European Virtual Smart Grid Lab

SES 11814, Deliverable A1300-AD1303 (Annex)

Distributed Micro-Generation: Fuel Cell Model (Software Module)

Daniele Miorandi, CREATE-NET, daniele.miorandi@create-net.org

EIT ICT Labs

1 Objectives

This document provides background information on the fuel cell model, developed and implemented by CREATE-NET for the integration into the joint Virtual Micro-grid Lab (VMGL) project as part of the European Virtual Smart Grid Lab Activity (EVSGL). Beside CREATE-NET, the EVSGL partners KTH, Ericsson, SICS, VTT, and TU Berlin has been contributed to the joint project.

The model has been developed with the following objectives in mind:

- To develop **mathematical models** of **micro-CHP devices** based on data coming from real deployments of solid oxyde fuel cells technology, to be used by other EVSGL partners, most notably by KTH within their optimization framework developed in EVSGL
- To develop **computational models**, based on state-of-art machine learning approaches, for the inclusion of micro-CHP emulated devices within the real-time feedback control loop mechanisms developed by KTH for VMGL.

2 Work Performed

2.1 Data Curation

The dataset used was provided to CREATE-NET by SOFCpower under an NDA agreement. The data refers to the installation located in the town of Roncegno (Trento). The deployment includes three micro-CHP devices, each one with a nominal electrical power of 500W. The plant was formally inaugurated on Jan. 25th, 2012[1]. The data made available by SOFCpower refers to the whole 2012 year.

The data was provided as a mix of Excel and CSV files. More than 50 parameters are monitored and exported by the PLC, with a granularity of 30′. A number of data entries were missing, which can be traced back to malfunctioning in the monitoring and logging system operations.

The data was pre-processed to obtain a consistent format and loaded into a standard SQL database. Visualization and processing was performed using Python.

After an initial discussion with the VMGL project leader, Dr. A. Parisio (KTH), it was decided to take a 'black box' approach to the modeling of micro-CHPs. Accordingly, micro-CHPs would be considered as devices that can be controlled to fulfill a target thermal/electrical load. In this sense the data analysis part focused on the relationship between the input power (gas) and the thermal/electrical power generated.

Both electrical power and input (gas) power were included in the dataset. Inconsistent data includes situations in which the system is consuming power (gas) but not producing any output in terms of electrical power or the ones in which the system is generating power without consuming any[2]. Accordingly, this data was not considered in the subsequent phases of the work.

Data about thermal energy was not explicitly provided in the dataset. A heat meter is included in the plant and data is logged by the PLC. Thermal energy data is measured with a 1 kWh granularity, which represents a big issue for devices of this size. Furthermore, the data presented a number of inconsistencies. From time to time the output data of the heat meter was not correctly logged, to then suddenly get

---

[1] http://www.trentinosviluppo.com/Contenuti-istituzionali/News/News/2012/A-Roncegno-presentata-l-Isola-Cogenerativa-primo-impianto-in-Italia

[2] In reality, a more subtle consideration should apply in terms of the fact that the device does not have an instantaneous reaction to changes in the input power. However this cannot be assessed with the dataset used and would require a much finer sampling granularity.

in sync with the actual value, resulting in long series of zero-power data followed by big jumps. When differentiated to obtain power data, this resulted in a very poor representation of the system's behavior.

To overcome this problem, a spline interpolation routine was executed on the original thermal energy dataset, in order to smooth peaks and mask inconsistent data while maintaining a global coherence. The resulting data was then differentiated and subject to the same cleaning process as done for electrical energy data.

2.2 Mathematical Modeling

The aim of this task was to develop a mathematical model of the relationship between the power consumed by the micro- CHP device (gas) and the one generated, further divided into electrical and thermal power. In order to do so, the data curated from task 1 were used, using a standard least-square polynomial fit. Polynomials of various degrees were used. In agreement with the activity leader, Dr. Parisio we decided to stick to a linear model, which provided a good fit.

The model has readily been used by KTH within their optimization algorithm for demand/response in micro-grids.

2.3 Computational Model and Software Development

In order to allow for real-time feedback control and for usage with MPC we also developed a computational model of the micro-CHP behaviour. For doing so, we resorted to state-of-art machine learning techniques, and in particular to Support Vector Machines. The models were developed for usage as regression (not classification). Various kernels were tested, before sticking to polynomial functions, which provided a good tradeoff between robustness and accuracy. The models were trained on the whole dataset.

Different feature set vectors were used:

- No memory, no dependence on external factors (e.g., temperature).
- With memory, no dependence on external factors. The idea here is that the device has an internal state, which is not observable directly. In this case the model is fed with (i) the current input (ii) the last M outputs, where M has been varied between 1 and 5.
- With memory, considering also dependence on external factors. In this case the temperature of the environment where the device is present is also considered as one of the features to be used for building the model.

Models were developed for the three aforementioned cases using the standard `scikit-learn` Python library. The resulting models were made available to KTH and the other activity partners in early December 2013. A Matlab wrapper was also provided in order to ease integration with other modules developed by EVSGL partners (in particular: KTH).

2.4 Conclusion

The software developed is fully operational and has been used by KTH in the VMGL use-cases. It is available for all EVSGL partners for usage. With CREATE-NET stepping out from EVSGL in 2014, the partners will be able to exploit the provided software toolkit to emulate complex scenarios involving micro-CHPs, such as VPPs, and experiment with them.