Fit for Solar Power - Computer-Assisted Planning of Regional Power Grids

Thomas Rist
Faculty of Computer Science
University of Applied Sciences Augsburg
Augsburg, Germany
e-mail: tr@rz.fh-augsburg.de

Michael Wiest
Faculty of Electrical Engineering
University of Applied Sciences Augsburg
Augsburg, Germany
e-mail: michael.wiest@hs-augsburg.de

***Abstract*—Additional power feed-in by newly installed photovoltaic panels may exceed the available capacity of an existing power grid and can seriously harm grid stability. Grid operators need to consider future scenarios with an increased share of solar power and examine whether the capacity of an existing grid will suffice or whether upgrades or extensions need to be made. In this contribution, we present IPDS, an Interactive Planning tool, which assists a grid planner in making predictions about such future scenarios. Starting from a cadastral map that shows the topological structure of an existing power grid, the tool estimates the yet unused roof surfaces of buildings, which are connected to a certain grid circuit. In turn, this estimation can be used to estimated future additional power feed-in.**

Keywords- Renewable energy - energy source integration models, network/grid plannin, integration of solar technologies.

I. PROBLEM STATEMENT

Due to favorable funding conditions, Germany recorded a rapid increase in photovoltaic (PV) solar power plants during the last years. According to a monthly publication of the German Federal Network Agency [1], the total installed capacity of all funded and registered PV installations reached a value of 34,186 MWp in June 2013. Following forecasts of the German energy industry [2], this development will continue even in case of expected declining public funding.

The increasing share of solar power generation contributes to the implementation of the politically encouraged energy turnaround from fossil fuels to renewable sources. On the other hand, this development challenges grid companies and stake-holders who need to decide on investments into a technically reliable and economically well-dimensioned grid infrastructure.

The capacity of an existing power grid is limited by the maximum load capacity of its components (such as cables and transformers). As a consequence, additional feed-in by newly installed PV panels may exceed available grid capacity and cause severe problems. In order to prepare for counter measures, grid operators need to consider future scenarios with an increased share of solar power and examine whether the capacity of an existing grid will still sufficiently meet the requirements of power quality [3], and if not, which components should be upgraded (e.g., larger cable sizing), or in which way a grid needs to be extended (e.g., additional lines and transformers).

Calculations of this kind are usually performed with the assistance of a dedicated power system analysis software, such as PowerFactory [4]. Typically, such programs rely on schematic maps to display local wiring together with other grid components, such as transformers, of a concrete power grid. However, calculations are performed on the provided input data. Since the result of such capacity calculations impacts decision making on whether or not to invest into a certain grid infrastructure, it is decisive that capacity calculation are performed on the basis of accurate assumptions about possible future scenarios. Unfortunately, it is difficult to predict in detail where additional PV sources may appear in the future as the installation of new PV panels is to a great extend in private hands (especially in rural areas by the owners of houses and land). In the sequel, we describe a tool which assists grid operators in making accurate predictions.

II. IPDS - AN INTERACTIVE TOOL FOR PLANNING GRID EXTENSIONS

Interviews with grid operators revealed that the amount of not yet used roof surfaces is a good starting point for making assumptions where new PV panels may appear in the future. Therefore, a grid planner may consult two sources of information: i) a cadastral map that shows the boundaries and ownership of land parcels and buildings together with the topological structure of an existing power grid, and ii) an aerial view (e.g., a street map or an aerial image) for finding out where are roof surfaces which are suitable for additional PV panel installations. Such working practices motivate the development of an interactive tool -called IPDS- that supports the following essential use cases:

A. *Use Case 1: Interactive examination of existing circuits*

As a basic data source we rely on cadastral maps that show the topological structure of an existing power grid. In order to gain some independence from proprietary data representation formats of an underlying drawing tool, or a certain geographic information system, we assume that such maps are available as ready-to-print PDF-documents. To this end, our IPDS tool comprises a PDF-scanner module which turns a static cadastral map into an interactive map view. More precisely, IPDS extracts from the PDF source document both cadastral information, such as buildings and streets, as well as grid components, such as power lines and transformers which may belong to different circuits.

Figure 1. An interacive cadastral map showing boundaries of land parcels and buildings, as well as the structure of an existing power grid.

After completion of the scan process the cadastral map with all grid circuits is displayed in the map-view panel of the IPDS tool (cf. Fig. 1). In addition, IPDS comprises an interactive tree-view showing a hierarchical view of all objects that have been extracted during the scan process. These are the individual power lines circuits (showed in different colors), and all buildings connected to those lines.

There is a cross-reference between the graphically displayed objects in the map-view and the named objects entailed in the tree-view. Since in IPDS's graphical user interface all objects are selectable (via mouse click), the grid planner can easily select or deselect a certain circuit in order to get an overview of the grid structure to be examined. To handle larger maps, the map-viewer also supports zooming-in/out as well as panning.

B. Use Case 2: Estimation of PV energy gain

Starting from the schematic representation of buildings as given by the cadastral map, an estimation of potential additional power feed-in through PV panel installations can be obtained by summing up the map area covered by buildings. However, in a power grid examination task the grid planner should be enabled to easily include and exclude buildings so that a variety of possible scenarios can be considered. To this end, IPDS supports a number of options for selecting objects (i.e., buildings and outhouses):

- *Selection of all buildings* which are connected to a certain grid circuit. This selection can be done using the tree-viewer. There, single circuits appear as colored top-level tree nodes. If selected, all sub-ordinate nodes (i.e., buildings) are selected, too.
- *Selection of a certain building*. In this case, the user simply clicks on the graphical representation of the building in the map view (cf. Fig. 2).
- *Selecting a group of adjacent buildings*. If interested in a certain neighborhood, IPDS allows the user to draw a rectangular frame (or likewise a closed polygonal line) around objects of interest shown in the map-view (cf. Fig. 2). All enclosed objects are considered as selected in proceeding calculations.
- *Exclusion of objects from a group*. In addition, it is possible to exclude a certain object from a group of selected objects. For instance, think of a church or a listed heritage building which should be excluded as an installation of PV panels is very unlikely.

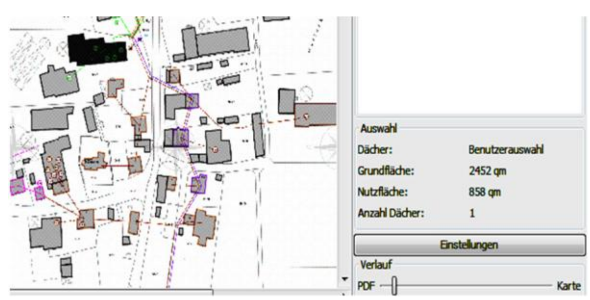

Figure 2. Selection of a single building (marked in black)

 ISBN: 978-1-61208-332-2

Figure 3. Selection of a group of buildings for estimating available roof surface area for additional PV panel installations.

PV-generated energy gain depends on a number of factors, including:

- Surface Area (in square meters) of installed PV panels.
- E_{PV_Type} - the specific solar module efficiency value of a certain PV panel type. This value is usually given in "Watt Peak" measured under standard test conditions (1000 W/m² global radiation, 25 °C module temperature, and air mass factor of 1.5). Sunlight conversion rates of current commercial PV panels typically range between 18% and 21%.
- $E_{Installation}$ - a factor to modify the E_{PV_Type} value based on the specific characteristics of a PV panel installation (i.e., latitude of location, cardinal direction, slope angle). In addition, an accurate value for solar radiation at a certain location can be computed by means of a solar position algorithm (SPA) [5].

For the power grid planner potential maximum values are of highest interest. As a consequence, the maximum available surface area for PV panel installations becomes the crucial variable to be estimated.

As soon as an object selection has been made, IPDS calculates the occupied ground area A_{object} (label "Grundfläche" in Fig. 2 and Fig. 3) of all selected buildings and estimates a potential usage area A_{usage} (label "Nutzfläche" in Fig. 2 and Fig. 3) for additional PV installations. Note that already installed PV-panels are known as they are part of the power grid and thus have reference points on the cadastral map.

We calculate A_{usage} as a certain percentage of A_{object}, i.e., the summed ground area given by the set of marked objects in the map-view. Assuming that in (German) rural villages gable roofs are dominant, and due to skylights, dormers and chimneys, parts of a roof area cannot be used for PV panel installation. Using the tool showed that a default value for A_{usage} may be chosen between 35% and 60%, which is in accordance with values reported in [6]. However, a grid planner is free to adjust this value (IPDS parameter "Nutzfaktor"), e.g., to account for actual roof types and cardinal direction of buildings.

To obtain an estimate for power feed-in generated by PV panels, the estimated usage area must be multiplied by a factor that accounts for the installed PV module efficiency. IPDS allows the grid planner to make specific adjustments of the above mentioned parameters E_{PV_Type} and $E_{Installation.}$ In most cases, for the sake of comparability, a grid planner may leave default settings unchanged when exploring different scenarios.

III. IMPROVING IPDS

The current version of IPDS supports grid planners who examine grids in order to identify necessary grid extensions which are needed for an additional feed-in from anticipated future PV sources. The tool is actually used in a project supported by a regional power company in southern Germany that also maintains power grids of a number of rural villages.

However, feed-back from grid planners who worked with IPDS suggests several improvements and extensions to be made, some of which are briefly discussed in the sequel.

A. Support for data exchange between IPDS and power system analysis software

An obvious inconvenience in the current grid planning workflow is the fact that a grid planner needs to work with two software systems, a power system analysis tool on the one hand, and IPDS on the other hand. While IPDS can be used to estimate the potential future feed-in through additional PV panels for an existing grid circuit, a power system analysis tool is needed to calculate the impact of the additional feed-in on the existing grid circuit.

Vice versa, if changes to the grid structure are made in the power system analysis tool, one would need to incorporate these changes into the grid representation used by IPDS. While technically less challenging, the issue of data exchange between IPDS and commercial power system analysis tools can only be solved in cooperation with the developers of such tools.

B. Improving estimates for PV-usable roof area by means of an aerial image

As elaborated in Section 2, IPDS performs a rough estimate of available roof surface area for additional installations of PV panels. The roof surface area is estimated on the basis of the ground area covered by buildings as indicated in a cadastral map.

Thanks to available map services on the Internet, such as the Google Maps API [7], it is possible to use an aerial image of a region as background in the IPDS map-view panel and superimpose a cadastral map together with a topological power grid visualization. For the purpose of demonstration, we added a Google Maps import function to IPDS that allows to import a map section.

By means of a slider, the transparency value of the satellite image can be continuously adjusted between 100% transparency, i.e., only the cadastral map is visible (left-hand frame of Fig. 4), and 0%, which displays the background map fully saturated. As shown by the right-hand frame of Fig. 4, a value of 20% renders the background map partly visible so that roof shapes are well recognizable.

Such an overlay provides a grid planner with additional information about the actual roof shapes, and thus allows

 ISBN: 978-1-61208-332-2

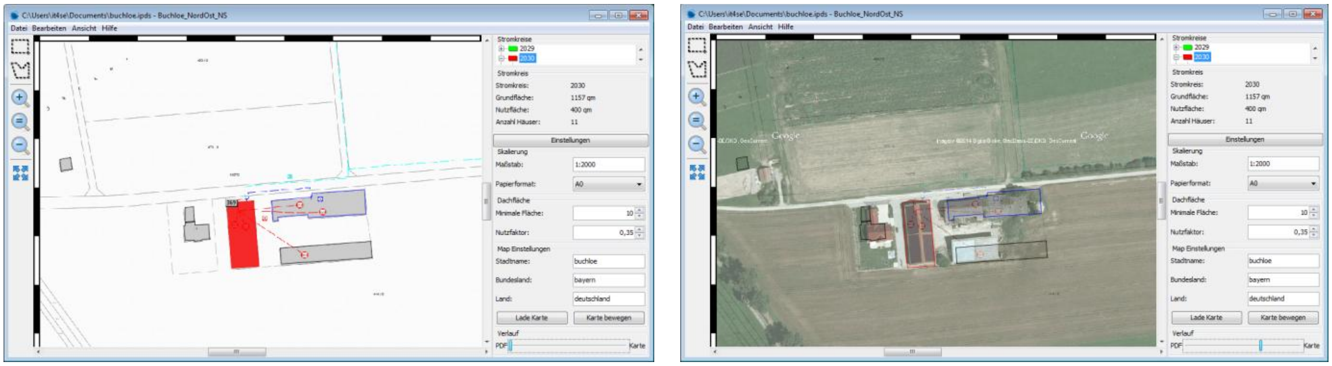

Figure 4. An interactive cadastral map with power lines (left) can be overlaid on a satellite image (retrieved via the Google Maps API).

her/him to set the parameter "Nutzfaktor" (cf. Use Case 2) more accurately.

C. Improving estimates for PV-usable roof area by means of image analysis techniques

In case of an aerial image is available, one can even go a step further and try to deploy image analysis techniques for an automated classification of roof shapes. To this end, we experimented with some simple edge detection filters, such as a Sobel discrete differentiation operator. Fig. 5 shows an aerial view of two gable roofs. After edge detection, roof princes appear as edges that run parallel to a pair of edges which belong to a roof's side boundaries.

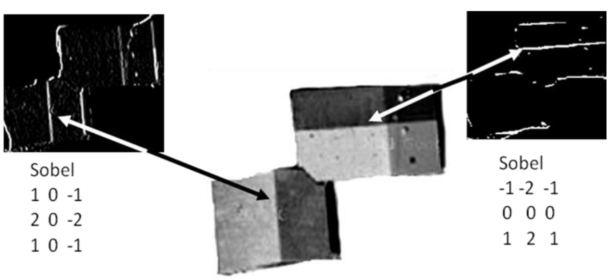

Figure 5. Automated detection of gable roofs by means of Sobel discrete differentiation operators for edge detection. After edge detection, roof princes stand out clearly in the image.

IV. CONCLUSIONS

In this contribution, we have presented IPDS, an interactive tool that assists a power grid planner in making accurate assumptions about potential additions of PV panel installations to an existing grid. In its current version, the tool supports several core functions, foremost the estimation of roof surface area of buildings, which are connected to a certain grid circuit and thus are candidates for additional PV panel installations.

While the tool is currently used and evaluated in the context of rural grid planning tasks, we also sketched some ideas for extension, such as the deployment of image analysis techniques for automated roof shape recognition.

A more accurate estimate of PV-usable roof area constitutes an upper bound for potential additional PV capacity. However, other factors, such as PV panel costs, public funding conditions, and community-specific building regulations are further parameters to be considered, too.

ACKNOWLEDGMENT

IPDS is has been developed in the context of the BMBF-funded German-New Zealand research collaboration IT4SE, grant number 01DR12041. Further information on IT4SE can be found under www.it4se.net

The development of IPDS has been motivated by scenarios as examined in the research project "Network Planning under Uncertainty", which is conducted by the Faculty of Electrical Engineering at the Univ. of Applied Sciences Augsburg in cooperation with the Technical University of Braunschweig.

The presented screenshots have been taken from an IPDS prototype, which was implemented by computer science students during the summer semester 2013. We would like to thank the group members for their dedication and perseverance.

REFERENCES

[1] Bundesneztagentur (German Federal Network Agency). [Online]. Available from: www.bundesnetzagentur.de 2014.02.14.

[2] M. Reichmuth, “Die EEG-Mittelfristprognose bis 2016". Energiewirtschaft-Recht-Technik und Umwelt, Section: Energiewirtschaftliche Tagesfragen. [Online]. Available from: www.et-energie-online.de/Zukunftsfragen/ 2014.02.14.

[3] VDE Association for Electrical, Electronic & Information Technologies, "VDE application rule: VDE-AR-N 4105". [Online]. Available from: www.vde.com/de/fnn/arbeitsgebiete/seiten/n4105.aspx 2014.02.14.

[4] PowerFactory is a product by DIgSILENT GmbH.

[5] I. Reda, A. Andreas, A. Solar Position Algorithm for Solar Radiation Applications. NREL Report No. TP-560-34302, 2003, revised version published January 2008. [Online]. Available from: www.nrel.gov/midc/spa/ 2014.02.14.

[6] G. Kerber "Aufnahmefähigkeit von Niederspannungsverteil-netzen für die Einspeisung aus Photovoltaikkleinanlagen" PhD Dissertation, Technical University Munich, 2011.

[7] Google Developers, "Google Maps API". [Online]. Available from: https://developers.google.com/maps 2014.02.14.