SmarSolar: PV production forecast used by the Swiss team, winner of the U.S. Department of Energy Solar Decathlon competition 2017 Denver, Colorado

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Abstract. The article introduces the SmarSolar platform which merges customer management relations tools and Photovoltaic forecast services. We will present the modelling hypothesis as well as the validation of the model. The forecast service has been successfully used by the Swiss team in the Solar decathlon Competition US 2017 who won the competition. In a more general perspective, since all data and results are centralized in a database with cloud computing services, the platform can be used by installation owners to optimize their self-consumption as well as by electrical producers managing their park of PV installations and optimizing the grid load.

1 Introduction

1.1 Optimizing local photovoltaics production and managing Smart grid
Harvesting energy produced by PV systems at district grid scale as well as optimizing energy self-consumption in buildings will rely on accurate system modelisation, hourly simulations and measurements feedback. The building managers, owners and electrical distributors, must have access to new services such as PV energy production forecast as well as daily diagnostic of the PV systems to avoid revenue losses. Furthermore, thanks to energy simulations and production forecast, they will be able to optimize the building microgrid and the district grid by introducing a proper electrical energy storage capacity driven by suitable algorithms. Those approaches have significant perspectives of reduction of carbon emission of buildings [1][2].

1.2 The Swiss house, US Solar Decathlon competition 2017
The Swiss Living Challenge (www.swiss-living-challenge.ch) is the project which designed the Swiss house “The NeighborHub” to participate in the Department of Energy Solar Decathlon 2017 Denver Colorado (www.solardecathlon.gov). The goal of this student competition is to design and build an innovative self-consumption sun-powered house [3]. The NeighborHub has been developed by more than 50 students from different backgrounds (engineering, architecture, communication, marketing, etc.). Boosted by a strong collaboration between the École polytechnique fédérale de Lausanne (EPFL), the School of Engineering and Architecture of Fribourg (HEIA-FR), the Geneva School of Art and Design of Geneva (HEAD) and the University of Fribourg (UNIFR), the Swiss team won the competition. The Swiss team obtained the first place in architecture, first place in engineering, and first place in water management. Thanks to an efficient PV system, energy production forecast and energy management algorithm with battery storage, the first place has been also obtained in the energy balance contest.

2 The platform SmarSOLAR

2.1 Cloud computing approach
The platform SmarSOLAR [4] is a Software as a Service (SaaS) which offers new services for the management of PV installations. The platform proposes a professional graphical interface to register and manage the customer informations, set-up the PV installation as well as to visualalize the data with
analysis tools, see illustration images taken from a web browser in figure 1. Towards predictive maintenance of PV systems as well as online diagnostics in case of efficiency drop, one must compare expected solar production obtained with weather data forecast with the actual production measurements. Thanks to this comparison, financial risks can be prevented by detecting hidden damages, system’s drifts, by proposing right time to use warranty and suggestions to optimize systems. Typically, the platform sends alerts to the customer in case of production drop.

Built on the cloud approach illustrated in figure 2, SmarSOLAR is ready for other services such as grid optimization with PV productions and electrical storage. All data are stored in a common database with data flux input and data flux output capabilities using suitable extract load transform tools (ETL) which can be customized with the customer system (inverters, datalogger, counter, database…). Finally, the platform includes the standard functionalities of Customer Management Relation and Enterprise Resource Planning tools (CRM/ERP) such as customer account management with billing, mailing, dashboard and report.

![Figure 1](image1.jpg)  
*Figure 1.* (a) SmarSOLAR [4] Graphical Interface from web browser, Salesforces based, in collaboration with the Swiss based company SMARSYS, sponsor Bronze Swiss Living challenge. The Platform merges CRM services and photovoltaic parameters setting and result analysis (b) typical visualization results

![Figure 2](image2.jpg)  
*Figure 2.* Cloud computing approach of the platform SmarSOLAR

### 2.2 Modeling of the PV system

The PV production simulation and forecast service required an accurate modelling of the PV system:

- Installation location for sun path, orientation and inclination of panels.
- Type of integration (free natural ventilation, integration on facades)
- PV module supplier characteristics, efficiency curve as a function of irradiance
- Inverter: supplier characteristics, efficiency curve as a function of output power
- Electrical and optical losses
- Hourly weather data: ambient temperature, global and diffuse sun irradiance with sky models and shading curve, albedo calculations.
As a simplified model, the output power $P_m$ of an installation with module efficiency $\eta_{STC}$ at STC conditions AM1.5 1000W/m², with surface area $A$ and under operating conditions module temperature $T_{module}$, global irradiance $G$ and ambient temperature $T_{ambient}$ can expressed as follows:

$$P_m = A \times \eta_{STC} \times \eta_1(T_{module}) \times \eta_2(G, \phi) \times G \times \cos(\phi) \ (W)$$

$$\eta_1 = 1 - \lambda(T_{module} - 25)$$

$$T_{module} = T_{ambient} + \frac{G}{800} \times (NOCT - 20) \ (^\circ C)$$

where $\eta_1$ a linear function as function of cell temperature coefficient $\lambda$ (%/°C), NOCT the nominal operating conditions temperature, $\phi$ the angle between direct sun rays and panels plan orientation, and $\eta_2$ the product of multiple efficiency curves taking into account the optical, panel, and inverter efficiency curves. All parameters as well as the non-linear function $\eta_2$ can with be manually introduced in the platform and default values are also proposed when choosing technologies or commercial product components. Customized product can therefore be set-up in the platform.

The model provides simulations by using historical hourly weather data that can be obtained from services such as Meteosuisse and IDAWEB portal [5]. The model can also provide energy production forecast by using meteorological forecast data instead of historical data, which can be obtained from other web service such as meteotest [5] with the help of an API REST.

2.3 Model validation with annual energy yield

PV simulations and forecast of about thirty installations in western Switzerland have been computed for the year 2009-2012. The validation of the PV model has been done using weather hourly historical data Meteosuisse of these existing reference installations and measured production by energy counters. Results for annual production for two installations in Morges 50 kWp (orientation south 180°, panel inclination 20°) and Bursins 24 kWp (orientation south 180°, panel inclination 20°) are presented in figure 3. As shown on graphics, simulations and measurements have a good matching over the four analysed years. Plotting and performing a linear regression of the hourly results of simulations and measurements have been performed. The coefficient of determination R-squared 0.985 and 0.988 are obtained for Morges and Bursins respectively. Taking into consideration the 30 installations, an average coefficient R-squared of 0.93 has been obtained (not shown).

![Figure 3](image)

**Figure 3.** Comparison of production simulation and measured production with counter. Results are also compared with installer or PVSystem calculations. (Left) 24 kWp installation in Bursins Switzerland; (right) 50 kWp installation in Morges Switzerland.

2.4 Diagnostics capabilities

By adjusting parameters in the model such as the efficiency curve $\eta_2$ as a function of irradiance, one can take into consideration possible defects in modules and other possible causes of malfunctions of a PV system: simulate the effect of soiling, micro-cracks with shunt resistance at low illumination, serial resistance under high illumination, inverter threshold.
The relative annual energy yield losses can be estimated by simulations. An example of relative energy losses for the installation of 50 kWp (Morges) has been calculated and results are reported in Table 1. The calculated total yearly estimated loss is 14.8%. The main interest for the installation owner is to compare the real time simulations with the energy measurements on site, and thus detect a real time efficiency drop and not after one year of production.

### Table 1. Simulation of various production losses with various scenario for a typical PV installation (Morges installation)

| Simulation of annual energy losses with malfunction causes | Period event | Influence | Frequency (days) | Instantaneous loss | Production Year Loss |
|------------------------------------------------------------|--------------|-----------|------------------|--------------------|---------------------|
| Snow                                                       | Nov-Feb      | Linear over day | 7                | 100%               | -1.4%               |
| Soiling                                                    | Year         | Linear over day | 120              | 10%                | -3.3%               |
| Soiling, micro shadowing                                   | Year         | Linear over day | 10               | 20%                | -0.5%               |
| Cable inverters                                            | Summer high Irrad. | Linear over day | 1                | 100%               | -0.5%               |
| Micro-cracks                                               | Year         | Low irrad.     | 365              | 2.31%              | -2.3%               |
| Serial resistance                                          | Year         | High irrad.    | 365              | 0.66%              | -0.7%               |
| Invertor threshold                                         | Year         | Day start/end, cloudy | 365     | 4.93%              | -4.9%               |
| Max power limited                                          | Year         | High irrad.    | 365              | 1.23%              | -1.2%               |
| Shadow (tree, building, mountains)                         | Year         | Not full day optimum | 365        |                    | -14.9%              |

### 2.5 Microgrid and smart-grid capabilities

Hourly data of production simulation, production forecast and measurements are stored in a common data base SmarSOLAR. Since data are integrated in a CRM platform (SalesForce), with native and complete powerful digital tool functions, aggregated data from a park of installation of a specific owner are easily retrieved. A local owner can optimize his self-production, and an energy distributor can forecast photovoltaics energy peaks and drop on the grid as well as reduce the carbon footprint on the grid thanks to PV installations and energy storage [1][2].

### 3 Hourly Simulations of the Swiss team house

#### 3.1 The PV system

#### 3.1.1 The strategy to produce with a multi-oriented façade

Instead of conventional roof positioning with optimized tilt, the Swiss house wanted to showcase how Building-integrated photovoltaics (BIPV) on façades could answer to electricity production on densified buildings [6][7][8]. Therefore, the South, West and East facades have been covered with BIPV elements (47.2 m²). Thanks to the movable doors supporting PV panels with an horizontal inclination 17°, the production will be particularly boosted in the summer time and in the mid-season. The advantage to use East and West facades is to slightly increase production in the morning and in the evening respectively, thus improving the self-sufficiency of the house.

The arrangement of the PV system, with different facades, varying inclinations of panels, was particularly interesting from the modeling point of view. The accuracy of the model has been tested by comparing measurements and production simulations.

#### 3.1.2 PV panels and power optimizers

The installed power is 9’715 kWp which was close to the maximum of 10 kWp allowed by the competition. High efficiency monocristalline panels Sunpower X21-335-BLK black have been installed on the three facades South, East and West, see figure. 4.
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Figure 4. (Left) Doors of the extended skin have multiple functions: solar protection, natural ventilation and PV production; (right) PV layout the 3 strings on the 3 facades including power optimizers and inverters Solar edge connected with the Sunpower X21-335-BLK black panels.

Because of the three different facade orientations as well as the variable inclination of the opening gates (see figure 4 (a.), one inverter with one string per façade has been installed, i.e three inverters in total. To overcome shadowing issues and the problem of current-voltage mismatch between panels of a same string, power optimizers have been connected to each panel. The use of power optimizers has also the advantage to reduce the efficiency drop due to any shadow caused by surrounding buildings and the opening gates. The Solaredge system comprises 29 DC-DC power optimizers P404-5R-M4M RM, 1 DC/AC inverter SE 3500H for the South string and two inverters SE2200H for the East and West strings, see figure 4. (b) for the PV layout on facades.

3.2 Hourly simulations

The hourly PV simulations take into account the measured meteorological irradiation and temperature from the closest meteorological station Fribourg / Posieux (meteosuisse data 2017), without shadowing. Simulations have been compared with the production measurements at Fribourg, see figure 5 (a). They have been performed for the two configurations: closed and open doors. During the period considered, the doors have been opened and closed for building commissioning purposes. On the 27 and 28th of May, the doors were open the whole day. It is worth noting that the measured production curve clearly lies between the two simulations curves corresponding to gate configurations, with a good matching on the 27 and 28th of May.

In figure 5 (b), productions and simulations per facade are shown for the 28th of May. Simulations reproduce well the measured production. The relative deteriorating of weather in the afternoon is revealed by both the simulations and the measurements. The East measured production can be clearly identified in the morning as well as the opening of south gates at 7h with a vertical positive shift of power (black dashed line).

Figure 5. (left) Comparison of PV simulations with measured output production (UTC time). The blue and green curves correspond to the open gate/closed gate configurations respectively, measurements in red; (right) Simulations and measurements per facade 28.05.17.
4 Conclusions and perspectives
The modeling of the PV system used in the cloud platform SmarSOLAR has been validated by comparing annual energy yields of thirty references installations in western Switzerland. The platform can be used as a planning tool with annual yield calculations, and the comparison of the PV power measurements with the hourly PV simulations allows to detect an efficiency drop of the PV installation in real time. The setting of all PV system parameters including non-linear efficiency curves of panels and inverters, allows a good matching between energy production simulations and the actual performance of the system with the energy measurements. Moreover, typical production yearly losses can be simulated over the year, which can be a good basis for the diagnostic of malfunctions of PV systems a posteriori. Further developments are planned such as implementing a machine learning algorithm to identify patterns in the production history and better match the monitored values.

The Swiss house US Solar Decathlon 2017 has been a concrete case study for the exploitation of PV simulations and forecast production. The whole PV system has been modeled in SmarSOLAR, the opening gates equipped with solar panels of the Swiss house has been revealed very effective to boost the production, with the measurements confirming the results simulations. During the competition, the production forecast has been used with success to optimize the self-consumption of the building and the Swiss team won the energy balance contests. The cloud approach of the platform offers an access to PV electrical production forecast which can be used to optimize self-consumption of small building owners as well as to optimize the district grid at a broader scale.

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