PV-OPTIM: A Smart Adaptive Optimization and Control Software

Version 1.1

Configuration Guide

Contents

1. Layer 1 - PV-OPTIM Forecast & Optimization

1.1. Prerequisites and dependencies

PV-OPTIM Layer 1 requires Python 3 and the following libraries: *pandas*, *numpy*, *scikit-learn*, *xgboost* and *matplotlib*.

1.2. Data files

Layer 1 uses the following .csv files located in the *data_folder* folder:

- *weather_readings.csv* - weather records for the last 30 days;
- *inverter_readings.csv* – inverter records for the last 30 days with the same timestamp used in *weather_readings.csv*.
- *weather_forecast.csv* – forecast data of the next 24 hours up to 10 days using the same parameters and metrics as in *weather_readings.csv*.
- *tariffs.csv* - tariff rates for the next 24 hours;
- *app_list.csv* – the list of the appliances that will operate the next day;
- *app_constraints.csv* – user preferences and the characteristics of the appliances.

The templates of the .csv files including sample data can be found in the *data_folder*.

Please do not change the templates!

1.3. Components

Layer 1 contains 2 components as follows:

1.3.1. PVForecast.py

Forecast the PV output for the next period depending on the time frame provided in *weather_forecast.csv*. Run the script to see the following metrics: RMSE, MAPE, R^2 and MAE of the forecast.

The forecasted values are saved into *inverter_forecast.csv*.

1.3.2. PVOptim.py

Optimize the schedule for day-ahead based on the PV available power estimated by *PVForecast.py* and the list of appliances and user preferences provided in *app_list.csv* and *app_constraints.csv*. Run the script to see the chart with the optimal schedule and the available PV power estimated for the next day.

The optimal schedule is saved in *optimal_schedule.csv* and the remaining quantities or the deficit is saved in *deficit_surplus.csv*.

The following parameters should be configured in *PVOptim.py*:

- `interval` - represents the interval for optimization in minutes (20, 30, 60). Default 30.
- `pcmax` - maximum load (W) per interval. Default 4500 W.
- `day` – day for optimization. Format `'yyyy-mm-dd'`. It should be a day for which the forecast has been made and is included in *inverter_forecast.csv*. Default '2022-08-02'.
- `TNP_load` – total non-programable load per interval or sum of the background consumption per interval (W). Default 200 W.

2. Layer 2 - PV-OPTIM Monitor & Control

2.1. Prerequisites and dependencies

PV-OPTIM Layer 2 requires Python 3 and the following libraries: *pandas, numpy, scikit-learn, xgboost, matplotlib, mysql.connector or mysqlclient, urllib, pytz*;

2.2. Data management

Layer 2 uses a database management system to store and manage data.
Install and configure MySQL or MariaDB. For full steps and documentation see: https://www.mysql.com/downloads/ or https://mariadb.org/.
After installation, configure the database schema for PV-OPTIM as follows:

1. Connect as *root* and create a new database user *PV_OPTIM* and set its default password to *pv_optim1234:*
   ```
   CREATE USER 'pv_optim'@'localhost' IDENTIFIED WITH mysql_native_password BY 'pv_optim1234';
   ```
2. Open and run the the script *db_create_PVOPTIM_schema.sql* to create the database tables.

As a result, the database schema is configured, and the following tables are created (figure 1):

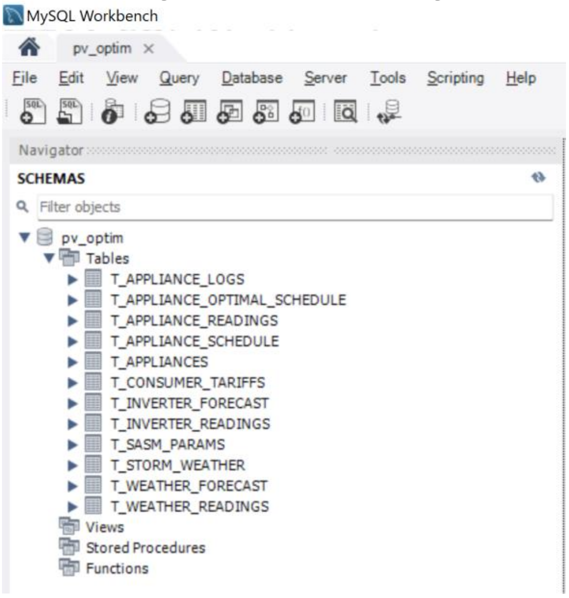


Figure 1 – PV-OPTIM database schema

3. Connect as *PV_OPTIM* and display the tables.
4. Optional – load sample data into PV-OPTIM schema by running *sample_data.sql*. This may take a few minutes. The data set contains records from one PV system of 5 kW collected between 17.02.2022-27.08.2022.

2.3. Configure the connection with the inverter to retrieve data

The current version of PV-OPTIM connects only to Growatt inverters using Growatt API implemented in the *growattServer* python library. Full documentation, methods and examples are available at: https://github.com/indykoning/PyPi_GrowattServer.
The connection with the inverter and the data collection process is implemented in *inverter.py*. Edit the script and update the username and password used for https://server.growatt.com/login page.

2.4. Set-up the smart plugs connectivity

PV-OPTIM can connect to various models of smart plugs from different providers.
The current implementation uses the following TP-Link smart plugs models: HS-110 and KP 115 with energy monitor options. For other models please check the providers' documentation to install and configure the devices and edit the orchestration flow as described in section 2.5.

Configure TP-Link smart-plugs as described in https://www.tp-link.com/us/home-networking/smart-plug/

Open your router administration page and see the IP allocated to the smart-plugs. It is recommended to reserve the IP for the smart-plugs using Address Reservation options on the console of the router. Use the allocated IP to configure the orchestration flow in section 2.5.

2.5. Configure the python scripts

Download the python files into a local directory and edit them to provide the required parameters as follows:

1. PVForecastL2.py
   - `tz` - specify the time zone. Default `'Europe/Bucharest'`
   - `day` – specify the start day for the forecast. Default current day: `dt.datetime.now().strftime('%Y-%m-%d')`
2. PVOptimL2.py
   - `interval` - represents the interval for optimization in minutes (20, 30, 60). Default 30.
   - `pcmax` - maximum load (W) per interval. Default 4500 W.
   - `day` – day for optimization. Default current day: `dt.datetime.now().strftime('%Y-%m-%d')`
3. open_weather.py
   - `plat` – latitude of the PV system
   - `plon` – longitude of the PV system
   - `API_key` – your API key to retrieve data from OpenWeather API (https://openweathermap.org/api).
4. storm_weather.py
   - `plat` – latitude of the PV system
   - `plon` – longitude of the PV system
   - `API_key` – your API key to retrieve data from StormGlass API (https://stormglass.io/).

2.6. Deploy the orchestration flow

The orchestration flow enables the connectivity and the processing steps between the smart-plugs, inverter, weather APIs and the python scripts.
The current version of the flow uses TP-Link smart-plugs configured via *Kasa* nodes. To use other smart-plugs from different providers (D-Link, Xiaomi, Broadlink) please see the requirements of the devices, configure their IP and add the corresponding nodes in the flow.
Follow the steps to configure the orchestration flow:

5. Install and configure Node-RED. See full documentation on: https://nodered.org/#get-started
6. Run Node-RED and open the console in a web browser. By default, it is accessible on http://localhost:1880/
7. Import the orchestration flow of PV-OPTIM provided in the repository in file *PVOptimFlow.json* . Use *Import* option from the Node-RED menu on the right corner of the console, select the file and load it. As a result, the *PVOptimFlow* will be loaded into the console (figure 2):

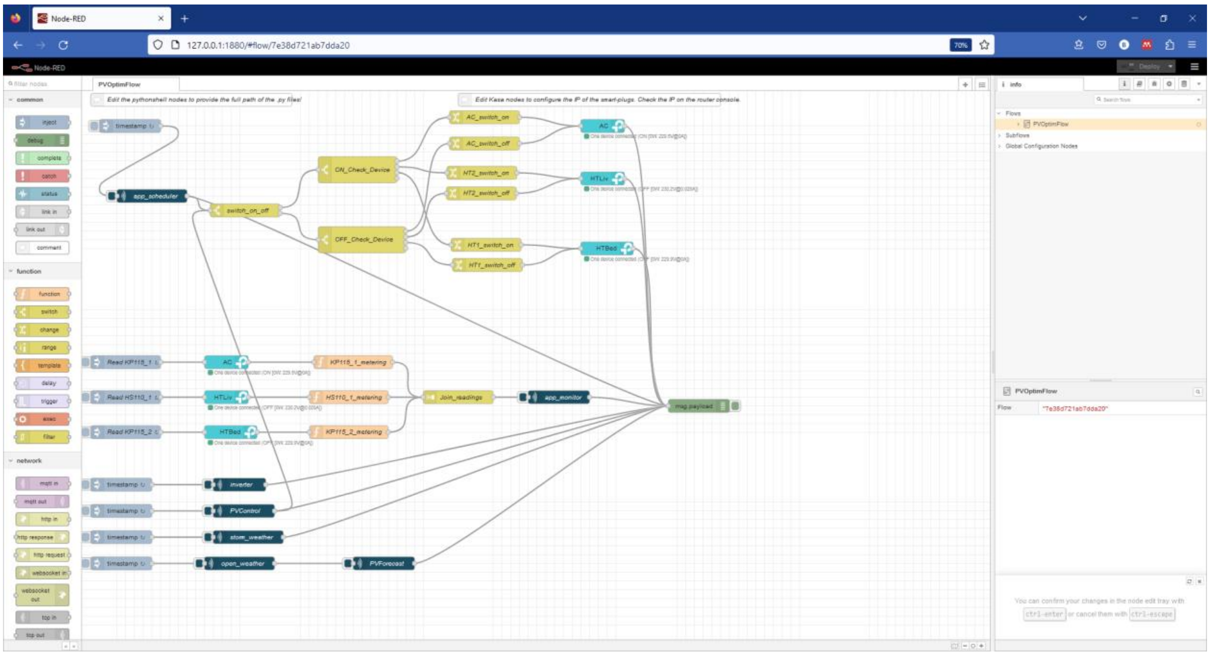


Figure 2 – PV-OPTIM orchestration flow in Node-RED

8. Resolve the dependencies of the nodes by installing *pythonshell* (node-red-contrib-pythonshell) and *Kasa* (node-red-contrib-tplink) nodes using Manage Pallete option from the Node-RED menu.
9. Edit the *Kasa* nodes to configure the IP and the name of the smart-plugs (figure 3):

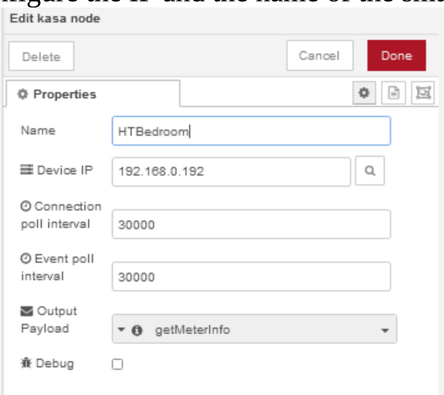


Figure 3 – Edit the properties of the *Kasa* nodes

10. Add/delete *Kasa* nodes to add or remove smart-plugs depending on the number of devices that need to be controlled. The current version uses two KP115 and one HS110 TP-Link smart-plugs with energy monitor option.
11. Edit the *pythonshell* nodes to specify the full path of the python scripts (figure 4):

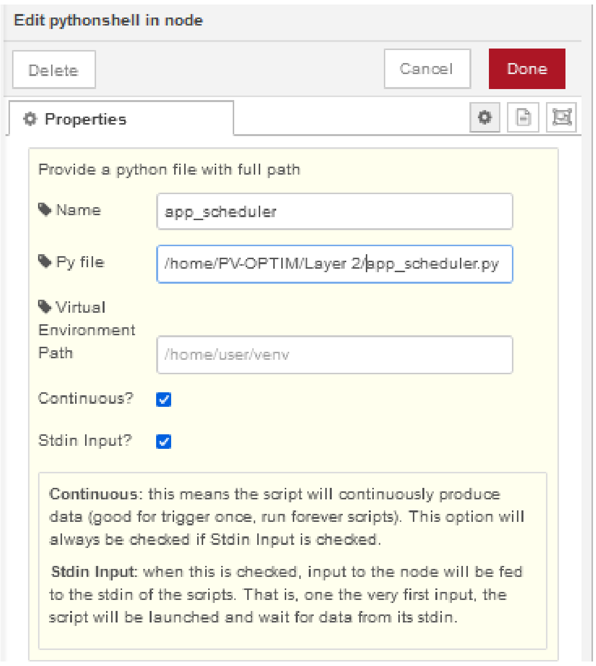


Figure 4 – Specify the full path of the python scripts in the *Pythonshell* nodes

12. Optional: edit the input (inject) nodes to change the time interval for requests. For example, the *timestamp* node corresponding to the *open_weather pythonshell* node can be edited to change the repeat interval to 6 hours (figure 5).

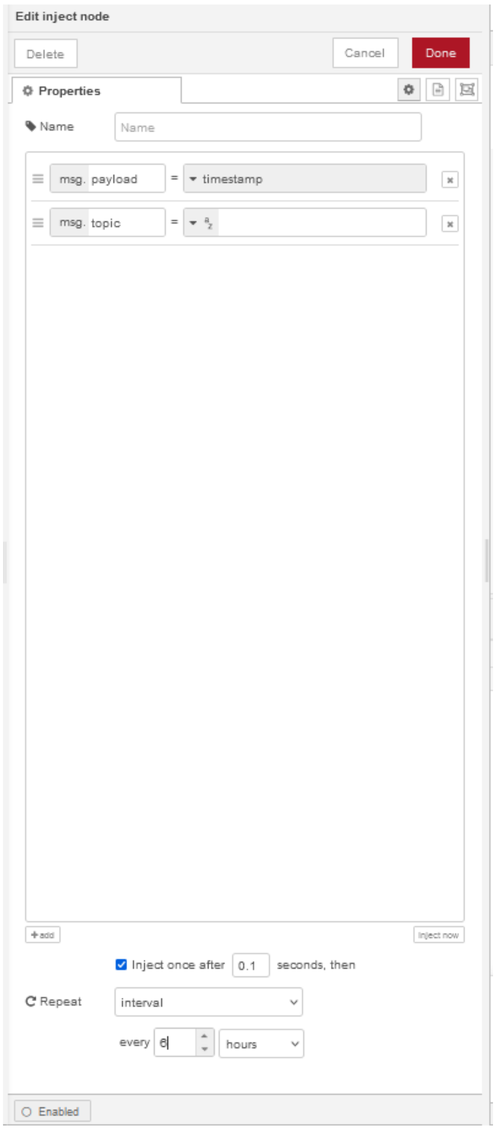


Figure 5 – Change the time interval for the requests

13. Deploy the entire flow and check the *Debug* window for messages. Correct the issues if any. As a result, the orchestration flow will run the python scripts, monitor and control the smart-plugs automatically. You may close the browser and let the Node-RED service running in the console.

3. Layer 3 - PV-OPTIM Dashboard

3.1. Prerequisites and dependencies

PV-OPTIM Layer 3 requires Python 3 and the following libraries: *pandas, numpy, scikit-learn, xgboost, matplotlib, mysql.connector or mysqlclient, urllib, pytz, flask, flask_sqlalchemy, flask_wtf, wtforms, WTForms-Alchemy, pymysql, flask_login, flask-bcrypt*.

First, you need to configure Layer 2 before using Layer 3. So, please follow section 2 to set-up and configure Layer 2.

3.2. Configuration

Edit the *run.py* file located in the HR folder of Layer 3 and edit the IP and the port on which the application will run. By default, the application will run on localhost:5000.

3.3. Deployment

Run the application (execute *run.py*) and access the dashboard on the web browser (figure 6).

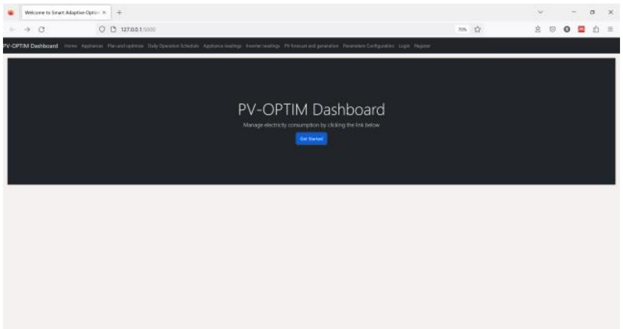


Figure 6 – PV-OPTIM home page

If you loaded the sample data in step 2.2, you can login with the default user account: *pv_optim/pv_optim1234*.

To access the sample data, click *Get Started* and then login with the above credentials.

To create an account, select Register from the main menu and provide an username and password. The credentials will be saved into the database in table T_USERS.

3.3.1. Appliances page

After login, the Appliances page is shown (figure 7) and you can add a new appliance or update the existing ones (in case you load the sample data). The appliances info are saved in the database table T_APPLIANCES.

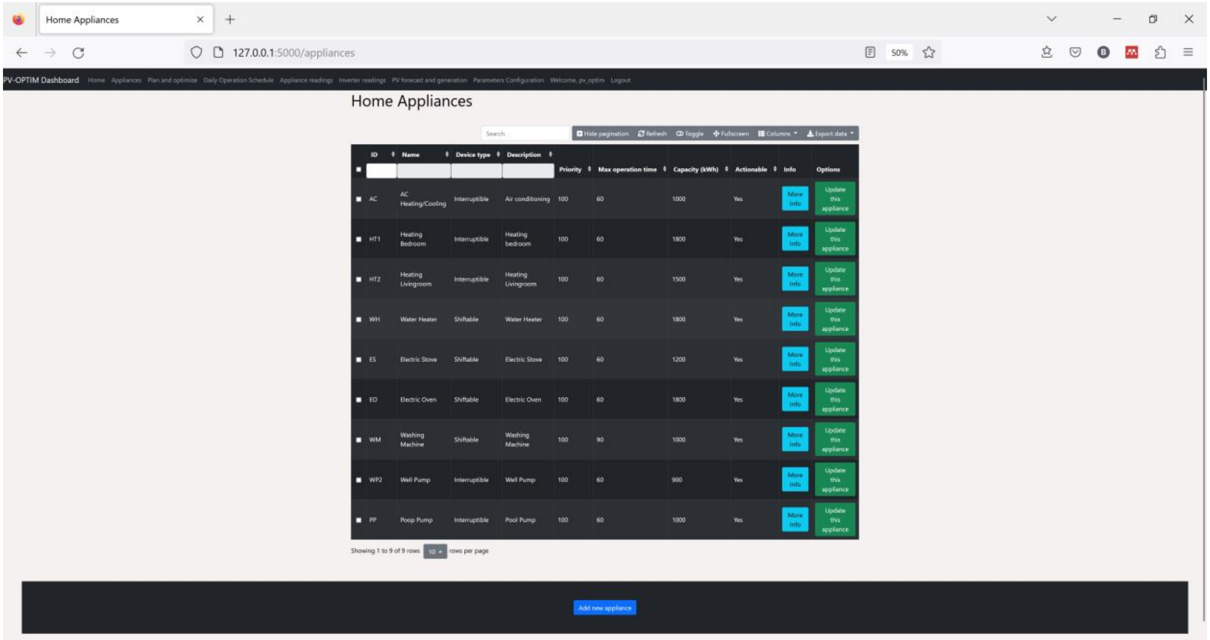
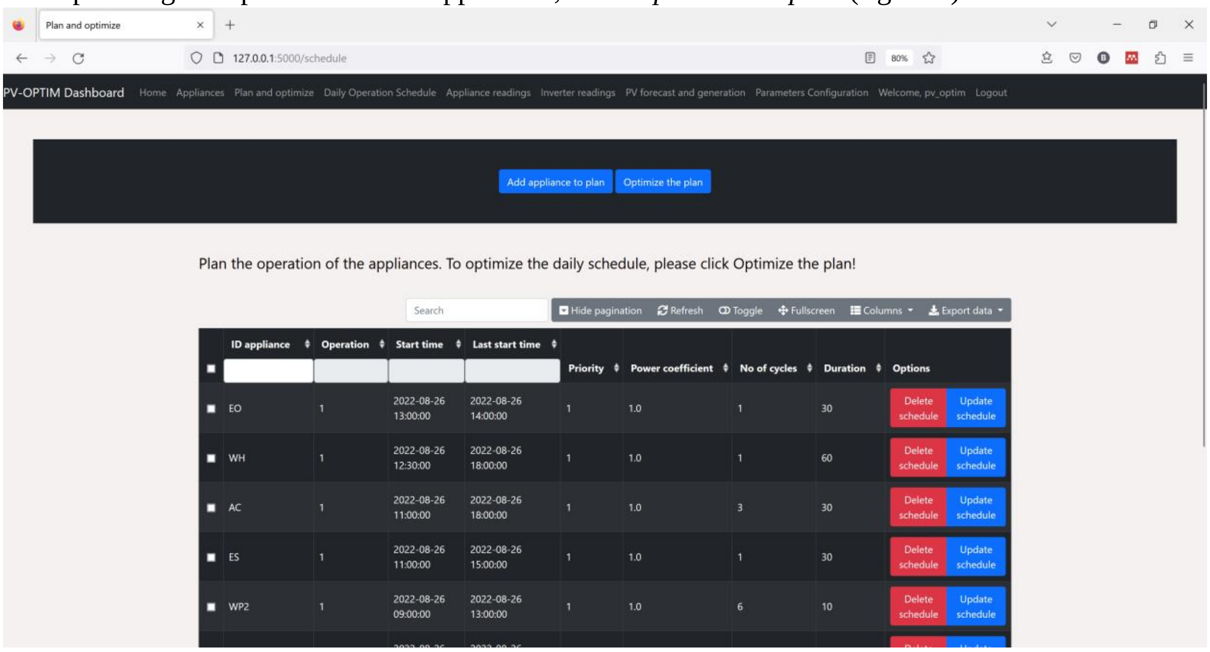


Figure 7 – Appliances page

3.3.2. Plan and optimize page

To plan the operation of the appliances on a specific day (day-ahead), click on *Add appliance to plan* and provide your preferences regarding the *start time*, *end time*, *number of cycles* (number of operations) and *duration*. If you plan to use an appliance with less than its full capacity, then set *Maximum Power coefficient* between 0.1 and 1. Click Save Schedule to return.

After planning the operations of the appliances, click *Optimize the plan* (figure 8).



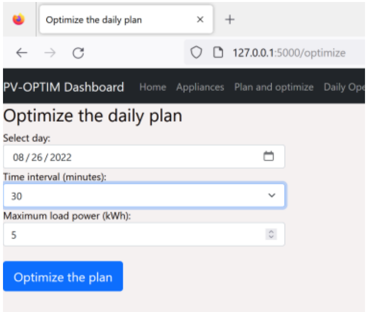


Figure 8 – Optimize the plan

Select day, time interval for optimization (in minutes) and maximum power load (in kW) accepted by your system. In case you loaded the sample data, you may select 26th of August 2022 or 29th of July 2022 to see an optimized schedule (figure 9).

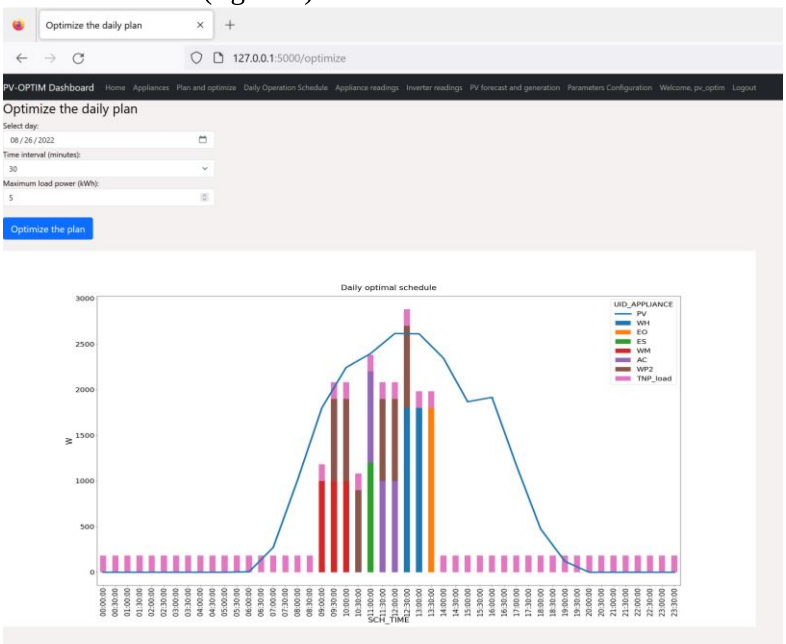


Figure 9 – See the optimal schedule on chart

The optimal schedule is saved into the database and can be accessed and edit (optionally) in the *Daily operation Schedule* page (see section 3.3.3).

3.3.3. Daily Operation Schedule page

After optimization, the optimal schedule can be see and updated. Click on Edit/Confirm schedule to make adjustments of the start time, end time or maximum end time. To enable real time control, choose Yes in the Set active: list (figure 10). To actually control an appliance you need to configure properly the orchestration flow as described in section 2.6.

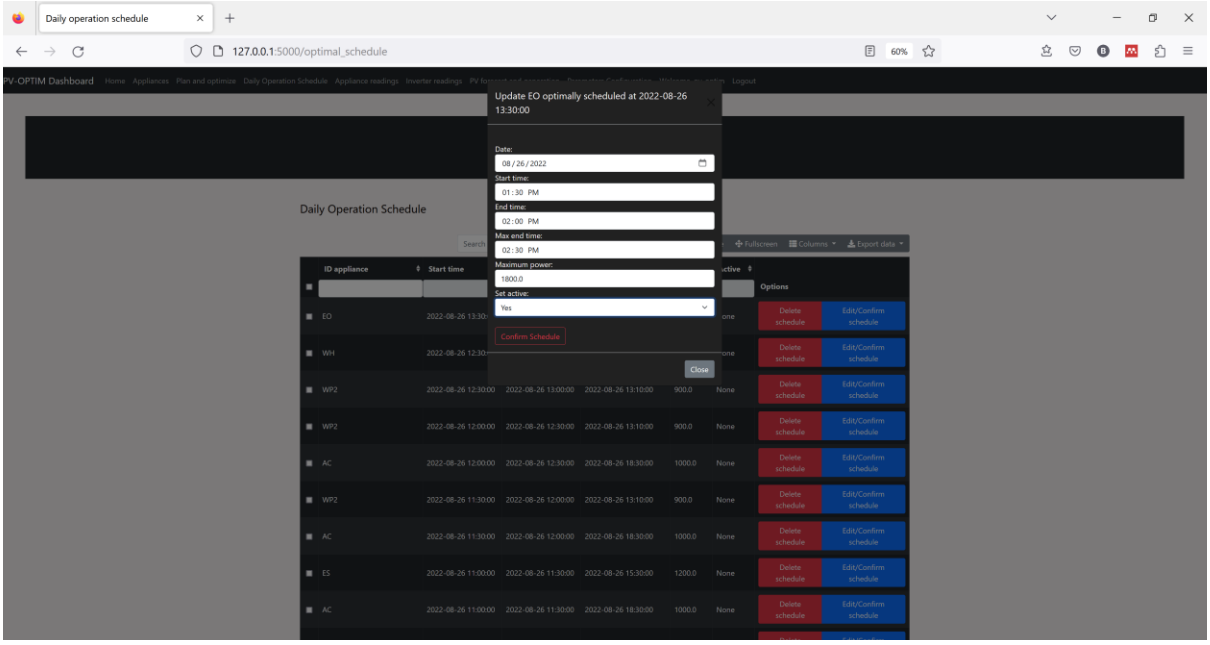


Figure 10 – Edit the optimal schedule to activate real time control for an appliance

In case you need to add a new appliance to the daily schedule, click on *Add appliance to the daily operation schedule* and provide the details regarding start time, end time.

The daily schedule is automatically saved in the database and will be controlled by *PVControl* in case you configure the orchestration flow in section 2.2.

3.3.4. Appliance readings page

To see the readings for an appliance, select a day and an appliance from the list and click on *Show readings*. The readings are collected only for the appliances connected to the smart-plugs configured in section 2.2.

3.3.5. Inverter readings page

To see the PV generation, load and battery SOC (if existing), select a day and click *Show readings* (figure 11). In case you loaded the sample data, you can select a day between February-August 2022.

Figure 11 – Inverter readings page

3.3.6. PV Forecast and generation page

To display a comparison between the PV output and the forecast, select a day and click *Show readings* (figure 12).

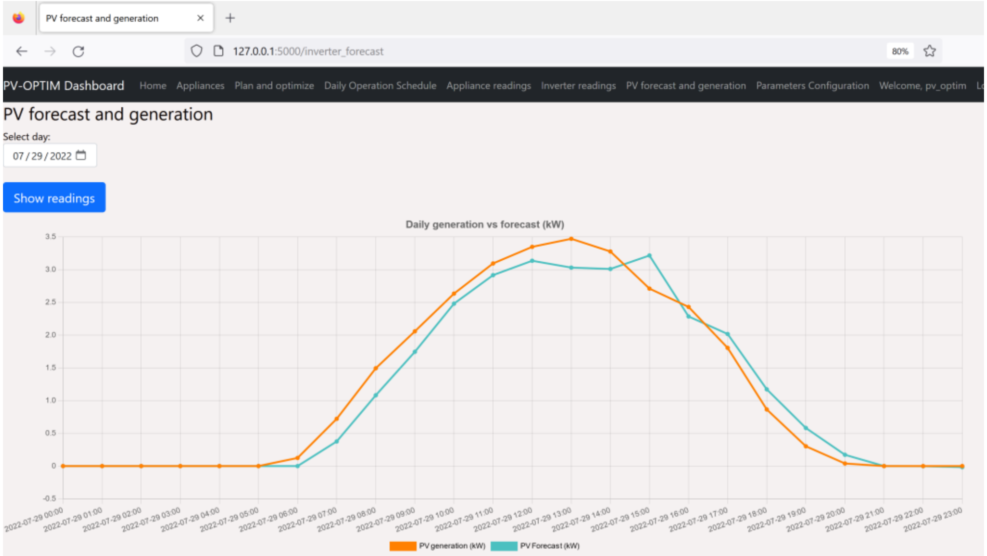


Figure 12 – Comparison between hourly forecast and generation

In the bottom of the page, the estimated PV power is provided as a minimum, average and maximum value (figure 13).

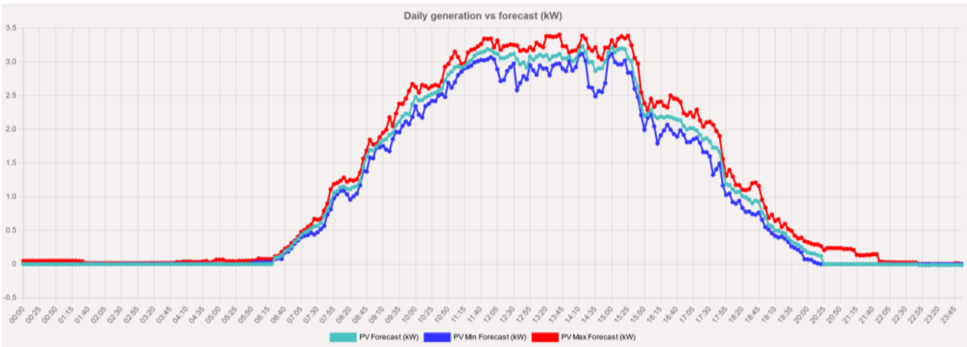


Figure 13 – Estimated values of the PV output (minimum, average and maximum)

3.3.7. Parameters Configuration page

The real time control (PV-OPTIM Control) is using the following parameters to decide whether to switch on/off appliances (figure 14):

- *papp_to_control* – the minimum value (W) of an appliance power that will be controlled. Devices with consumption below the specified value will not be turned off;
- *pbat_discharge* – The power limit from battery (W) that is allowed for the consumption. If the total load exceeds this value, then some appliances will be switched off;
- *sasm_control* – To enable PV-OPTIM Control set its value to 1, to disable it set the value to 0;
- *sasm_load_rate* – The power limit (W) allowed to exceed the PV generation. If the total load exceeds this value, then some appliances will be switched off;

- *sasm_soc_charged* – The SOC state (%) that allows extra loads when battery is charging;
- *sasm_soc_discharged* – The SOC state (%) that allows extra loads when battery is discharging.

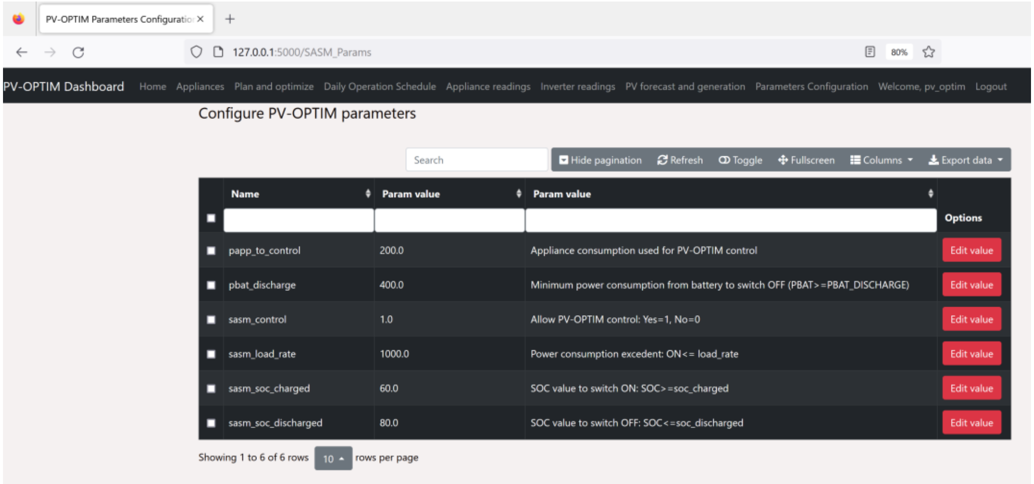


Figure 14 – Configure PV-OPTIM Control parameters