Photovoltaic-Battery System – A Generic Example

Written for PSCAD v4.5 and v4.6.

1 General description of the photovoltaic system

This document outlines a Photovoltaic (PV) and battery system in PSCAD. Figure 1 shows the PSCAD main page of the PV-battery system PV_Battery_generic_May2017.pscx. This example is not designed to work under stand-alone condition.

> **Note**
> See Appendix A to set up the simulation correctly.

A general description of the entire system and the functionality of each module are given to explain how the system works and what parameters can be controlled by the system.

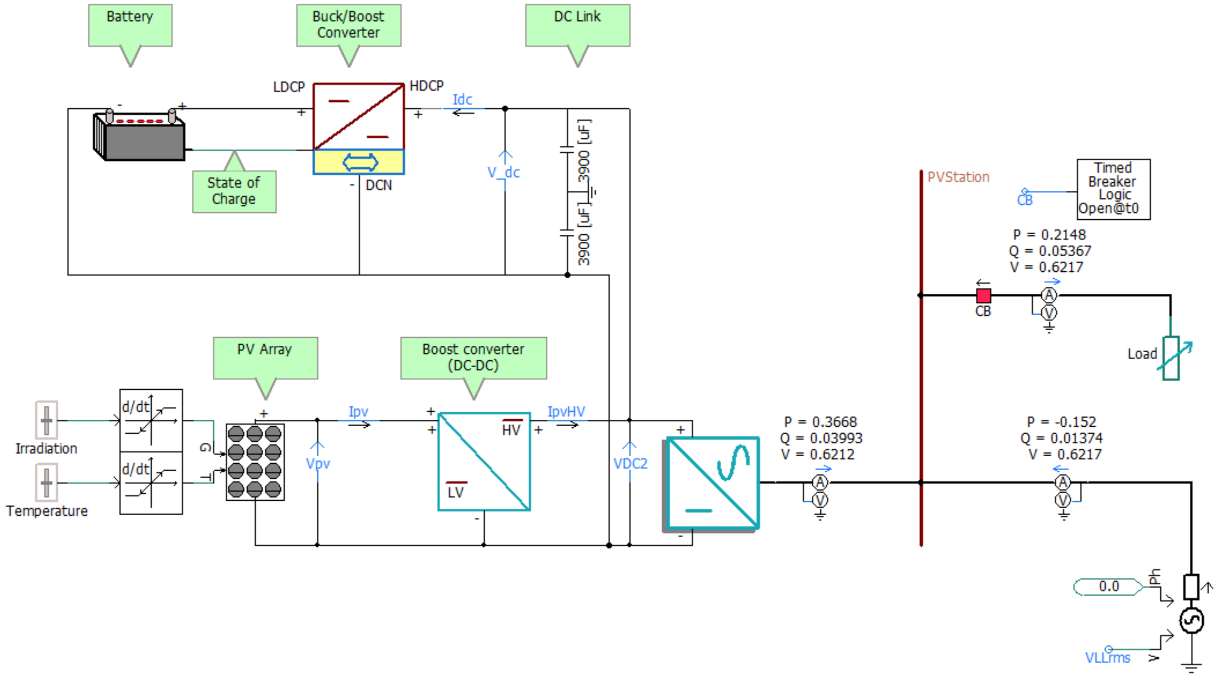


Figure 1: Overall PV-battery system connected to equivalent voltage source (stand-alone is not activated)

The PV array is connected to a DC-DC converter (boost converter). The output power of the PV array is a function of the inputs namely irradiation and temperature (see Figure 2).

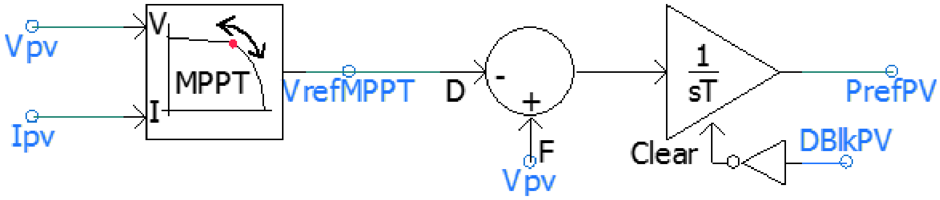


Figure 2: Maximum power point tracker and the reference power control system

Based on the reference power generated by the maximum power point tracker (MPPT) the boost converter adjusts the dc link current IpvHV (see Figure 1). The voltage source converter (VSC) controls the dc voltage VDC2 and tries to maintain it its reference value.

For example, if the PV power increases because of an irradiation increase on the PV array, the boost converter increases its duty cycle so that more current is drawn from the PV array. As a result the dc link voltage VDC2 increases. To maintain the dc voltage level on the dc link the VSC draw more current from the dc link. Therefore regulating the dc link voltage and meeting the power reference from the MPPT.

More detailed description of the system is given in the following sections.

1.1 PV Array

Figure 3 shows the output power of PV array as a function of irradition (W/m2) when the temperature is 30C and irradition increases from from 700W/m2 to 1500W/m2. Figure 4 shows power variations when irradition is constat and equal to 1500W/m2 while temprature increases from 10°C to 50°C.

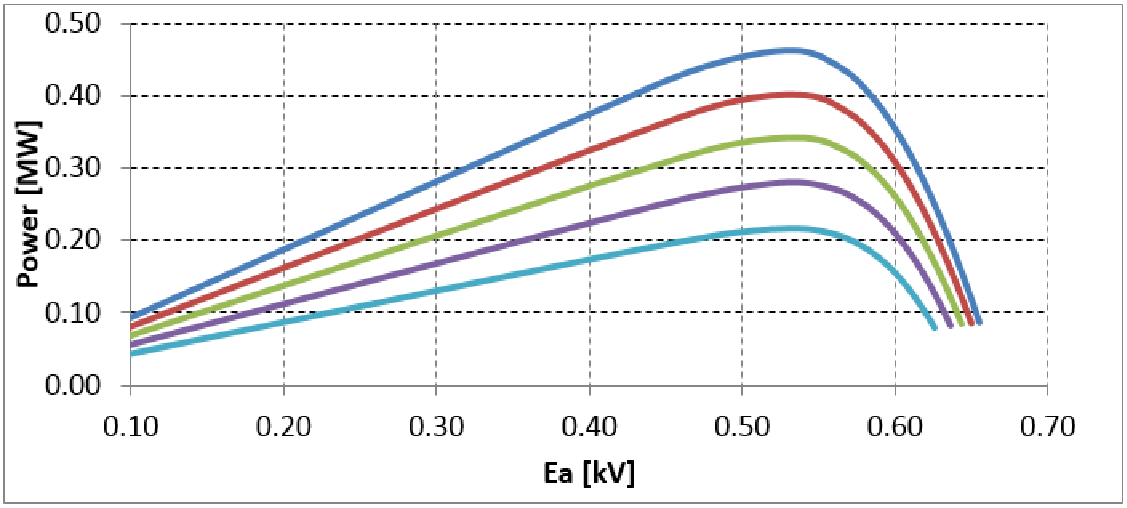


Figure 3: Variation of Power as a function of irradition (varies from 700W/m2 to 1500W/m2) vesuse Ea

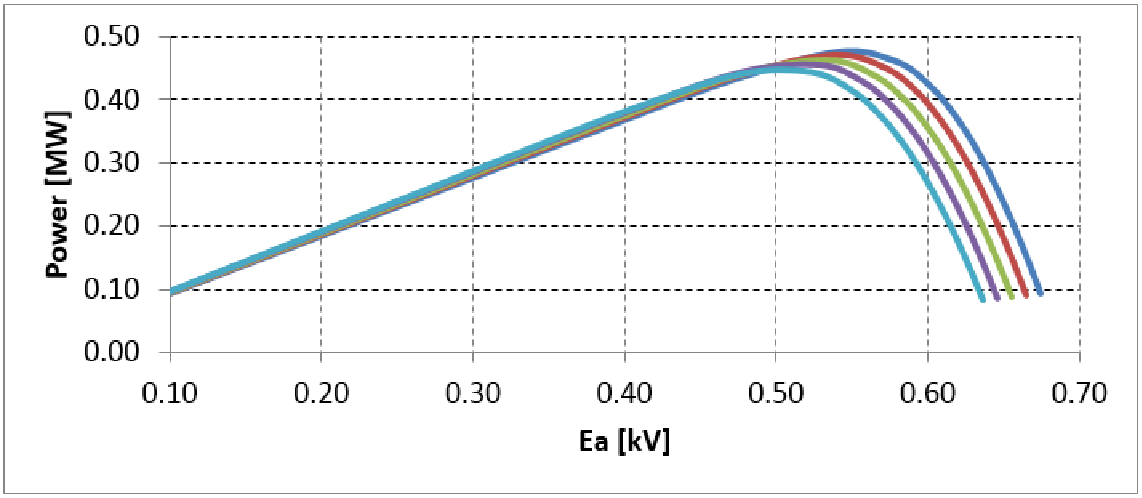


Figure 4: Variation of Power as a function of temprature (varies from 10°C to 50°C) versus Ea

1.2 Boost converter (DC-DC)

The boost converter shown in Figure 5 consists of a low pass filter at the input side. The controller is shown in Figure 6 where the reference power (Pref) is compared to the dc link power (Pdc) and the error signal is given to a PI controller to generate the boost converter duty cycle (Ref_Boost). The PI controller coefficients (i.e. KpBoost and TiBoost) and its output limit (DmaxBoost) can be adjusted using the control panel shown in Figure 6.

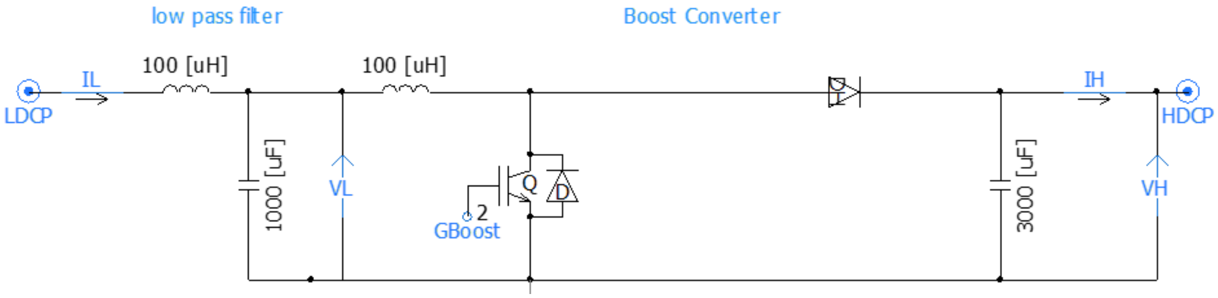
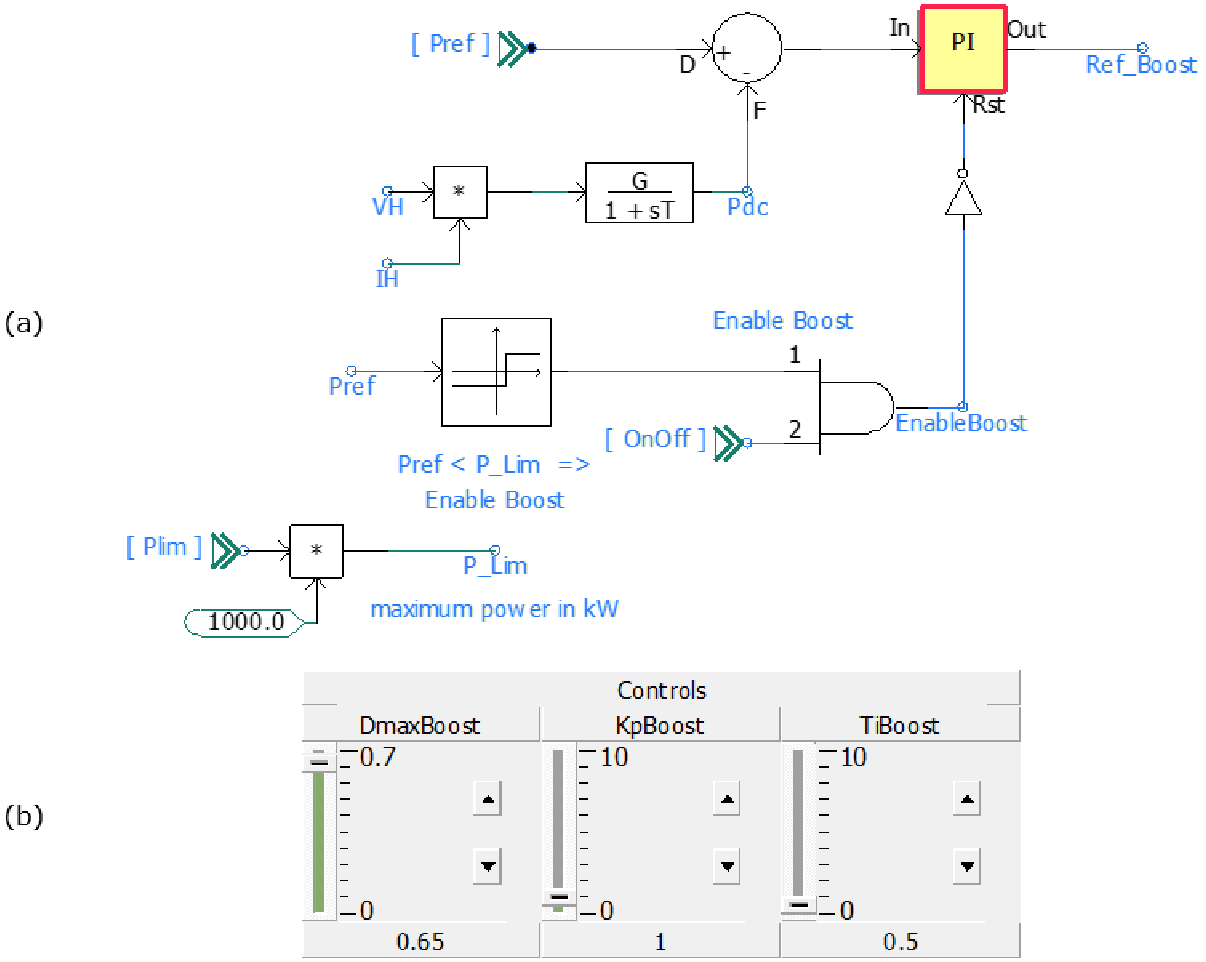


Figure 5: Boost converter

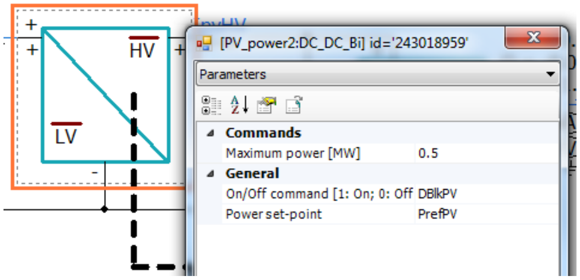


DmaxBoost 0.65
KpBoost 1
TiBoost 0.5

Figure 6

Figure 6: (a)Power controller (b) PI controller coefficients and limit

To protect the boost converter against high currents the reference power is limited to a maximum power (P_lim). To see the limit, right click on the boost converter component and select "Edit Parameters". A window opens showing maximum power which is 0.5 MW in this example (see Figure 7).

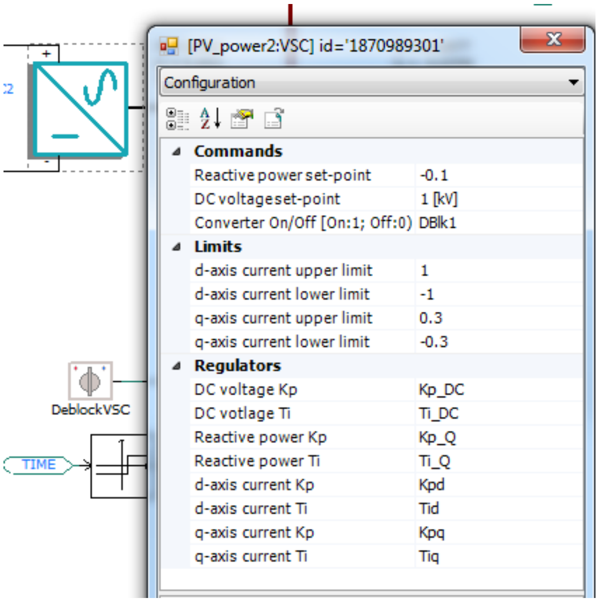


Commands
Maximum power [MW] 0.5
General
On/Off command [1: On; 0: Off DBlkPV
Power set-point PrefPV

Figure 7: Viewing parameters

1.3 Voltage source converter (VSC)

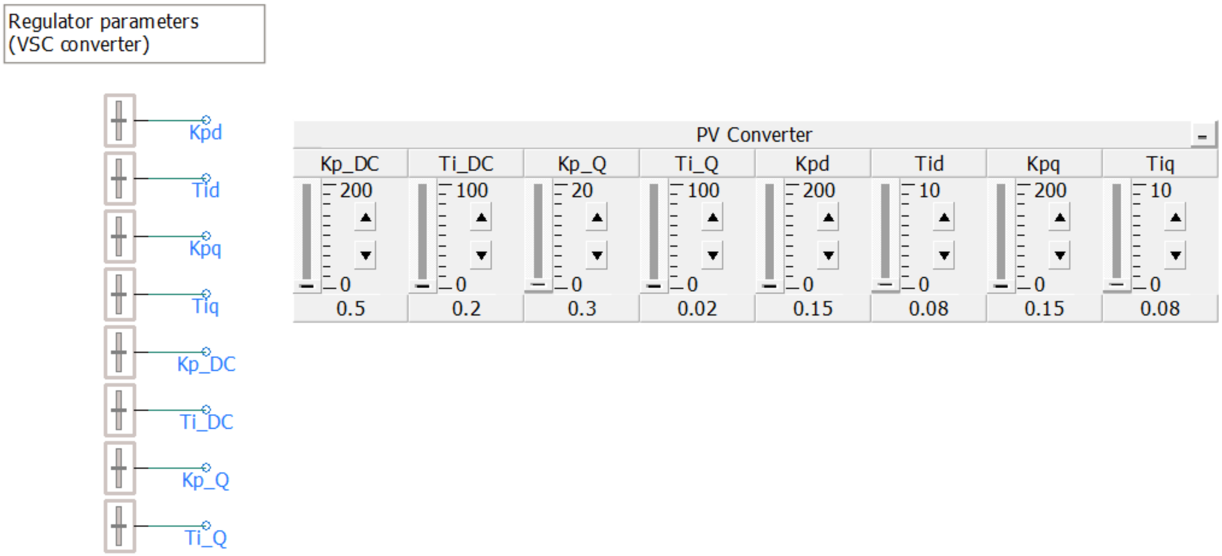
To edit the parameters of the VSC, right click on the VSC component and select “Edit parameters”, see Figure 8. The reference reactive power is in MVAr (Negative value indicates the VSC generates reactive power, and positive value indicates the VSC consumes reactive power).



Commands	
Reactive power set-point	-0.1
DC voltageset-point	1 [kV]
Converter On/Off [On:1; Off:0)	DBlk1
Limits	
d-axis current upper limit	1
d-axis current lower limit	-1
q-axis current upper limit	0.3
q-axis current lower limit	-0.3
Regulators	
DC voltage Kp	Kp_DC
DC votlage Ti	Ti_DC
Reactive power Kp	Kp_Q
Reactive power Ti	Ti_Q
d-axis current Kp	Kpd
d-axis current Ti	Tid
q-axis current Kp	Kpq
q-axis current Ti	Tiq

Figure 8: Voltage source converter module and the input parameters

Figure 9 shows the coefficients for PI controlles and the panels to modify the values if required



Kp_DC	Ti_DC	Kp_Q	Ti_Q	Kpd	Tid	Kpq	Tiq
200	100	20	100	200	10	200	10
0	0	0	0	0	0	0	0
0.5	0.2	0.3	0.02	0.15	0.08	0.15	0.08

Figure 9: The Kp and Ti coeficients of the PI controllers for VSC

The power electronic circuit of the VSC converter is shown in Figure 10. The dc link capacitors are 3.9 mF.

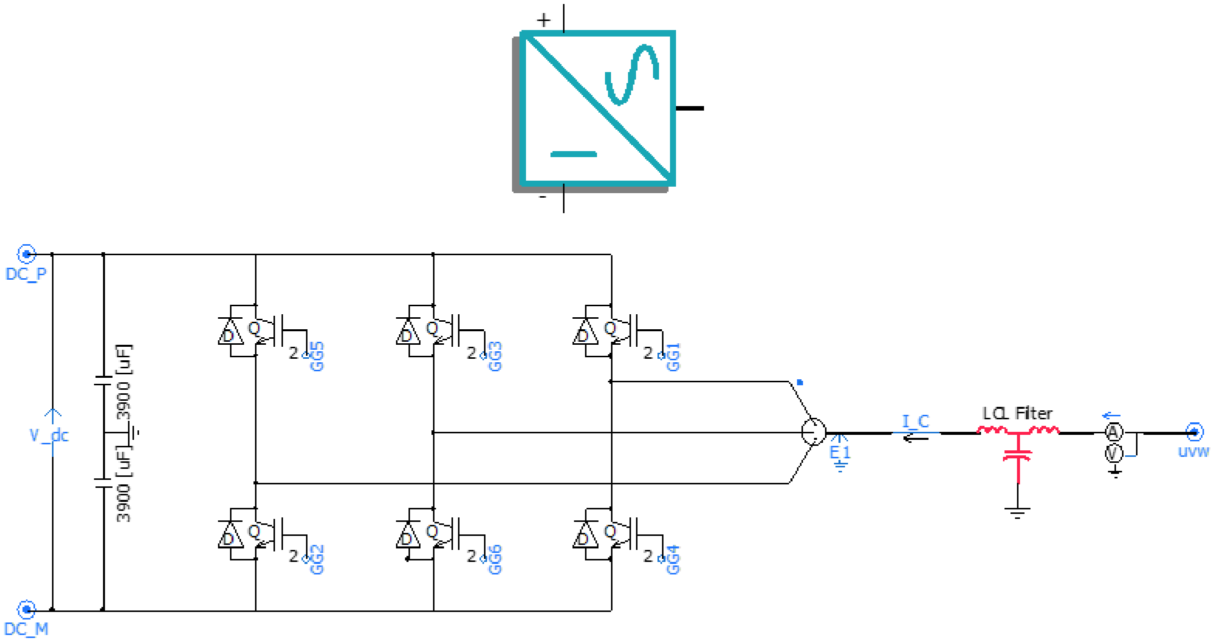


Figure 10: The voltage source converter the dc link capacitors and the ac side filter

The dc voltage controller is shown in Figure 11.

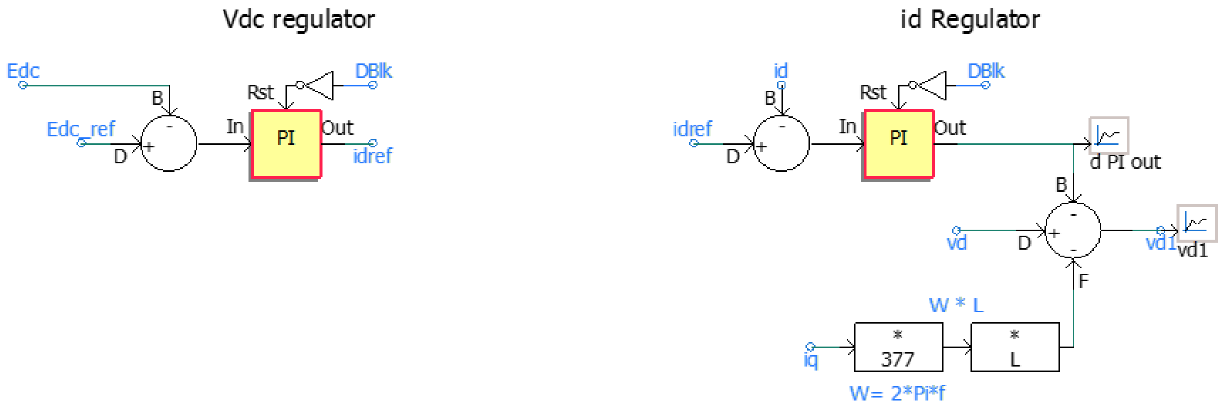


Figure 11: The dc voltage controller

The reactive power controller is shown in Figure 12.

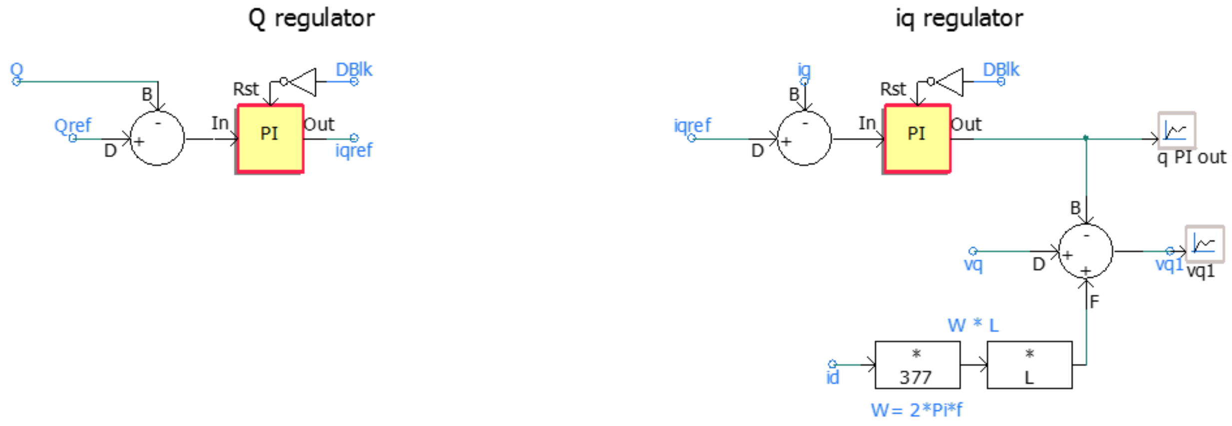


Figure 12: The reactive power controller

2 General Description of the Battery System

This document outlines the implementation of a single-phase Battery system in PSCAD. Figure 13 shows the Battery system on the main canvas of “BatteryModel1PhaseMay2017.pscx”. A general description of the system and the functionality of each module are given to explain how the system works and what functionality can be expected form this system.

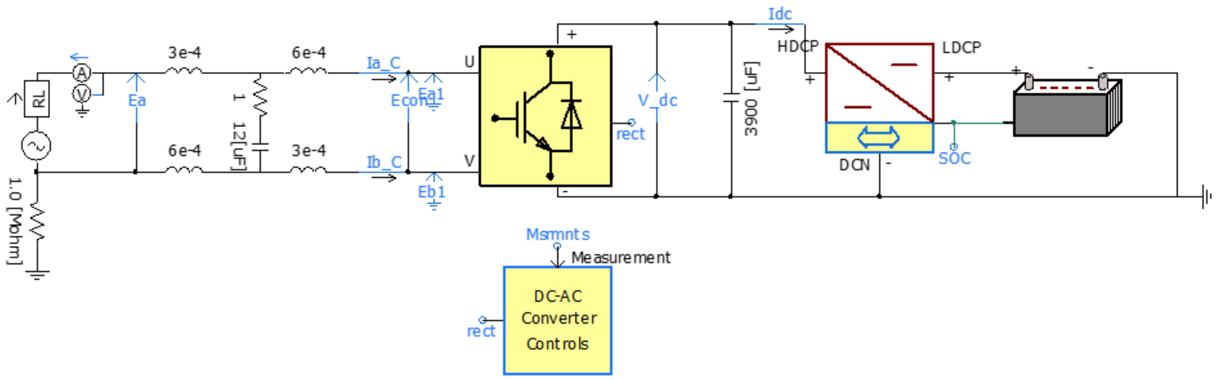


Figure 13: Overall battery system connected to a single-phase grid via DC-DC and DC-AC converters

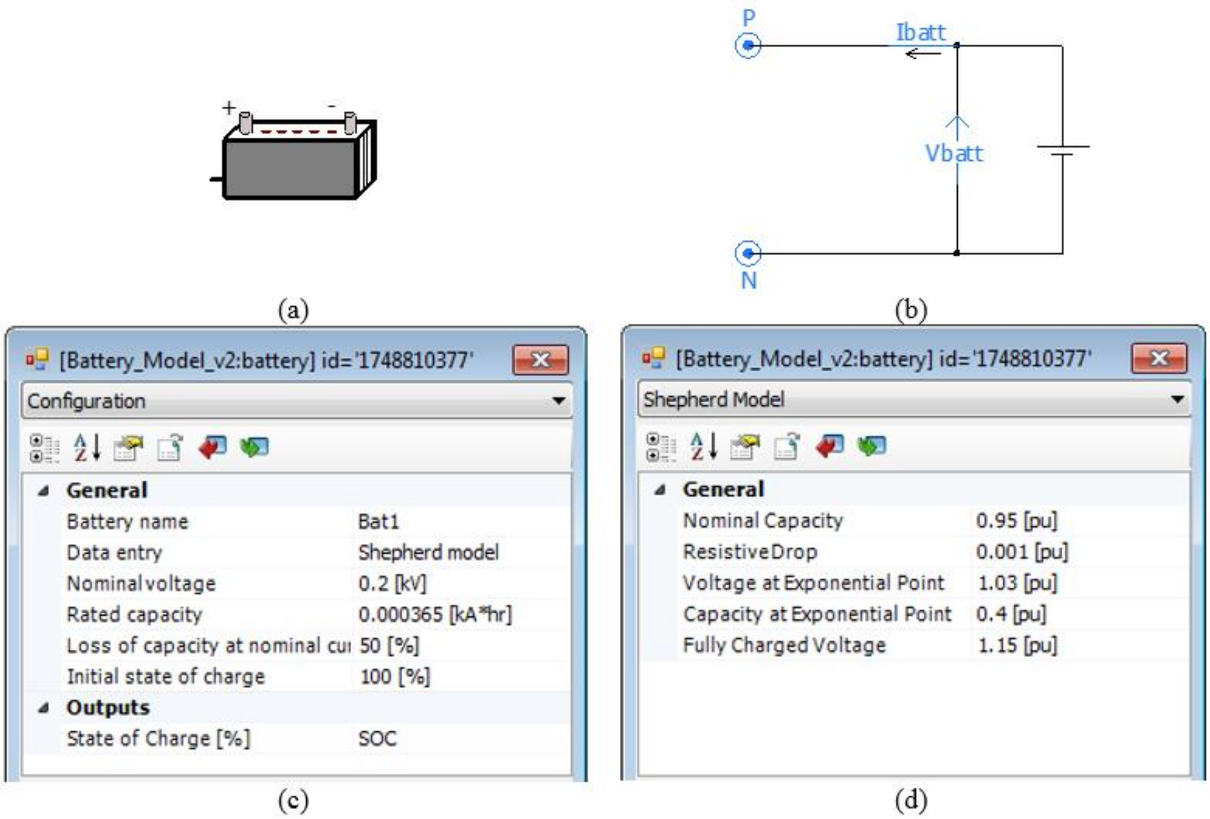
The battery is connected to a DC-DC converter (Buck/Boost converter). The DC-DC converter operates as a Buck or Boost converter to charge or discharge the Battery. The DC-DC converter connects to the DC-AC converter via a DC Link system of 3900 micro F capacitors. The DC-AC converter controls the DC voltage (V_dc) on the DC Link.

2.1 Battery

Figure 14 shows the battery model and its parameters. Double click on the Battery module shown as follows (it can be found in the main canvas) to see the circuit.

The DC voltage rating for the battery is defined as 200V. This model is based on a few simplifying assumptions and has some limitations [1].

- Assumptions:
  - During the charge and discharge cycles, the internal resistance is assumed to be constant.
  - The amplitude of the current does not have any effect on the internal resistance.
  - The discharge characteristics curve of the battery is used to derive the battery parameters, since the discharge and charge characteristics are assumed to be the same.
  - The amplitude of the current does not have any effect on the capacity of the battery (No Peukert effect).
  - Temperature does not change the model's behavior.
  - Self-discharge of the battery is not represented.
  - Charge and discharge history does not affect battery characteristics (i.e. No hysteresis).
- Limitations:
  - The battery voltage cannot be negative and the maximum battery voltage is not limited.
  - The capacity of the battery cannot be negative and the maximum capacity is not limited.



[Battery_Model_v2:battery] id='1748810377'

Configuration

General	
Battery name	Bat1
Data entry	Shepherd model
Nominal voltage	0.2 [kV]
Rated capacity	0.000365 [kA*hr]
Loss of capacity at nominal cu	50 [%]
Initial state of charge	100 [%]
Outputs	
State of Charge [%]	SOC

[Battery_Model_v2:battery] id='1748810377'

Shepherd Model

General	
Nominal Capacity	0.95 [pu]
ResistiveDrop	0.001 [pu]
Voltage at Exponential Point	1.03 [pu]
Capacity at Exponential Point	0.4 [pu]
Fully Charged Voltage	1.15 [pu]

Figure 14: Battery modeled and parameters

2.2 Buck/Boost Converter

The Buck/Boost converter is shown in Figure 15. It is connected to the battery (Low voltage: 200V) on the right side and connects to DC link system on the left side (High voltage: 250V).

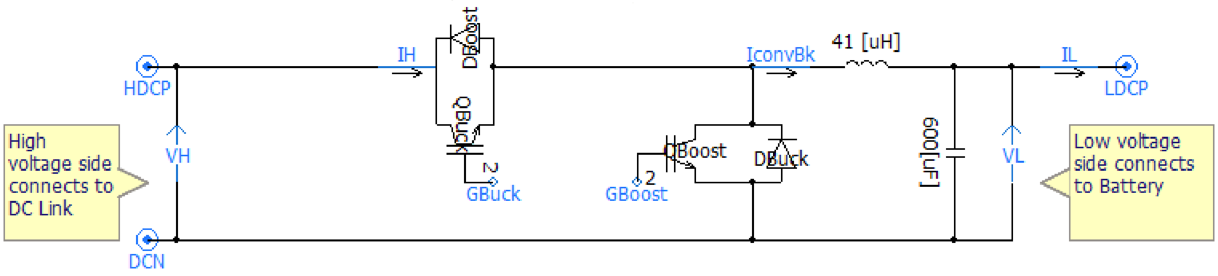


Figure 15: Buck/Boost converter

2.3 Upper level control system and ratings

The upper level control system is shown in Figure 16. This control system is manual and also achievable in the “Graphs_and_Controls” module.

The control panel “Charger On/Off” is to enable/disables the Buck/Boost converter manually. This controller can also be provided automatically based on an over-voltage or an over-current protection system.

The other controller is “Mode” which controls the mode of operation for the converter. In other words using this control the battery can be charged or discharged. This controller is also manual. However it can be programmed automatically bases on a power management system.

The SOCpermit is a signal that does not permit charging or discharging when SOC is above 100% or less than 5% respectively.

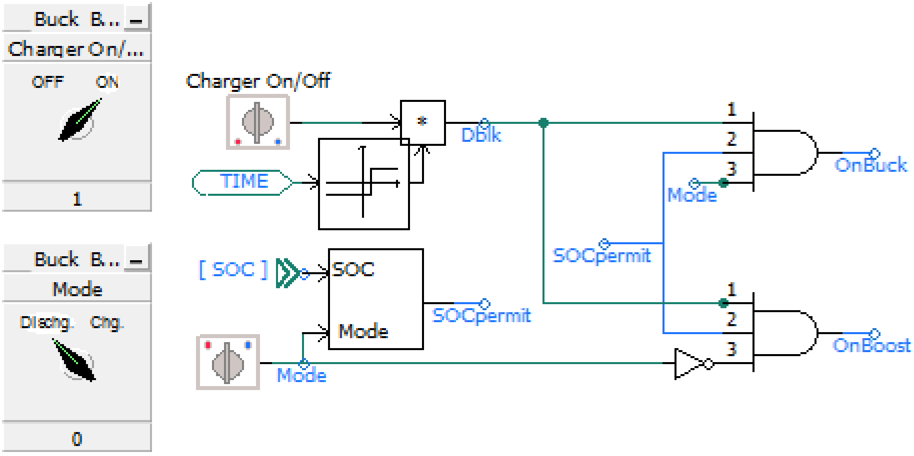


Figure 16: Upper level controllers

The reference voltage can be selected for the converter using the slider shown in Figure 17. This value is selected based on the ratings of the battery which is 200V.

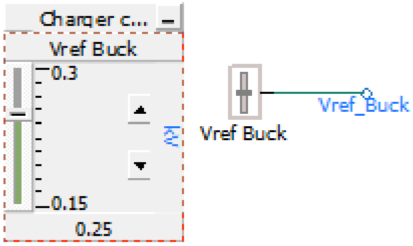


Figure 17: Variable input slider showing the reference voltage

To protect the converter and the battery form over-currents maximum charging and discharging allowable currents are selected and shown in Figure 18. For example, these values may be calculated or obtained from the datasheet of the semiconductor switches.

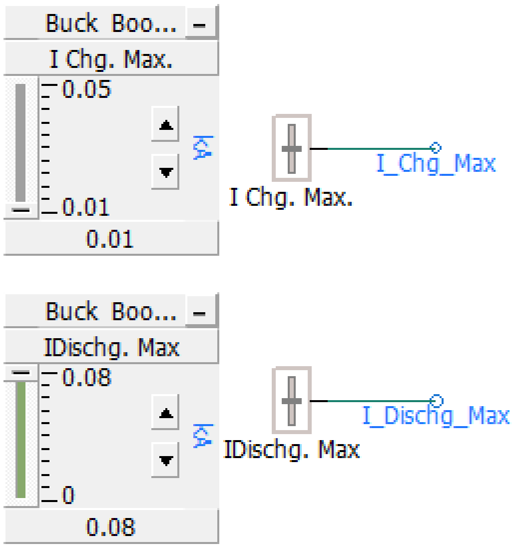


Figure 18: Variable input slider showing the maximum allowable currents for the converter during charging and discharging mode

2.4 Lower level controllers

When the converter operates at charging mode, the Buck converter is enabled (see Figure 16). The Buck controller is shown in Figure 19 where the reference voltage is compared against the low voltage side voltage (VL). The error signal applies to a PI controller with KpBuck and TiBuck coefficients.

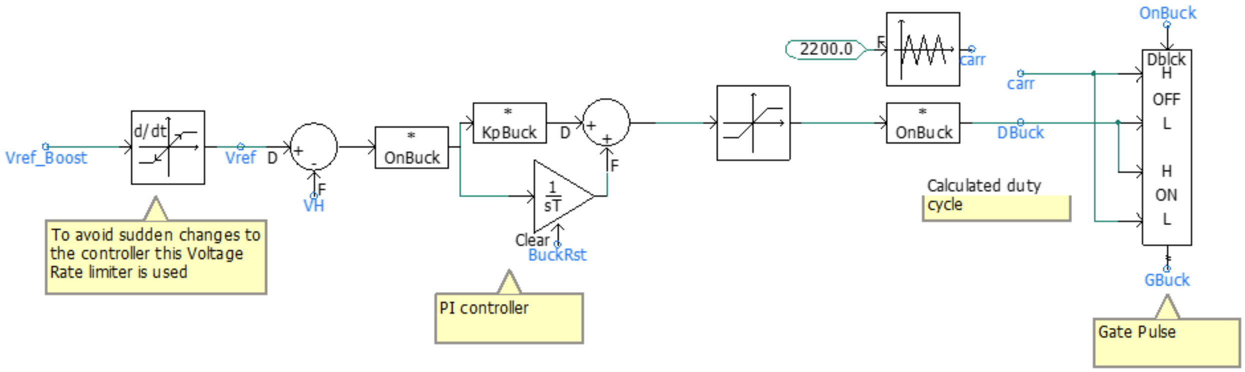


Figure 19: The charger controller for Buck converter

To protect the Buck converter and Battery against high currents the duty cycle of the converter is limited based on a function of the maximum allowable current (I_chg_Max) as shown in Figure 20.

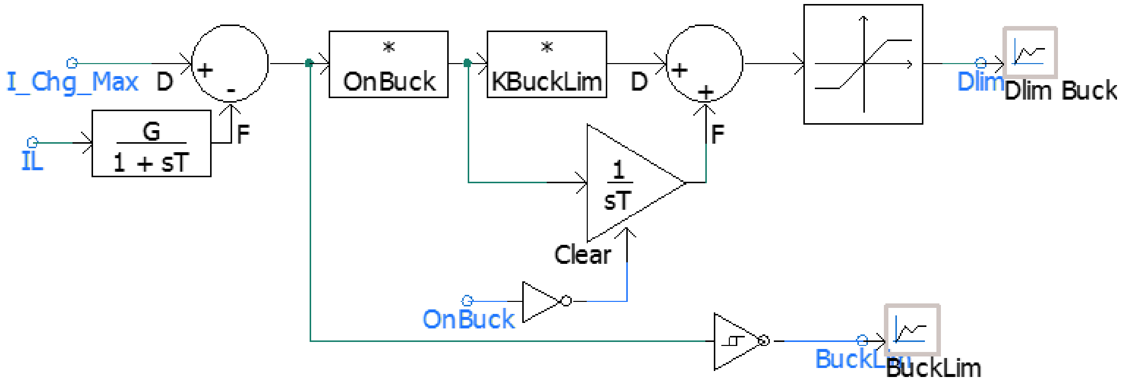


Figure 20: Overcurrent protection to limit the duty cycle of the Buck converter during charging

When the converter operates at discharging mode, the Boost converter is enabled (see Figure 16). The Boost controller is shown in Figure 21 where the reference voltage is compared against the low voltage side voltage (VL). The error signal applies to a PI controller with KpBoost and TiBoost coefficients.

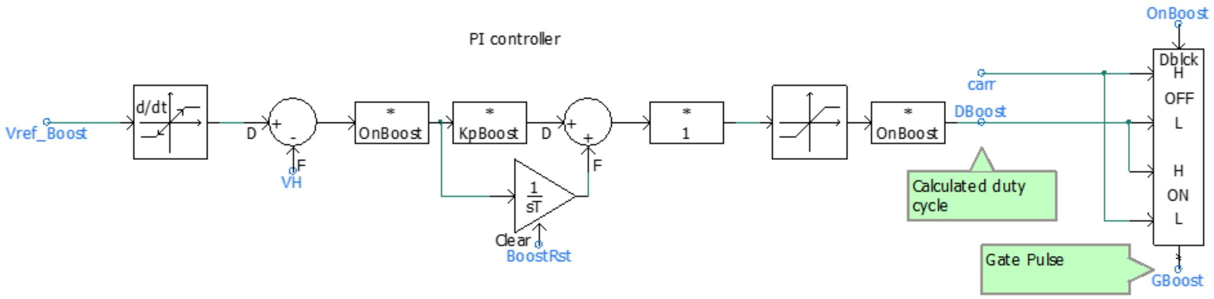


Figure 21: The discharger controller for Boost converter

To protect the Boost converter and Battery against high currents the duty cycle of the converter is limited based on a function of the maximum allowable current (I_dischg_Max) as shown in Figure 22.

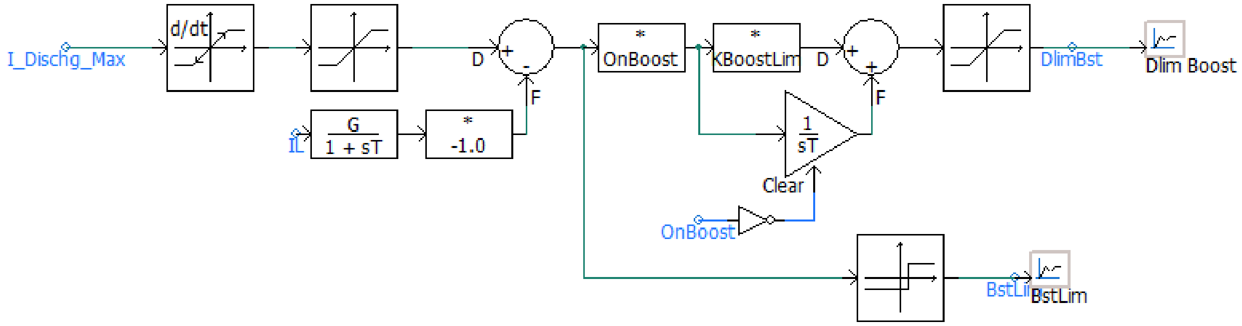


Figure 22: Overcurrent protection to limit the duty cycle of the Boost converter during discharging

3 Simulation results

3.1 Simulation results for discharging mode

The battery is at 50 percent state of charge (SOC) at the beginning. The dynamic of the system for discharging mode of operation is shown in Figure 23 and Figure 24. The State of charge (SOC) slowly reduces to 5 % when the SOCprmit block the controllers and shut down the converter. The current increases while the voltage decreases during the discharge process. Please note that the discharging process is exaggerated to shorten the simulation time. Otherwise it may take hours to discharge a battery fully.

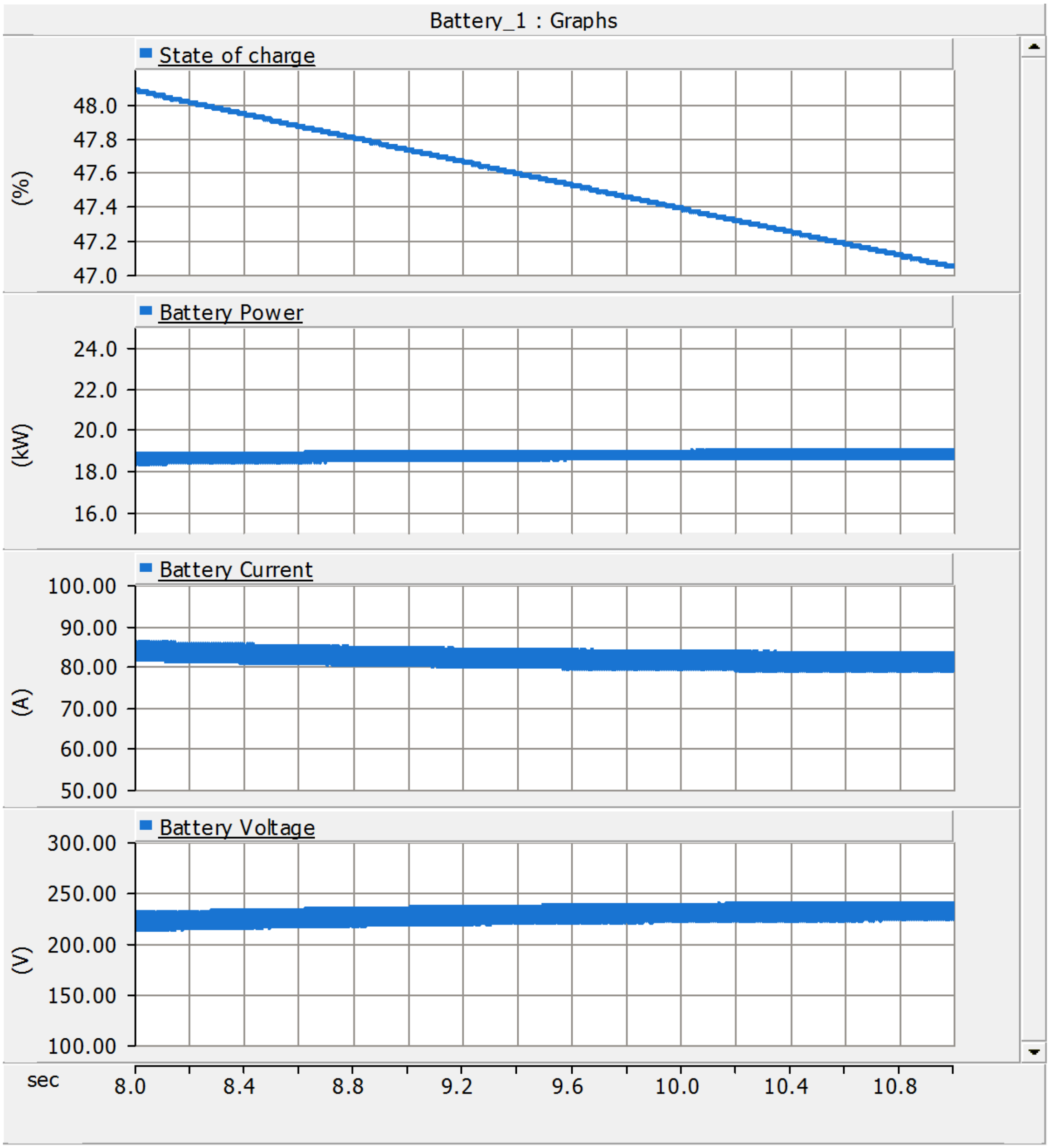


Figure 23: Discharging mode of operation and battery waveforms

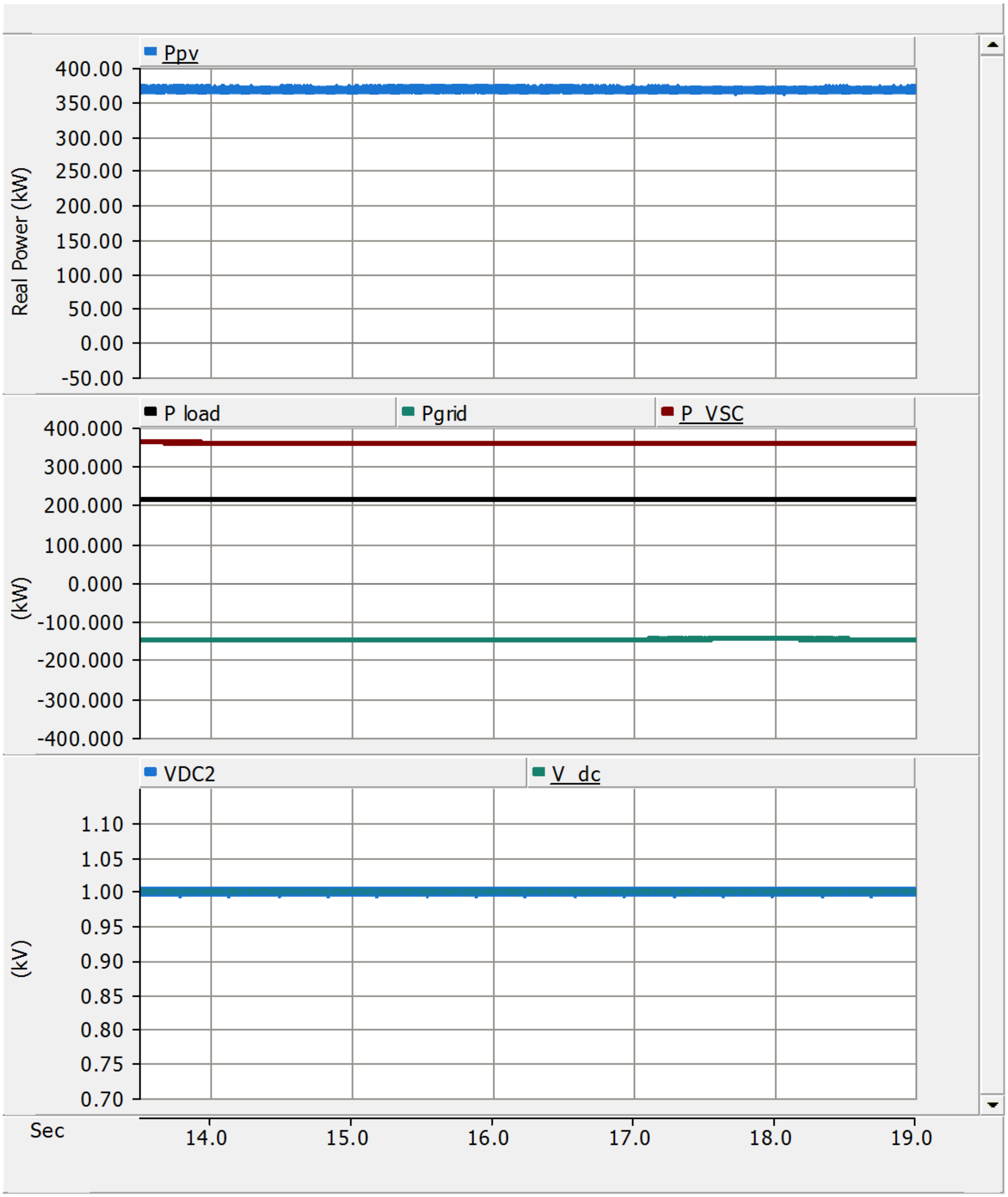


Figure 24: Discharging mode of operation and simulation results

3.2 Simulation results for charging mode

The dynamic of the system for charging mode of operation is shown in Figure 25. SOC increases until it reached 100% and the SOCpermit block the converter to stop it from charging more.

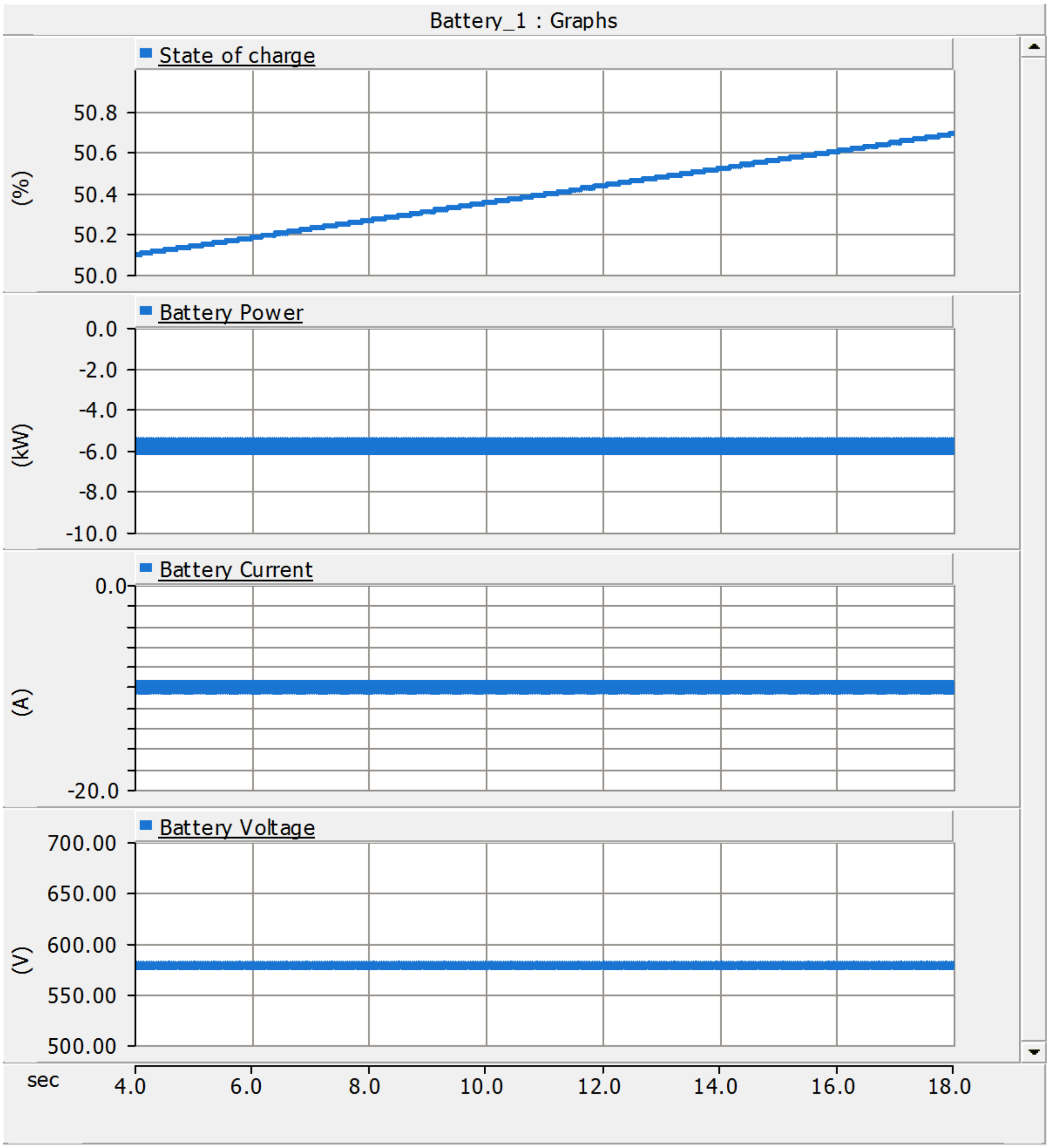


Figure 25: Charging mode of operation and battery waveforms

3.3 Simulation results for load and irradiation changes

The dynamic of the system is shown in Figure 26 when a load connects to the system at 3.5 sec. When the load is connected to the system the PV system power P_VSC remains constant however the grid power Pgrid varies accordingly.

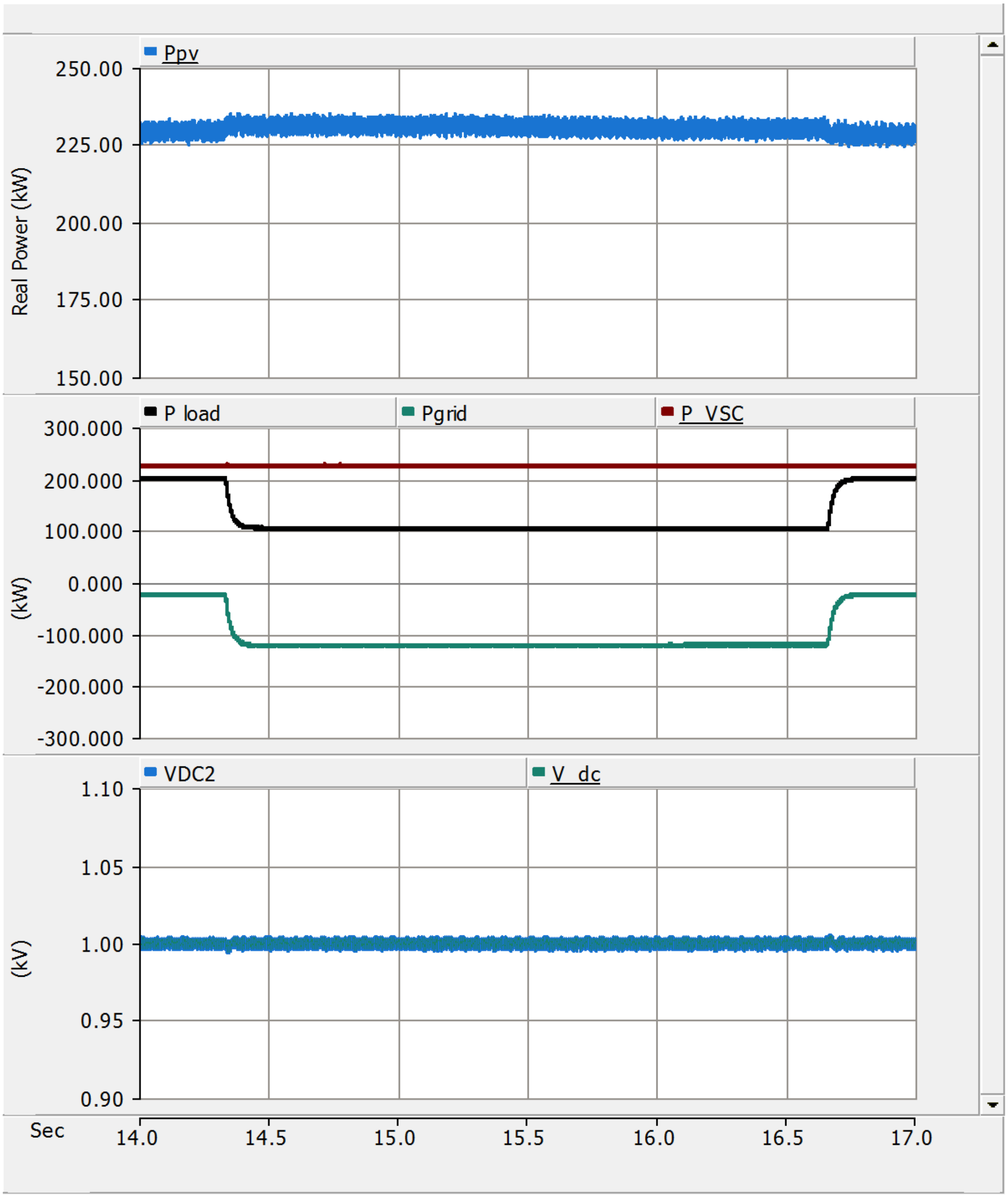


Figure 26: The dynamic of the load when it changes from 0.2MW to 0.1MW and back

Irradiation decreases from 1200 W/m2 to 800 W/m2. Therefore the power reference from the MPPT reduces and the dynamics are shown in Figure 27.

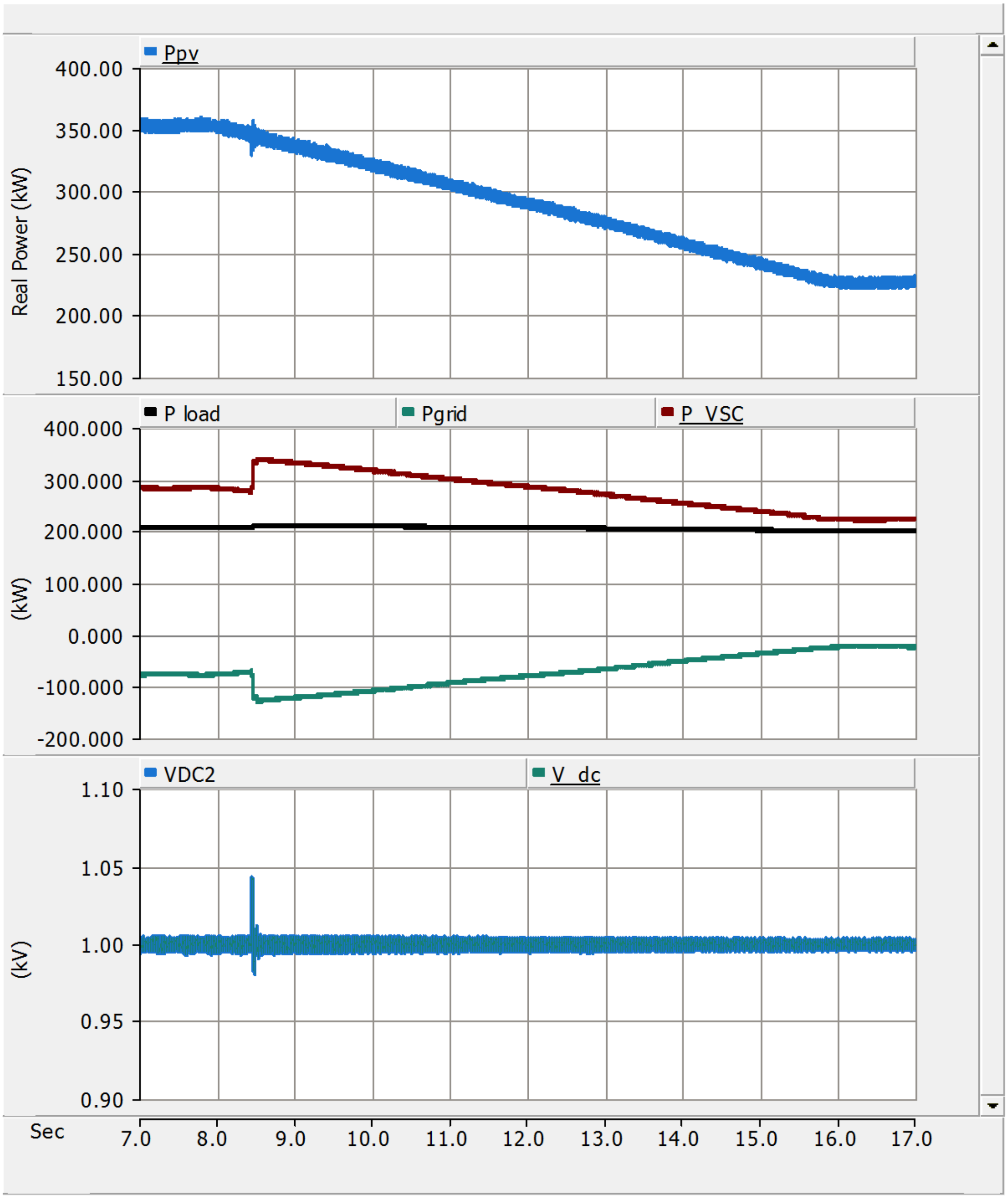


Figure 27: The dynamic of PV power as the irradiation reduces

4 Reference

[1] Tremblay, O., Dessaint, L.-A., Dekkiche, A.-I., A Generic Battery Model for the Dynamic Simulation of Hybrid Electric Vehicles, Vehicle Power and Propulsion Conference, 2007, VPPC 2007, IEEE vol., no., pp.284-289, 9-12 Sept., 2007.

Appendix A: How to set up the Simulation

Please load the library (Battery_Model_v2.pslx) in to PSCAD and link the library to one of the .lib file (Battery_Model_v2.lib they are in the zip file “ ”). In each folder there is one .lib file which is compatible with associated compiler.

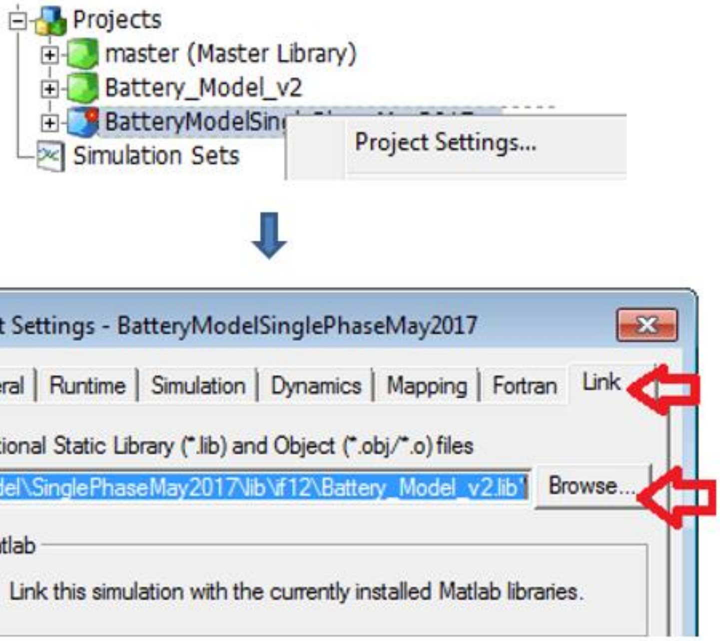
For example:

The .lib file in “ if15 ” is compatible with Intel-Fortran Version 15 compiler

Or

The .lib file in “ gf42 ” is compatible with GFortran version 4.2 compiler

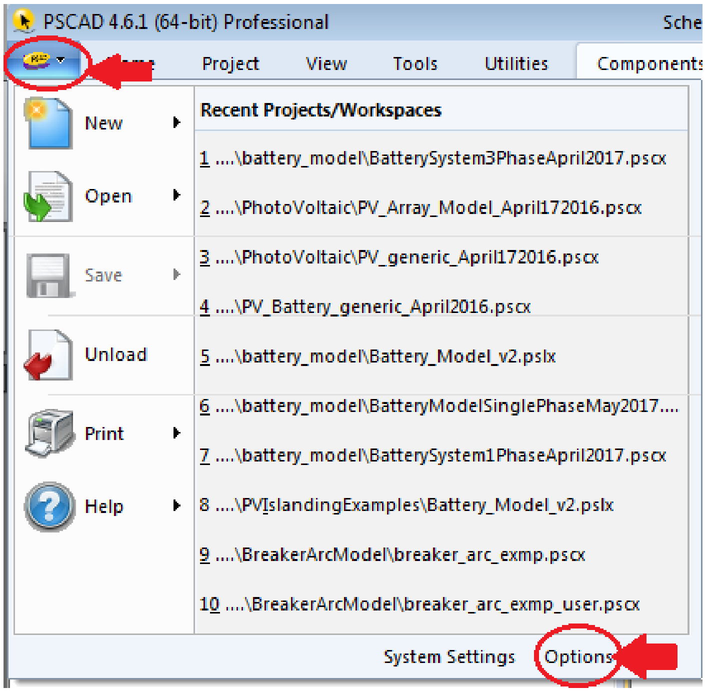
To link to the library a right-click on the Library title in the workspace window, and selecting Project Settings from the pop-up menu. The following figure shows the procedure.



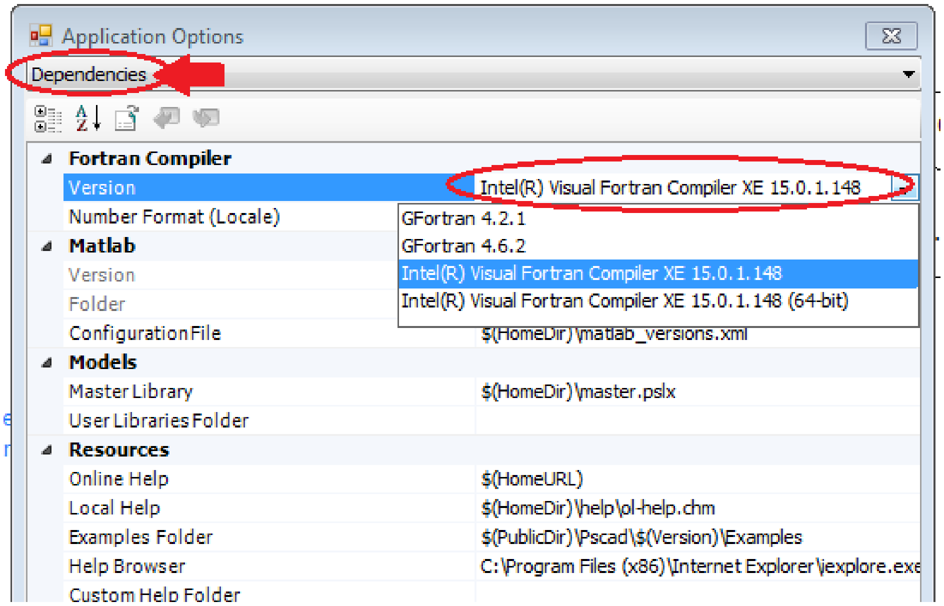
Additional Static Library (*.lib) and Object (*.obj/*.o) files: model\SinglePhaseMay2017\lib\if12\Battery_Model_v2.lib

☐ Link this simulation with the currently installed Matlab libraries.

The following procedure shows how to determine the compiler for PSCAD.

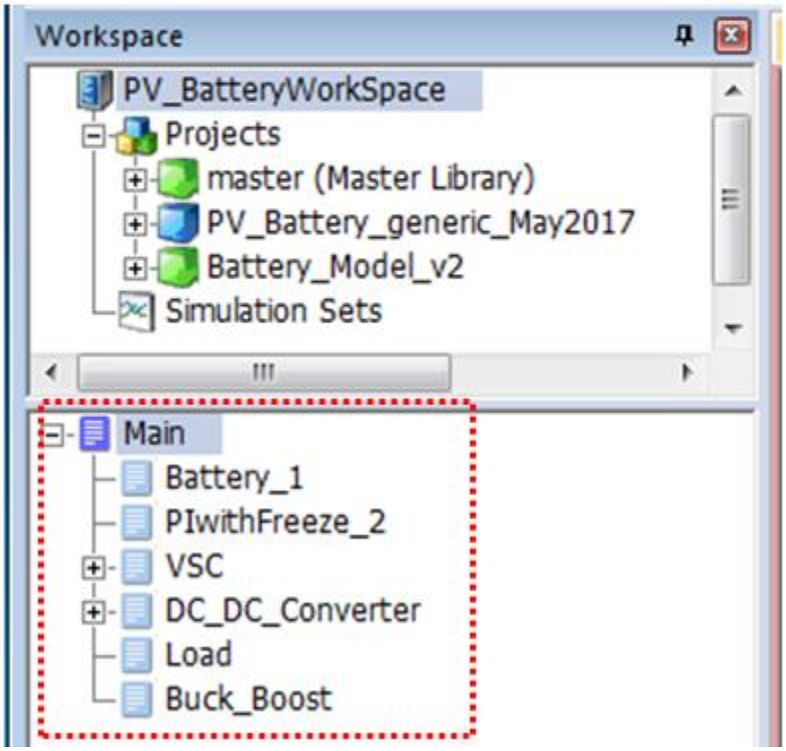


Click on the “Option” a new window opens as follows: the “Dependencies” shows which compilers are installed.



Fortran Compiler	
Version	Intel(R) Visual Fortran Compiler XE 15.0.1.148
Number Format (Locale)	
Matlab	
Version	
Folder	
Configuration File	$(HomeDir)\matlab_versions.xml
Models	
Master Library	$(HomeDir)\master.pslx
User Libraries Folder	
Resources	
Online Help	$(HomeURL)
Local Help	$(HomeDir)\help\ol-help.chm
Examples Folder	$(PublicDir)\Pscad\$(Version)\Examples
Help Browser	C:\Program Files (x86)\Internet Explorer\iexplore.exe
Custom Help Folder	

Also when the case (PV_Battery_generic_May2017.pscx) loaded into Workspace of PSCAD, DoubleClick on it to see the sub-modules in the project tree as show as follows:



Also the signals in the canvas can be traced using “virtual wires” option shown as follows. The simulation must be compiled to activate “virtual wires”.