest power output from the solar system. When the temperature is at 80 percents of the nominal value, the power output decreases. However, increasing the nominal temperature to 120 percent negatively affects the power generated by the solar system.

- DIFFERENT IRRADIANCE

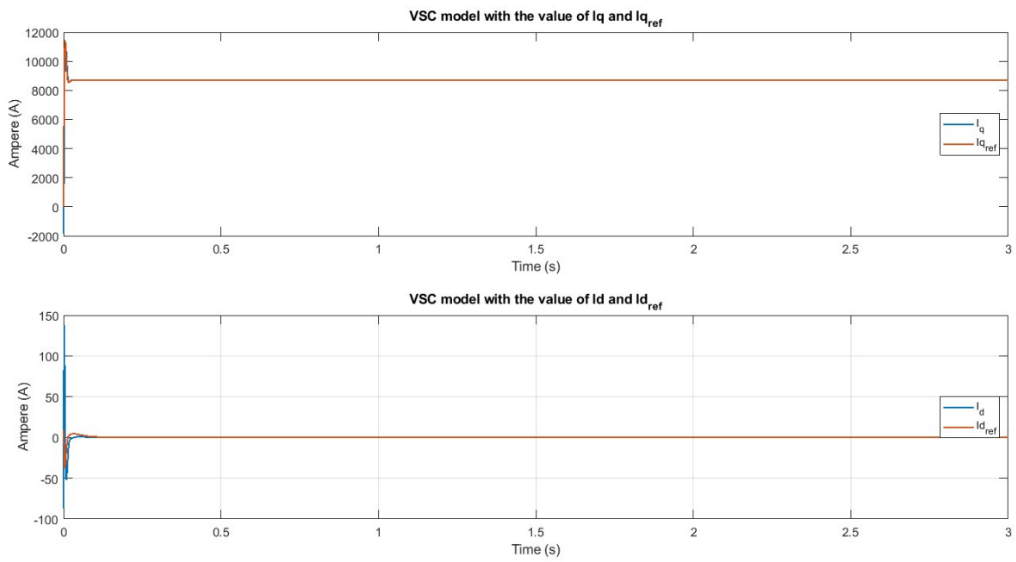

FIGURE 3.5: CURRENT TRACKING

Current loop works correctly.Iq reaches reference value,Id is 0

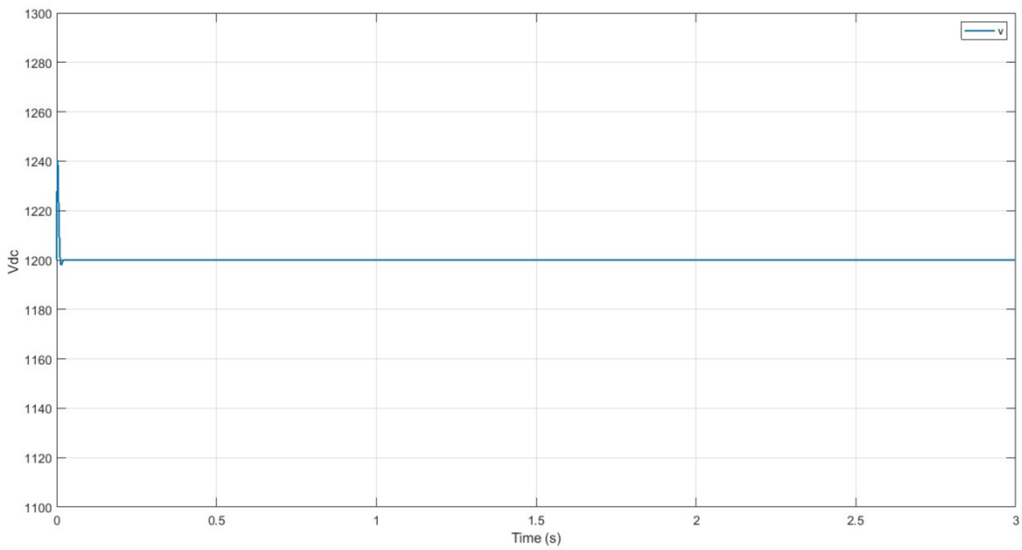

FIGURE 3.6: DC VOLTAGE TRACKING
Vdc voltages also reaches reference value.

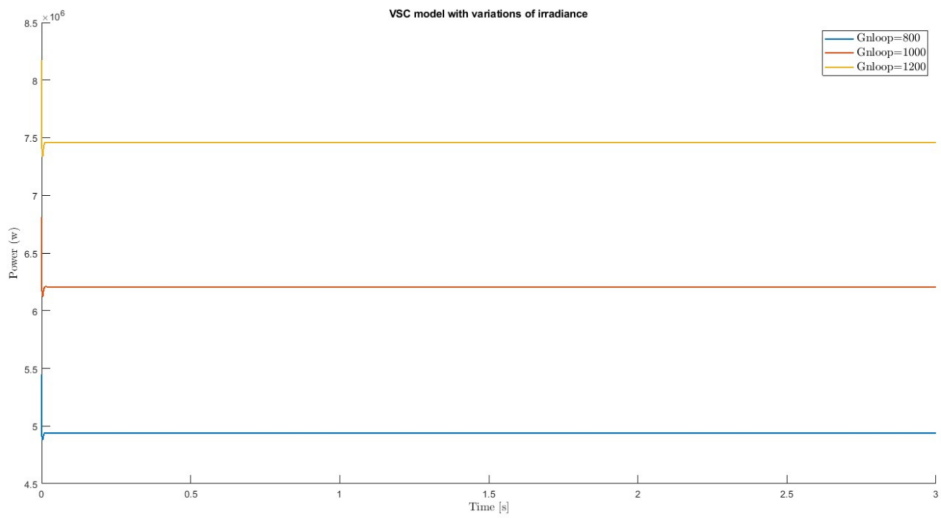

FIGURE 3.7: Power from solar system
Analysis: It is observable that the irradiance value is directly proportional to the current output of the PV system. Higher irradiance results in a higher current from the solar system. Given that the DC voltage Vdc remains steady at 1200 V, the power output from the solar system is also proportional.

Chapter 4

MAXIMUM POWER POINT TRACKING

4.1 MPPT - Provides maximum power that is available

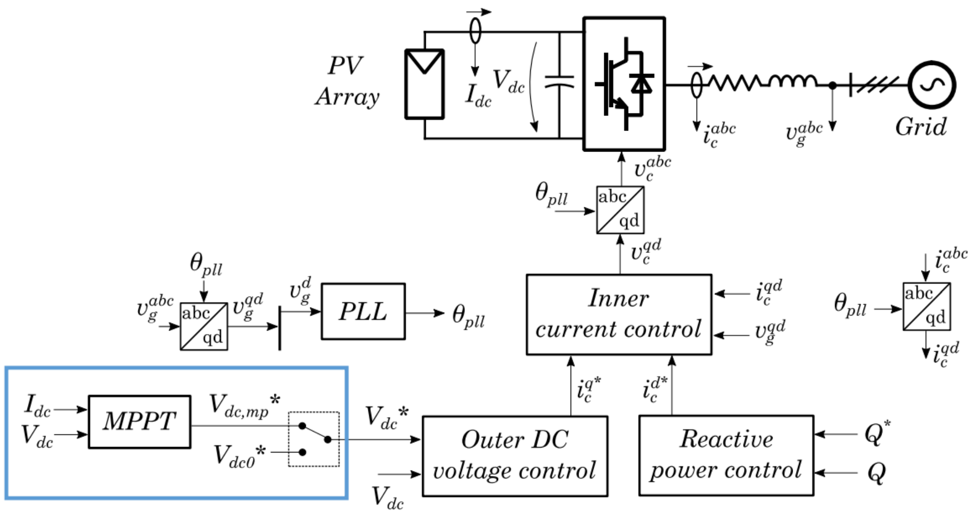

FIGURE 4.1: Complete diagram of solar PV combined with VSC

The fixed DC voltage reference needs to be substituted with an MPPT (Maximum Power Point Tracking) system, which ensures the optimal DC voltage reference. The most straightforward approach involves employing the open-circuit method, wherein the DC voltage reference is calculated accordingly (refer also to the solutions of PV activities).

In the latter portion of the assignment, MPPT control is introduced. This control method operates in an open-loop fashion, estimating the Maximum Power Point (MPP) voltage, Vmpp, based on the PV temperature. Subsequently, this Vmpp value is established as the reference voltage for the Vdc control. Furthermore, a switch is integrated to enable the deactivation of MPPT, allowing for the substitution of a constant reference voltage. This setup encapsulates two scenarios in PV system control via a converter: If the power demand equals or exceeds the maximum output power of the PV array, the system operates at the MPP. Conversely, if the power demand is lower than that of the MPP, the converter must identify an alternative operating point that aligns with the demand, typically opting for the one with lower current to minimize losses.

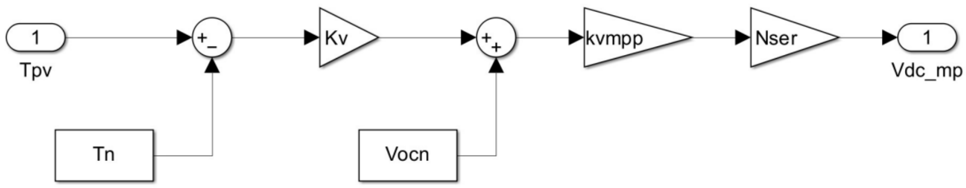

Figure 4.2: MPPT

Also, the MPPT algorithm seeks to optimize the power output of the solar PV system by dynamically adjusting the operating voltage and current. Upon the completion of the MPPT, different scenarios were tested as seen below:

4.2 CASE 1: Varying Temperature; Effect on Power

When the temperature rises above the nominal value, the power output of the solar PV system decreases. However, with MPPT implemented, the algorithm adjusts the operating point by decreasing the voltage and increasing the current to compensate for the decrease in power. The MPPT controller continuously tracks the maximum power point to ensure optimal power extraction. Conversely, when the temperature drops below the nominal value, the power output of the solar PV system tends to increase. The MPPT algorithm adjusts the operating point by increasing the voltage and decreasing the current to maintain maximum power extraction. This compensates for the increase in power due to the lower temperature. In figure 4.3, the nominal temperature corresponds to the highest power extracted (Temp 298.15K). Here it is seen that the temperature above the nominal power corresponds to the least power extracted (Temp 357.38K).

4.3 CASE 2: Varying Temperature; Effect on Voltage

As mentioned earlier, when the temperature increases above the nominal value, the voltage output of the solar panel decreases. However, the MPPT algorithm actively adjusts the operating voltage to maintain maximum power output. It lowers the voltage to counteract the decrease caused by the temperature rise and maintains the optimal power point. Similarly,when the temperature drops below the nominal value (298.15K), the voltage output of the solar panel tends to increase. In figure 4.4, the MPPT algorithm responds by adjusting the operating voltage to the appropriate level, ensuring maximum

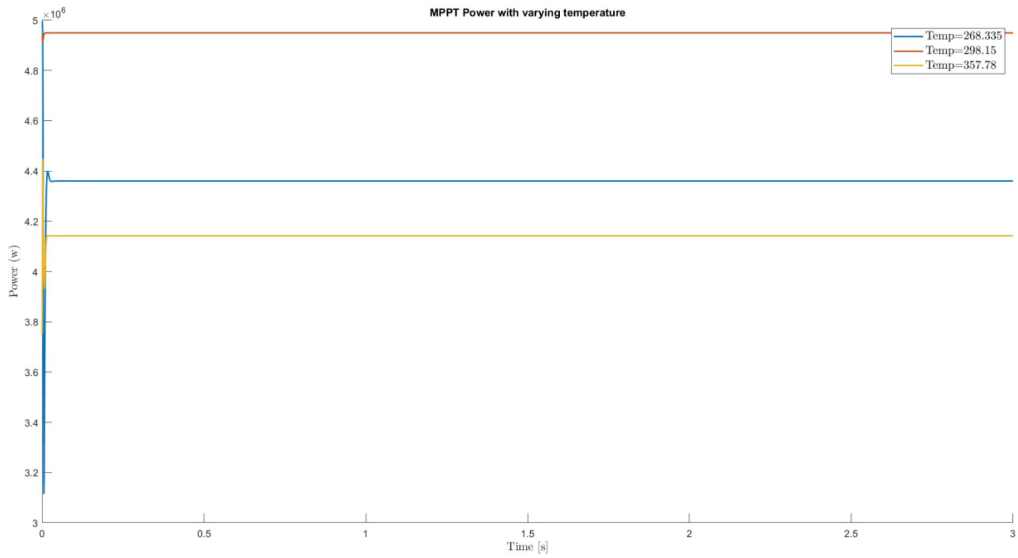

FIGURE 4.3: MPPT WITH VARYING TEMPERATURE

power extraction. It increases the voltage to compensate for the voltage rise caused by the lower temperature.

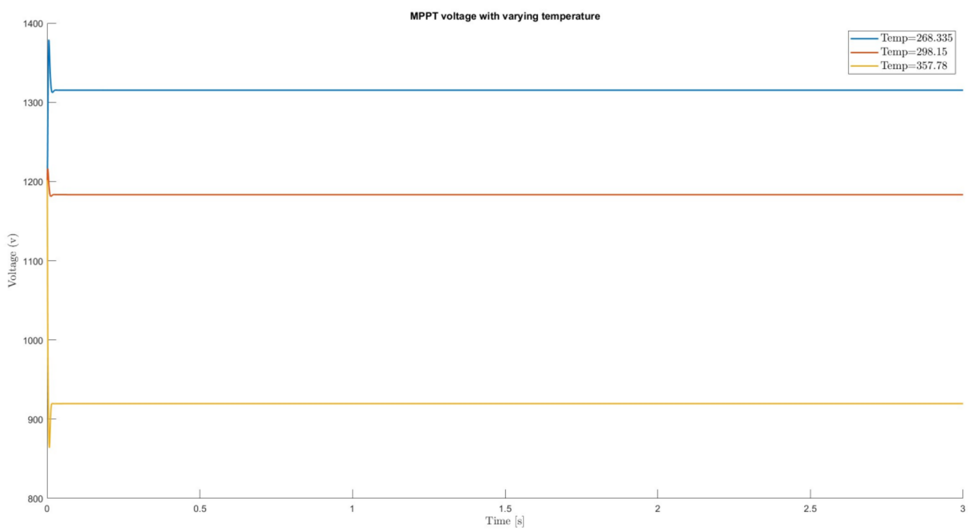

FIGURE 4.4: MPPT Voltage with varying Temperature

4.4 CASE 3: Varying Temperature; Effect on Current

The MPPT algorithm also manages the current output of the solar PV system based on temperature variations. When the temperature rises above the nominal value, the current output of the solar panel decreases. The MPPT algorithm counteracts this by adjusting the operating current to maintain maximum power output. It increases the current to compensate for the decrease caused by the higher temperature. Conversely, when the temperature drops below the nominal value, the current output of the solar panel tends to increase. The MPPT algorithm adjusts the operating current to maintain maximum power extraction. It decreases the current to compensate for the increase caused by the lower temperature. This increase is seen in figure 4.5

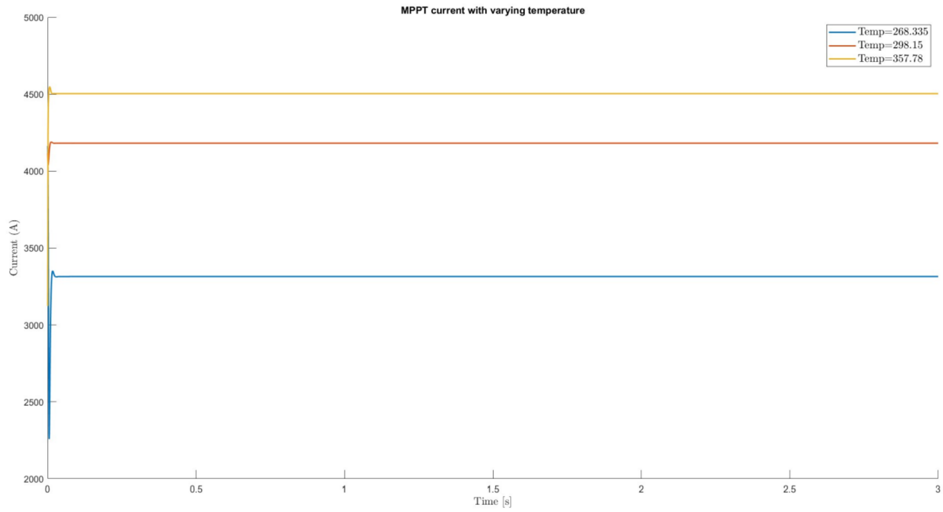

FIGURE 4.5: MPPT Current with varying Temperature

4.5 CASE 4: Results with Varying Irradiance

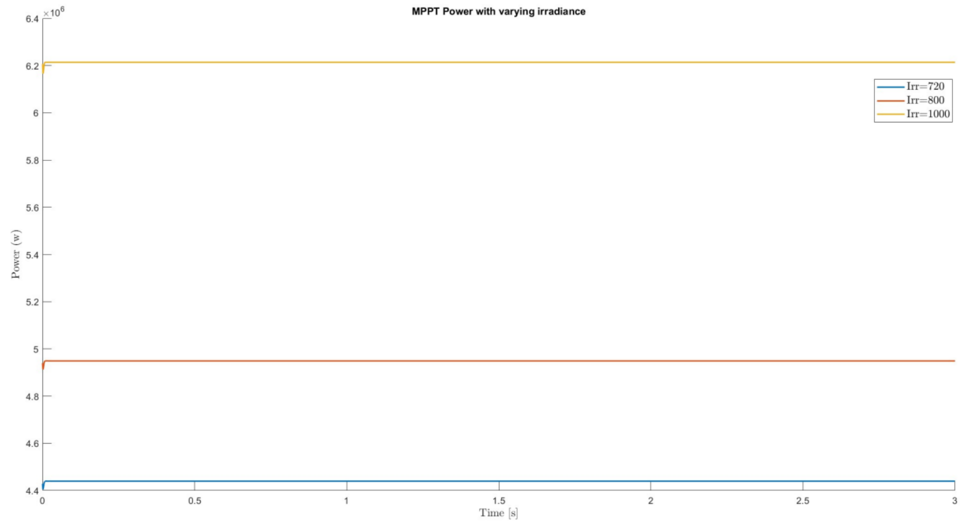

FIGURE 4.6: MPPT Power with varying Irradiance

Results in figure 4.6, 4.7, 4.8 are the same as in section 3. This is due to irradiance doesn't effect on the voltage of the solar system in this case and we get same voltage level for all cases 1184 V, but amplitude for 0s differs: the more irradience, the higher amplitude. In this case power is proportional to the current of the solar system which is

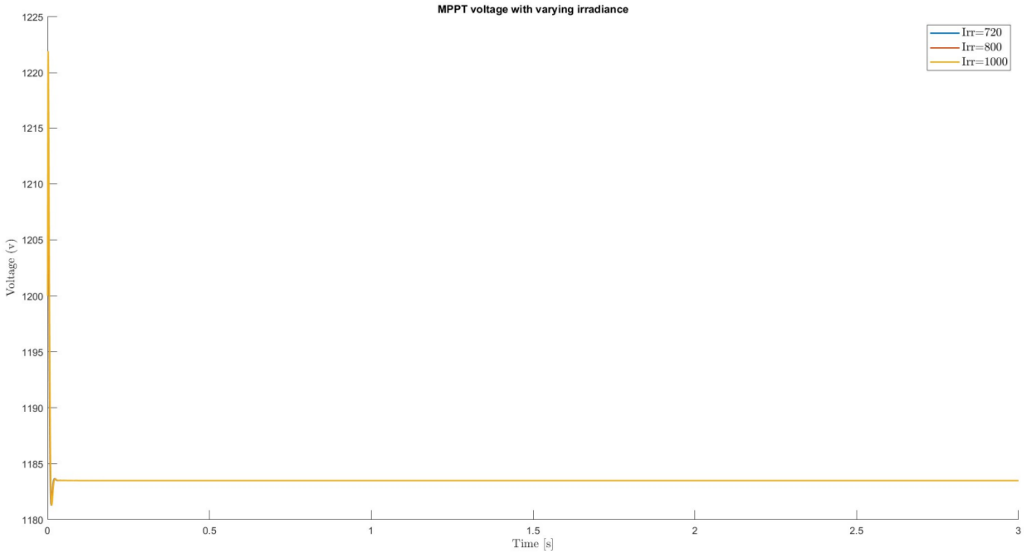

FIGURE 4.7: MPPT Voltage with varying Irradiance

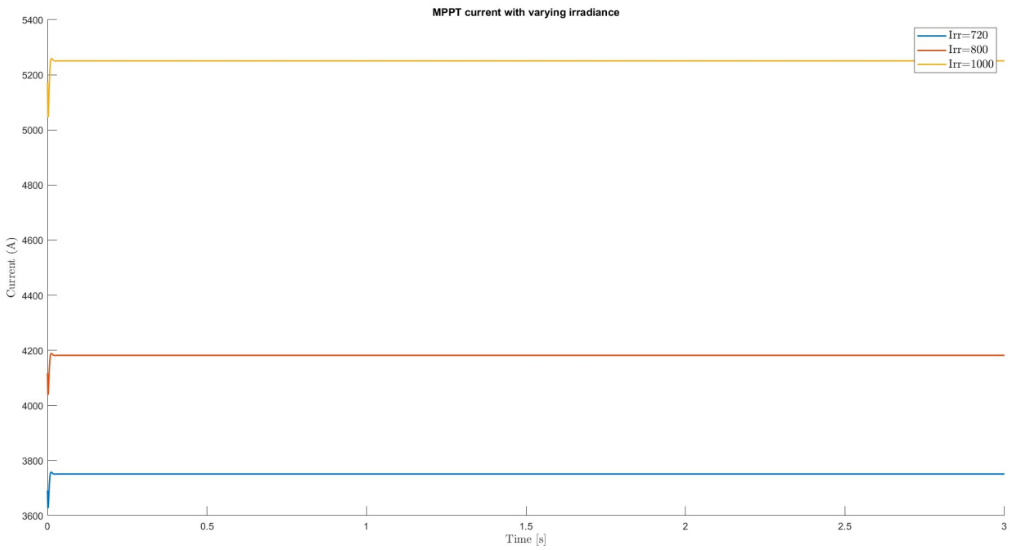

FIGURE 4.8: MPPT Current with varying Irradiance

proportional to irradiance. So, it means that for biggest value of irradiance we get the biggest value of the power.

4.6 CASE 5: Effect of step change in Temperature

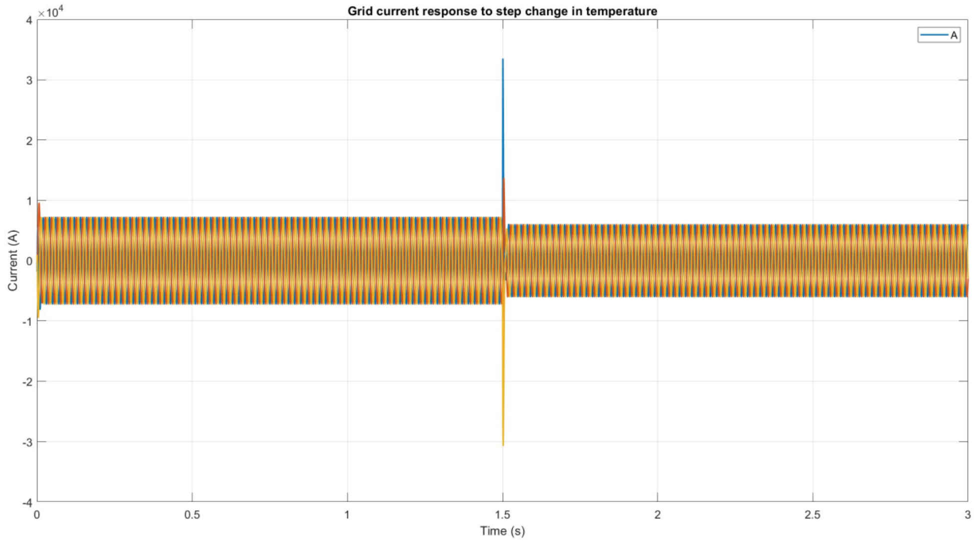

FIGURE 4.9: Grid current response to a step change in temperature

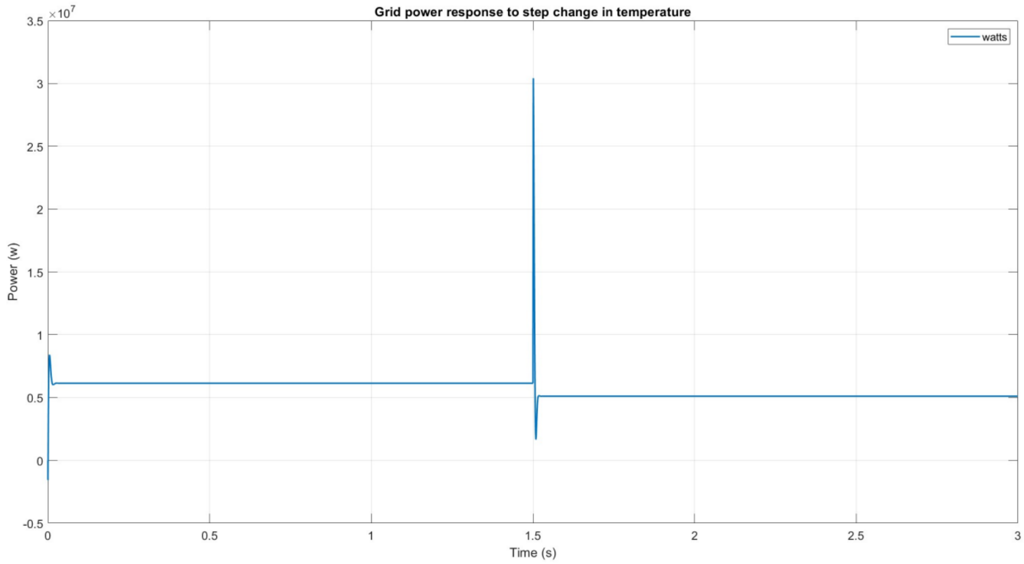

FIGURE 4.10: Grid power response to a step change in temperature

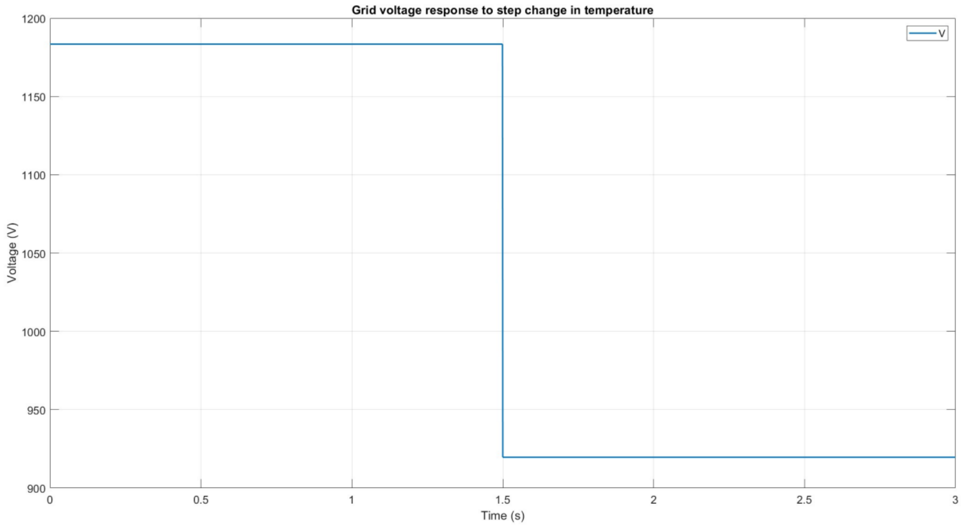

FIGURE 4.11: PV voltage response to a step change in temperature

Results in figure 29, 30, and 31 are for the effect of a 1.2 increase step change in grid current, grid power, and PV dc voltage at time 1.5secs.An increase in nominal temperature affects the grid current indirectly by altering the output power of the PV system. When the temperature rises, the PV module's efficiency typically decreases, resulting in lower power output. As a result, the grid current also decreases slightly due to the reduced power being injected into the grid. Similarly, the grid power is determined by the product of the grid voltage and grid current. With a decrease in PV power output due to higher temperatures, the grid power decreases accordingly. Also, an increase in temperature results in a decrease in the PV module's voltage output.