SmartEnergyHub - A Big-Data Approach for the Optimization of Energy-Intensive Infrastructures

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***Abstract*—The Energiewende in Germany comes with growing uncertainties due to constantly changing regulatory requirements, volatile and less controllable generation from renewables and rising energy costs for consumers. As a result, operators of large-scale infrastructures, such as airports or production industries, have to reconsider their energy supply and management. Prognosis and combined optimization of multiple forms of energy are mandatory to reduce costs and to profit from monetary incentives. For solving such an optimization problem in real-time and subsequently controlling the energy supply and demand respectively, information and communication technology (ICT) is mandatory. Within the SmartEnergyHub research project an approach is developed to identify energy optimization potentials based on a big data approach, which uses high volumes of sensor data. Therefore, SmartEnergyHub combines models for energy demand prediction, as well as optimization techniques for efficient energy consumption, production and procurement to find optimal operating schedules. This paper describes the software requirements that have to be met by such a system and presents an architectural concept for its design using the Stuttgart Airport as an example.**

***Keywords*–energy management; big data; smart data; in-memory database; infrastructures.**

I. Introduction

Infrastructure operators especially in Germany have to cope with rapidly changing energy markets and regulations as a consequence to the German Energiewende. Considerable fluctuations in electricity generated from wind and solar energy and a related increase of energy costs through the Renewable Energy Act levy force infrastructure operators to improve their energy efficiency and reinvent their energy management [1]. The energy market is currently undergoing a rapid transformation - from a consumer driven market to a producer driven market [2], which gives energy-intensive infrastructures the opportunity to actively participate in the energy market and, thus, potentially improve their economic situation.

Infrastructures such as airports, harbors, industrial or chemical parks, factories and public facilities are considerable producers and consumers of energy. They are confronted with new technologies and requirements such as energy storages, load profile forecasting or demand side management [3]. In addition to the stepwise implementation of these technologies and process models, they have to ensure that their technical infrastructure provides safe, stable and efficient energy services. In light of these developments managers of infrastructures face the challenge of ever-increasing energy costs, as well as the need to utilize the advantages offered by active energy market participation, which allows a considerable cost reduction through flexible purchasing times.

Small and medium producers and consumers of energy do usually not have the resources and knowledge to optimize their energy systems in an integrated approach. A survey of the Fraunhofer Institute stated that only 31 % of small and medium enterprises (50-249 employees) actively monitor and manage their energy supply and demand [4]. However, conventional energy management systems already reach their limits with respect to the new challenges as optimization approaches in most cases only relate to individual components. This is why innovative approaches are needed. The solution described in this paper aims at an intelligent and more efficient use of already available data by applying big data technologies. The objective is to develop a scalable energy management IT platform built on top of existing infrastructure systems in order to optimize both internal energy flows and the energy procurement strategies. The major contributions of the SmartEnergyHub project are the real-time integration of sensors in a high-performance platform, that provides a holistic optimization of the energy system, the automated computation of schedules for energy generation and consumption units, as well as methods for decision support which take the current market situation into account.

The SmartEnergyHub Architecture addresses the following challenges:

- Analysis of big streams of data needs to be done fast and reliably.
- Information related to subsystems needs to be integrated into larger contexts, which allows a comprehensive view of the system and an improvement of the energy efficiency by connecting formerly unrelated information.
- Results of the energy management optimization in the form of schedules help to adjust the system continually.
- Load forecasts need to be considered to adjust the system in advance.

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- In addition to a short-term optimization long-term energy procurement strategies are taken into consideration.

This work is structured as follows. Section II gives an overview of ICT solutions, which are comparable to the SmartEnergyHub in a way that they either deal with the integration of large amounts of sensor data, offer the integration of forecasting models or enable optimization of energy systems. In addition to the introduction of state-of-the-art software platforms, several ideas, techniques and approaches in the context of smart grid architectures are explained. Section III addresses different requirements that are necessary for a sensor-based and cloud-based platform. In Section IV, the architectural concept of the SmartEnergyHub is illustrated and core processes are described.

II. Related Work

Katiraei et al. [5] provide a framework for the control and operation aspects of smart grids. They focus on existing smart grids and the description of approaches for market participation. An autonomous demand side management was developed by Mohensian-Rad et al. [6]. The model is based on a common electricity net but does not deal with heating, cooling and air condition. Agent prices are determined with game theory approaches. Real-time pricing models have advantages but are restricted to the technology (see Mohensian-Rad and Leon-Garcia [7]). There are several mathematical models that can be used for optimizing infrastructures and smart grids [8]–[10]. The security and safety of data is addressed in [11]. A communication model based on heterogenous data sources was introduced in [12]. The design of a data driven communication model was also discussed from a microeconomic point of view in [13]. Other publications focus on web-based modeling of a smart grid [14], optimal energy flow management for distributed energy hubs [15] and load file forecasting [16]–[19]. Aman et al. discussed measures for the evaluation of the prediction models [20]. The integration of fault detection and diagnosis in the context of energy consumption into a comprehensive energy management system is described in [21]. The analysis of the existing literature gives an overview of various aspects of energy management, which should be considered in the comprehensive approach in the SmartEnergyHub project. The following sections will focus on the question how these approaches can be reflected throughout the modules to build a SmartEnergyHub.

III. Requirements

In the SmartEnergyHub project, new approaches for energy optimization of large infrastructure providers are developed and applied at the Stuttgart Airport. Stuttgart Airport handles about 10 million passengers each year, which requires the operation of an infrastructure comparable with a small city. Therefore, the Stuttgart Airport takes on the role of both an energy consumer and producer. Energy generation facilities include a combined heat and power unit, photovoltaic plants, as well as emergency power generators. Energy has to be provided mainly for heating, cooling and ventilation but is also necessary for baggage handling systems or apron lighting. About 10,000 sensors distributed throughout the infrastructure area constantly record power and gas consumption, temperature or air quality and numerous other parameters, which are also partially influenced by visitor behavior. As the infrastructure and the sensor landscape is getting more and more complex, the quantity of data is growing fast. In addition, the frequency of the data collection is expected to increase. Currently most of the sensors supply values every minute or every fifteen minutes. The project SEH aims to extract necessary information about optimization potentials by using *big data processing*. Beyond the use of existing sensor data, external data sources (e.g., weather forecasts, energy price forecasts or passenger numbers) will be connected to a new scalable platform, which relies on a high performance in-memory database. The SmartEnergyHub project aims at a comprehensive approach, which takes into account all energy facilities. The main modules of the SmartEnergyHub are:

- **Data import:** The system has to support data import of different sources. These include sensor data available through the infrastructure system, weather forecasts, as well as price forward curves.
- **Data cleansing:** The system has to support the cleansing of imported raw data and offer possibilities to convert heterogeneous data to a standardized data format. One of the major challenges will be to realize a sufficient import speed and frequency in combination with a data cleaning process that ensures the necessary data quality for subsequent processes. The correct interpretation of outliers e.g., as measurement error or as an actual critical system state, plays a key role.
- **Data storage:** The system must be able to store different data types. These include time series of sensors, weather and price data but also master data, calculation results and system control plans.
- **Optimization:** The system must generate system control plans for the next 24-hours with regard to a minimization of energy costs. Changes in key parameters should trigger a recalculation or adaption of the control plans.
- **Market interaction:** The system must create recommendations for optimizing the energy procurement process to support a procurement manager to make efficient decisions.
- **Forecasts:** The system should be able to forecast the energy consumption based on historic and current sensor, weather data and further parameters. Those forecasts are a necessary input for the optimization and the market functions. Whereas the optimization has its focus on the near future and thus needs short-term predictions for the upcoming hours, market functions require a long-term forecast of load curves for the next 2 to 3 years.
- **User interface:** The system must support decisions, as well as offer near-time visualization. This includes also the approval of system control plans through authorized users with the help of a user interface. The system must also present energy procurement recommendations to the user.
- **Control plans:** The system has to be able to pass control plans to the infrastructure system after approval through authorized users.

IV. Architecture

Based on the functional and non-functional requirements described in the previous section, an architecture was designed.

To ensure a sufficient level of performance, the in-memory database SAP HANA [22] was chosen as the application backbone. Database operations needed during the generation of optimal control plans, forecasts or energy procurement recommendations, are encapsulated in an intermediate layer called *Model-Interface*, which exposes common operations via a generic interface supporting interchangeability of individual modules.

A. Modular Architecture

The system has a modular design as illustrated by the architecture diagram in Figure 1. Modules, displayed as boxes in the figure, expose their functionality via interfaces and communicate with other modules with the help of a message broker. The architecture contains a data, application and a presentation tier. General purpose functions are provided by the module 'Basic Services and Orchestration'. The system architecture consists of the following modules:

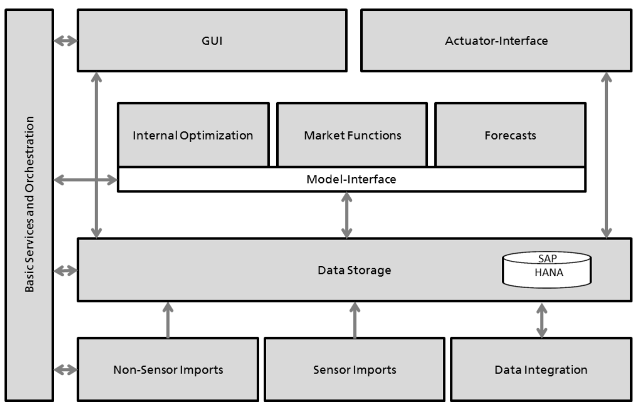

Figure 1. Overview of architecture and methodology (focus of this work highlighted in grey).

- **Sensor-Imports:** Sensor-data is imported through an interface to the existing infrastructure system, which is a building control system in the case of the Stuttgart Airport. Imported raw data is converted into a standardized data format.
- **Non-Sensor Imports:** Non-sensor data in this case is data that is not collected by sensors within the infrastructure, but is offered by other providers (containing data like weather or energy prices). This data is also imported and then converted to the standardized data format and stored in the database.
- **Data Integration:** This module transforms imported raw data into adjusted data using a generic time series data model for incoming sensor data and a hierarchical data model to store sensor master data.
- **Data Storage:** This module provides functions related to the storage and processing data within the database.
- **Internal Optimization:** Based on sensor, master and forecast data an optimal infrastructure control plan for energy facilities is generated. Database operations are executed with the help of the model interface, which offers generic methods for database interactions. The optimal infrastructure control plan is written to the database.
- **Market Functions:** Based on sensor and forecast data this module creates action recommendations for interaction with energy markets. Those action recommendations are also written to the database. Conceived as a decision support system for the energy manager, this module should also allow a smooth handover of chosen interaction strategies
- **Forecasts:** Based on sensor and external forecast data, this module generates forecasts, which can be used by the Internal Optimization module or the Market Functions module. Thus the forecast data is written to the database.
- **GUI:** The GUI module provides a user interface to support especially the approval process of generated infrastructure control plans or action recommendations related to the energy market.
- **Actuator Interface:** After a new infrastructure control plan has been created and approved by an administrator, the control plan is passed to the infrastructure system.
- **Basic Services and Orchestration:** This module coordinates the module communication and sequence control.

B. Core Processes

The following core processes provide a dynamic cross-module view of the planned system:

1) Import: The import process is responsible for loading all relevant data into the database. This includes sensor data which is available through the infrastructure system like sensor or master data, as well as data from external sources. The received data is transformed into a standardized data format and saved into the database. After recording the data in the database, subsequent processes can be triggered via the message broker.

2) Data Cleansing: After the recognition of new data the data cleansing process starts and writes modified data back to the database. Data cleansing supports for example the interpolation of missing values.

3) Forecasts: Within the forecast process all relevant data such as sensor, weather and energy price data is used to generate forecasts for the expected load curve. For accessing the input data, the model interface is used, which offers generic methods to read and write data, but also to process data within the database in case of time-critical operations. After a new forecast curve was produced this data is written to the database.

4) Internal Optimization: During the internal optimization process, an optimization algorithm is used to generate an optimal infrastructure control plan for energy relevant facilities. The input for the optimization algorithm consists of sensor, weather and energy price data, as well as calculated forecasts. The optimization algorithm will consider both technical and contractual constraints. For example, reaction times of technical systems, as well as legal requirements concerning clean air policies, will be modeled. Generic methods of the model interface can be used for both loading data from the database, as well as for delegating calculations to the database. Upon completion of the algorithm, the result in form of an optimal infrastructure control plan is written to the database.

5) Market Functions: The process market functions supports the energy procurement and the interaction with energy markets through recommendations. Sensor, energy price data and forecasts serve as input. Based on both current and predicted energy prices as well as the energy load curve, an optimal procurement plan is developed.

V. Preliminary Evaluation

The requirements described in this paper can be met by the presented system architecture. The system contains several modules, which support the required functions such as importing data from different sources, data cleansing, generating optimal control plans, forecasts and procurement recommendations, as well as human approval and passing control plans to the infrastructure system. Building on top of a *in-memory database*, the system supports high performance sensor data processing. The requirements were collected in cooperation with the Stuttgart Airport as the first pilot user. The evaluation of the system will start in 2016 as a pilot project and help to verify and ensure the feasibility of the developed solution. Through a continuous operation of the system until the end of the project 2017 the components will gradually be improved and extended. Further infrastructure managers and users who will be involved in a newly founded user group, will take part in the implementation and evaluation process as well.

VI. Conclusions and Outlook

This paper describes the current state of the SmartEnergyHub architecture, which lays the foundation for a high-performance smart data platform to optimize energy management in infrastructures such as airports, factories and public facilities. Applying big data technologies to energy management systems, SmartEnergyHub helps to make use of all kinds of available sensor data to optimize internal and external energy flows. In addition to meter and sensor data, external data providers are connected to the platform, which allows to take additional information such as weather or energy price forecasts into account. The data pool, which is enriched in this way, enables the generation of accurate short and long term load forecasts with regard to the overall system, as well as for subsystems. The forecasts itself are used to optimize the system in an integrated approach to control the individual plants and components proactively. This also allows to use current market opportunities such as temporary low-price phases to reduce energy costs. The required core processes and corresponding modules (see Figure 1) are described in detail in this paper. In future work, the implementation of the modules as well as the enhancement of the system architecture is planed. One of the major challenges for the future implementation consists in the design of forecast and optimization algorithms for huge amounts of data so that they can meet the real-time requirements. By involving further infrastructure operators the transferability of the solution will be shown.

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References

[1] E. Gawel et al., "The future of the energy transition in germany," Energy, Sustainability and Society, vol. 4, no. 1, 2014, pp. 1–9.

[2] German Federal Ministry for Economic Affairs and Energy, "An electricity market for germanys energy transition (green paper)," 2014.

[3] Y. Simmhan et al., "Cloud-based software platform for big data analytics in smart grids," Computing in Science & Engineering, vol. 15, no. 4, 2013, pp. 38–47.

[4] R. Jochem, P. Karcher, and M. Siemer, "Betriebliches Energiemanagement in produzierenden Unternehmen Deutschland 2013," Fraunhofer IPK, Tech. Rep. 4, 2013.

[5] F. Katiraei, R. Iravani, N. Hatziargyriou, and A. Dimeas, "Microgrids management," Power and Energy Magazine, IEEE, vol. 6, no. 3, 2008, pp. 54–65.

[6] A.-H. Mohsenian-Rad, V. W. Wong, J. Jatskevich, R. Schober, and A. Leon-Garcia, "Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid," Smart Grid, IEEE Transactions on, vol. 1, no. 3, 2010, pp. 320–331.

[7] A.-H. Mohsenian-Rad and A. Leon-Garcia, "Optimal residential load control with price prediction in real-time electricity pricing environments," Smart Grid, IEEE Transactions on, vol. 1, no. 2, 2010, pp. 120–133.

[8] M. C. Bozchalui, S. A. Hashmi, H. Hassen, C. A. Cañizares, and K. Bhattacharya, "Optimal operation of residential energy hubs in smart grids," Smart Grid, IEEE Transactions on, vol. 3, no. 4, 2012, pp. 1755–1766.

[9] A. Parisio, C. Del Vecchio, and G. Velotto, "Robust optimization of operations in energy hub," in Decision and Control and European Control Conference (CDC-ECC), 2011 50th IEEE Conference on. IEEE, 2011, pp. 4943–4948.

[10] P. Mancarella and G. Chicco, "Real-time demand response from energy shifting in distributed multi-generation," Smart Grid, IEEE Transactions on, vol. 4, no. 4, 2013, pp. 1928–1938.

[11] S. Uludag, S. Zeadally, and M. Badra, "Techniques, taxonomy, and challenges of privacy protection in the smart grid," in Privacy in a Digital, Networked World. Springer, 2015, pp. 343–390.

[12] S. Uludag, K.-S. Lui, W. Ren, and K. Nahrstedt, "Secure and scalable data collection with time minimization in the smart grid," Smart Grid, IEEE Transactions on, vol. PP, no. 99, 2015, pp. 1–1.

[13] M. Steurer, M. Miller, U. Fahl, and K. Hufendiek, "Enabling demand side integration–assessment of appropriate information and communication technology infrastructures, their costs and possible impacts on the electricity system," E. SmartER Europe Smart Energy Research at the crossroads of Engineering and C. Science, Eds., 2015.

[14] A. Vaccaro, M. Popov, D. Villacci, and V. Terzija, "An integrated framework for smart microgrids modeling, monitoring, control, communication, and verification," Proceedings of the IEEE, vol. 99, no. 1, 2011, pp. 119–132.

[15] M. La Scala, A. Vaccaro, and A. Zobaa, "A goal programming methodology for multiobjective optimization of distributed energy hubs operation," Applied Thermal Engineering, vol. 71, no. 2, 2014, pp. 658–666.

[16] N. Amjady, F. Keynia, and H. Zareipour, "Short-term load forecast of microgrids by a new bilevel prediction strategy," Smart Grid, IEEE Transactions on, vol. 1, no. 3, 2010, pp. 286–294.

[17] G. Zhang, B. E. Patuwo, and M. Y. Hu, "Forecasting with artificial neural networks:: The state of the art," International journal of forecasting, vol. 14, no. 1, 1998, pp. 35–62.

[18] G. P. Zhang, "Time series forecasting using a hybrid arima and neural network model," Neurocomputing, vol. 50, 2003, pp. 159–175.

[19] R. Sevlian and R. Rajagopal, "Short term electricity load forecasting on varying levels of aggregation," arXiv preprint arXiv:1404.0058, 2014.

[20] S. Aman, Y. Simmhan, and V. K. Prasanna, "Holistic measures for evaluating prediction models in smart grids," Knowledge and Data Engineering, IEEE Transactions on, vol. 27, no. 2, 2015, pp. 475–488.

[21] L. M. Blanes, A. Costa, N. Réhault, and M. M. Keane, "Integration of fault detection and diagnosis with energy management standard iso 50001 and operations and maitenance of hvac systems," Clima 2013, 2013.

[22] SAP. Sap hana. [Online]. Available: http://hana.sap.com (04, 2016)