Remote Lab: Microgrid balancing

In this section the Remote Lab application at CRES laboratory is presented.

i) Laboratory exercise objectives

The specific remote lab exercise aims to make users familiar with the following concepts:
- Power balancing control of microgrids based on specific market policies
- Real-time simulation of photovoltaics based on environmental condition measurements by physical sensors
- Interoperability of SCADA applications by different vendors

ii) Test Setup

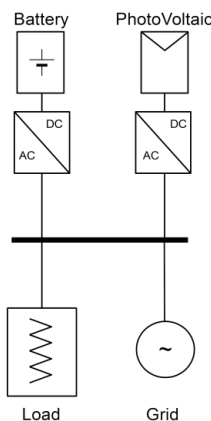The diagram below (Figure 1) illustrates the configuration assumed for the lab exercise.

Figure 1: Selected microgrid setup for the CRES' remote lab application

As it is shown in Figure 1, the setup includes four different resources, namely one Battery Storage System, one Load, one PV and one grid interconnection. In the setup the battery, load, and grid connection are all physical equipment, whereas the PV unit was simulated. The reason for selecting the PV as a simulated unit instead of a physical one was to introduce in the setup the analytical mathematical models that one can use for the analysis of PV systems. In our application these models include calculation of irradiance from actual measurements on the horizontal plane to the plane of the simulated PVs, calculation of the I-V characteristic of the selected PV modules, calculation of the Maximum Power Point that the selected PV panel can achieve and finally, calculation of the AC power that the simulated PV system injects to the grid, taking into account the inverter's efficiency. The whole modelling is done in MATLAB/Simulink. The input signals to the PV model are Global Horizontal Irradiance and Ambient Temperature from two actual sensors of the microgrid. In order to obtain the sensors output, the Simulink model communicates with the microgrid SCADA using OPC. Also, by means of the same toolbox, the Simulink model selects the set-point values for the loads and battery inverter. The load set-point is specified by a preset load profile and the battery set-point is determined by a policy controller which calculates the power the battery has to

absorb or inject in order to maintain balance. Figure 2 provides an overview of the main blocks used in the Simulink model as well as its interactions with the outside world. It is worth noting that the Simulink model allows also the recording and storage of various parameters of the system that can be used for post processing by the user.
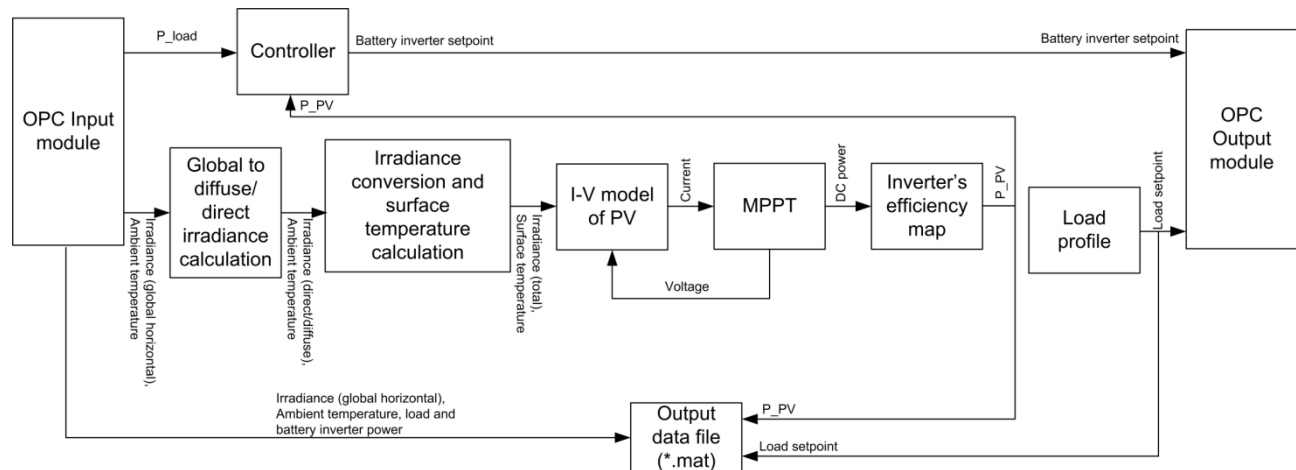

Figure 2: Analytical illustration of the MATLAB/Simulink blocks used in the CRES' remote lab

Concerning the mathematical formulation of the various Simulink blocks, it should be noted that the models concerning the irradiance conversion have been analytically presented in [1]. The reader could refer to the following equations from this book, all of which have been used in this application:

- Conversion of Global Horizontal to Diffuse and Beam (eq. 8.12.1, 8.12.2, 4.2.9, 1.2.3, 1.3.3, 1.2.2, 1.4.1, and 1.4.2)
- Conversion of Beam/Diffuse to Inclined-Plane global irradiance (eq. 11.2.5, 11.3.5, 11.5.7)

The mathematical model for the PV module, in turn, has been presented in [2] and is the same model used in the JRA2.2 activities (FMU model of PVs). The algorithm considered for the MPPT block of the model is based in the widely used 'Perturb & Observe' method [3]. The analytical presentation of these mathematical models is omitted from this document.

The controller, on the other hand, makes use of a simple strategy that selects a set-point value for the batteries based on the current values of the PV and load's power. The strategy is divided into two scenarios, namely "sell priority" and "buy priority". The first scenario prioritises the injection of the PV power surplus to the grid. Thus, when the PVs produce more power than the consumed one, the battery inverter should allow the surplus power to be injected to the grid (P_battery setpoint becomes zero). In the case of PV power deficit, the battery inverter is controlled to provide the difference in order not to allow any power flow from the grid to the loads. The operation of the "buy priority" is similar nevertheless, in this scenario the battery allows power import from the grid to the loads and covers the imbalance by absorbing any PV power surplus. The behaviour of the controller can be summarised in the following equations.

Buy priority:

$$P_{bat-setpoint} = \begin{cases} 0, & P_{PV} < P_{Load} \\ P_{Load} - P_{PV}, & P_{PV} > P_{Load} \end{cases} \qquad (1)$$

Sell priority:

$$P_{bat-setpoint} = \begin{cases} 0, & P_{PV} > P_{Load} \\ P_{Load} - P_{PV}, & P_{PV} < P_{Load} \end{cases} \qquad (2)$$

iii) Graphical User Interface

The operation and remote control of the experiment can be done by means of a GUI developed in MATLAB/Simulink using the Dashboard library elements. A snapshot of the GUI is depicted in Figure 3. By means of this GUI the user can modify some of the model parameters such as the modules parameters (e.g. V_{mp}, I_{mp} etc.) the number of modules and their interconnection in the panel, as well as the load and policy scenarios. In addition to the data logged, the user can in real time see the most important operating parameters in the form of numeric indicators and diagrams.
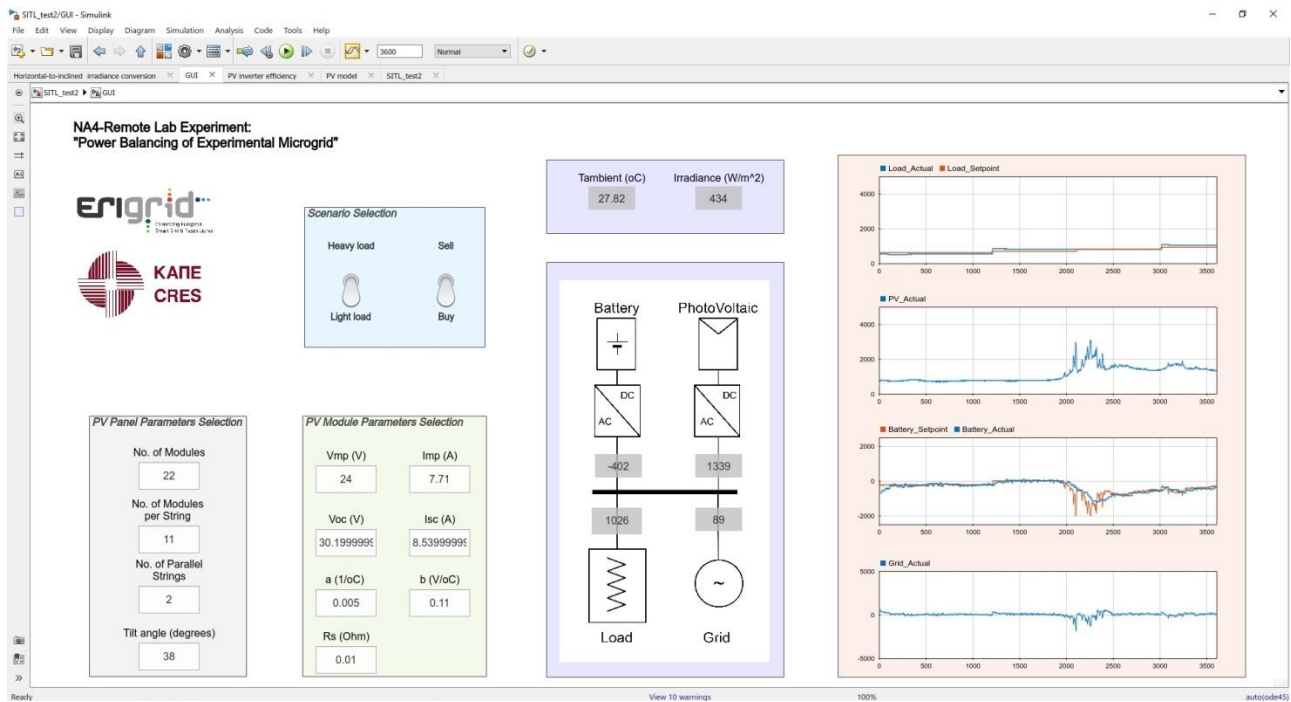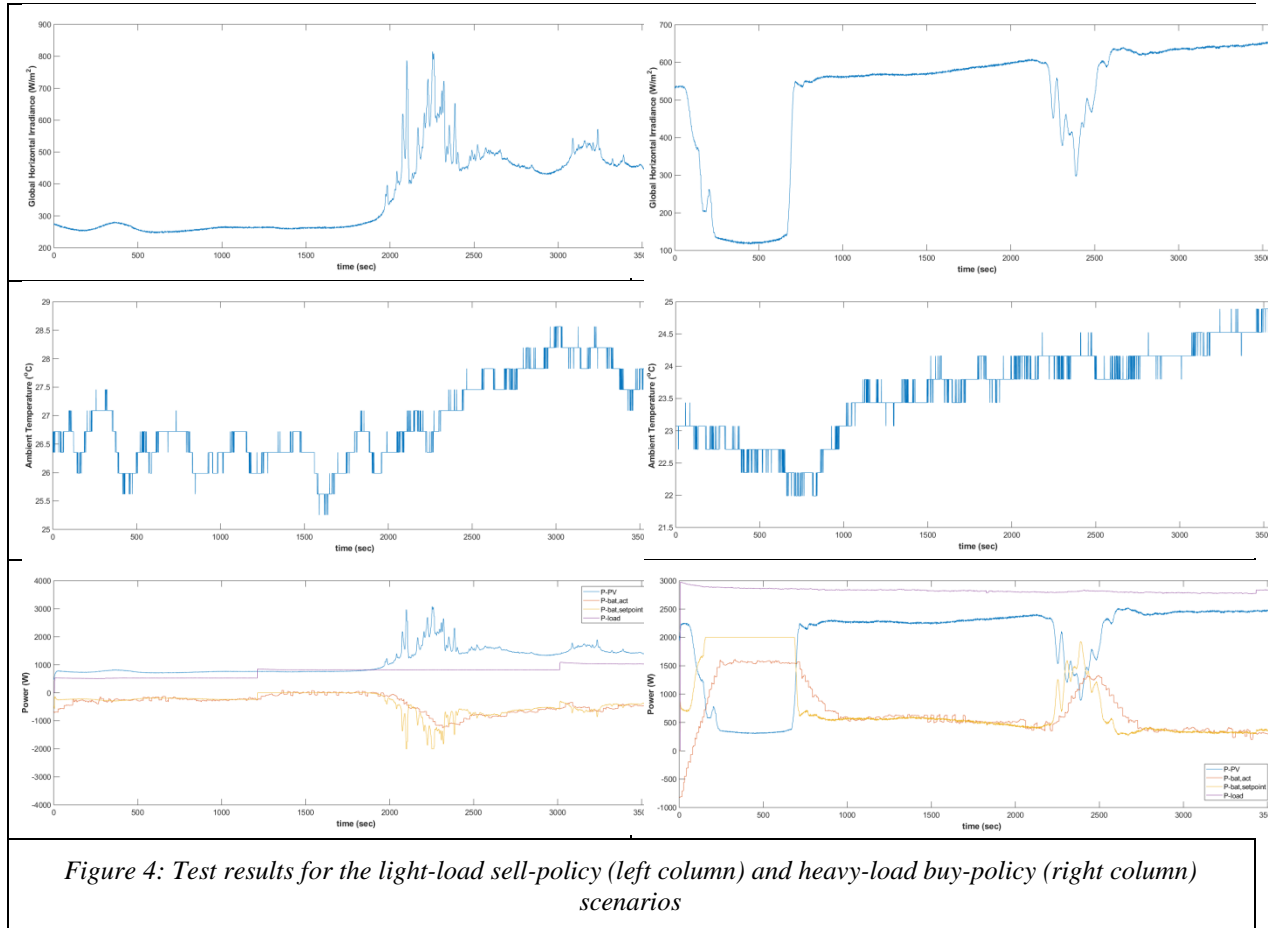

Figure 3: MATLAB/Simulink GUI for the operation of the CRES' remote lab experiment

iv) Test Results

Four tests have been conducted to validate the selected setup. These four tests include all possible combinations of load and policy scenarios. Each test has one-hour duration. Two of these test results are

depicted in Figure 4.

Figure 4: Test results for the light-load sell-policy (left column) and heavy-load buy-policy (right column) scenarios

References:

[1] M. Iqbal, An introduction to solar radiation, Don Mills, Ontario: Academic Press Canada, 1983, 1983.

[2] K. H. K. Khouzam, "Real-Time Simulation of Photovoltaic Modules," *Solar Energy,* Vol. 56, No. 6, pp. 521-526, 1996.

[3] D. P. Hohm and M. E. Ropp, "Comparative study of Maximum Power Point Tracking Algorithms," *Progr. Photovolt: Res. Appl.,* Vol. 11, pp. 47-62, 2003.