# Improving HVL SolarLab's Performance: Energy Management & PV Production Forecast Model

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## SolarLab Overview

HVL Bergen's SolarLab is an **off-grid** passive house with a PV installation operating in a northern climate that simulates a traditional **Norwegian "hytte"** (cabin).

The SolarLab is equipped with:

- 1680 Wp of monocrystalline PVs
- 1650 Wp of polycrystalline PVs
- 1440 Wp of vertical east/west facing PVs
- 14.40 kWh of lithium battery
- 3 pilotable loads (2 car chargers and 1 heater)
- 1 pyranometer (data available at www.solarlab.online)

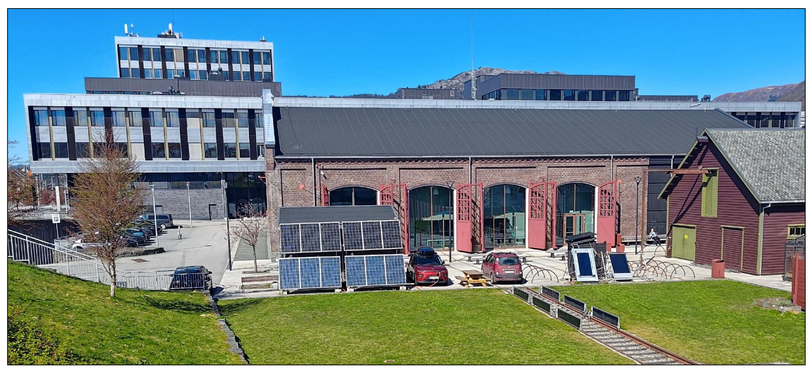


*Fig 1. The SolarLab installations close to the HVL buildings*

The SolarLab is an educational project. It has been upgraded by students over the past 5 years. The goal of the installations is to produce **data for student projects** or researchers, such as irradiance or PV production data.

## Objectives

Norway is not known for is PV production potential due to its climate, but recent study shows that a **huge PV potential** exist in for **decentralised applications** like remote cabins. [1]

To counterbalance and absorb the fluctuations in energy production between summer and winter, it is important to have optimised off-grid systems. [2]

The work carried out during the MSRI was therefore intended to **improve and optimise the SolarLab**. Here are some of the objectives:

- Optimisation of PV production
- Automation of energy management
- Managing system crashes and automating reboots
- Data analysis
- PV production forecast model
- And other minor modification

Some of the work done during this MSRI are detailed in the following sections.

## Optimisation of PV production

Initially, the PV string configuration (two parallel strings of three panels in series) caused the **inverters** (1 and 2) to become **overloaded** (current of 17.5A > 10A limit), **limiting output** to a plateau of 950–1000 W instead of the theoretical 1600 W.

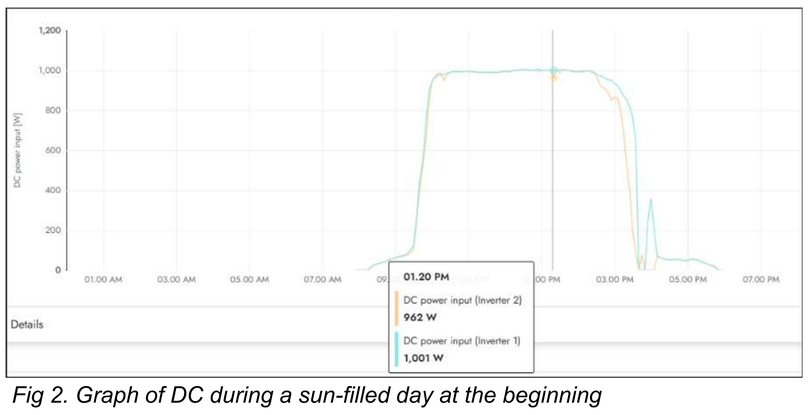



*Fig 2. Graph of DC during a sun-filled day at the beginning*

Following an analysis of the datasheets and calculations, the solution was a **complete strings reconfiguration** (one string of six panels).

By doing so, the DC **current was halved to 8.75A** and the voltage doubled (both still within the inverter range). The result was a **bell-shaped output curve** with a peak of 1,500–1,600 W per inverter, representing a significant increase in total peak power (**from 2,000 W to 3,000 W**).

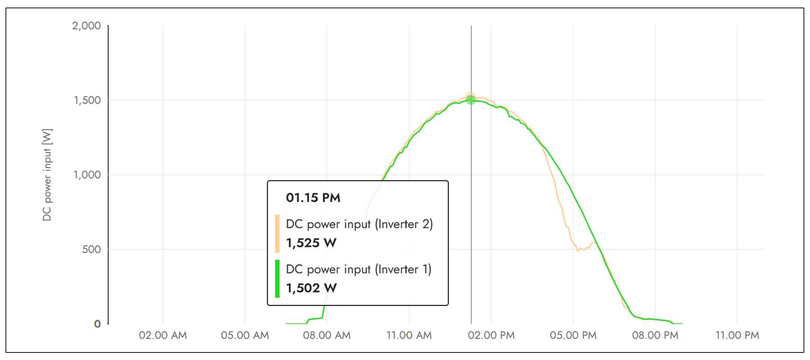



*Fig 3. Graph of DC during a sun-filled day after modifications*

## PV Production Forecast Model

SolarLab initially operated without a forecasting model, which limited the ability to anticipate energy production. A model using **GPS-coordinates**, range of the study, **ground albedo** [4][5], PV implementation characteristics was developed using Excel. The model calculates the sun position in the sky, incidence angle with PVs and direct, diffuse and albedo radiations.

At first a **linear model** between radiation received by PVs and power output, was used:

$$power\ output = total\ radiation\ received\ by\ PV * PV\ area * efficiency$$

*Eq 1. First version of the model, a linear one (V1)*

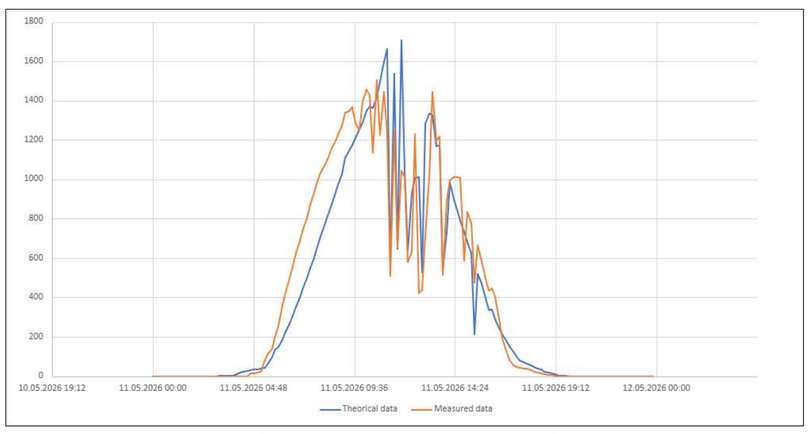



*Fig 4. Graph comparing theoretical and measured output of mono PV (W)*

This model tends to **underestimate** the production when the **sun is full**, and then to **overestimate** it when the **light is low**.

Linear models have some limitations; for example, they are unable to capture **non-linearities**, such as saturation at high irradiance or variations in panel efficiency as a function of temperature and irradiance. [6]

To improve this, a **2nd degree polynomial model** was introduced:

$$power\ output\ = \left(a * total\ radiation\ received\ by\ PV^2 + b * total\ radiation\ received\ by\ PV\right) * PV\ area * efficiency$$

*Eq 2. Second version of the model, a 2nd polynomial one (V2)*

Using an **Excel solver**, the optimal coefficients have been determined: : $a = -0.0003$ and $b = 1.2866$.

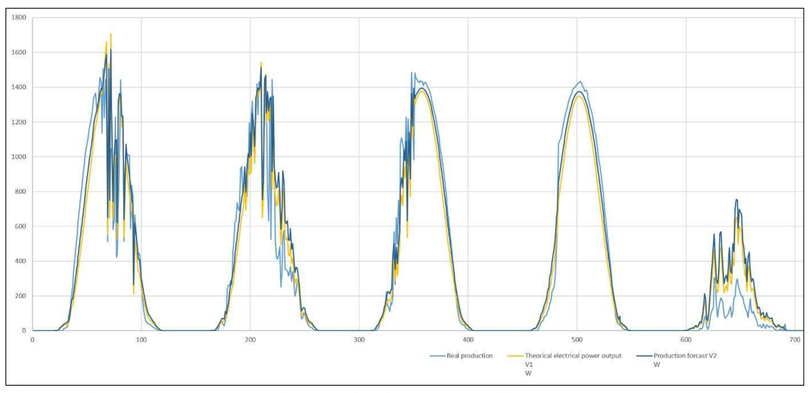



*Fig 5. Graph comparing actual output, V1 and V2 model for mono PV*

| Criteria: \ Model: | Linear (V1) | 2nd degree polynomial (V2) | Variation |
|---|---|---|---|
| Correlation coeffcient (\|R\|) | 97.16 % | 97.47 % | + 0.31 % |
| Share of variance ($R^2$) | 94.45 % | 95.01 % | + 0.56 % |
| Average error | - 9.36 % | - 1.87 % | - 7.49 % |
| RMSE | 136.33W | 117.65W | - 18.68W |
| Relative RMSE | 33.75 % | 28.63 % | - 5.12 % |

*Tab 1. V1 and V2 model accuracy evaluation*

This second model **improves the forecast**. The model still suffers, to a lesser extent, the same issue as the first model.

This forecast system performs well over the course of the day, but **poorly when it comes to rapid fluctuations** in irradiance. The reason: sampling time difference between sources.

To improve even more the model, a possibility would be to use a **model with thresholds** to best reflect the actual conditions of the panels.

## Automation of energy management

In an off-grid system, it is important to **manage energy usage**. This is because when the battery is fully charged, power generation stops, leading to a **loss of energy**. On the other hand, excessive energy consumption forces the **emergency generator to start up**.

Previously, the controllable loads (car charging points and the heater) were **controlled manually** via the Shelly app. This method was not very scalable and prone to human error [2].

Inspired by **rule-based strategies** (fixed SOC threshold) [3], a Python system was developed to automat the SolarLab's energy management.

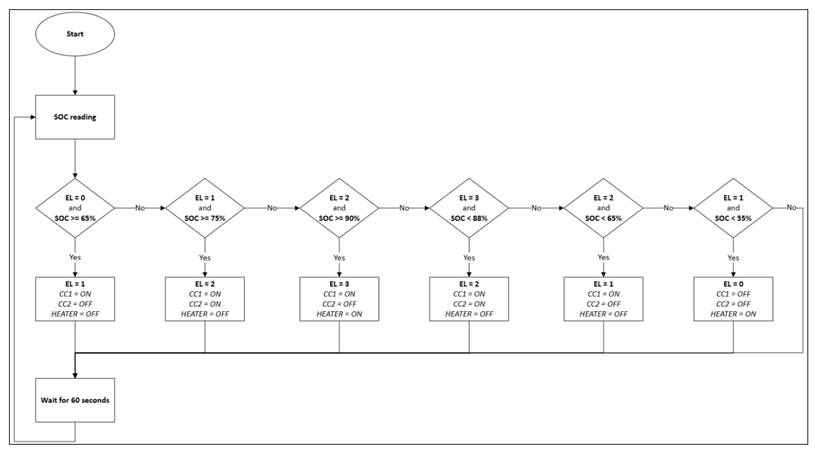
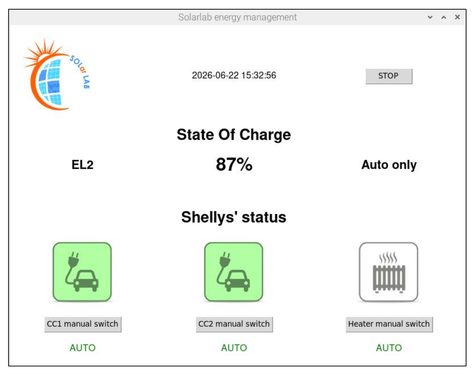



*Fig 6. Algorithm diagram of the automated energy management system*

The script runs **every 60s**. The principle behind the Python code is as follows:

- SOC reading by Modbus TCP
- Definition of energy levels (EL) with **hysteresis logic**
- Control of the Shelly devices via REST API




A **Graphical User Interface** (GUI) was also created to give the user some key information.

*Fig 7. Energy management GUIs*

A way to improve this system will be to **implement the production forecast** model within the automation. This will allow the use of variable SOC threshold.




*Fig 8. Production forecast integration logic*

## Conclusion

The improvements made to the SolarLab during this MSRI, such as PV strings reconfiguration, production forecast model and automated energy management, have enabled unprecedented **energy self-sufficiency**.

Indeed, the SolarLab has now a **more optimised production**, a better resource management and an increased resilience to outages. These simple yet effective solutions pave the way for **future developments**, such as the integration of dynamic thresholds for even smarter management.

## References

[1] Mæhlum, E., et al. (2024). Technical potential of solar energy in buildings across Norway: capacity and demand. Solar Energy.

[2] Li, W., et al. (2020). Optimal Strategies in Home Energy Management System Integrating Solar Power, Energy Storage, and Vehicle-to-Grid for Grid Support and Energy Efficiency. IEEE Access.

[3] Khan, M., et al. (2023). Energy management strategies of hybrid renewable energy systems: A review. Energy Exploration & Exploitation.

[4] Pavlovic, T., et al. (2023). Determination of the Installation Efficiency of Vertical Stationary Photovoltaic Modules with a Double-Sided "East–West"-Oriented Solar Panel. Energies.

[5] Al-Nuaimi, A., et al. (2022). East-west oriented photovoltaic power systems: model, benefits and technical evaluation. Renewable Energy.

[6] López, A., et al. (2025). Analysis of the impact of irradiance and temperature on photovoltaic production: A statistical and machine learning approach. Journal of Cleaner Production.