Master's thesis project specification

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Problem definition

Background

PV (photovoltaic) systems are collections of solar panels connected to power inverters, a product which transforms the DC power from solar panels to the grid (AC power). Optistring is a startup building digital inverters that are capable of achieving better efficiency than traditional systems. Part of the existing product is a stream of data containing measurements from all solar panels in the system, making analysis of the system in various aspects possible.

One challenge is to detect when solar panel faults occur, such as broken panels or performance degradation over time. This occurs naturally in cases such as dust accumulation on the panel, preventing the panel from being reached by all the incoming sunlight. Two different kinds of failure conditions in solar panels are relevant: instantaneous power loss due to faulty solar panels, and gradual power degradation over time. In addition to panel faults there might also be decreased power output due to partial shading, which is temporary shading limiting the available solar energy. Partial shading can be assumed to occur as a regular power loss pattern and needs to be separated from the case of panel faults.

Problem statement

Can potential faults in a solar panel, in the context of installations with the specified properties, be detected by studying the available measurements? This includes the capability of differentiating panel faults from partial shading of the panel. The problem is how to perform detection efficiently in the presence of different system configurations, but also geographic and thermal dependencies, since all systems deliver different power curves.

Project goals

Motivation

Faults in solar panels are important to detect due to several reasons. Since faults will lower power production until corrected, there is a direct loss in terms of lost output. The alternative approach to fault detection is having manual supervision requiring constant monitoring by costly service personnel. Finally, it is of interest to determine degradation over time. Since panels typically have a maximum expected degradation over time, as given by the warranty, the panels can be replaced if classified as faulty. Automated analysis is likely more fine-grained and capable of detecting faulty panels to a higher degree.

Target audience

The main target audience interested in the outcome of this project are companies building products in the field of PV power electronics. Fault detection in solar panels is an active research area and

continually evolves, demonstrating an academic interest as well. The main party interested in the results is of course the supervising company, whom are likely to integrate a functional solution into their final product.

In order to understand the report it is suitable to have a background in the PV industry, which will be the targeted reader community. Hence it is important to reflect on practical uses and describe how the solution fits within the whole picture and innovates upon existing solutions, including possible constraints and future work.

The results will be scientifically relevant since the constraints are unique for this project and a specific set of conditions will be surveyed. Previous studies typically involve a uniform set of solar panels and make different kinds of assumptions.

Previous work

The main source of information regarding fault detection will be publicly available research papers. Fault detection is a field in PV power electronics and has seen some recent development, such as systems capable of learning over time. In addition, it is important to understand the different kind of faults that might occur. These will be gathered by surveying specific faults and different kinds of real-life conditions.

The following list of papers provide a starting point of the literature study. Computer science is present to a varying degree but many fault detection papers contain at least an algorithmic description.

Zhao, Ye, et al. *Graph-based semi-supervised learning for fault detection and classification in solar photovoltaic arrays.* Energy Conversion Congress and Exposition (ECCE), 2013 IEEE. IEEE, 2013.

Zhao, Ye, et al. *Decision tree-based fault detection and classification in solar photovoltaic arrays.* Applied Power Electronics Conference and Exposition (APEC), 2012 Twenty-Seventh Annual IEEE. IEEE, 2012.

Chouder, A., and S. Silvestre. *Automatic supervision and fault detection of PV systems based on power losses analysis.* Energy conversion and Management 51.10 (2010): 1929-1937.

Chouder, A., and S. Silvestre. *Analysis model of mismatch power losses in PV systems.* Journal of Solar Energy Engineering 131.2 (2009): 24504.

Stettler, S., et al. *Failure detection routine for grid-connected PV systems as part of the PVSAT-2 project.* Proceedings of the 20th European Photovoltaic Solar Energy Conference & Exhibition, Barcelona, Spain. 2005.

Drews, A., et al. *Monitoring and remote failure detection of grid-connected PV systems based on satellite observations.* Solar Energy 81.4 (2007): 548-564.

Method

The first of the part of the project is the literature study. All of the papers listed as previous work, and possibly more, will be read and understood. This will result in a literature study focused on how these concepts should be applied onto fault detection subject to existing constraints.

The problem statement should be answered by surveying possible approaches to performing classification in continuously changing measurements. This includes understanding how statistical methods are applicable to the problem of classifying the state of solar panels.

Most likely, the two different kind of faults require different methods in order to perform reliable classification. Both cases will however also require research into how to differentiate between partial shading and panel faults. In practice this will be done by reading up on state-of-the-art research and build an understanding of how to attack the problem. Currently there are some candidate approaches

such as outlier detection based on comparing normal distributions, and classification using decision trees.

An important part of the project is to validate and determine the classification performance of the developed method. Due to the nature of panel faults this will require simulation of panel systems. Different kinds of faults will then be injected into the system while the classifier output is monitored. This simulator will be built upon existing data and correspond to an approximation of real-life conditions.

Evaluation

The success of the project can be evaluated by considering the classification performance of the developed methods. This involves running all the classifiers on both the simulated data but also real-life measurements, in order to consider the rate of false-positives and false-negatives. In the end the implemented methods are likely to be limited since for example partial shading can not always be distinguished from faulty panels.

Concretely, the following list of expected performance bounds have been identified. They are applicable assuming that the classifier has a sufficient amount of data available.

- Partial shading shall be classified better than random guessing, assuming that the solar panel is delivering less than expected.

- Sudden power loss should be successfully classified assuming at least a degradation rate of 10% per minute, with no false-positives.

- Degradation measurements should have a maximum percentual error of $\pm 5\%$. Classification should be successful within the same bounds.

Project scope

Limit of scope

The most important scope limitation is that systems should only be studied passively, i.e. the available measurements are used to detect faulty panels. Some technical constraints are present as well:

- The solar panels have 60 or 72 cells built of mono- or poly-crystalline silicon

- The installations have 14 to 24 panels connected within a small geographic area

- The available measurements (from each panel) are: U [1], I [2] and T_{module} [3].

This reflects the consumer market of smaller panel installations with some of the most common panel types. The type of solar panels constrains the possible output power range and defines appropriate parameters for testing. Due to time constraints, the simulation of solar panels will largely be based on existing data streams. These will be used a basis of generating approximate individual panel curves, limiting the amount of effort required.

Available resources

As of today, there are data feeds providing real time measurements of several PV installations in Sweden. This data is accumulated in a central database and can be analyzed. Using this data it will be possible to verify real-life performance of the classification system, primarily to verify that working systems are not classified as faulty.

Additionally there are other sources that can be used to build realistic simulation models, such as measured solar energy over several years.

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[1] Panel voltage at an optimal load
[2] Panel current at an optimal load
[3] Low resolution temperature measurement from within the PV inverter

Project plan

Partial goals

1. Simulation framework capable of injecting faults in solar panels.

2. Classification of sudden power loss in solar panels.

3. Measurement of solar panel degradation over some time period.

4. Identification of partial shading conditions.

5. Classification of partial shading and power degradation.

Time plan

The following points in time have been identified as suitable deadlines. Hand-ins are based on the official schedule established by the thesis group. The numbered headings refer to partial goals described previously. All of the tasks will be executed sequentially.

Background and Theory section complete

Deadline: 2014-02-27
This includes gathering interesting material and doing the literature study. Different kinds of failure conditions should be surveyed and understood in terms of detection.

(1) Simulation framework complete

Deadline: 2014-03-07
The first part of the work will be to establish a simulation framework. This will be heavily based on existing data streams and only serve as an approximation of real-life installations.

Report skeleton complete

Deadline: 2014-03-19
By now the report will have all headings and basic keywords outlined, and should be ready for completion with the established results.

(2) Classification of immediate failures

Deadline: 2014-03-21
This corresponds to detecting sudden power loss from solar panels in the context of a larger system. Simulation will be performed to verify that it works properly and investigate the classification rate.

(3) Measurement of degradation

Deadline: 2014-03-28
Degradation in solar panel performance needs to be measured in order to quantify the state of a panel. This analysis will result in the percentual performance decrease over a given time interval.

(4) Classification of partial shading

Deadline: 2014-04-09
This involves understanding regular patterns in the power output of solar panels. These patterns will then be accounted for in additional analysis of possible faults.

(5) Classification of partial shading and degradation

Deadline: 2014-04-18
A completely working implementation that is capable of detecting faults of the different types. Partial shading should be classified as well, at least with success rate within reasonable expectations.

Preliminary report complete

Deadline: 2014-04-30
Preliminary report with all content included. This will then serve as a basis for improvements based on feedback from the thesis group and other parties.

Report complete

Preliminary deadline: 2014-06-13
Final submission of the completed report.