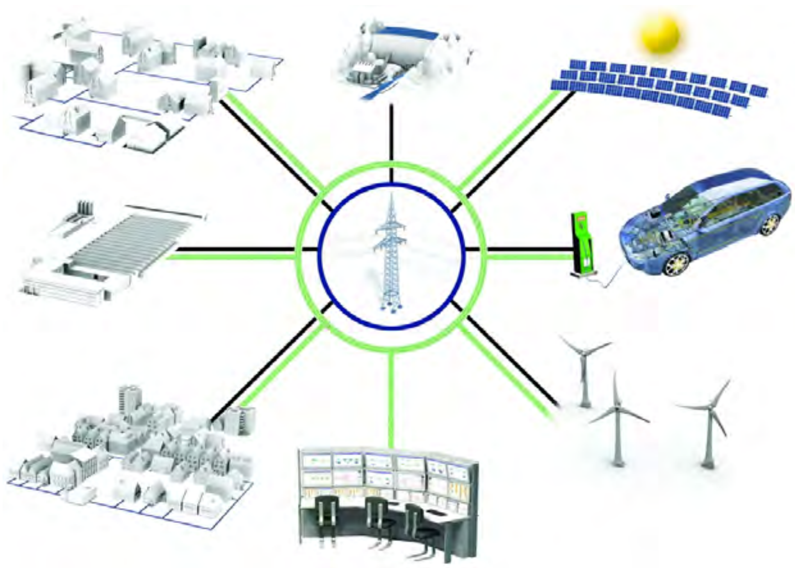
Smart Grid



Experiment Objectives

New technologies will permit power grids to be better prepared for future requirements. More flexible network management is to make rising proportions of renewable energy supply compatible with conventional power plant infrastructure. The numbers and diversity of such decentralized power plants requires a new type of management in the operation of power grids - an intelligent network or "smart grid".

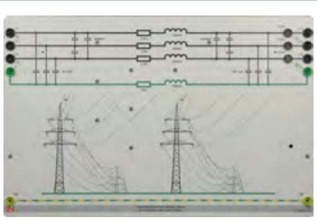
- Combination of energy sources and consumers for the purpose of studying the basic relationships found in smart grids.
- Study line protection using a time over-current relay.
- Energy management's design to reduce peak loading.
- Improved coordination between power demand and generation.
- Use of modern information technology such as Internet, sensors, controllers and wireless transmission equipment.
- Smart metering - digital electricity meters measure power consumption at power grid's end points.
- Shifts in household consumption away from peak load periods.
- Running of flexible applications such as air conditioning directly by power supply companies outside peak load periods.
- Network configuration for a smart grid.
- Integration of a photovoltaic system into the smart grid.
- Integration of a battery storage system into the smart grid.

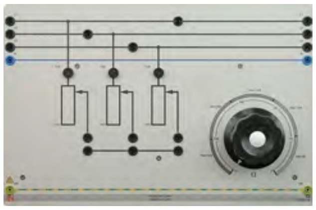
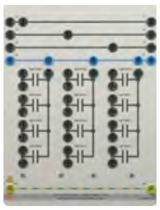
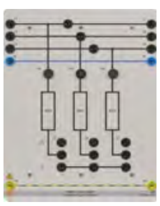
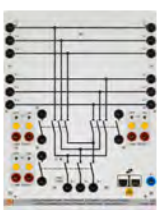
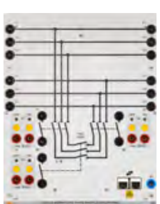
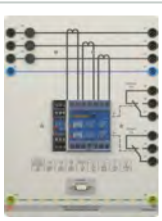
Equipment

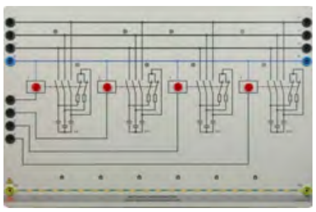
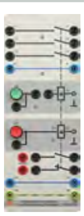
General instructions on handling the equipments

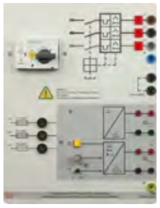
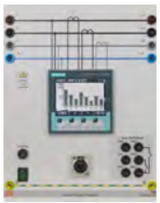
- Due to the heat generated by the electrical loads, ensure adequate ventilation and safety clearance to other devices.
- Interruptions in current can induce high voltages on inductors. For this reason, changes to the experimental configuration must only be performed in the de-energized state.
- Using a phase rotation tester, check in advance whether your power supply has clockwise rotation

- EMERGENCY-STOP mechanisms must remain accessible at all times.
- Nominal voltages and currents must not be exceeded.
- Capacitors can still carry a charge after deactivation, i.e. a voltage might still be present across the terminals.
- All busbars should be powered by the same source. If different voltage sources are nonetheless used (generator, transformer, constant voltage source etc.), they must be preceded by a synchronization mechanism (refer to the experiment on generator control and synchronization). **Make sure not to interchange phases during wiring.**
- Ensure that the knurled screws at the motor's base and the coupling sleeve (power grip) on the motor's shaft are securely in place.
- Use shaft and coupling guards.
- Operating machines under high loads for too long causes the machines to heat up significantly.
- The extreme case involving machine standstill should only be allowed to occur briefly.
- All machines are equipped with thermal switches which respond when the permissible operating temperature is exceeded. The switch contacts are routed to the terminal board and must always be connected to the corresponding jacks on the power supply unit or controller.
- All readings are obtained by means of standard measuring instruments (primarily class 1.5) using standard machines connected to the normal power grid voltage (120/208 V +5% -10% 60 Hz). Based on experience, the readings should therefore lie within a tolerance range of +/- 15% with respect to the specified values.
- All experiments on synchronization require your utmost attention and caution.
- The generator must never be connected asynchronously to the network.
- If the power supply does not have clockwise rotation, the servo drive's direction of rotation must be changed accordingly.

Equipment	Description	Part Number
	Transmission line model	CO3301-3A

Equipment	Description	Part Number
	Resistive Load (Three-phase, 1 kW)	CO3301-3F
	Capacitive Load (Three-phase, 1 kW)	CO3301-3E
	Inductive Load (Three-phase, 1 kW)	CO3301-3D
	Resistive load (3 x 560 Ω)	CO3301-3H
	Double Busbar Unit (Three-phase, incoming/outgoing feeders)	CO3301-5R
	Double Busbar Unit (Three-phase, coupler panel)	CO3301-5S
	Time Overcurrent Relay	CO3301-4J Manual
	Three-phase Motor (1 kW) with Squirrel-Cage Rotor	SE2672-5G7

Equipment	Description	Part Number
	Star-Delta Switch	CO3212-2D
	Reactive Power Controller	CO3301-5C Manual
	Switchable Capacitor Battery	CO3301-5E7
	Lamp Board, 120 V	CO3208-1L8
	Servo Machine Test Bench for 1 kW Machines, including ActiveServo software (D, GB, F, E)	CO3636-6W7 Manual
	Power Switch	CO3301-5P Manual
	Adjustable, Three-phase Power Supply (0 - 400 V/2A)	CO3301-3Z7 (ST8008-4S) Manual

Equipment	Description	Part Number
	Power Supply for Electric Machines	CO3212-5U7 Manual
	Power Quality Meter with Graphic Display and Long-term Memory	CO5127-1S Manual

Experiments

Smart Grid: Generation, Transmission and Distribution (ESG 1.1)

Case 1: Combination of Energy Sources

1. Assemble the circuit in accordance with the layout and wiring diagram of Figure 1.
2. Save the file from the following link, "ESG_1_1.pvc", in a working folder on your PC.
3. Open the "SCADA Viewer" program directly from Labsoft (top right) and select the file you have just saved. The SCADA user interface will look as Figure 2.
4. Click or go to "Diagnostics" → "Device Manager..." and configure all the equipment in SCADA such that communication can be established with all devices as specified in the section "Configuring SCADA for PowerLab".
5. Set the DIP switches of the protective relay (CO3301-4J) as shown in the Figure 3 below. (Yellow background = Set).
6. Set over current stage I> on relay XI1-I to **0.75 A** and all other potentiometers to 0 as shown in Figure 4.
7. Switch on the adjustable three-phase power supply CO3301-3Z7 and set to a line voltage of $\mathbf{V_{L\text{-}L} = 220\ V}$.
8. Operate the line transmission model (CO3301-3A) with a line length of 150 km (**use the overlay mask**).
9. Set up the resistor load (CO3301-3H) in star configuration (**Y**).

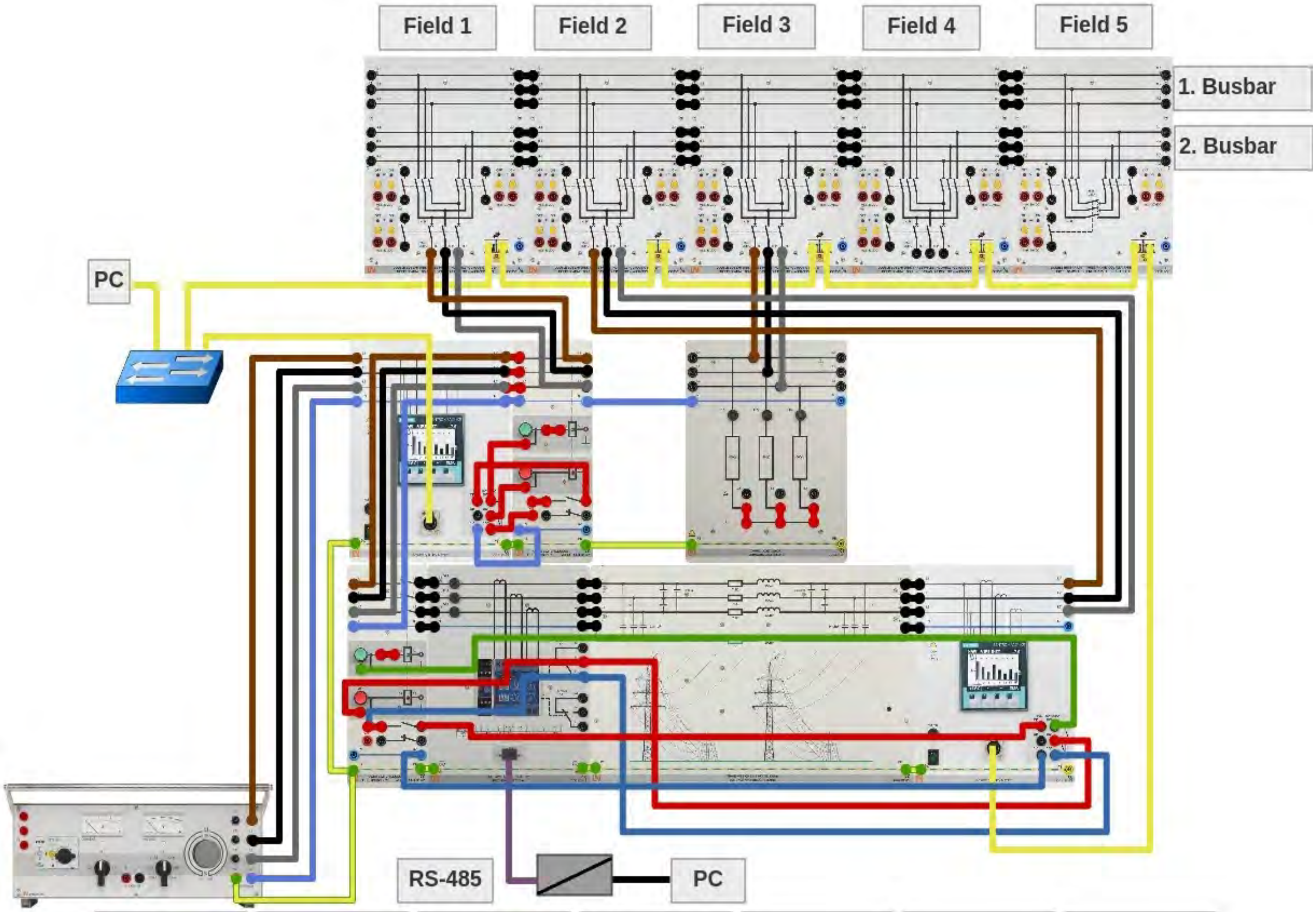


Figure 1:
Basic Setup of the ESG 1.1 Training Station

10. Start the program SCADA Viewer by pressing the Start/Stop symbol or F5.
11. Press the ON button of the power switch of the balance point.
12. Switch on the busbar of the balance point (first isolator **Q1** and then circuit breaker **Q3**).
13. Connect the busbar of the "Consumer I" (first isolator **Q1** and then circuit breaker **Q3**).
14. Record the current (I_{BP}) when the load is fed via field 1 (Balance Point) in Table 1.
15. Switch off the busbar of the "Consumer I" (first circuit-breaker **Q3** and then isolator **Q1**).
16. Switch off the busbar of the balance point (first circuit-breaker **Q**3 and then circuit-breaker **Q1**).
17. Open the power switch of the balance point. (OFF button)
18. Press the ON button of the power switch of the transmission Line.
19. Switch on the Transmission Line busbar (first isolator **Q1** and then circuit breaker **Q3**).
20. Connect the busbar of the "Consumer I" (first isolator **Q1** and then circuit breaker **Q3**).
21. Record the voltage drop across the line model (V_{DROP}) when the load is fed via field 2 (Transmission Line) in Table 1.

22. Switch off the busbar of the "Consumer I" (first circuit-breaker **Q3** and then isolator **Q1**).
23. Record the voltage drop across the line model (V_{DROP}) when no load is fed via field 2 (Transmission Line) in Table 1.
24. Turn all the busbars and the power switches off .
25. Stop the simulation in the SCADA Viewer by pressing the Start/Stop button  or F5.

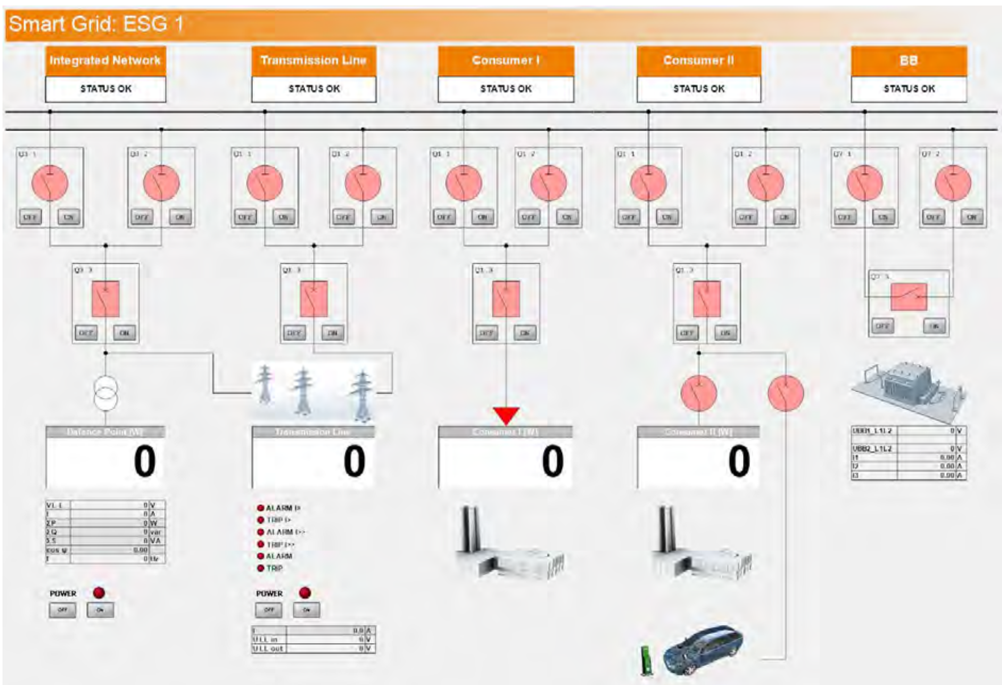


Figure 2:
Screenshot of SCADA for Power Lab: ESG_1_1

Function	Trip	Trip	Trip	Block I>	Block I>>	f	t I>	t I>
DIP switch	1	2	3	4	5	6	7	8
ON	Inverse	Strong i.	Extreme i.	Yes	Yes	60 Hz	x 10 s	x 100 s
OFF	DEFT	DEFT	DEFT	No	No	50 Hz	x 1 s	x 1 s

Figure 3:
DIP switches

Figure 4:
Potentiometers

I_{BP} (A)	
V_{DROP} @ Load (V)	
V_{DROP} @ No Load (V)	

Table 1

Case 2: Line protection

1. Keep the circuit in accordance with the layout and wiring diagram of Figure 1.
2. Keep the DIP switches of the protective relay (CO3301-4J) as shown in Figure 3 above. (Yellow background = Set).
3. Set overcurrent stage I> on relay XI1-I to **0.5 A**, and all other potentiometers to 0 as shown in Figure 5.
4. Switch on the adjustable three-phase power supply CO3301-3Z7 and set to a line voltage of $\mathbf{V_{L\text{-}L} = 0\ V}$.
5. Set up the resistor load (CO3301-3H) in delta configuration (**Δ**).
6. Start the simulation in the SCADA Viewer by pressing the Start/Stop button or F5.
7. Supply the "Consumer I" via field 2 (Transmission Line):
   - Press the ON button of the power switch of the transmission line.
   - Switch on the transmission line busbar (first isolator **Q1** and then circuit breaker **Q3**).
   - Connect the busbar of the "Consumer I" (first isolator **Q1** and then circuit breaker **Q3**).
8. Slowly increase the adjustable three-phase power supply until the relay is energized (upper red LED comes on).
9. Record the voltage at which is the relay energized and the line current at this instant in Table 2.
10. Switch off the busbar of the "Consumer I" (first circuit-breaker **Q3** and then isolator **Q1**).
11. Now connect the resistor load (CO3301-3H) in star configuration (**Y**).
    Switch on the busbar of the "Consumer I" (first isolator **Q1** and then circuit-breaker **Q3**).
12. Repeat steps 8 and 9.
13. Turn all the busbars and the power switch off.
16. Stop the simulation in the SCADA Viewer by pressing the Start/Stop button or F5.

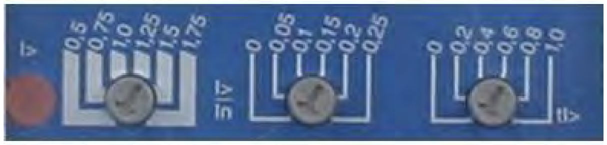


Figure 5:
Potentiometers

Delta Load (**Δ**)		
V_{L-L} (V)	V_{L1-N} (V)	I_L (A)
Star Load (**Y**)		
V_{L-L} (V)	V_{L1-N} (V)	I_L (A)

Table 2

Smart Grid: Energy Management (ESG 1.2)

Load Regulation

Due to the ongoing transformation in the way that energy is generated in many countries, power is increasingly being supplied from renewable energy sources. Energy generation from such sources inherently fluctuates depending on the time of day or year and indeed on the weather. Energy requirements cannot therefore be covered by generating electricity as needed from sources which store energy intrinsically, which means that the energy available needs to be use more intelligently, in a way that is aligned to when the energy is produced. Some of the energy requirements need to be delayed until such time as wind power plants and photovoltaic systems can generate the energy in question.

Consumers utilize electrical energy and transform it into a variety of forms, most often to make things hot or cold. Heat or even absence of heat can actually be stored much more easily than electricity itself. In a fridge, electrical energy is transformed into thermal energy with the help of the refrigeration equipment, allowing the inside of the fridge to be maintained at a low temperature, "storing" the cold in a sense. The fridge remains cold even if its cooling machinery is switched off. The cooling would only then need to be reactivated once the temperature in the cold compartment had risen sufficiently to require it. Figure 6 below indicates how temperature in a fridge (in blue) changes over time, while the power consumed to operate the refrigeration equipment and make it lower the temperature is shown in red.

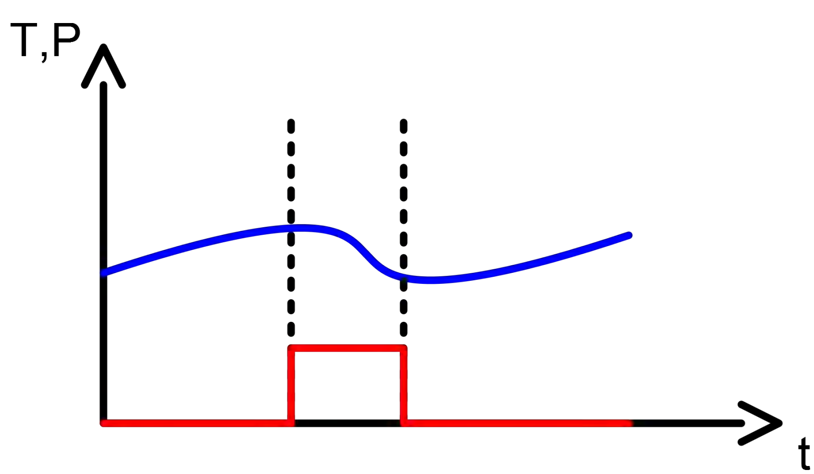


Figure 6:
Changes in Temperature (blue) and Power Consumption (red) for a Fridge

Equipment capable of thermal storage, such as fridges, can be used to postpone consumption of power in the same way that at electrical storage device like a battery could do. Acceptance of such procedures is likely to be greater in comparison to changing the way that such things as washing machines or driers are used, since thermal storage is not something which requires human involvement. It is therefore possible for fridges to be activated at times when there is a surplus of energy being produced by renewable energy, by which part of that energy would be stored "as cold" by lowering the temperature of a fridge or freezer compartment a few degrees more than otherwise necessary. This allows the refrigeration equipment to be turned off when less energy is being generated until the temperature exceeds a maximum allowed level. At that point the refrigeration needs to be reactivated to ensure that the items being refrigerated "keep" as required.

Turning consumers on and off results in positive or negative changes to the power needed to balance the grid. A positive power requirement implies that a comparable grid without stored energy needs to provide more power from generators. Having energy storage can mean that such positive power is no longer needed. The difference in power needed when the maximum amount of power is stored in the storage system is expressed as a negative power requirement for the grid. Figure 7 illustrates where the power requirements arise using direct heating and storage heating by way of example. For example, storage systems as used in Germany are designed in such a way that the full complement of energy is stored up ("charged") within 8 hours and can be put to use ("discharged") for the next 16 hours. In the case of a heating system, the heating and storage performance would be dependent on the prevailing ambient temperature.

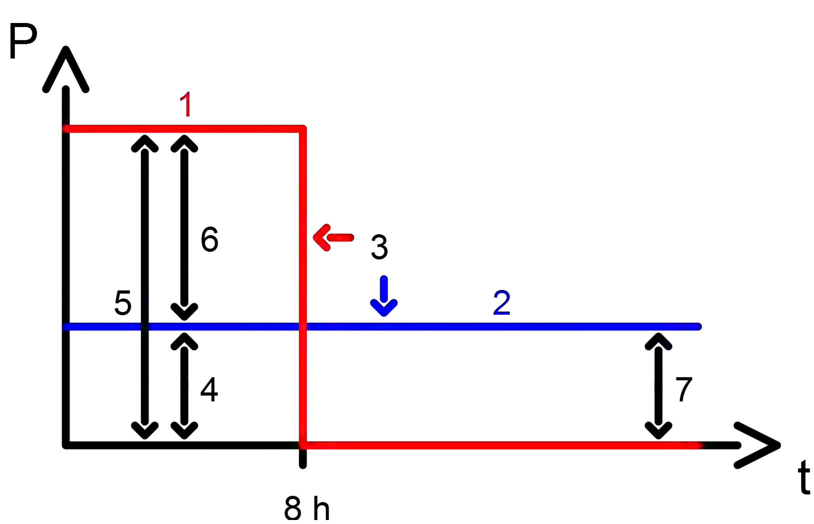


Figure 7:
Power Requirements from the Grid.

1. Storage heating (coldest day).
2. Direct electrical heating (coldest day).
3. Increasing ambient temperature.
4. Power used for heating without storage.
5. Maximum power expended on storage.
6. Negative power requirement for grid.
7. Positive power requirement for grid.

Until now, the storage of energy in a storage heating system has been activated by a general control signal which initiates "charging" of the storage system at a cheaper overnight tariff. Charging of storage heating for the purpose of postponing (or shifting) the load would always be required to occur when there is more power being produced than is being consumed. Full charging of the storage facility may therefore occur during multiple cycles over the course of a day.

In addition to storage heating systems, many other applications are suitable for the postponement of energy usage. Table 3 shows the three most common applications in which electrical energy is transformed into thermal energy and lists the potential each provides for balancing power requirements.

Table 3: Potential for Balancing of Power Requirements in Germany

	Potential for load shifting per annum	Positive power requirement for grid	Negative power requirement for grid
Storage heating (coldest day)	27 TWh	14 GW	40 GW
Electric water heating (insulated tank)	7 TWh	800 MW	5 GW
Electric refrigeration (refrigeration of food)	23 TWh	1.1 GW	2.8 GW

Similar applications can also be found in industrial processes. It should be noted that although industrial plant requires more operating power, the total power consumed by household fridges, for example, still considerably exceeds the total power used for refrigeration in industry. Furthermore, industry attempts to run its machinery at full power for longer periods of time which makes it more difficult to be flexible. Transformation of energy generation and use in Germany will therefore need the involvement of industry as well as households.

Depending on the applications in question, it may also be possible to implement other energy management scenarios, which have not been described here. A distinction is then made between the types of grid loading control depicted in Figure 8.

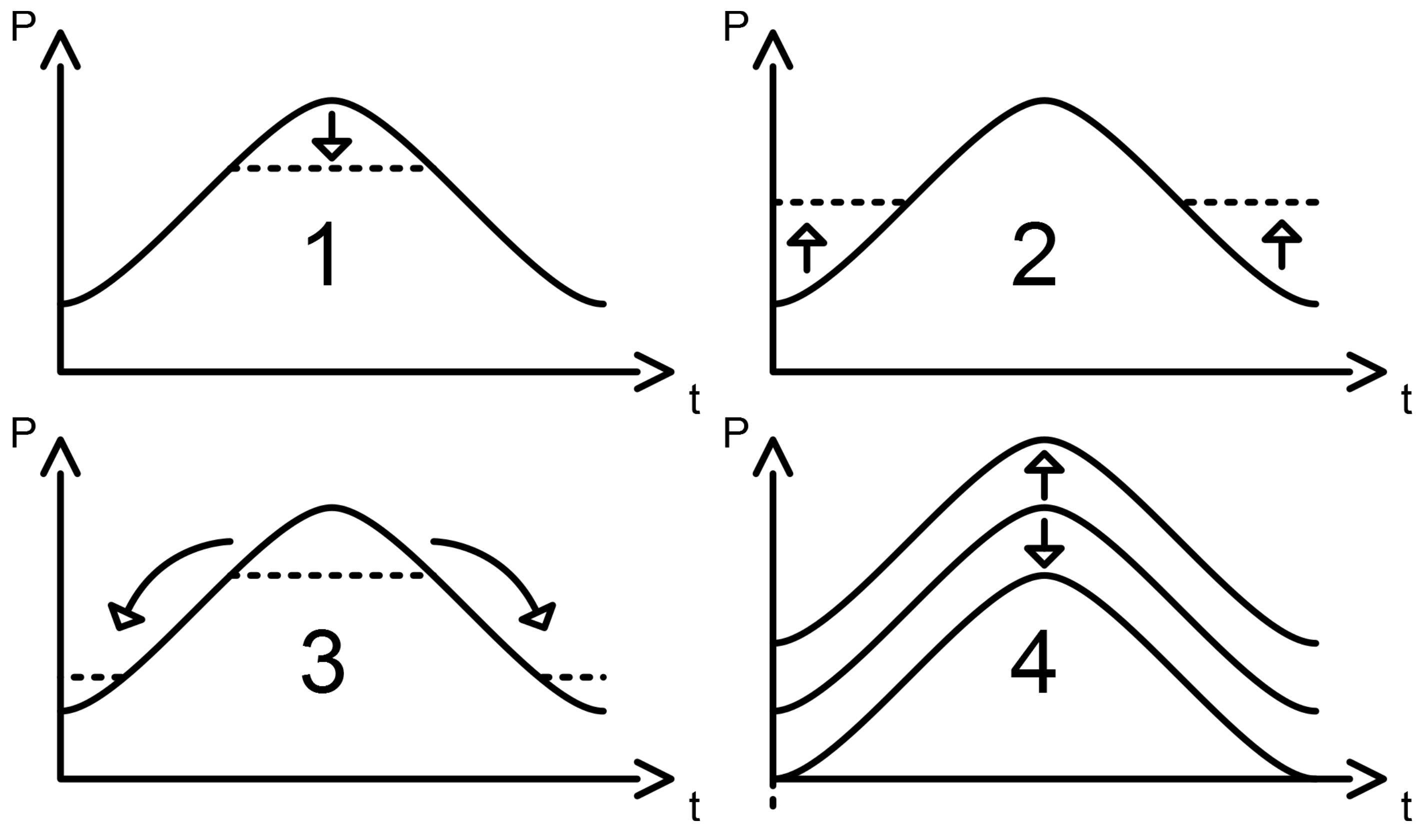


Figure 8:
Types of Load Control

1. Reduction of peak load (peak shaving).
2. Increase in base load/off-peak loading (valley filling).
3. Postponement of loading (load shifting).
4. Increase/reduction of power requirement (conservation/load building).

The current usage of storage heating, using systems developed in the 1960s which sought to change the load requirements of power plants where output was difficult to control in such a way as to improve their efficiency, would belong to the second category, valley filling. The type of operation which will be increasingly important and modern would however belong to category 3, load shifting.

Operate the experiment stand without the ESG 1.1 set-up. Use the CO3212-5U7 power supply for this purpose.

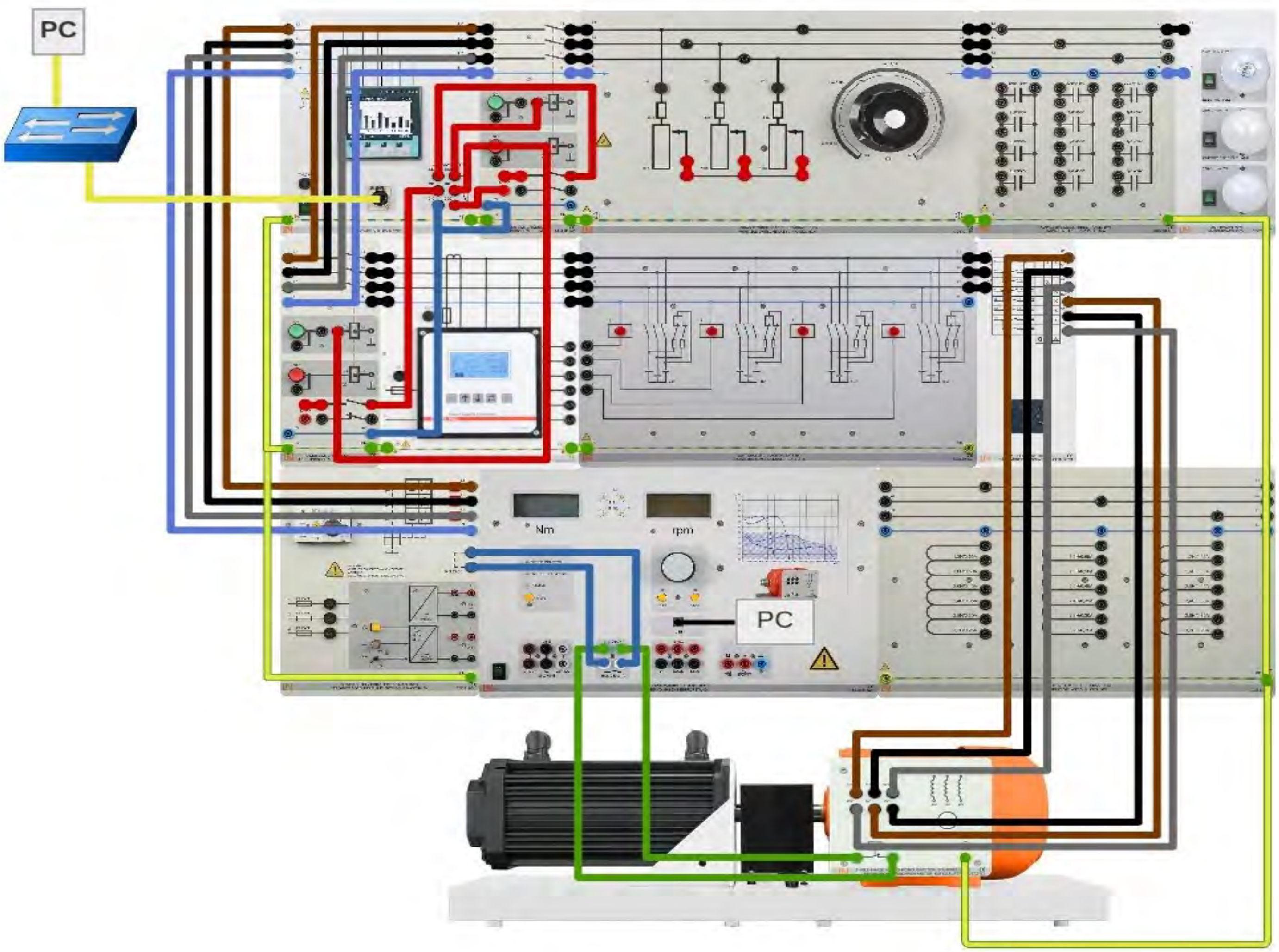


Figure 9:
Experiment Set-up for Load Regulation

Remove all the jumpers to the capacitors for the switchable capacitor battery CO3301-5E7.

1. Assemble the circuit in accordance with the layout and wiring diagram of Figure 9.
2. Adjust the resistor load to a resistance value of 300 Ω.
3. Use the star-delta switch CO3212-2D to switch the asynchronous machine to a star configuration. The motor should not start running yet. Test the circuit set-up and control of the power switch if needed.

The asynchronous machine is now turned on and off via the SCADA interface. Before switching on, always make sure you have followed the safety instructions.

4. Save the file at the following link, "ESG_DemandSideManagement.pvc", in a working folder on your PC.
5. Open the "SCADA Viewer" program directly from Labsoft (top right) and select the file you have just saved. The SCADA user interface will look as Figure 10.
6. Click or go to "Diagnostics" → "Device Manager..." and configure all the equipment in SCADA such that communication can be established with all devices as specified in the section "Configuring SCADA for PowerLab".

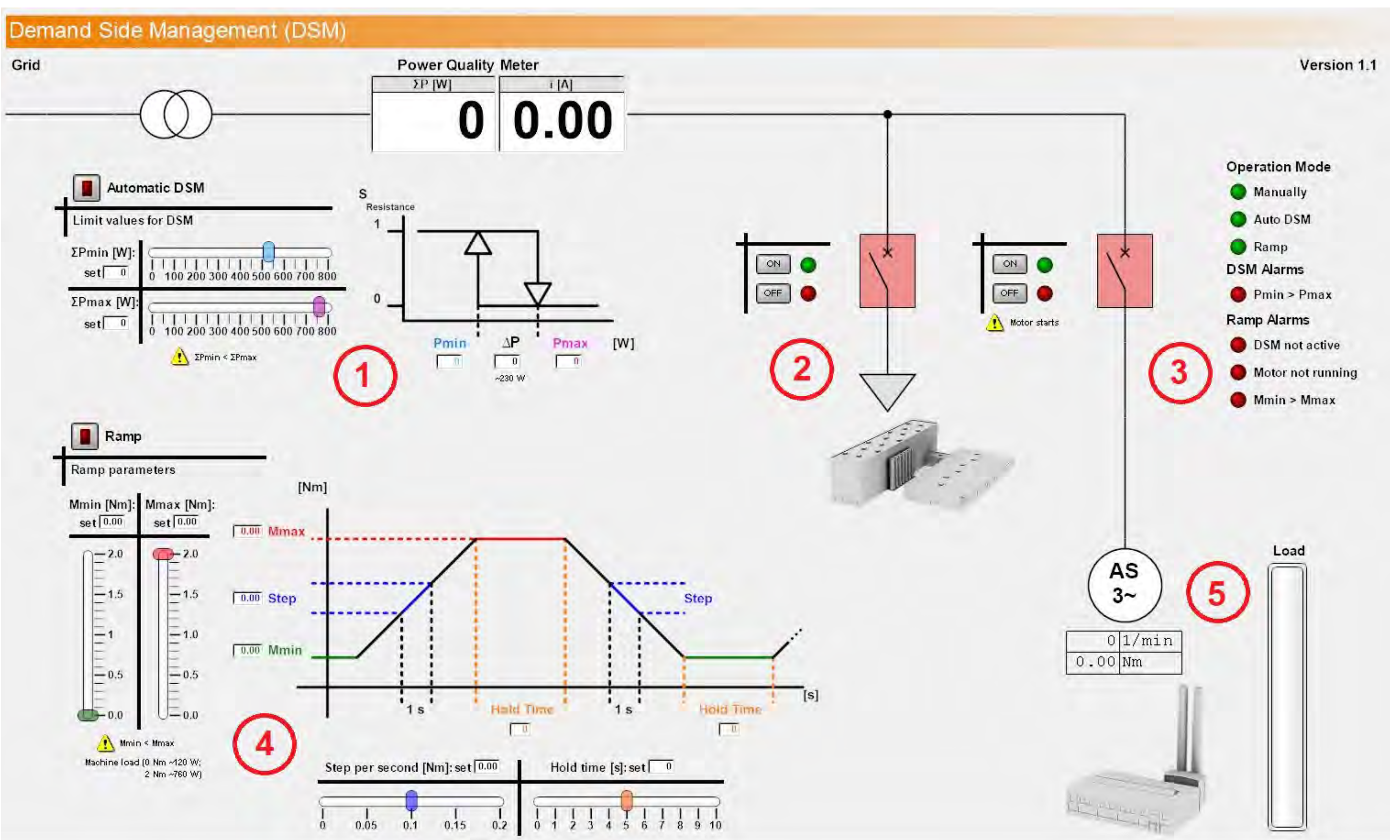


Figure 10:
SCADA Interface for "Smart grid: Load Regulation"

For safety reasons the dynamic load must *always* be turned on manually. Refer to the "Experiment set-up" section.

1. Operation of load regulation and configuration of limits.
2. Manual control of loads via load switches.
3. Display of operating mode and status.
4. Configuration of ramp for dynamic load.
5. Dynamic load with visual load display.

Selecting "Diagnostics" from the drop-down menu and setting the "Reset" option resets all the values. This can also be done using the key combination "ctrl + r".

7. Set the following values from Table 4:

Table 4: Standard values for SCADA interface, load regulation ("demand side management (DSM)")

	$\sum P_{min}$ [W]	$\sum P_{max}$ [W]	M_{min} [Nm]	M_{max} [Nm]	Step per second [Nm]	Hold time [s]
Standard values:	530	760	0	1.5	0.1	5

With the help of the data logger, values from the appliances and the PLC system can be recorded and observed over time. The logger may have to be reconfigured for the load regulation experiments if settings have been changed and the SCADA file saved.

8. Open the logger from the drop-down menu under "Instruments" → "Logger".
9. Set the necessary signals of total active power, torque and switch status for the power switches as listed in Table 5. Follow:

➢ "Settings" → "Values..." → Tab: "Values", & "Status"

Table 5: Setting of Signals from the Data Logger

Tab	Available Signals	Active Signals
Values	CO5127-1S	Total Active Power
	CO3636-6W7	Torque
Status	CO5127-1S	Digital Input I0
		Digital Input I1

10. To display the values, take the limit settings from Table 6.

Table 6: Setting of limits for signals				
	Time for recording [s]	Time for measurement [ms] ("Settings" → "Time for measurement")	Power [VA]	Torque [Nm]
Values	120	500	0 to 1000	0 to 2.5

11. Open "Options" and configure the following settings:
   - "Continue, but keep 50% of the last values".
   - "Start recording automatically".

As soon as the SCADA interface is started, the data logger should now start recording data with the configured values.

12. Run the SCADA interface by clicking Start/Stop or F5 and switch on the constant (resistive) load via the power switch on the left.
13. Enter the values of $\sum P$ and I from the SCADA interface in Table 7.
14. Open the data logger from the drop-down menu under "Instruments" → "Logger".
   - The logger should start recording when you click to start the SCADA interface.
15. Start the static load manually via the load switch in the SCADA interface.
16. Activate the ramp of the dynamic load and switch this on, too.
17. Run the simulation for at least one cycle and copy/save the graphic of the SCADA logger's measurement results.
18. Enter the values of $\sum P_{WODSM}$, I , and the switch off period from the SCADA interface in Table 7.
19. Repeat steps 14 to 18 with DSM turn on.
20. Reduce the dynamic load by changing the torque to M_{max} = 1 Nm and M_{min} = 0.5 Nm.
21. Record the value of $\sum P_{max}$ from the SCADA interface in Table 7.
22. Now reduce $\sum P_{max}$ to 500 W.
23. Record the value of $\sum P_{min}$ and hysteresis of the DSM system (ΔP) from the SCADA interface in Table 7. What happens to the static load?
24. Use the $\sum P_{min}$ setting and change the hysteresis of the DSM system (ΔP) to 100 W. What is the control system's behavior?
25. Stop the simulation in the SCADA Viewer by pressing the Start/Stop button or F5.

Step 13		Step 18			Step 19			Step 21	Step 23	
$\sum P$	I	$\sum P_{WODSM}$	I	t_{off}	$\sum P_{WDSM}$	I	t_{off}	$\sum P_{max}$	$\sum P_{min}$	ΔP

Table 7:
"Smart grid: Load regulation"

Smart Grid: Basic Setup (ESG 1) = (ESG 1.1 + ESG 1.2)

In this experiment, the feeder from ESG 1.2 (CO3212-5U) is replaced by a connection to field 4 of the ESG 1.1 experiment module. ESG 1.2 is therefore now supplied by experiment module ESG 1.1, which thus acts as a central unit from which all systems can be controlled. This also applies to future extensions.

1. Assemble the circuit in accordance with the layout and wiring diagram of Figure 11.
2. Save the file at the following link, ESG_1.pvc, in a working folder on your PC.
3. Open the "SCADA Viewer" program directly from Labsoft (top right) and select the file you have just saved. The SCADA user interface will look as Figure 12.
4. Click or go to "Diagnostics" → "Device Manager..." and configure all the equipment in SCADA such that communication can be established with all devices as specified in the section "Configuring SCADA for PowerLab".

From now on you can use the SCADA Software to carry out any switching operation and experiments on the Smart Grid:

5. Set the three-phase supply to a line voltage of $V_{L\text{-}L}$= 208 V.
6. Set the switches using SCADA for the input/output fields of the double busbar as shown in Table 8. If you have more than 4 fields available, turn all the switches OFF ✗. Do the same for the grid-coupling field which will not be required either.

Table 8: Switch settings for double busbar inputs/outputs in smart grid :basic set up

	Field X		Field 1		Field 2		Field 3		Field 4		Field 5		Field 6	
Isolating switch	**Q1**	**Q2**	✓	✗	✗	✓	✗	✓	✗	✓	✗	✗	✗	✗
Power switches	**Q3**		✓		✓		✓		✓		✗		✗	

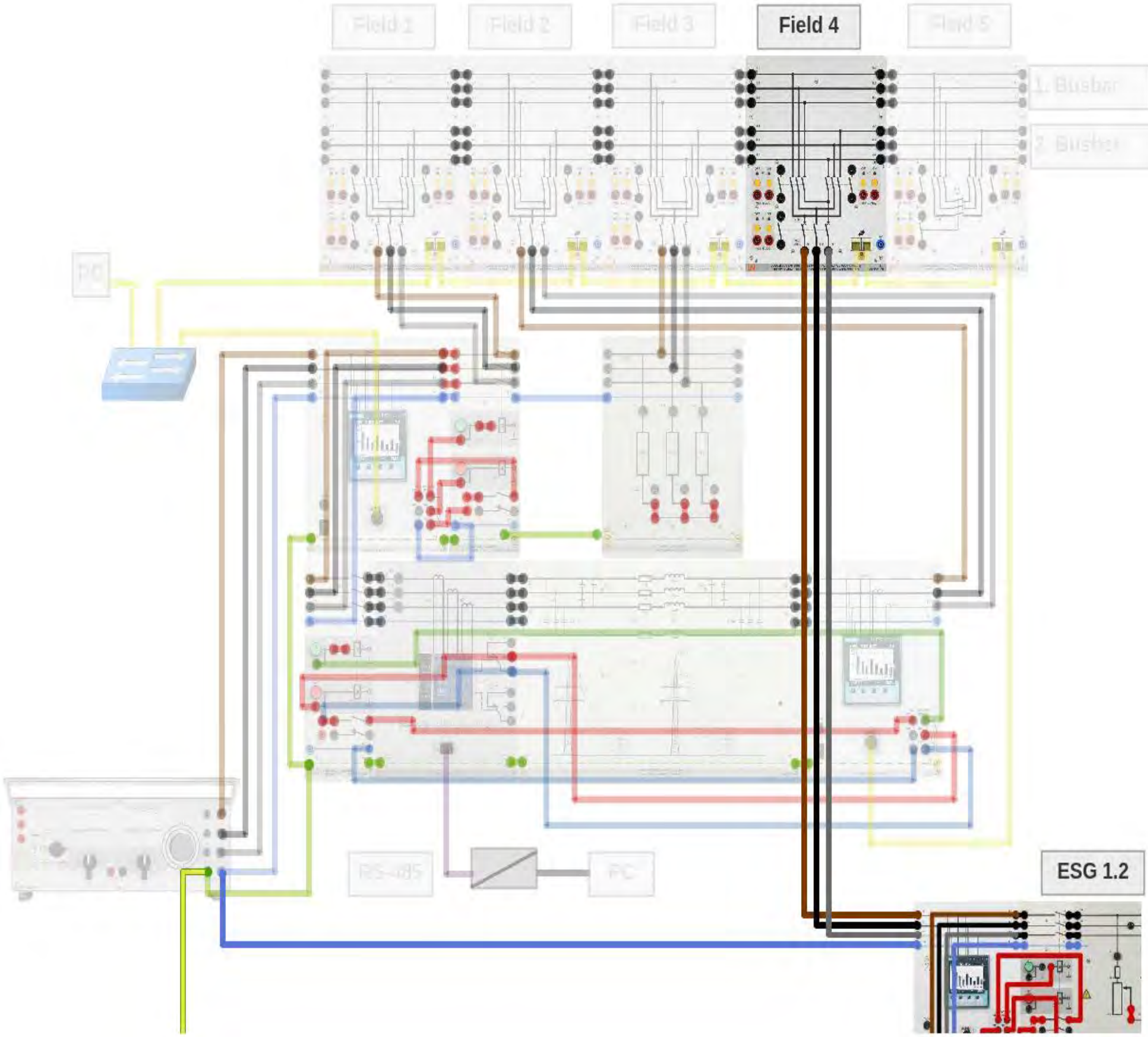


Figure 11:
Basic Experimental Configuration

The SCADA software's integrated logger offers additional evaluation options as shown in Figure 13.
The PLC system integrated into the SCADA software allows you to implement switching operations according to your own ideas as seen in Figure 14.
The *ActiveServo* software allows you to create any required load profile and study how the smart grid responds to changing loads as shown in Figure 15.

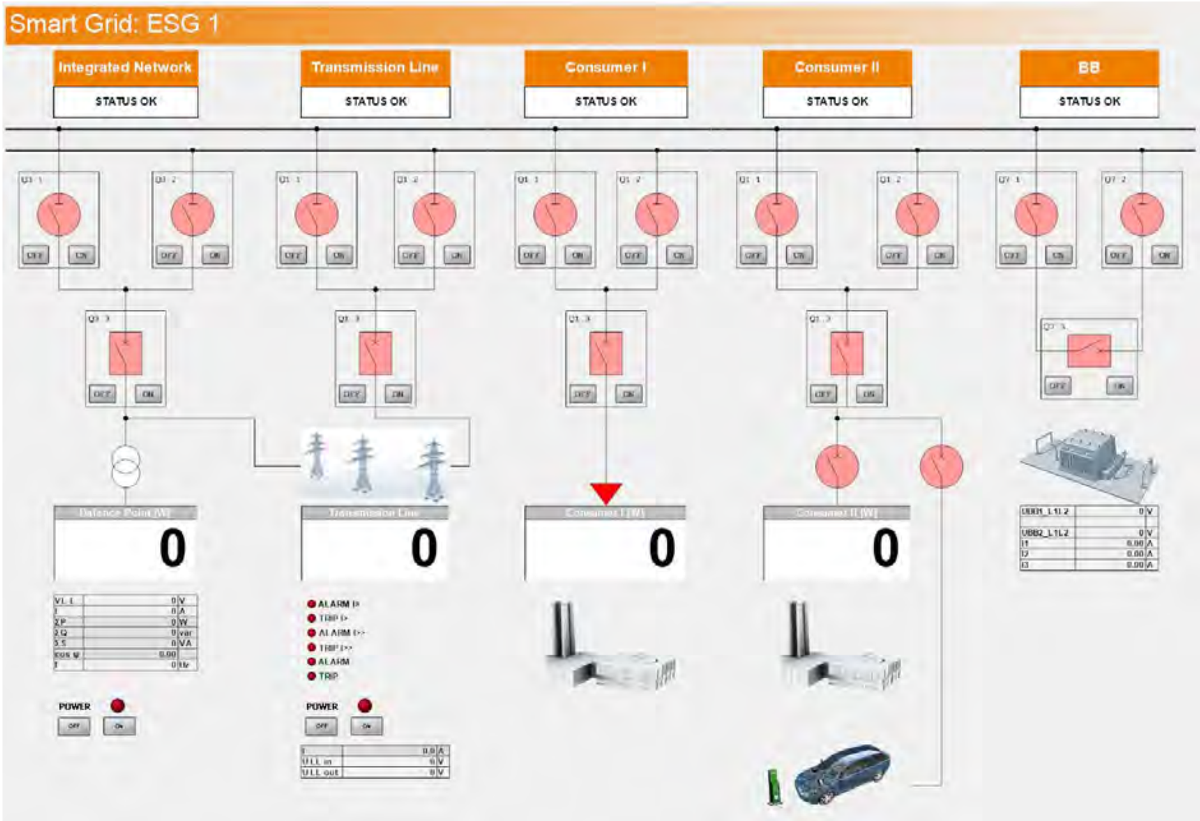


Figure 12:
Screenshot of SCADA for Power Lab - ESG_1_1

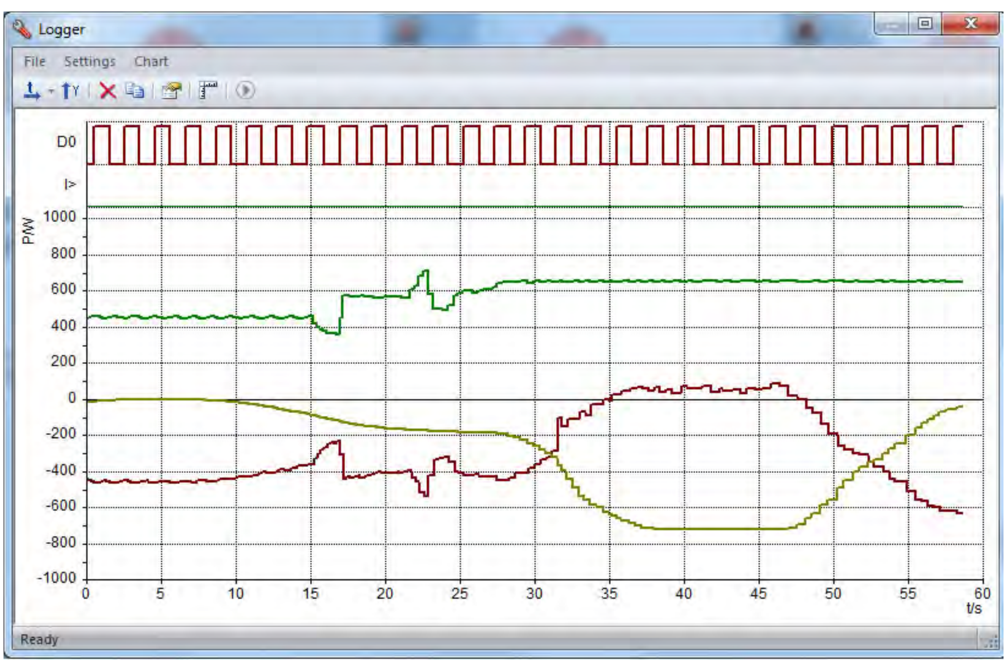


Figure 13:
Screenshot of SCADA for Power Lab - Logger

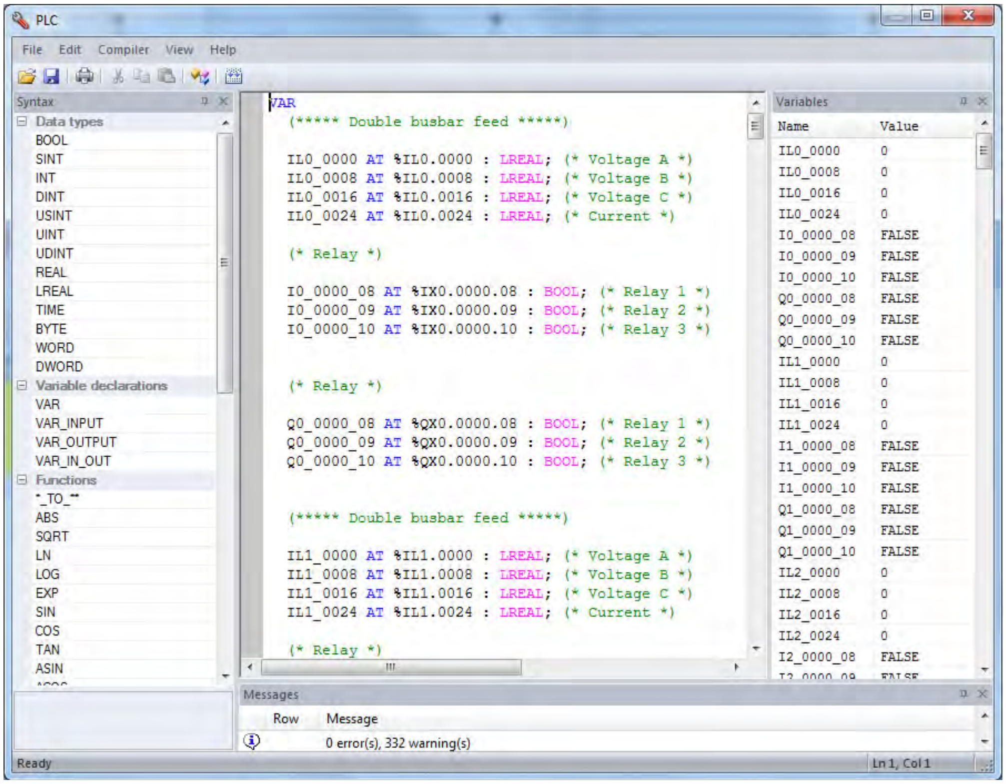


Figure 14:
Screenshot of SCADA for Power Lab - PLC

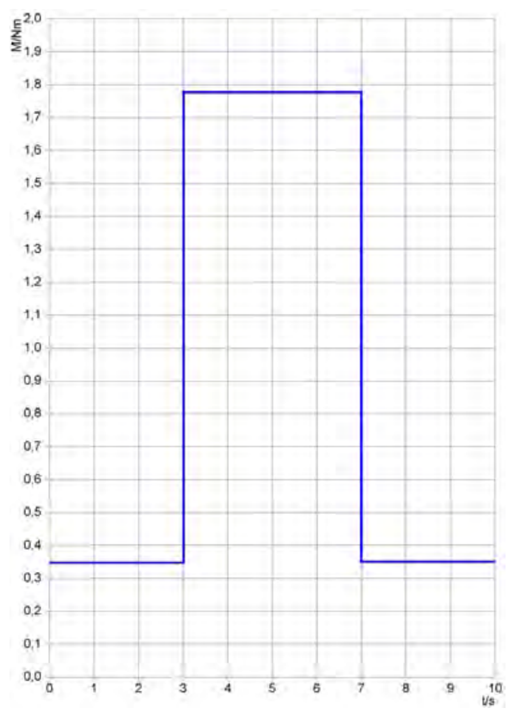


Figure 15:
Load profile

Smart Grid: Extension

A Smart Grid consists of a large number of distributed systems for generation, distribution, measurement and protection. The individual systems are always controlled on site by appropriate control systems. Depending on the complexity of the system, additional monitoring is carried out by personnel in the immediate vicinity. Deviations and complex correlations can usually be detected more quickly by humans and corrected by adapting the control system. This is mainly the case in power plants with conventional energy sources. The maintenance personnel on site must also be able to intervene in the systems.

The specifications of the individual systems are made by a control centre.

Experiment stand ESG 1.1 is extended here by means of further double busbars (CO3301-5R) serving as input/output fields for other systems. In the smart grid extension, the power supply of the supplementary systems (generally CO3212-5U7) is replaced by a connection to additional busbars (CO3301-5R) of the experiment bench ESG1.1. The additional systems are therefore supplied by the ESG1.1 You can find further information about the specific extensions on the following experiments.

The SCADA user interface of Figure 16 used for the Smart grid extensions is first explained here:

1. Save the file at the following link, "ESG_Ext.pvc", in a working folder on your PC.
2. Open the "SCADA Viewer" directly in Labsoft (top right) and select the file you have just saved.

- *File → Open...*
- Navigate to working folder and open the file.
- The SCADA user interface will look similar to Figure 16.

Description of SCADA user interface's panels:

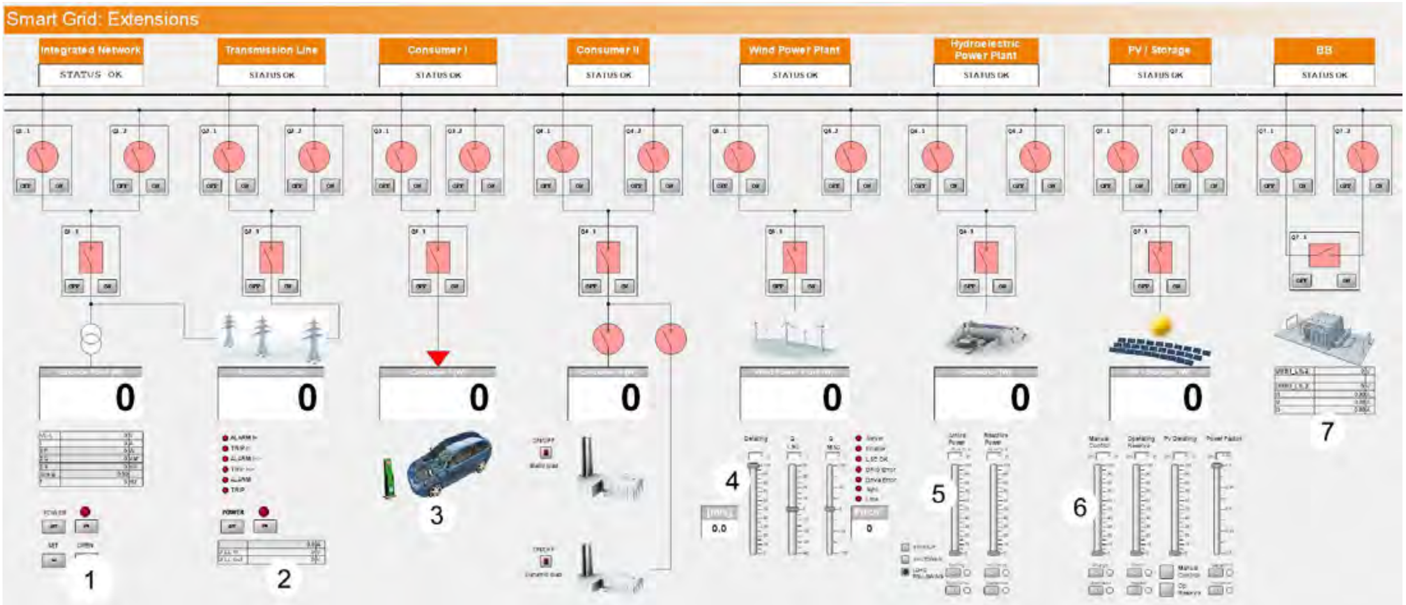


Figure 16:
Screenshot SCADA for Power Lab: Smart Grid - Extensions

1. **Operation and Network Parameters of the Balance Point:**

- ❖ Display of the network parameters of the balance Point.
- ❖ The smart grid can be connected or disconnected by pressing the "POWER ON/ OFF" buttons.
- ❖ SET SG: connects all the busbars of the smart grid at the same time.
- ❖ OPEN ALL: disconnects all the busbars of the smart grid at the same time.

2. **Operation and status of the transmission line:**

- ❖ The transmission line can be connected or disconnected by pressing the "POWER ON/OFF" button.
- ❖ Alarm I>: Over current $I_{>}$ detected.
- ❖ Trip I>: Over current $I_{>}$ stage was activated. The power switch CO3301-5P will be opened.
- ❖ Alarm I>>: Short circuit stage $I_{>>}$ detected.
- ❖ Trip I>>: Short circuit stage $I_{>>}$ was activated.
- ❖ Alarm: Over current $I_{>}$ or short circuit stage $I_{>>}$ detected.
- ❖ Trip: Over current $I_{>}$ or short circuit stage $I_{>>}$ was activated.

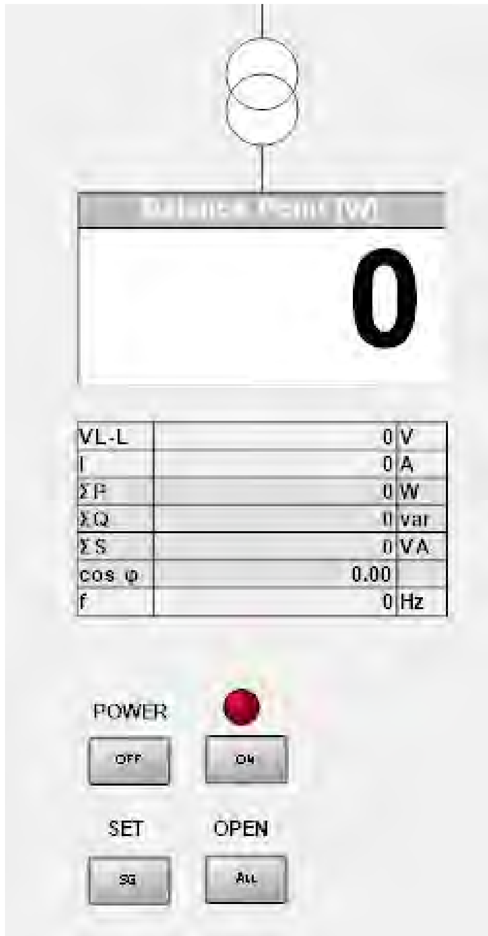


Figure 17:
Screenshot Panel Balance Point

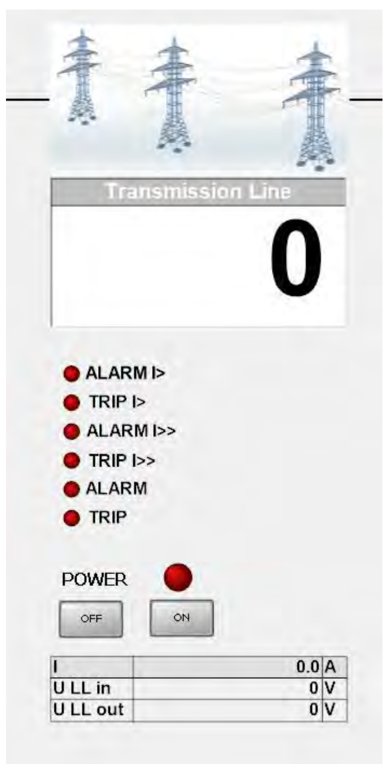


Figure 18:
Screenshot Panel Transmission Line

3. Display of the Consumed Power of the Consumers:

The absorbed power of "Consumer I" is calculated from the current and voltage values of the busbar. The value applies only to resistive loads.

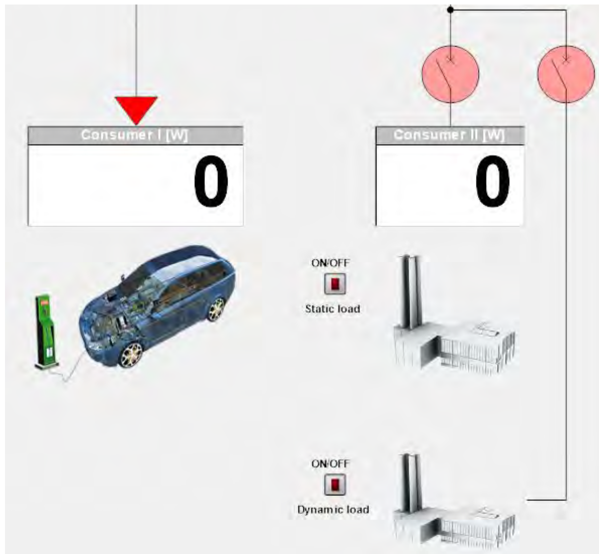


Figure 19:
Screenshot Panel Consumers

4. Operation and Status of the Wind Power Plant:

- Wind Power Plant [W]: Display of the consumed or supplied active power.
- [m/s]: Display of the wind speed.
- Pitch °: Display of the Pitch angle.
- Derating (%): Setting of the active power derating in % (0% means no power limitation. 100% means full power limitation = no active power is fed into the grid.)
- Q LSC (%): Reactive power feed in or consumption of the LSCs (Line Side Converter)
- Q MSC (%): Reactive power feed in or consumption of the MSCs (Machine Side Converter)

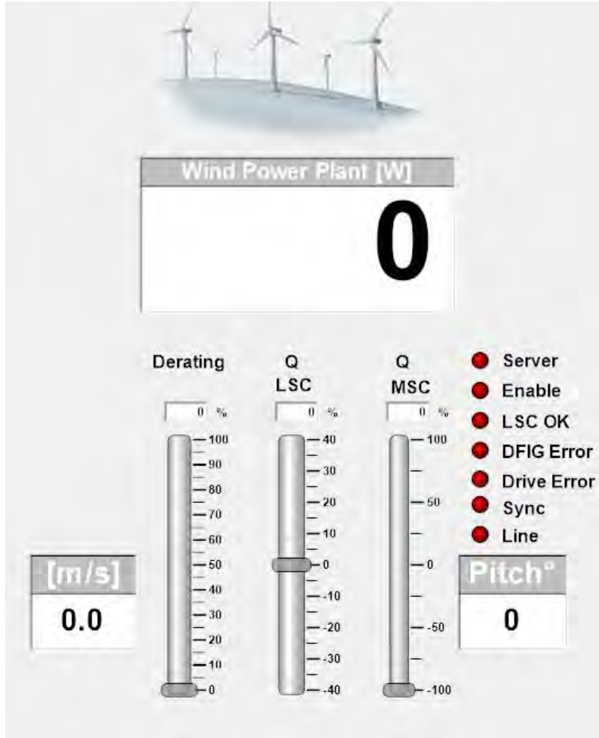


Figure 20:
Screenshot Panel Wind Power Plant

5. Operation and Status of the Pumped Storage Power Plant:

- Generator [W]: Display of the consumed or supplied active power.
- STARTUP: starts the machinery, synchronizes it and feeds or consumes power in accordance with the settings.
- SHUTDOWN: reduces the machinery power to zero, stops synchronization and shuts down the machine.
- LOAD FOLLOWING: Automatic load sequence operation.the power P/Q is measured at the balance node with the generator compensated.
- Active Power: Manual control of the active power. P/Q is regulated as a percentage of S/VA. That means that at 800 VA, you can supply or consume power P of -800 W to 800 W. The direction in which this takes effect can be modified by means of the buttons "Storing" and "Supplying".
- Reactive Power: Reactive power is adjusted in the same way, with the type of reactive power being specified by "Inductive/Under-Excited" and "Capacitive/Over-Excited"

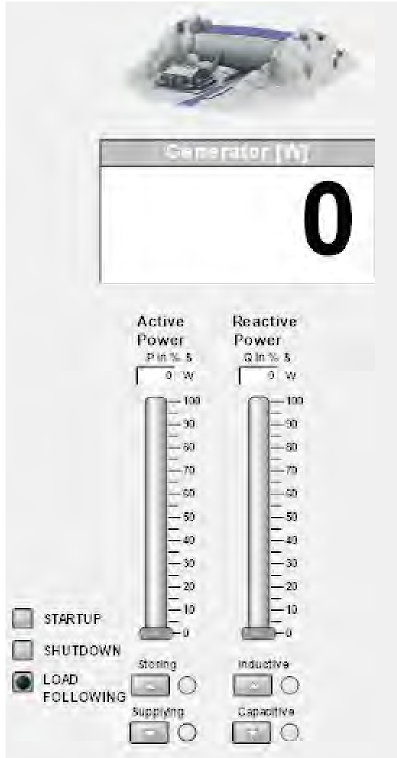


Figure 21:
Screenshot Panel Pumped-storage Power Plant

6. Operation and Status of the Photovoltaic System with Battery Storage Device:

- ❖ PV/Storage [W]: display of the supplied or consumed active power.
- ❖ Manual Control: Manual battery control.
  - Charge: Charging the battery storage.
  - Discharge: Discharging the battery storage.
- ❖ Operating reserve: Specification of the control power for the complete house system. (Consumers, generation with the photovoltaic panel and battery storage system). Depending on the system state, the specified power cannot be made available.
  - Positive: Power consumption of the house connection (Regulation by battery storage system).
  - Negative: Power fed into the grid from the house connection (Regulation by battery storage system).
- ❖ PV Derating: Power limitation of the photovoltaic system power as a percentage of the nominal power.
- ❖ Power Factor: Provision of reactive power of the photovoltaic system (capacitive or inductive).

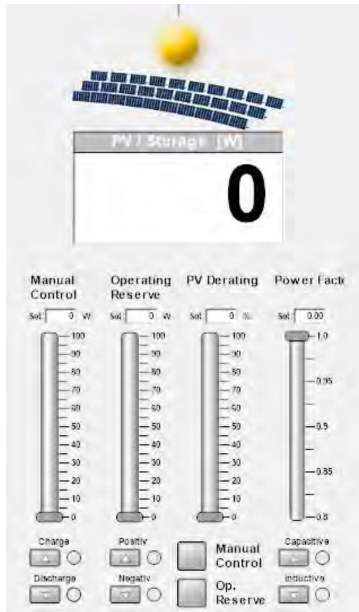


Figure 22:
Screenshot Panel Photovoltaic System

7. Display of the Network Parameters of the Coupler

Note:

> If you do not use a field, you must deactivate the corresponding devices under  or "Diagnostics" → "Device Manager..." of the SCADA Software, otherwise the connection between PC and the devices cannot be established.

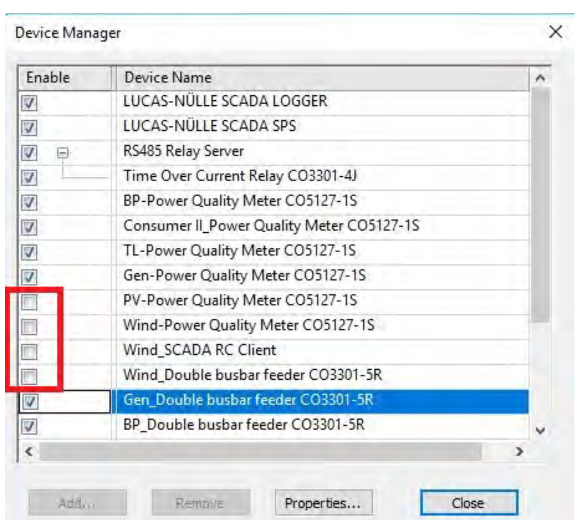


Figure 23:
Device Manager: Example without Wind Power Plant

Case 1: Photovoltaic Facility Extension

The following is a selection of possible scenarios that can be examined:

- Effect of the fluctuating generation of renewable energies in the Smart Grid.
- Busbar change with an energy generator.

The photovoltaic system is first disconnected from the power supply for electrical machines (CO3212-5U7). The grid connection is then re-established via a free incoming/outgoing field (CO3301-5R) at the ESG 1.1 experiment stand. An additional double busbar can be integrated as an incoming/outgoing field (CO3301-5R).

Always use only one mains connection in your experiment setup!

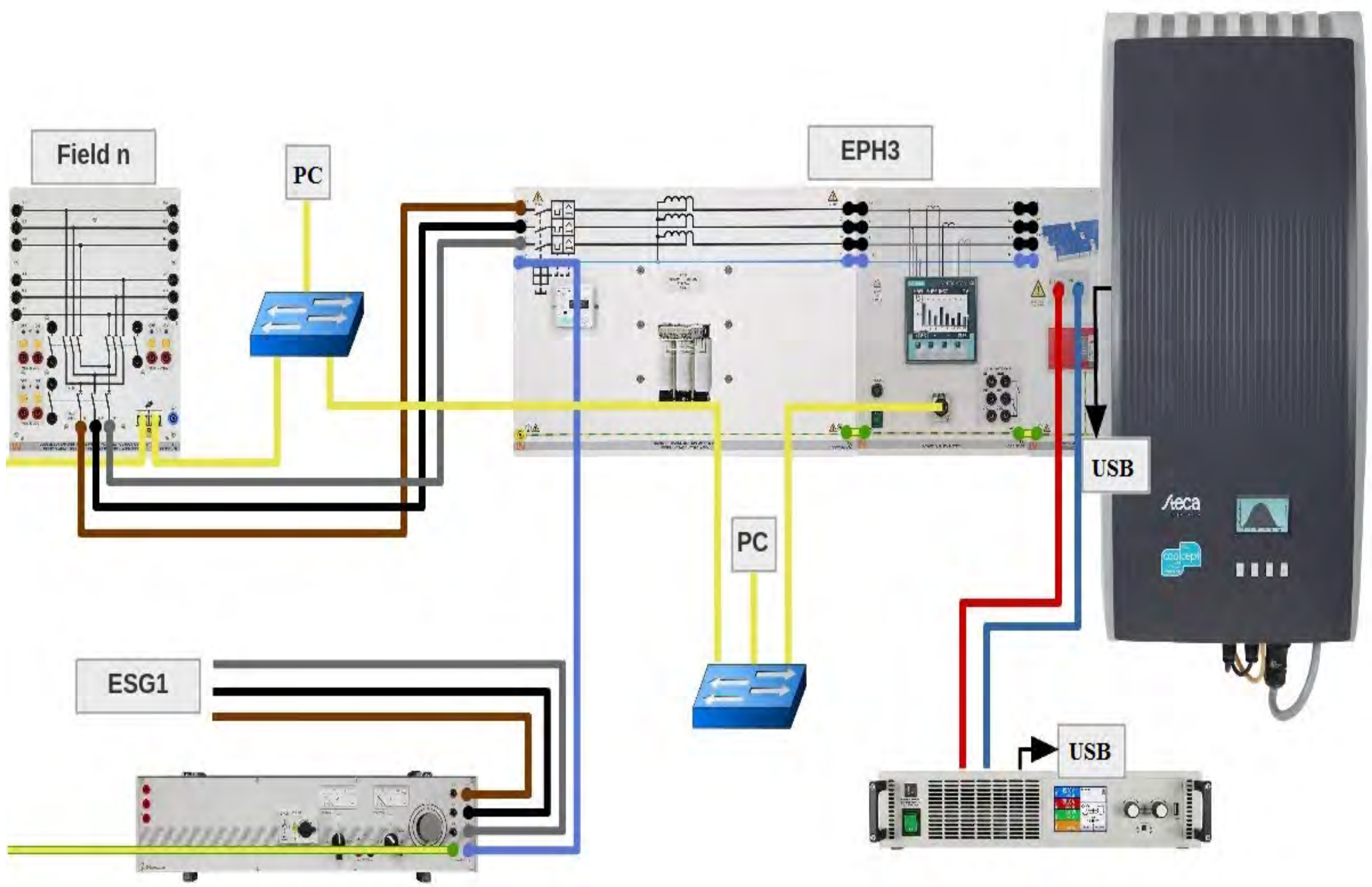


Figure 24:
Photovoltaic Facility Extension

Each system has its own control, here computer, and is supplemented by a remote control. Therefore, a computer is required at each experiment stand and must be configured accordingly.

- Configure the TCP/IP network.
- Observe all devices connected to the network.
    - Duplicated IP addresses lead to communication problems!

The photovoltaic system consists of two components which can be controlled by different applications:

- The solar field is simulated by a configurable DC power supply CO3208-1P7. With the help of the "**Solar Panel**" application, the behavior of a solar field is emulated realistically.
- Unless otherwise parameterized, the PV inverter always feeds in the maximum power of the solar field.
    - Control is possible via SCADA:
        - Derating / limitation of the maximum feed-in power.
        - Provision of reactive power.
        -

The Solar Panel application is connected to the hardware via USB

1. Solar field characteristic.
2. Selection of the shading conditions:
    - Changes can only be made if the application has been disconnected from the hardware (POWER button).
3. Current operating point of the replica or PV inverter.
4. Selection of irradiance or solar profile.
5. Diagrams:
    - Characteristic
    - Solar profile

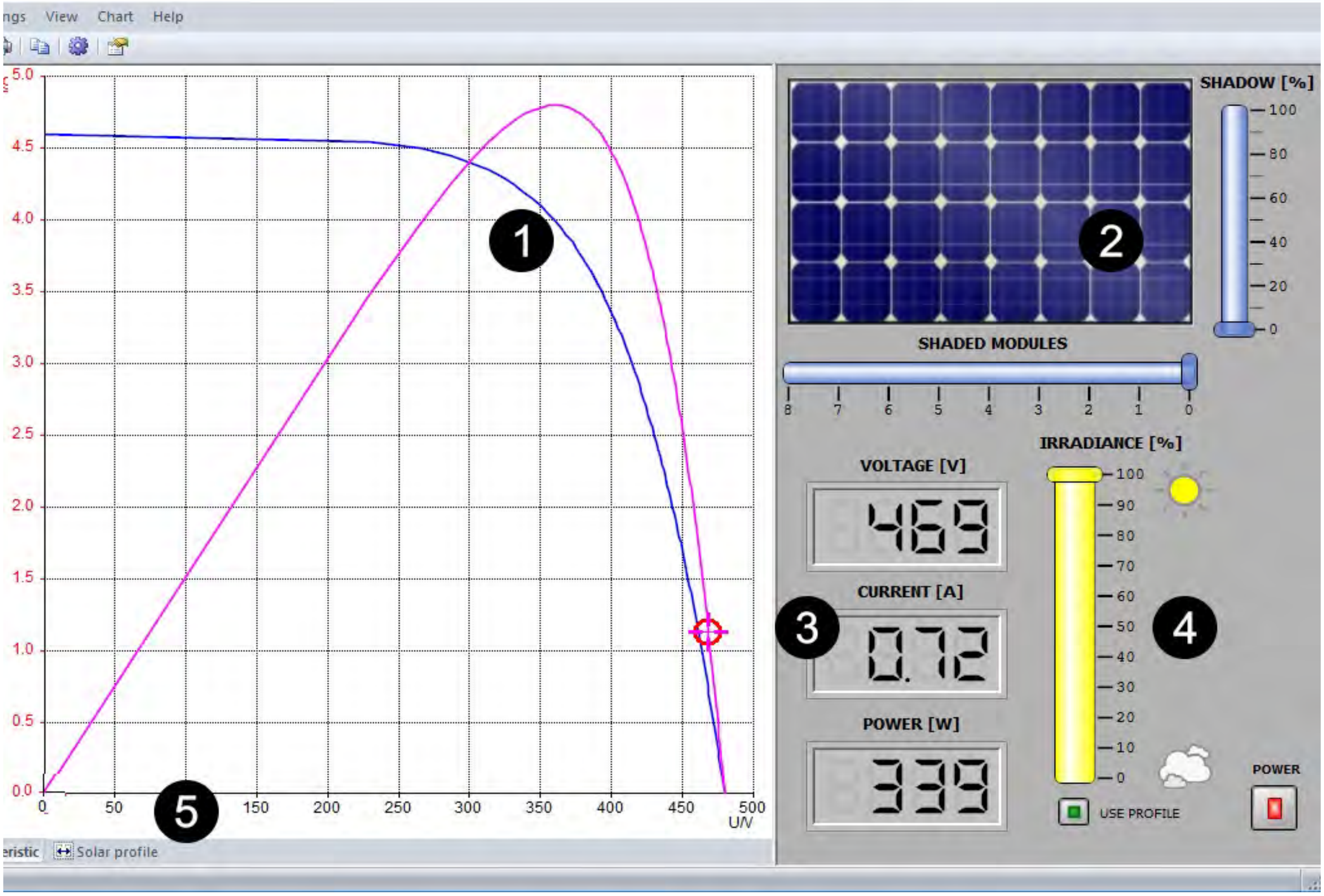


Figure 25:
Solar Panel Emulator

The PV inverter is supplied via the grid and not via a separate grid connection. According to the experiment setup in Figure 24, the grid connection must first be established via the busbars. Then the PV inverter switches on and a connection with SCADA is possible (optional).

The grid connection can be established in two ways:

- Via the hardware buttons on the devices
    - Double busbars CO3301-5R
    - Power switch CO3301-5P
- Via the SCADA interface of the Smart Grid
    - Please also refer to the section "Settings SCADA Viewer for Smart Grid".

Use the following SCADA interface for the control of the photovoltaic system in Smart Grid:

- Save the file at the following link, ESG_EPH3.pvc , in a working folder on your PC.
- Open the "SCADA Viewer" program directly from Labsoft (top right) and select the file you have just saved.
  - *File → Open...*
  - Navigate to the file location and open it.
- Eventually, you must configure on the Device Manager (F8) via or *Diagnostics → Device Manager...* the interfaces and/or the addresses of the devices.
  - Refer to the section "Configuring SCADA for Power Lab"

You can find more SCADA interfaces in the experiment Modern Professional Photovoltaic System in Grid-couple Operation.

In the event of a power failure, the PV inverter switches off directly and the USB connection is interrupted. The USB connection with SCADA must be re-initialized after the mains power has been restored.

The PV inverter is connected locally to SCADA via USB. Remote control can therefore only be implemented with SCADA Advanced Remote Control Server/Client (optional). The SCADA interface of the PV inverter assumes the role of a SCADA Advanced Remote Control Server.

- Configure the SCADA Advanced Remote Control Server
  - *Device Manager (F8) via or Diagnostics → Device Manager...*
  - Properties...
- Select here the IP address of the computer in the network

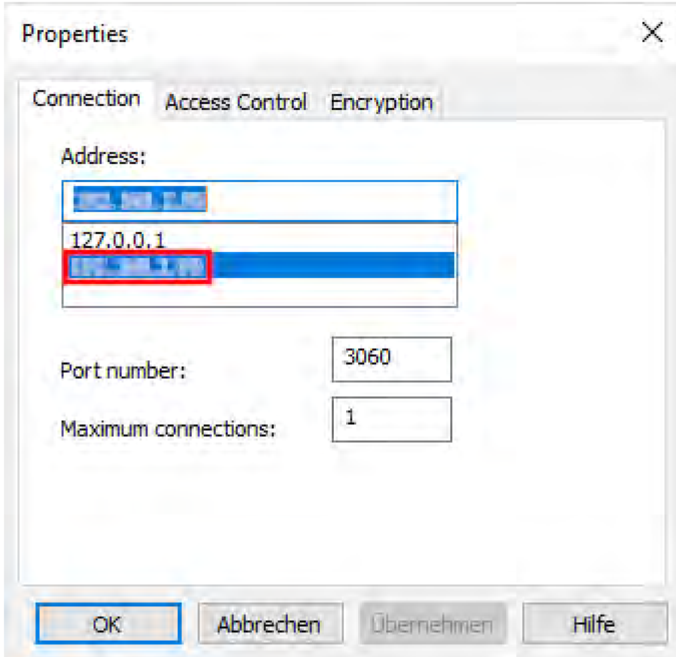


Figure 26:
Selection of the IP-Address of the SCADA Advanced Remote Control Server

1. Assemble the circuit in accordance with the layout and wiring diagram of Figure 24.
2. Save the file at the following link, ESG_Ext.pvc , in a working folder on your PC.
3. Open the "SCADA Viewer" program directly from Labsoft (top right) and select the file you have just saved.
   - ❖ *File → Open...*
   - ❖ Navigate to the file location and open it.
   - ❖ The SCADA user interface will look as Figure 16.
4. Eventually, you must configure on the *Device Manager (F8) via* or *Diagnostics → Device Manager...* the interfaces and/or the addresses of the devices:
   - ❖ Please also refer to the section "Configuring SCADA for PowerLab"
   - ❖ ☑ Activate all the devices and components that you will use via the Checkbox "☐ Enable".
   - ❖ ☐ Deactivate all the devices and components which are not needed.
   - ❖ Configure ☑ activated devices via *Properties...*
   - ❖

If you are not using SCADA Remote Control Server, disable the PV/Battery_SCADA RC Client.

Deactivate the component PV/Battery_SCADA RC Client also, if you want to connect the PV-Inverter with the grid.

Table 9: Device Manager /Example of a Smart Grid- Configuration: ESG1.1, ESG1.2, EPH3

Enable	Device Name	System
☑	LUCAS-NÜLLE SCADA LOGGER	Smart Grid
☑	LUCAS-NÜLLE SCADA SPS	Smart Grid
☑	RS485 Relay Server	Smart Grid
☑	Time Over Current Relay CO3301-4J	Smart Grid
☑	BP-Power Quality Meter	Smart Grid - Balance point
☑	Consumer II_Power Quality Meter CO5127-1S	Energy management
☑	TL_Power Quality Meter CO5127-1S	Smart Grid -Transmission line
☐	Gen-Power Quality Meter CO5127-1S	Pumped-storage power station
☑	**PV-Power Quality Meter CO5127-1S**	**Photovoltaic system**
☐	Wind-Power Power Quality Meter CO5127-1S	Wind power plant
☐	Wind_SCADA RC Client	Wind power plant
☐	Wind_Double busbar feeder CO3301-5R	Wind power plant
☐	Gen_Double busbar feeder CO3301-5R	Pumped-storage power station
☑	BP_Double busbar feeder CO3301-5R	Smart Grid - Balance point
☑	**PV_Double busbar feeder CO3301-5R**	**Photovoltaic system**
☑	Double busbar coupler CO3301-5S	Smart Grid
☐	Gen_SCADA RC Client	Pumped-storage power station
☑	TL_Double busbar feeder CO3301-5R	Smart Grid -Transmission line
☑	Consumer II_Double busbar feeder CO3301-5R	Energy management
☑	Consumer I_Double busbar feeder CO3301-5R	Smart Grid
☐ (☑)	**PV/Battery_SCADA RC Client**	**Photovoltaic system**

5. The configuration of the *SCADA Advanced Remote Control Client* (optional) is done via Properties... in the *Device Manager* (F8) under or menu *Diagnostics → Device Manager...*

- Specify the IP address of the server via *Select...*
- A connection test is initiated via *Test Connection*.
  - ❖ The *SCADA Advanced Remote Control Server* must be started for this purpose.

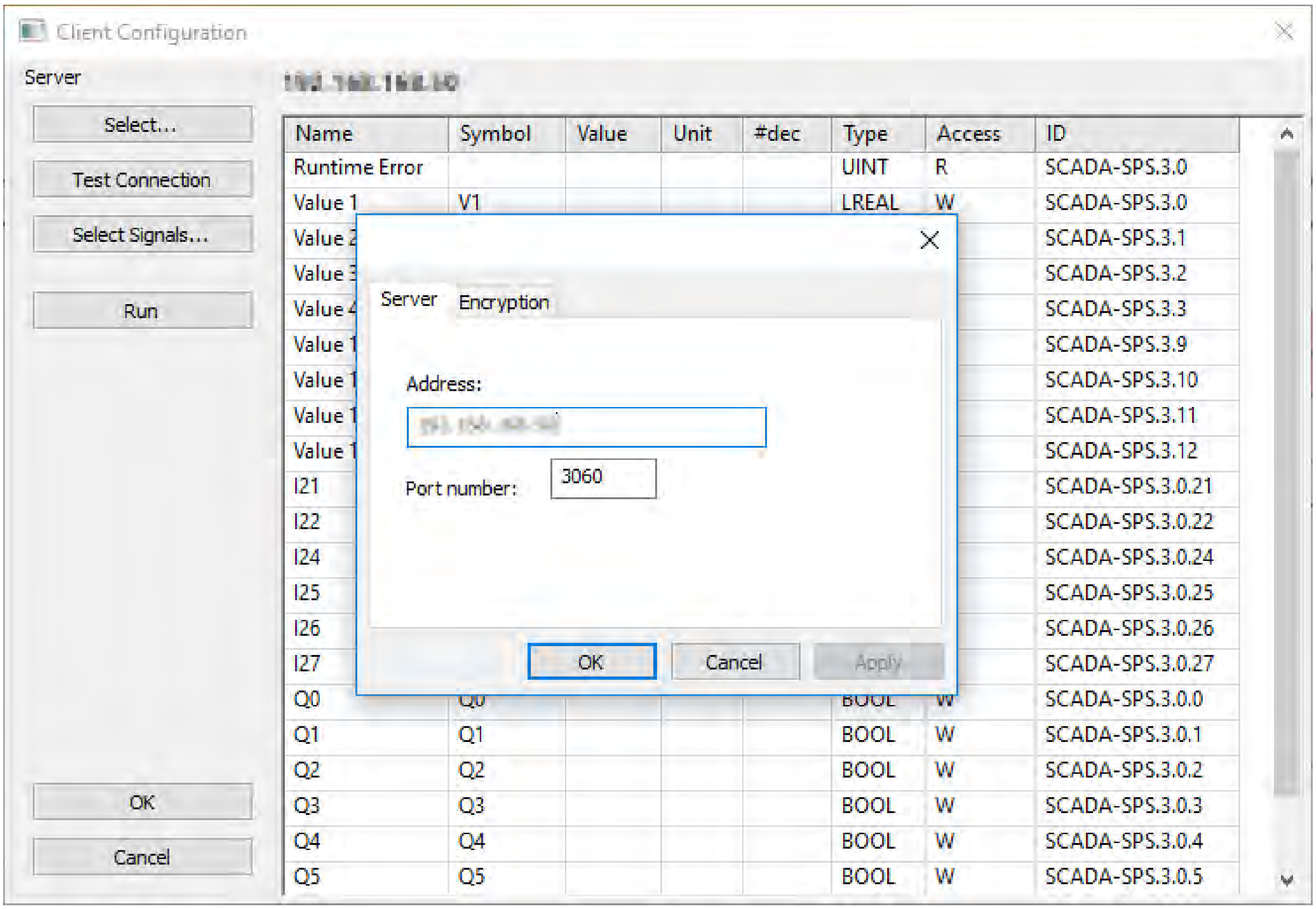


Figure 27:
SCADA Advance Remote Control Client

6. Start the SCADA *Viewer/Designer* via or in menu *Diagnostics → Start Diagnostics*
7. If necessary, open the SCADA Logger
   - ❖ Via menu *Instruments→ Logger*
8. Stop the *SCADA Viewer/Designer* via or in menu *Diagnostics → Stop Diagnostics*
   - ❖ The application can only be ended by stopping it first.

9. Proceed as follows to set up the SCADA Advanced Remote Control Server/Client (optional).

- ❖ Connect the PV inverter to the grid.
  - If necessary, first deactivate the SCADA Advanced Remote Control **Client** in the **SCADA interface of the Smart Grid**.
    - Perform all circuits for the grid connection of the PV inverter.
- ❖ Start (F5) the SCADA *Viewer* via or *Diagnostics → Start Diagnostics*.
  - 1st. the SCADA interface of the **PV-System** with the SCADA Remote Control **Server**
  - 2nd. the SCADA interface of the **Smart Grid** system with he SCADA Remote Control **Client**

Case 2: Battery Storage Devices Extension

The following is a selection of possible scenarios that can be examined:

- ➢ Battery storage system as buffer for the fluctuating generation of regenerative energies in the Smart Grid.
  - ❖ High-capacity central battery storage.
- ➢ Provision of control power through decentralized battery storage systems with photovoltaic system in private households.
  - ❖ Keywords: virtual (large) storage, interconnection of storage systems, virtual power plant.

The battery storage system will initially be disconnected from the power supply for electrical machines (CO3212-5U7). The mains connection is then re-established via a free input/output panel (CO3301-5R) at the ESG 1.1 experiment stand. An additional double busbar can be integrated as an input/output section (CO3301-5R).

Always use only one mains connection in your setup!

When disconnecting the battery storage system from the power supply and switching it off, be sure to observe the operating instructions!

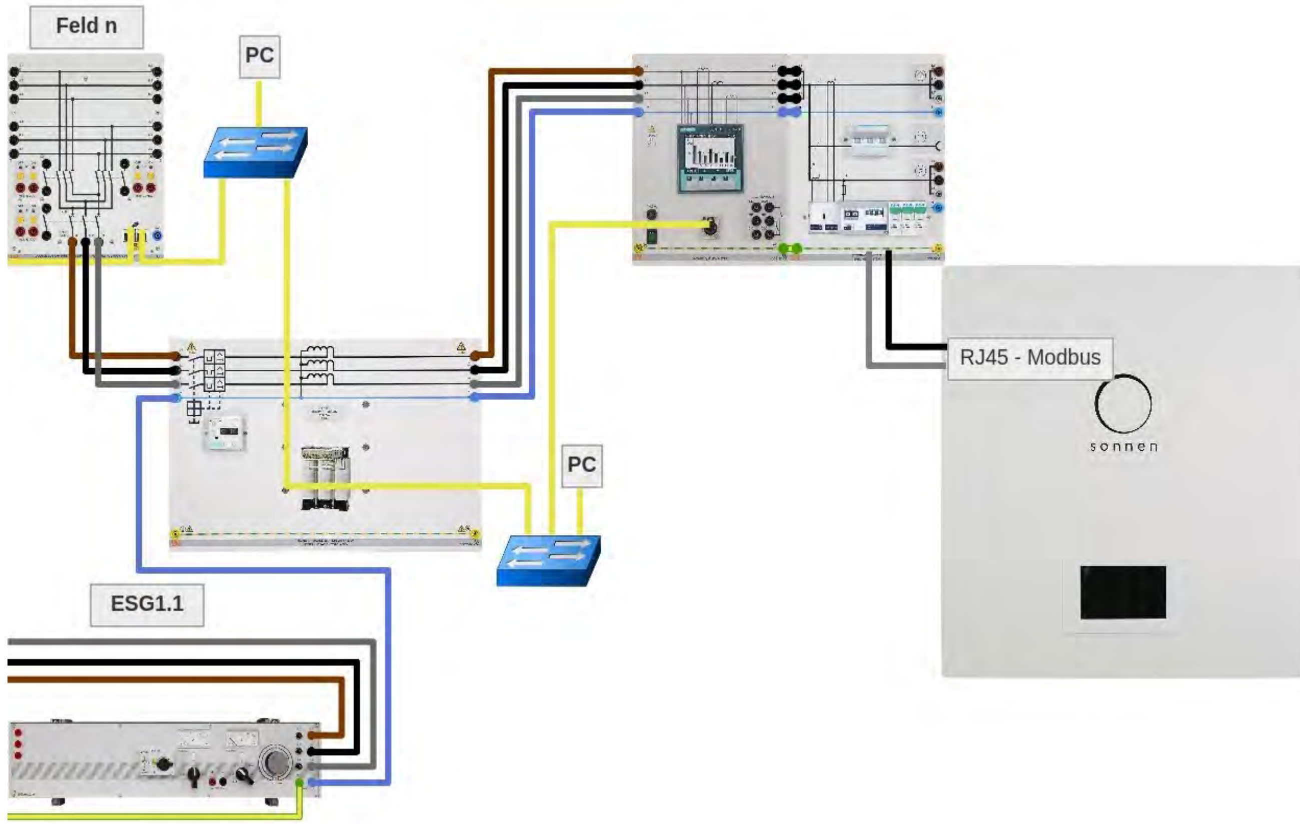


Figure 28:
Battery Storage Devices Extension

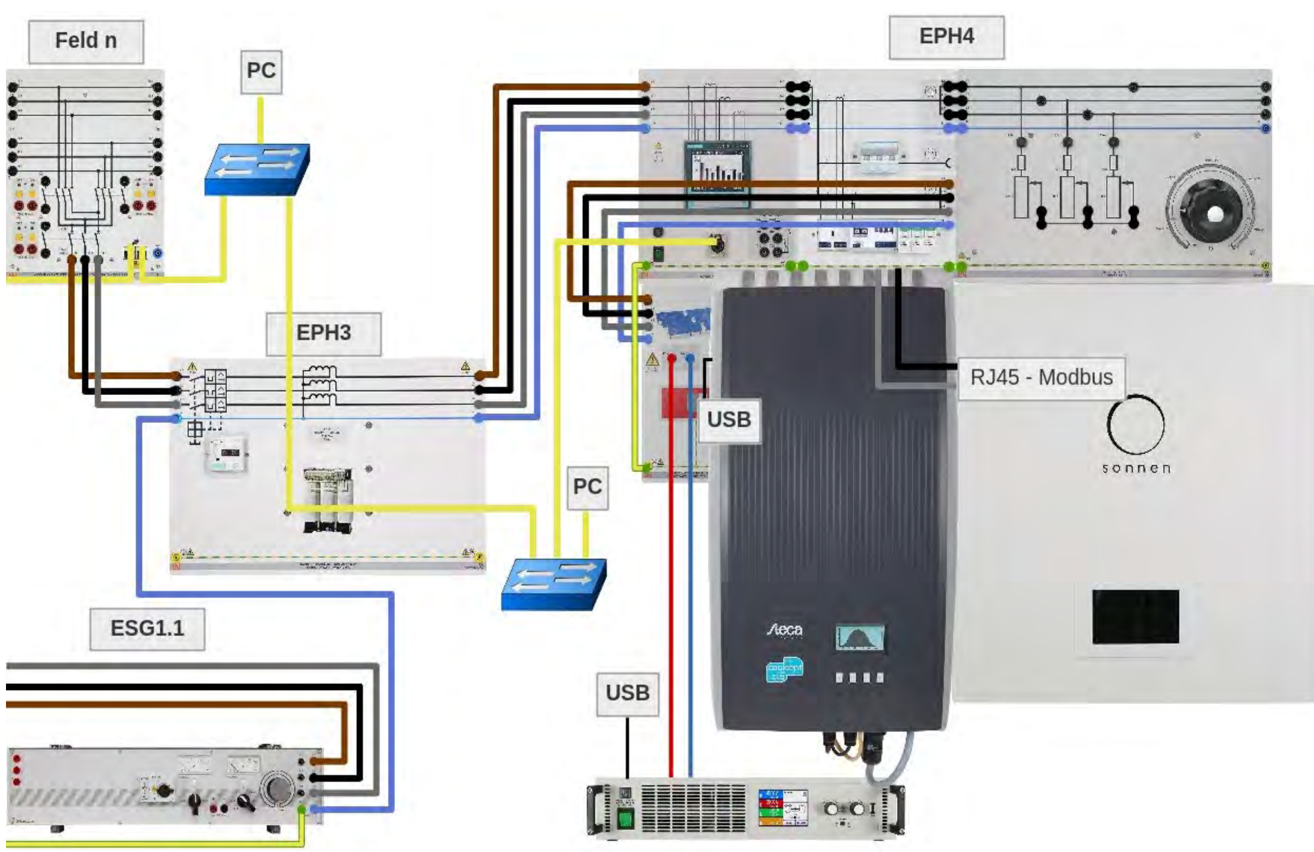


Figure 29:
Structure of a Decentralized Battery Storage System with Photovoltaic System in a Private Household

Each system has its own control, here computer, and is extended by a remote control. Therefore, a computer is required at each experiment stand and must be configured accordingly.

- Configure the TCP/IP network.
- Observe all devices connected to the network.
    - Duplicated IP addresses result in communication problems!

Refer to "Case 1: Photovoltaic Facility Extension" for control of the photovoltaic system.

In normal operation, the storage system automatically adjusts its mains connection (1) to zero. To do this, the consumers (2) and generators (4) must be connected according to the connection plate of the storage system (Figure 30):

- 1: Mains connection.
- 2: Connection of loads.
- 3: Connection of the battery storage system.
- 4: Connection of generators (CHP, PV, Wind).
- 4: Power measurement of the storage system.

Make sure that all fuses are switched on.

The power for charging or discharging the storage system can be set via SCADA (optional). Depending on the state of the system, switching between charging and discharging takes some time. Use the following SCADA interface to control the battery storage system with PV inverter in the Smart Grid.

- Save the linked file ESG_EPH4.pvc in a working folder of the computer.
- Open the "SCADA Viewer" program directly in Labsoft (top right) and select from the previously saved file.
    - *File → Open...*
    - Navigate to the location of the file and open it.

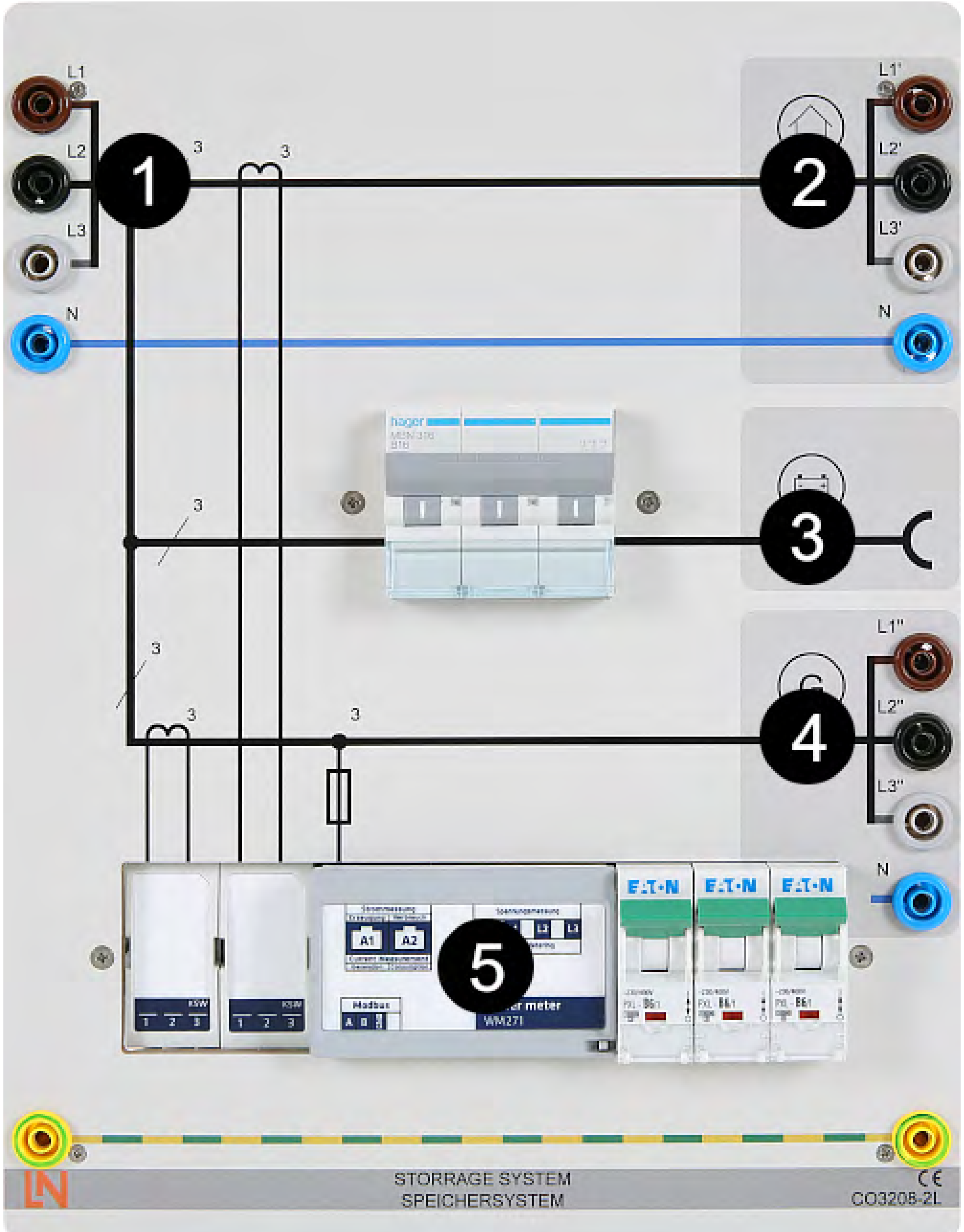


Figure 30:
Battery Storage System Connection Plate

- You might have to set the interface and/or address of the equipment in the *device manager (F8)* or under *Diagnostics → Device Manager....*
    - In this case, keep in mind the section "Configuring SCADA for PowerLab".

Further SCADA interfaces can be found in the experiment Modern Professional Photovoltaic System in Grid-couple Operation.

The storage system communicates via Ethernet and remote control can be implemented in two ways (optional):

Direct access with SCADA.
SCADA Advanced Remote Control Server/Client.

If an experimental setup as shown in Figure 28 is used, direct access via Ethernet with SCADA makes sense. Experimental set-ups similar to figure 29 require a SCADA Advanced Remote Control Server/Client configuration. In this case, direct access to the storage system can no longer be useful.

A remote control is already implemented in the file ESG_EPH4.pvc with SCADA Advanced Remote Control Server/Client. The SCADA interface of the power plant assumes the function of a SCADA Advanced Remote Control Server.

- Configure the SCADA Advanced Remote Control Server
  - Device Manager (F8) under  or Diagnostics → Device Manager...
  - Properties...
- Select the IP address of the computer in the network here.

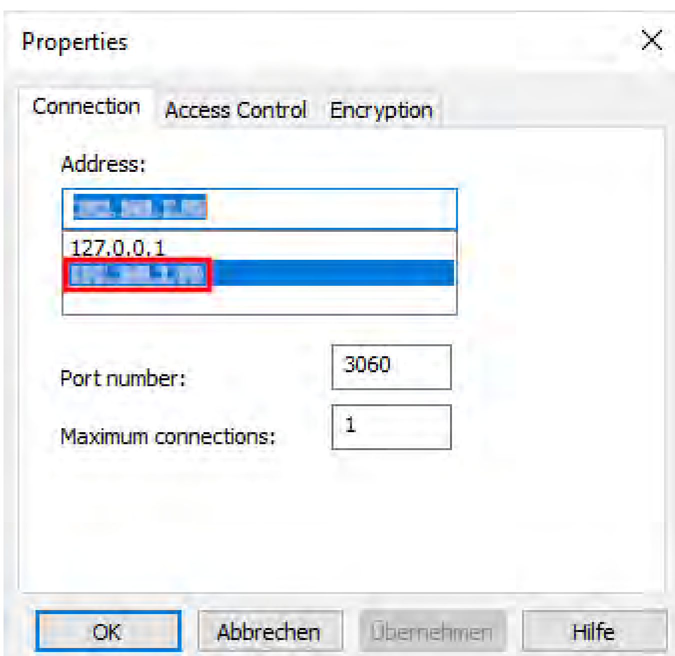


Figure 31:
Setting the IP address of the SCADA Advanced Remote Control Servers

1. Assemble the circuit in accordance with the layout and wiring diagram of your scenario:
   - ❖ Battery Storage Devices Extension (Figure 28).
   - ❖ Decentralized Battery Storage System with Photovoltaic System in a Private Household (Figure 29)
2. Save the linked file ESG_Ext.pvc in a working folder of the computer.
3. Open the "SCADA Viewer" program directly in Labsoft (top right) and select from the previously saved file.
   - ❖ *File → Open...*
   - ❖ Navigate to the file location and open it.
   - ❖ The SCADA user interface will look as Figure 16.
4. You might have to set the interface and/or address of the equipment in the *device manager (F8)* or under *Diagnostics → Device Manager....*
   - ❖ In this case, keep in mind the section "Configuring SCADA for PowerLab"
   - ❖ ☑ Activate all devices or components you use via the check box " ☐ Enable".
   - ❖ ☐ Also deactivate all devices or components that are not required.
   - ❖ Configure all activated devices ☑ via Properties...

> If you do not use SCADA Advanced Remote Client, deactivate the component "PV/ Battery_SCADA RC Client".

Table 10: Device Manager/Example from a Smart Grid-Configuration: ESG1.1, ESG1.2 and EPH4

Enable	Device Name	System
☑	LUCAS-NÜLLE SCADA LOGGER	Smart Grid
☑	LUCAS-NÜLLE SCADA SPS	Smart Grid
☑	RS485 Relay Server	Smart Grid
☑	Time Over Current Relay CO3301-4J	Smart Grid
☑	BP-Power Quality Meter	Smart Grid - Balance point
☑	Consumer II_Power Quality Meter CO5127-1S	Energy management
☑	TL_Power Quality Meter CO5127-1S	Transmission line

☐	Gen-Power Quality Meter CO5127-1S	Pumped-storage power station
☑	**PV-Power Quality Meter CO5127-1S**	**Photovoltaic Professional with battery storage device**
☐	Wind-Power Power Quality Meter CO5127-1S	Wind power plant
☐	Wind_SCADA RC Client	Wind power plant
☐	Wind_Double busbar feeder CO3301-5R	Wind power plant
☐	Gen_Double busbar feeder CO3301-5R	Pumped-storage power station
☑	BP_Double busbar feeder CO3301-5R	Smart Grid - Balance point
☑	**PV_Double busbar feeder CO3301-5R**	**Photovoltaic Professional with battery storage device**
☑	Double busbar coupler CO3301-5S	Smart Grid
☐	Gen_SCADA RC Client	Pumped-storage power station
☑	TL_Double busbar feeder CO3301-5R	Smart Grid - Transmission line
☑	Consumer II_Double busbar feeder CO3301-5R	Energy management
☑	Consumer I_Double busbar feeder CO3301-5R	Smart Grid
☐ (☑)	**PV/Battery_SCADA RC Client**	**Photovoltaic Professional with battery storage device**

5. The configuration of the SCADA Advanced Remote Control Client (optional) is done via Properties... in the Device Manager (F8) under or Diagnostics → Device Manager...

- ➢ Use Select... to specify the IP address of the server.
- ➢ A connection test is initiated via Test Connections.
  - ❖ The SCADA Advanced Remote Control Server must be started for this purpose.

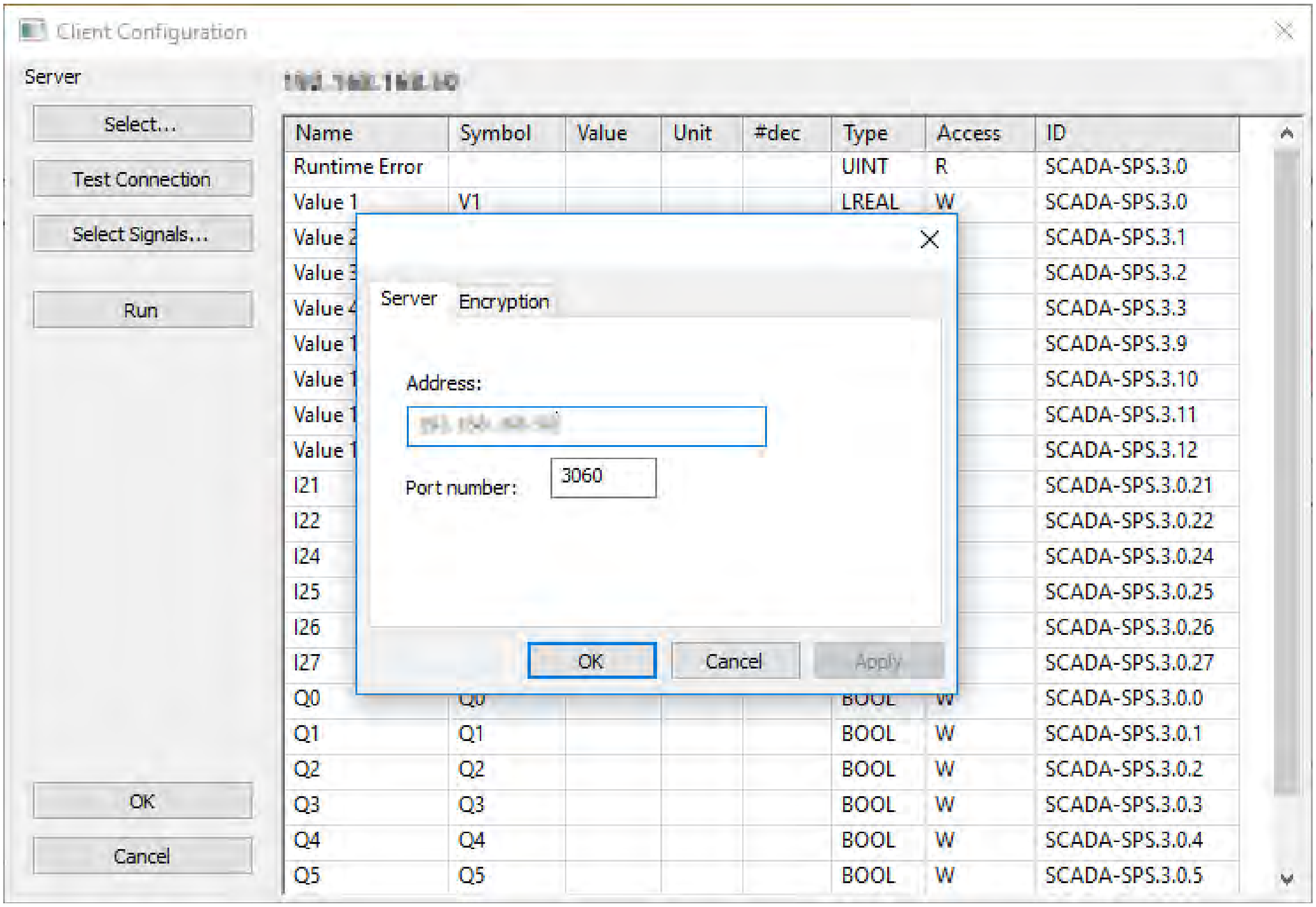


Figure 32:
SCADA Advanced Remote Control Client

6. Start (F5) the SCADA Viewer via or via *Diagnostics → Start Diagnostics*
7. Open the SCADA logger if necessary.

Select Instruments → Logger

8. Stop(F5) the SCADA Viewer again via or via *Diagnostics → Stop Diagnostics*

The application can only be ended by stopping it first!

9. Proceed as follows to set up the SCADA Advanced Remote Control Server/Client (optional):

❖ Start (F5) the SCADA *Viewer* via or *Diagnostics → Start Diagnostics*

- 1st. SCADA Advanced Remote Control **Server**.
- 2nd. SCADA Advanced Remote Control **Client**.

Report Questions

1. At which overcurrent level $I_>$ must the relay be set to ensure that it does not trip in the line protection's experiment?
2. Display the graphic of the SCADA logger's measurement results without load (DSM off). Step 17.
3. Display the graphic of the SCADA logger's measurement results with load (DSM on). Step 19.
4. What is the control system's behavior when you change the hysteresis of the DSM system (ΔP) to 100 W?

References

Jörg Ludwig, *Smart Grid*, Lucas-Nülle GmbH, 2019.