

Remote Lab: Voltage control, microgrids and Virtual Power Plants

Apart from the Virtual Lab for voltage control and microgrid operation, which can be accessed here (<https://erigrd.eu/education-training/#software>), a Remote Lab has been developed, which provides online access to the actual laboratory of ICCS-NTUA. At the Remote Lab, measurement and control of hardware equipment (e.g. PV inverter, loads) is performed via the laboratory SCADA, whereas the Virtual Lab uses a mathematical representation of the system. The GUI and control options offered to the user are exactly the same at the Remote Lab and Virtual Lab application.

The specific Remote Lab application supports the following experiments:

- 1) Voltage control
- 2) Microgrid operation
- 3) Virtual Power Plant using a Multi Agent System

The first two experiments are also part of the Virtual Lab application. The third experiment is available only as a Remote Lab application.

1) Voltage control

The main objectives of this experiment are to demonstrate the voltage rise issue that can occur in distribution networks, due to the high production of Distributed Generation (DG) (mainly Photovoltaics), but also the ancillary services that modern DG inverters offer in order to mitigate the aforementioned voltage rise.

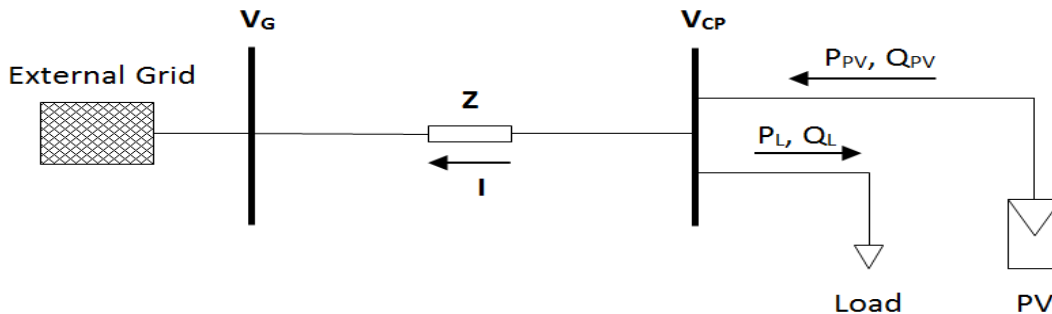


Figure 1: Two bus system

According to power system theory, the voltage drop or rise along a line (R , X) where at the end a load and/or PV is connected (Figure 1), can be approximated with the following equation:

$$\Delta V \approx \frac{(P_{pv} - P_{Load}) \cdot R + (Q_{pv} - Q_{load}) \cdot X}{V_G}$$

Therefore, if $P_{pv} \cdot R > (P_{load} \cdot R + Q_{load} \cdot X)$ and $Q_{pv} = 0$, the voltage of the coupling point (V_{CP}) will be higher than the grid voltage (V_G). The impact of active and reactive power on the voltage depends on the resistance (R) and inductance (X) of the line (e.g. in low voltage networks where R is higher than X , the impact of the

active power is stronger than the reactive power). The voltage rise can be mitigated if the PV inverter absorbs reactive power (Q_{pv}), according to the above equation.

The hardware laboratory setup that is used for this experiment can be seen in Figure 2 (i.e. a hardware R-L line module is connected between the utility grid and a hardware PV inverter). In order to better demonstrate the voltage rise problem there is no load connected at the end of the line. Therefore, if the reactive power of the inverter is also zero, there will always be a voltage rise due to the PV production.

The GUI for this experiment is presented in Figure 3 and Figure 4. As shown in Figure 3, the user can monitor the voltage, active power, reactive power and power factor of both the PV inverter and the main grid. From the control panel on the left side of the screen, the user can perform three main actions:

- Adjust the operating power factor of the inverter (available values are 0.8, 0.85, 0.9, 0.95 and 1, according to the capabilities of the inverter). All power factor values that are less than unity represent absorption of reactive power.
- Adjust the active power set-point of the inverter (i.e. in order to curtail active power). If the set-point is set above the Maximum Power Point (P_{mpp}) value, the inverter will operate at P_{mpp} instead.
- Activate or deactivate the Voltage-Reactive Power $Q(V)$ droop control. Activating the $Q(V)$ droop control, disables the power factor set-point that the user has set on the 1st input field.

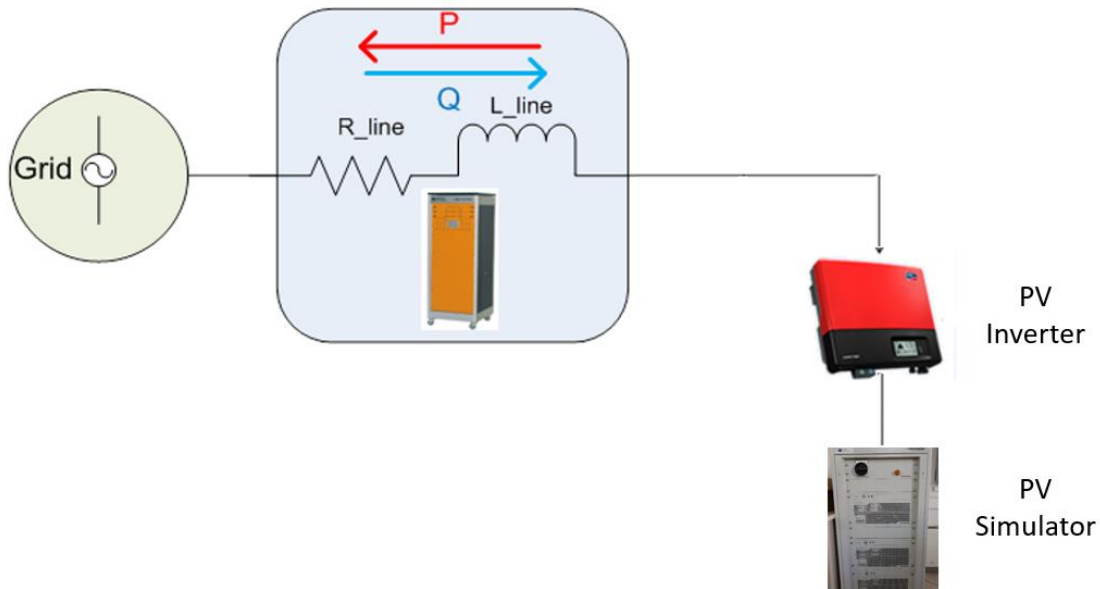


Figure 2: Setup of the voltage rise experiment

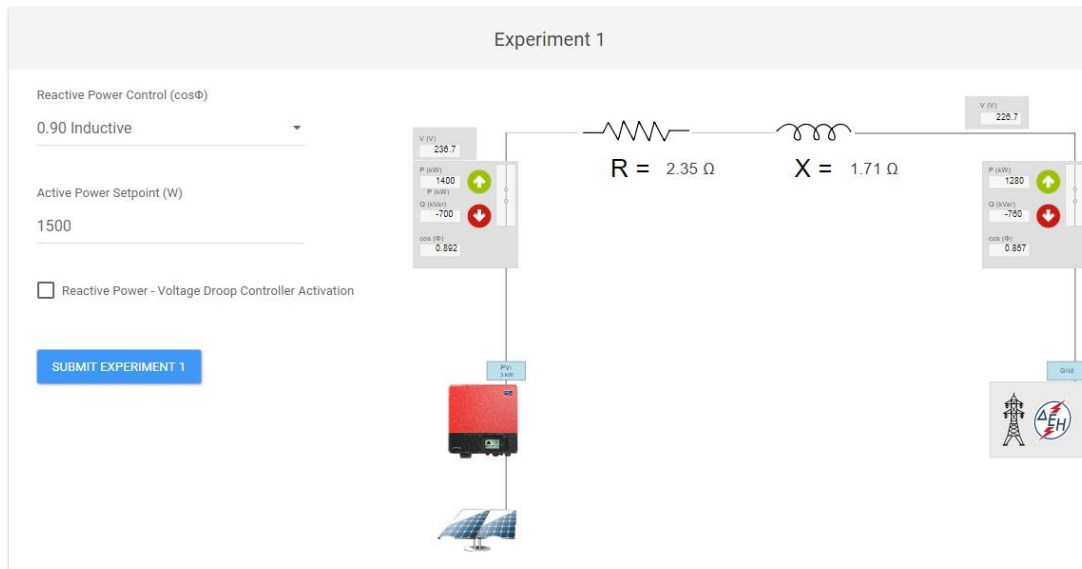


Figure 3: Graphical User Interface of the voltage control experiment

Below this part of the GUI, the user is presented with four line charts displaying the voltage, active power, reactive power and power factor of the PV inverter respectively. The X-axis of the charts displays the UTC time. A new data point is added on the charts every 5 seconds. The data points are imported from the SCADA system's database. Figure 4 shows the four line charts of the experiment during a change of the power factor of the inverter from unity (1) to 0.85 inductive (e.g. according to a command by the distribution system operator). The change occurs at 08:59:35 UTC, as seen on the charts. It is shown that when the power factor is set to 0.85 inductive, the PV inverter starts absorbing reactive power (850 VAR) in order to mitigate the voltage rise (the voltage is reduced from 245.5 V to 238 V).



Figure 4: Voltage, active power, reactive power and power factor of the inverter via the GUI

2) Microgrid operation

The objective of the second experiment is to familiarize the user with the concept of microgrids in both grid-connected and islanded operating modes. The single phase microgrid of the laboratory of ICCS-NTUA is used. The online GUI can be seen in Figure 5 and Figure 6. Figure 5 displays the main part of the GUI, where the user can monitor the state of all the units that comprise the hardware microgrid, which are (from left to right): a wind turbine with its inverter, a lead-acid battery bank with its inverter, PV panels with their inverter, resistive and inductive loads and the utility grid. The active power, reactive power and power factor is monitored for each unit, as well as the voltage and frequency of the AC bus where all the units are connected on. On the left side of this part of the GUI, the user can select different values for the microgrid's hardware resistive loads. The available values are: 250 W, 750 W, 1250 W, 1750 W and 2250 W according to the capabilities of the laboratory.

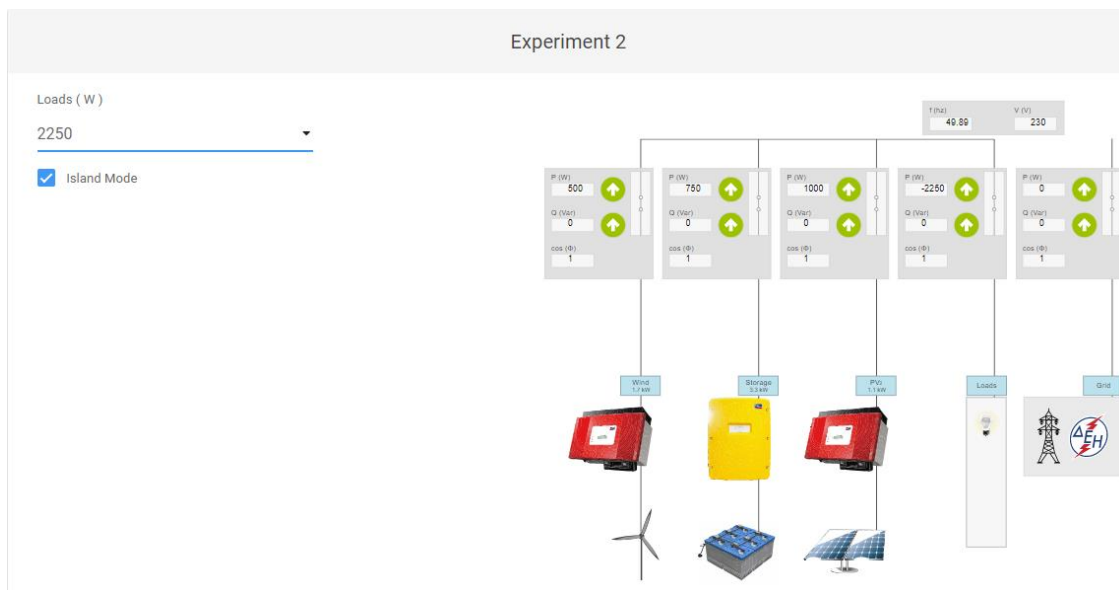


Figure 5: Graphical User Interface of the microgrid operation experiment

Figure 6 depicts two charts. The top chart represents the microgrid active power balancing, showing the active power of all the microgrid's units and the utility grid. The user can select or deselect a specific unit's graph line by using the legend on the bottom side of the chart, which allows an efficient visual representation. The bottom chart displays the microgrid's AC bus frequency. The active power of all the microgrid's units and the utility grid, as well as the frequency, are imported from the SCADA system's database and added on the chart every 5 seconds, while control of the loads is also performed via the SCADA.



Figure 6: Active power balance and frequency of the microgrid

The experiment starts with the microgrid in grid-connected mode, where the user observes that the utility grid is responsible for the power balancing of the microgrid's units when changes in the loads and production occur, while the battery inverter is in idle state, acting according to its Battery Management System (BMS).

Next, the microgrid is switched to islanded mode. In this state, the user again performs changes in the loads and monitors the response of the battery inverter, which is now responsible for the power balancing, since the utility grid is disconnected. The frequency of the microgrid is also monitored which depends on the $f(P)$ droop characteristic of the battery inverter (similar to synchronous generators). Figure 6 shows that at the transition to islanded mode the frequency rises, because the RES production exceeds the load and the battery inverter absorbs active power. Next, the load is increased leading to a reduction of the frequency.

3) Virtual Power Plant using a Multi Agent System

This remote experiment aims to familiarize the user with the concept of Virtual Power Plants (VPP) and Multi Agent Systems. A VPP platform was developed by ICCS-NTUA in the framework of the H2020 SmarterEMC2 project (www.smarteremc2.eu) and was extended and enhanced for educational purposes in the ERIGrid project. The VPP platform has been developed using Java programming language, and its GUI is presented in Figure 7.

The VPP platform monitors and controls several DER and loads. Some of them are actual hardware units, while some are simulated. Specifically, the actual laboratory microgrid's units (wind turbine, PVs, batteries and loads) act as the real controllable DER of the VPP, whereas 6 households with controllable loads are simulated. The platform imports the power measurements of the hardware units from the SCADA system's database in real-time and sends the calculated set-points back to the SCADA.

The main purpose of the VPP is to participate in the energy market as an individual economic entity and implement a specific power production daily profile, similar to conventional power plants.

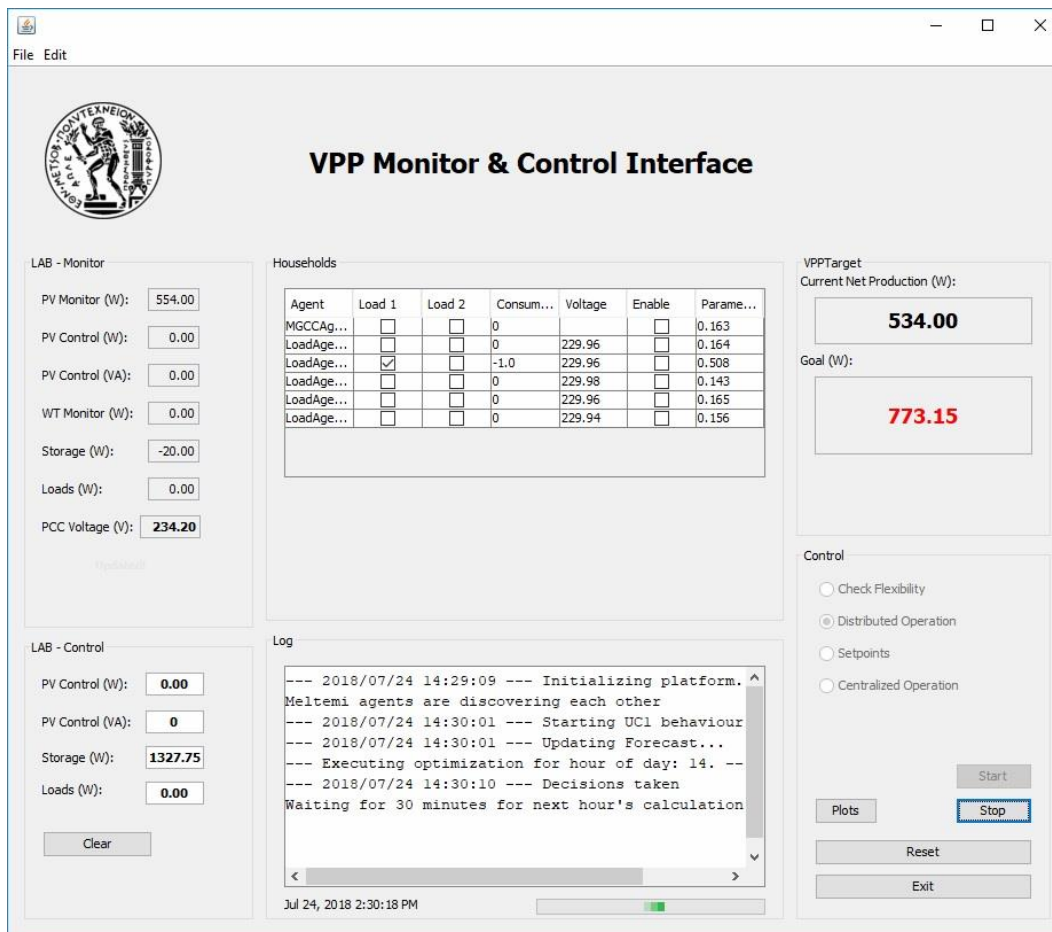


Figure 7: GUI of the VPP platform

In order for the VPP's DER to operate in a coordinated manner to achieve the target net power production, suitable control is required. A Multi Agent System has been developed and incorporated in the VPP platform. Multi Agent Systems are generally used for decentralized/distributed control, where each involved entity has its own agent. When a decision needs to be taken, the responsible agents communicate with their neighbouring agents in order to solve an optimization problem. Once all the agents agree that they have converged to the optimal solution, the calculated outcome is implemented. The main agents implemented in the specific application are listed below:

- Market operator agent
- VPP aggregator agent
- Wind turbine (hardware) agent
- PV (hardware) monitor agent
- PV (hardware) control agent
- Battery (hardware) agent
- Loads (hardware) agent
- 6 agents for the simulated households
- Forecast agent

The user is able to observe the exchange of messages between the agents, using a separate window of the application, which is presented in Figure 8. The red blocks on the top represent the agents of the system, while the pointed lines represent the various messages that are exchanged between them. By double clicking on a specific pointed line, detailed information about the message is displayed (sender, recipients, content, etc.).

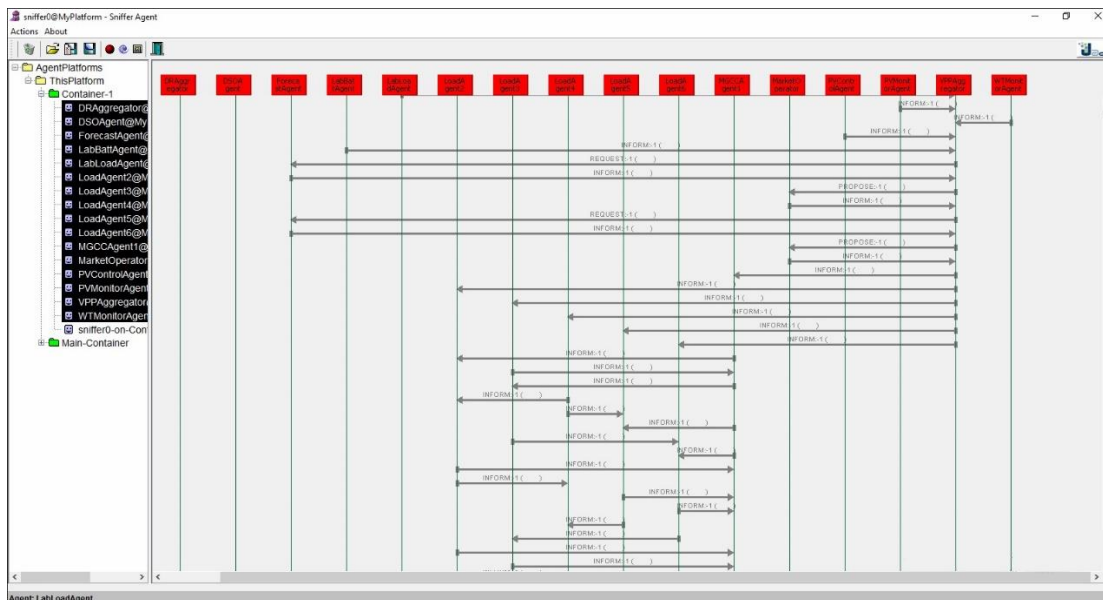


Figure 8: Exchange of messages between the agents

As described before, the main purpose of the VPP is to participate in the energy market and implement the scheduled net power production profile. Ten different such profiles have been created and the user can freely select any of them when using the platform. Additionally, once the agents have converged to the

optimal solution for the remaining hours of the day, the user can observe the results in three charts (Figure 9).

The bottom chart (“Total Schedule – Net VPP production”) depicts two graph lines. The light blue one (titled “Schedule”) displays the power production profile that the VPP has agreed to realize for the rest of the day. The orange line (titled “Realized”) is the actual net production profile that the VPP manages to implement, based on forecasted data and flexibility, for the remaining hours of the day.

The top right chart (“Lab Scheduling”) depicts the scheduled operation of the laboratory’s DER. If the light blue line (“PV_{curtailed}”) and purple line (“PV_{forecast}”) are identical, it means that no curtailment is required on the power production of the PV panels for the rest of the day in order to realize the requested profile, based on the forecasted values for the PV production.

Finally, the top left chart (“Loads Scheduling”) depicts the usage of the 6 simulated household controllable loads. The X-axis shows the remaining hours of the day and the Y-axis the active power of the loads in kW. For example, in the displayed chart, Load 2 will be turned on several minutes before 15:00, Load 5 several minutes after 16:00, etc. Three of the loads are not used in this specific example.

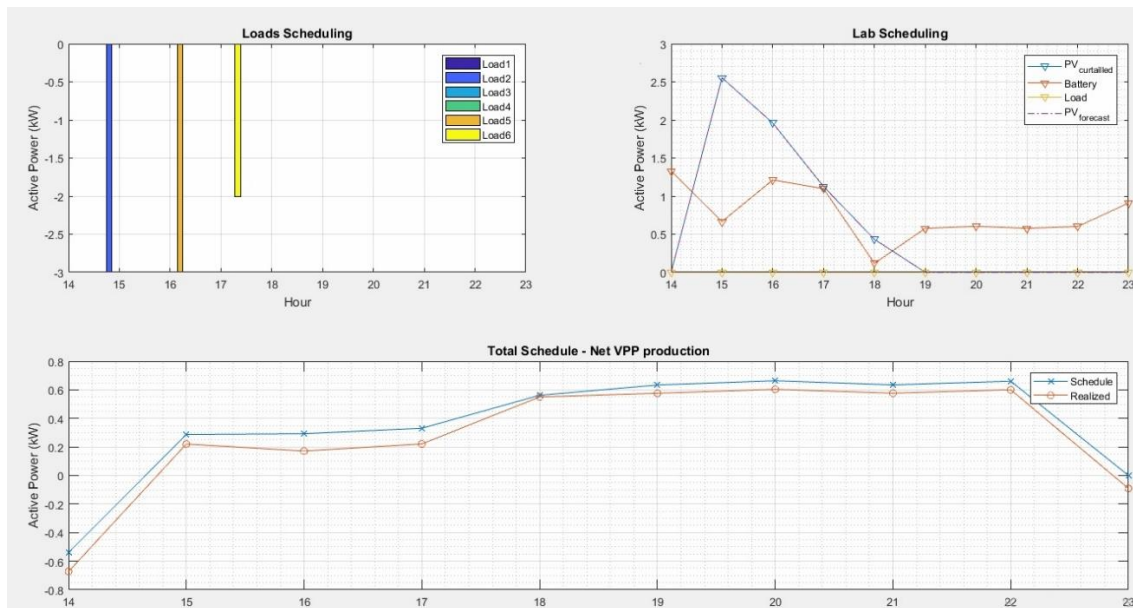


Figure 9: User profile generation results