ONTOLOGY BASED DESCRIPTION OF DER'S LEARNED ENVIRONMENTAL PERFORMANCE INDICATORS

Managing the Environmental Performance of Distributed Energy Resources

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Abstract: The current technology's upheaval in the electricity sector is leading to a need for new distributed control schemes for distributed electricity generation. In order to enable optimization of electricity generation and consumption for global objectives in distributed search spaces, meta-models of constrained spaces of operable schedules are indispensable for efficient communication. In order to qualify for being a green technology, indicators for individual environmental performance have to be incorporated into these meta-models. We here present insight into ongoing work concerning the integration of environmental performance indicators into the distributed control of energy resources. In order to ensure interoperability on the indicators, we will discuss the need for an ontology defining the description of such indicators.

1 INTRODUCTION

In order to allow for a transition of the current central market and network structure of today's electricity grid to a decentralized smart grid, an efficient management of numerous distributed energy resources (DER) will become more and more indispensable.

We here consider rather small, distributed electricity producers that are supposed to pool together with likewise distributed electricity consumers and prosumers (like batteries) in order to jointly gain more degrees of freedom in choosing load profiles. In this way, they become a controllable entity with sufficient market power. In order to manage such a pool of DER, the following distributed optimization problem has to be frequently solved: A partition of a demanded aggregate schedule has to be determined in order to fairly distribute the load among all participating DER. Optimality usually refers to local (individual cost) as well as to global (e.g. environmental impact) objectives in addition to the main goal: Resemble the wanted overall load schedule as close as possible.

When determining an optimal partition of the schedule for load distribution, exactly one alternative schedule is taken from each DER's search space of individual operable schedules in order to assemble the desired aggregate schedule. For optimization, a scheduling algorithm (whether centralized or not) must know for each DER which schedules are operable and which are not. Therefore, the set of alternative, operable schedules (obeying multiple constraints like allowed power or voltage bands or buffer charging levels) has to be encoded by an appropriate, standardizable model for inclusion into optimization. An example for such a model has been presented by (Bremer et al., 2010). If alternative solutions are to be chosen environmentally conscious, appropriate indicators must be included into the model of the search space and therefore into the description of each alternative schedule. Such an indicator allows a conclusion about a single type of environmental impact (e.g. CO_2 emissions) of a schedule.

Each DER has to serve the purpose it has been built for. But, usually this purpose may be achieved in different alternative ways. For example, it is the (intended) purpose of a CHP (a small in-house plant for combined heat and power production) to deliver enough heat for the varying heat demand in a household at every moment in time. Nevertheless, if heat usage can be decoupled from heat production by using a thermal buffer store, different production profiles may be used for generating the heat. This leads, in turn, to different respective electric load profiles that may be offered as alternatives to a scheduling algorithm.

With each of these alternatives, different environmental impacts are associated. If it becomes possible, to make information about different environ-

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mental impacts (globally) available, then optimization for environmental conscious operation of all DER became true even in distributed optimization environments with a control scheme that comprises (large) groups of DER.

We here present insights into an ongoing research that aims at the integration of ontology based descriptions of environmental performance indicators (EPIs) and support vector based meta-models of distributed, constrained search spaces for DER as have for example been developed by (Bremer et al., 2011a) or (Blank et al., 2011).

Developing a set of standardized EPI descriptions and a software solution for collecting and managing environmental performance information from distributed sources and reporting based on EPIs is the main goal of the OEPI-project (http://www.oepi-project.eu). We will extend these ideas to the field of optimizing DER in a smart grid environment.

In this position paper, we present our road map and preliminary concepts that aim at an adaptation of ontology based services for monitoring and calculating EPIs within enterprises production planning schemes and supply chains to the new use case of DER optimization. We discuss our approach for integrating EPIs with search space meta-models and present a preliminary formal representation. We conclude with a discussion of the ontologies role for interoperability.

2 DESCRIBING ENVIRONMENTAL PERFORMANCE

Environmental performance indicators like carbon, water or energy footprint usually measure the environmental impact of the activities of organizations. In this way, they are a measure that reflects the performance in achieving the actual objectives with respect to environmental issues (cf. (Hřebíček et al., 2007)).

Up to now, no general standardized description model for exchanging information on environmental performance in general exists. It is later argued that also for the smart grid domain there is a need to communicate environmental issues that have to be commonly understood among communicating and interacting distributed devices. As a starting point for further development, we chose our ontology from the OEPI project. The OEPI project aims at developing a set of standardized EPI descriptions and a software solution for collecting and managing environmental performance information from distributed sources and reporting based on EPIs (Meyerholt et al., 2010). The vision of the OEPI project aims at business users – across industries and supply chains – and at a continuous reduction of environmental impacts of daily operations. To achieve this, the visibility and comparability of EPIs of alternative decisions in corporate and supply chain operations is enlarged. In the smart grid domain, individual EPIs must be made visible for interacting devices what entails a much higher degree of automation and way shorter time periods than in the business sector.

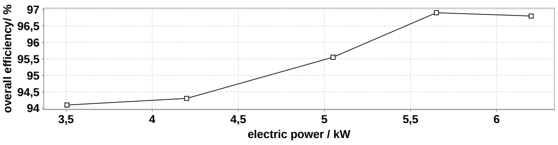


Figure 1: Relationship between generation rate and overall efficiency for a SOLO-Stirling-CHP. Modified from (Thomas, 2007).

Some examples for EPIs concerning DER in the context of a virtual power plant (VPP) are:

- Static losses, i.e. the loss of energy due to imperfect insulation e.g. in a thermal buffer store. The higher the temperature is in the store, the higher are the losses.
- Too many cold starts entail increased fuel consumption and abrasion.
- Low generation rates often lead to a declined efficiency as Figure 1 shows using the example of the SOLO-Stirling-CHP (Thomas, 2007).

If EPIs from different DER are to be compared during a design or optimization process for environmentally conscious decision making, a unified description language is required that unambiguously defines how an EPI was computed, what data was considered and – most important – how it may be further processed and related to other EPIs. OEPI develops such a language using a reference-ontology to describe EPI semantics and to achieve interoperability among different EPI related services and processes along supply chains in the business domain. Currently, such measures are - if at all - applied on a long term (mostly annual) or on a one-time basis, what limits the scope of application for such EPIs. Annual sustainability reporting is one example for today's use of EPIs - with the aim of merely gaining legal compliance. At present, the need for a shift from such a strong operational focus to a more strategically oriented realignment of e.g. corporate environmental management information systems (CEMIS) can be observed (Teuteberg and Gómez, 2010). In the smart grid domain, much shorter terms are required

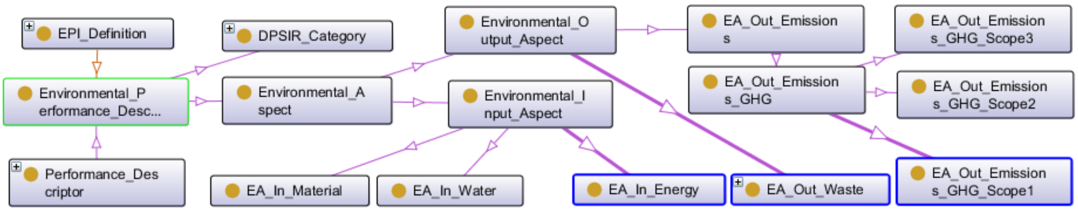


Figure 2: Excerpt from OEPI's preliminary EPI ontology with respect to DER impacts.

for spreading environmental information. One goal of OEPI is the development of a standardized exchange format for EPIs. Figure 2 shows an excerpt from an early version of the reference ontology emphasizing already inherent aspects that are important to DER:

- Energy input, i.e. primary energy usage and avoidable losses.
- Direct green house gas emissions (scope 1); these might be counted as scope 2 emissions for processes using the generated energy.
- Waste refers to needs due to possibly increased maintenance requirements.

3 DESIGN FOR ENVIRONMENT

Before discussing sustainable procurement for distributed energy management, we will have a short look at the related processes in the business domain.

In order to get environmentally sound products out of the design phase, it is important to provide product engineers with concepts and tools that make them aware of the environmental impacts of their design decisions on the whole product life cycle. This will be achieved by integrating EPIs into the design optimization process. As a result, evaluation of design alternatives with lower overall environmental footprint will become much faster.

The term IT-for-Green has recently been established in order to distinguish clearly between sustainability issues of hardware/software and sustainability achieved by means of IT (Rapp et al., 2011). The realm is an increased environmental friendliness of companies and their processes. However, conventional CEMIS are not sufficient to achieve this objective, as they serve mainly for ensuring legal compliance with relevant environmental regulations in order to avoid financial sanctions from state authorities. With such a strong operational focus, the requirements entailed by the concept of sustainable development can only be fulfilled to a very limited degree.

But, companies may achieve profits by applying sustainable development measures and by implementing new CEMIS: they reduce costs through material and energy efficiency and increase their turnovers through sustainable products and services, corporate image improvement and advantages in competition. Similar incentives should be considered for the smart grid domain to enforce an environmental conscious electricity grid.

Sustainable procurement is another example for a use case calling for EPIs being available virtually on demand. Such procurement integrates a concept for supplier-dependent EPIs into business processes for procurement. Here, one goal is to enable a business user to take action (and responsibility) according to different environmental impacts of different alternative sources for raw materials for production. This task is currently hardly achievable because individual variations are not captured in the procurement information systems (Dada et al., 2010).

4 THE CASE OF VIRTUAL POWER PLANTS

These business domain use cases are now to be transferred to the smart grid domain using the example of virtual power plants.

We consider a VPP as an orchestrated group of DER that communicate with and are controlled by a central controlling unit that is responsible for seeing that the group as a whole fulfils certain objectives like bundling for greater market power or grid stabilizing by reduced stochastic feed-in. A VPP helps integrating DER into the (smart) energy grid of the future (Lukovic et al., 2010). We do not deal with any concrete objective here, but we assume that a central scheduling unit has to search the space of alternative load schedules for each DER in order to find an appropriate one that fits bests for the problem at hand, although we do not exclude further extensions to future distributed control schemes.

If the central scheduler is supposed to select alternative schedules according to their individual environmental performance as well as according to their appropriateness for the main objective, then such information must be incorporated as additional fea-

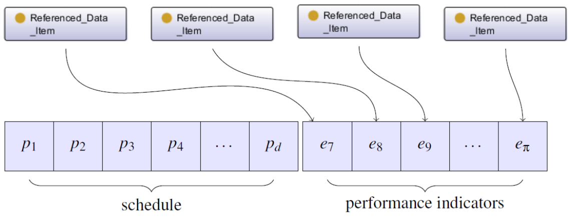


Figure 3: Integration scheme for scheduling algorithms.

ture sub-space into the schedule search space and its model. In this paper, we follow the support vector approach in (Bremer et al., 2010) for encoding the load schedules of a DER. This approach already has been proven as flexible enough to incorporate additional information about the individual environmental performance of each alternative into the learned model (Bremer et al., 2011b). While learning the geometrical structure of the space of feasible schedules, the approach is able to concurrently learn the functional relation of assigned performance indicators. In this way, each individual alternative load schedule can at least be annotated with numerical values of respective environmental performances.

4.1 Adapting the Use Cases

Both use cases from the business domain can be adapted for the load planning process within a VPP. In this way, we consider the procurement of a different product. In a VPP, each DER may offer several alternative load schedules. These are the products that are sought after by the controller. As every material (physical) product, it is also possible in such scenario, to assign measures of individual environmental performance to each alternative load schedule.

- Different DER and the controller make up a supply chain.
- Collaborating DER jointly produce a product (an aggregated schedule).
- Environmental impacts from one DER has an impact on the performance of all others and therefore on the whole VPP.
- Reducing the planning horizon or precautious integration of appropriate information may lead to strategic avoidance of negative impacts.
- In both cases, environmental performance has to be communicated.

On an abstract level, a VPP is a business like any other, but with an highly automated and highly frequent product design and procurement process.

4.2 Encoding the Indicators

The format of the information (incl. EPIs) for a schedule that might be offered by a DER is currently discussed to be of the following format:

$$\begin{aligned} x &= (x_1,\ldots,x_d,e_1,\ldots,e_\pi) \\ &= (x_1,\ldots,x_d,f_1(x_1,\ldots,x_d),\ldots,f_\pi(x_1,\ldots,x_d)). \end{aligned}$$

Herein x denotes a schedule (with x_i denoting load at time interval i) with associated ancillary information about the individual environmental performance represented by one or more EPI $e_1,\ldots,e_\pi$. The EPI in turn, usually is a function of the schedule itself, e.g. the heat losses resulting from that specific operation: $(e_1,\ldots,e_\pi) = (f_1(x),\ldots,f_\pi(x))$.

In this form, the schedules (together with the attached indicator values) may be taken as input for the mentioned support vector models for learning and encoding the set of operable schedules for communication to the scheduler without a need for adaption. After decoding on scheduler side, the schedules will still have the same information on load per time interval and the values of the indicators (Bremer et al., 2011b). Now the scheduling unit needs to know the individual meanings of the indicator values.

Figure 3 shows the envisaged integration scheme for scheduling algorithms. When the model of the search space is built-up from a DER upon request from the scheduler, the model will be accompanied by a set of meta-information objects – one for each requested EPI. Each meta-object contains information structured as shown in Figure 2. Associated to each EPI-definition, is a numeric data item that, in the case of VPP, will be an instance of a referenced data item. This means, that the actual value of the EPI is not directly included (like in the other cases), but is a reference to some external value. We here consider a relative addressing of elements of a schedule (starting from the first element referring to an EPI).

Thus, only one meta-information object for each EPI is needed for all schedules in the model, whereas the actual EPI values are reconstructed by the encoded functional relationship from the search space model. After reconstruction, schedules have the format shown in Figure 3. For each EPI value in the schedule, a meta-information object exists (communicated from the DER together with the model), that serves for interpreting the values.

If comparability is ensured for all participating DER, respective referenced EPI values may then be integrated into the objective function of the scheduler and are therefore used for environmentally conscious judging of different solutions during the scheduling process.

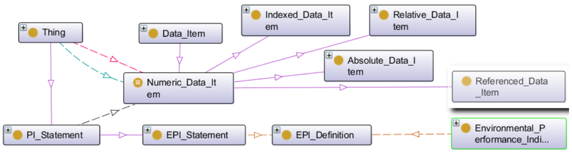


Figure 4: Referencing external data values with the EPI ontology.

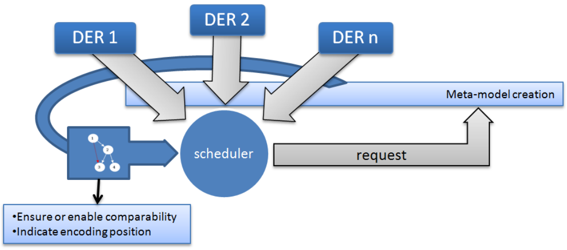
4.3 The Role of the EPI Ontology

In engineering, ontologies always comprise a specialized vocabulary as well as an explicit set of assumptions regarding intended meanings of data. Entities within an ontology either describe concepts (e.g energy losses) or relations between them (e.g. CO_2 *is a* greenhouse gas). Such shared agreement within a system environment with distributed entities allows for a common understanding of exchanged information. In the case of a virtual power plant, or (more general) in the case of interacting distributed devices and appliances in a smart grid environment, the need for several standards for ensuring interoperability arises. On a technical integration level, standards for integration – e.g. (IEC 61850-7-420:2009, 2009) – exist (although rarely implemented in practice) and the common information model (CIM) is discussed as an ontology based model for operating data exchange (Uslar, 2005).

For describing the individual environmental performance of alternative schedules and their production schemes that might be considered in a VPP, currently no appropriate description standard exists. For this reason, we will take the OEPI ontology as a starting point.

A cost effective and high-quality ontology heavily relies on the reuse of existing ones. The reuse of already existing ontologies (or at least parts of them) not only prevents reinventing the wheel in some cases but also reduces the effort required for ontology building.

Ontology engineering has meanwhile grown to a mature discipline. Different methodologies and tools for support are readily available. Nevertheless, according to (Bontas, 2005) most ontologies are still a result of some ad-hoc application- and domain-dependent engineering process. Building ontologies from scratch is time-consuming and error-prone. In order to weaken this challenge for the development of new ontologies, knowledge sources available on the web should be harnessed. If such existing ontological knowledge is used as an input source for the creation of new ontologies; this process is called ontology reuse.



•Ensure or enable comparability
•Indicate encoding position

Figure 5: Integration of EPI-ontology into distributed energy management schemes.

Reusing the OEPI ontology will mean using it as a base ontology and derive a DER environmental performance related one from it by extending the concepts for communicating environmental performance of energy schedules as discussed. The most important extension (as a prerequisite to our approach) will be the definition of EPI classes whose actual value is just a pointer to some externally stored data (Figure 4) rather than included data values of any sort. As we have seen in the previous section, individual environmental performance can – even in more than on dimension – easily be incorporated in a schedule description as mere number values. But, what are the meanings of these values? Different appliances may consider different performance indicators and therefore communicate different sets of indicators. Some indicators might be related to money instead of environmental cost. As an example, static losses do not make sense for systems without a thermal buffer store. On the other hand, these are energy losses and might be mapped (or at least compared) to other energy loss related indicators like e.g. losses through conversion. This gives rise to some questions:

- What is the impact of different indicators?
- Which indicators can be mapped for comparison and – more important – how can this mapping be done?
- What does optimization mean in the light of a given indicator?

Clearly, an optimization algorithm that wants to process EPIs attached to individual schedules in order to choose and evaluate schedules in a many objective scenario, needs a description of meaning and relationships of the EPIs.

The role of our ontology as interoperability ensuring entity within a VPP use case is depicted in Figure 5. Each individual DER has access to the ontology as common knowledge and therefore can create a proper meta-description of each indicator that is encoded together with the schedules. One description is created for each indicator position in the schedule (Figure 3).

A central scheduler in charge of finding optimal schedules for each DER may then harness the indicator descriptions and use the ontology to find out, how to treat them during evaluating a schedule, how to convert indicators or how to map them to each other.

5 CONCLUSIONS AND FURTHER WORK

It is to be expected that future architectures for smart grids will call for the ability of DER to frequently attach themselves to different groups depending on the situation at hand. Unlike VPPs, such groups will be drawn together rather by market forces. This transition to volatile groups of independent DER will be gradual. Due to universal applicability to central, decentral and distributed scheduling approaches, our method should be able to serve the needs during the whole transition process as the ontology approach is independent of specific smart grid architectures.

Research has just started out. Up to now we have gained a clear understanding of how the integration of distributed knowledge about individual environmental performance into a centralized (and in the long run decentralized) energy management control scheme might be done. A meta-model of search spaces that is based on geometric subspace descriptions, provides an ideal connecting point for the integration of environmental information about alternatives by simply extending the mathematical model of a schedule to additional dimensions for EPIs. In this way, necessary information is directly incorporated into the meta-model of the load schedules and therewith into the schedules themselves.

At the same time, correct interpretation of the EPI values may be ensured with the help of a extended EPI ontology. Our next steps will be the extension of the OEPI ontology as discussed and the definition of a standard set of EPIs for the sketched scenarios before we will start implementing a planned simulation environment to test our approach.

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REFERENCES

Blank, M., Gerwinn, S., Krause, O., and Lehnhoff, S. (2011). Support vector machines for an efficient representation of voltage band constraints. In *Innovative Smart Grid Technologies*. IEEE PES.

Bontas, E. P.; Mochol, M. (2005). Towards a reuse-oriented methodology for ontology engineering. In *7th International Conference on Terminology and Knowledge Engineering*, Copenhagen, Denmark. Shaker Verlag, Aachen.

Bremer, J., Rapp, B., and Sonnenschein, M. (2010). Support vector based encoding of distributed energy resources feasible load spaces. In *IEEE PES Conference on Innovative Smart Grid Technologies Europe*, Chalmers Lindholmen, Gothenburg, Sweden.

Bremer, J., Rapp, B., and Sonnenschein, M. (2011a). Encoding distributed search spaces for virtual power plants. In *IEEE Symposium Series in Computational Intelligence 2011 (SSCI 2011)*, Paris, France.

Bremer, J., Rapp, B., and Sonnenschein, M. (2011b). Including Environmental Performance Indicators into Kernel based Search Space Representations. *Information Technologies in Environmental Engineering (ITEE 2011)*.

Dada, A., Staake, T., and Fleisch, E. (2010). Reducing environmental impact in procurement by integrating material parameters in information systems: The example of apple sourcing. *AMCIS 2010 Proceedings*.

Hřebíček, J., Misařová, P., and Hyršlová, J. (2007). Environmental Key Performance Indicators and Corporate Reporting. In *Environmental Accounting and Sustainable Development Indicators (EA-SDI 2007)*, pages 978–980. Universita Jana Evangelisty Purkyně.

IEC 61850-7-420:2009 (2009). *Communication networks and systems for power utility automation - Part 7-420: Basic communication structure - Distributed energy resources logical nodes*. IEC, Geneva, Switzerland.

Lukovic, S., Kaitovic, I., Mura, M., and Bondi, U. (2010). Virtual power plant as a bridge between distributed energy resources and smart grid. *Hawaii International Conference on System Sciences*, 0:1–8.

Meyerholt, D., Marx Gómez, J., Dada, A., Bremer, J., and Rapp, B. (2010). Bringing sustainability to the daily business: The oepi project. *Proceedings of the Workshop "Environmental Information Systems and Services - Infrastructures and Platforms*.

Rapp, B., Solsbach, A., Mahmoud, T., Memari, A., and Bremer, J. (2011). It-for-green: Next generation cemis for environmental, energy and resource management. In Pillmann, W., Schade, S., and Smits, P., editors, *EnviroInfo 2011 - Innovations in Sharing Environmental Observation and Information, Proceedings of the 25th EnviroInfo Conference 'Environmental Informatics'*, pages 573 – 581. Shaker Verlag. ISBN 978-3-8440-0451-9.

Teuteberg, F. and Gómez, J. M. (2010). Green computing & sustainability - status quo und herausforderungen für buis der nächsten generation. *Praxis der Wirtschaftsinformatik*, 47(274):6–17.

Thomas, B. (2007). *Mini-Blockheizkraftwerke: Grundlagen, Gerätetechnik, Betriebsdaten*. Vogel Buchverlag.

Uslar, Mathias; Schmedes, T. L. A. L. T. W. L. A. H.-J. (2005). Interaction of ems related systems by using the cim standard. In *Proceedings of the ITEE 2005 Magdeburg*, pages 596–610. Shaker Verlag, Aachen.