Prospective Products and Benefits of the Green AGH Campus Project
Providing Scaled-down Future Smart Grid Experience

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Abstract: Smart grid stakeholders have partially opposing goals. New tools and utilities are needed to reach them. The paper discusses prospective products and benefits of the Green AGH Campus Project. The project provides energy management infrastructure being a test bed for future smart grid solutions. It is based on three main components: an Advanced Distribution Management System, a Power Data Warehouse and a Simulation System. Coupled together, they are capable of providing advices regarding either optimization of grid operations, or its design and topology. The optimizations are multicriteria and multivariant balancing stakeholders' needs.

1 INTRODUCTION

"A smart grid is an electricity network that can cost efficiently integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" (European Commission, 2011). Parties involved in smart grid management are identified as either operators or consumers. The operators are responsible for managing the grid. They are subdivided further mainly into: Transmission System Operators (TSO), Distribution System Operators (DSO), Energy Generators (producers).

TSOs manage the very high voltage grid such as 400 or 225 kV. They connect all regional electricity grids with each other. TSOs are responsible for correcting the imbalance in the network regarding energy demand and supply. They are decoupled from retail and generation. DSOs are responsible for energy distribution at the regional level. They handle high voltage (below 60 kV), medium voltage (1–30 kV) and low voltage. Their main responsibility is to deliver energy to the consumers. Producers provide electricity, which is distributed through TSO and DSO grids.

Consumers use electricity delivered by DSOs and are subdivided into residential and commercial ones. Taking into account a decentralized energy generation a new category of consumers has emerged, so-called prosumers: producing consumers. An introduction of distributed generation, including renewable energy sources, is a major game changer for the electricity delivery. It is no longer a uni-directional flow from the producers through TSO and DSO grids to the consumers but a multidirectional flow which can be controlled only by proper ICT (Information and Communications Technology) systems. There are very high requirements for such systems. They need to be: geographically distributed, heterogeneous, real-time and must allow for partial disconnections. What is more they generate massive amounts of data. The electric grid, in this context, is perceived as the most wide spread adoption of the Internet of Things concept.

The stakeholders of the energy business have multiple, even opposing, goals. Among others these are: non technical loss identifications (theft), energy price and usage optimization, energy quality assurance, emergency response time minimization etc. There are multiple efforts carried out to provide proper ICT tools. They regard grid planning, simulation and real-time management.

There are several big IT players involved, including: IBM, Oracle, SAP, Google, Cisco[1]. The main focus of rapidly progressing smart grid solutions is to provide more insight into processes taking place on the grid and beyond to provide integration with Smart City concepts. There are also emerging businesses offering added values on top of data analytics such as

[1] source: European Utility Week 2014, Amsterdam: http://www.european-utility-week.com

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Opower or Nest Labs.

This paper focuses on the DSO perspective and surroundings. It involves the end customers, including prosumers, and sellers. The aim is to present an overview of products and benefits of the Green AGH Campus project (Szmuc et al., 2012). The project takes into consideration a campus area. It is a model of a scaled down urban area representing a distribution network. Thus it serves as a testbed to research new energy management strategies, develop new tools for future smart grid, being a living lab. The project is led by AGH University of Science and Technology, hence its name.

2 STAKEHOLDERS

There are three major stakeholders taken into consideration. These are: a DSO, an end customer, and sales (the producers or prosumers), see Fig. 1 for details. They are targeted at simple yet divergent goals. A DSO's goal is to maintain grid operations. A customer wants to lower his electricity bills. While sales want to maximize their income.

There are two main observable drivers than: customer satisfaction and compliance with regulations. The customer satisfaction drives all stakeholders however after analyzing it, it turns out, that it regards different, even opposing goals such as: income maximization and energy bill reduction. The main assessments of this driver are: non interruptible delivery, better power quality and wise energy usage. The non interruptible delivery and better power quality contribute to the DSO's main goal which is maintaining grid operations. The wise energy usage contributes towards the income maximization for the sales as well as energy bill reduction for the customer.

The compliance with regulations drives the DSO. It is a complex driver which main components can be characterized as: regarding renewables, CO2 emission and reliability[2]. The compliance is usually forced upon DSOs by regulators and law. Assessing this compliance results in: non interruptible delivery and better power quality, which regard maintaining grid operations and income maximization goals which are main objectives for the DSO and sales respectively.

So, as it can be seen from the above, these three parties and their goals are highly entangled. Fulfilling them is a great challenge. Providing proper tools which can support reaching the goals is the ultimate goal for the proposed research. The tools regard ICT solutions, including algorithms, software, and analysis, as well as methodologies and good practices. They focus on two major areas being either topology optimization or control optimization (see Fig. 2), the former regarding grid design, the latter regarding grid operations. Thus these are the requirements that realize the goals (energy bill reduction, income maximization, maintaining grid operations). Particularly optimizing grid operations is a complex requirement which consists, among others, of providing dynamic tariffs, restore service after a failure as soon as possible while minimizing number of disconnected loads, and stabilize grid to provide uninterrupted operations.

[2]EU climate and energy package http://ec.europa.eu/clima/policies/package/index_en.htm

3 PRODUCTS AND BENEFITS

There are three main product categories of the proposed Green AGH Campus Project. These are: scientific, commercial, didactic.

The scientific category ranges from researching topics related to distributed computing, agent-based systems, optimization, to artificial intelligence (AI). Distributed computing in this contexts regards analysis of large volumes of data, often referred to as Big Data. Significance of this topic is reinforced by sole nature of power grid which is distributed by nature. Amount of data generated by grid sensors, including smart meters, and their high scale is uncomparable and without precedence. Microgrid and islanded operations force smart grid solutions to be more flexible and capable of distributed processing. Contemporary grid managements are usually centralized, thus further applied and interdisciplinary research regarding agent-based applications and systems is required. As it has been already researched (Wojnicki et al., 2013; Kotulski, 2008; Kotulski and Sedziwy, 2012), applying agent-based approach both to process large volumes of data and provide optimized control could offer proper solutions.

The above systems need to be supported with artificial intelligence, mostly to optimize their modus operandi. It is expected to research and deploy machine learning with advanced pattern recognition and planning and preference modeling (Klimek et al., 2013). It could serve identification of processes taking place on the grid and supporting operators with admissible solutions.

Considering the above there is a need for knowledge management at the grid level as well as to provide proper inputs and outputs for AI methods. Similarly, there is a need for formal specifications for such distributed control systems to verify their behavior

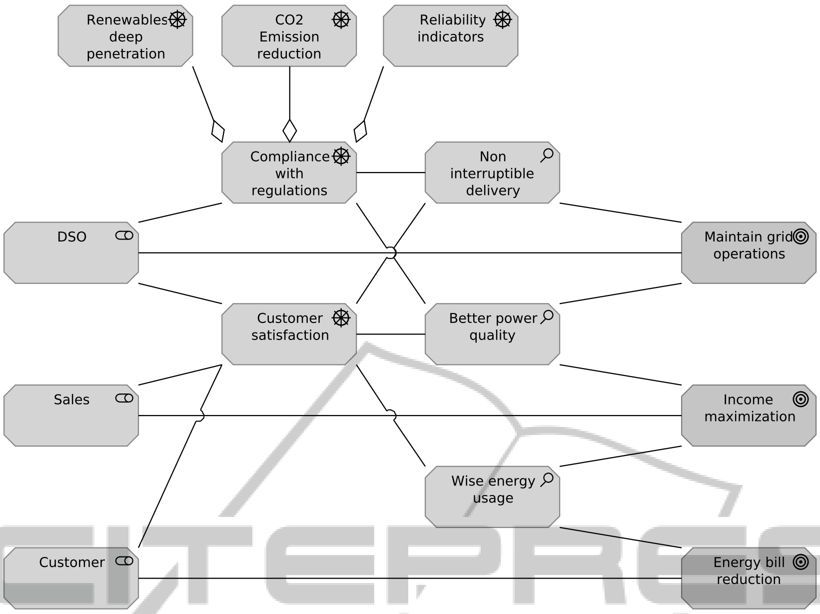

Figure 1: Stakeholders and goals.

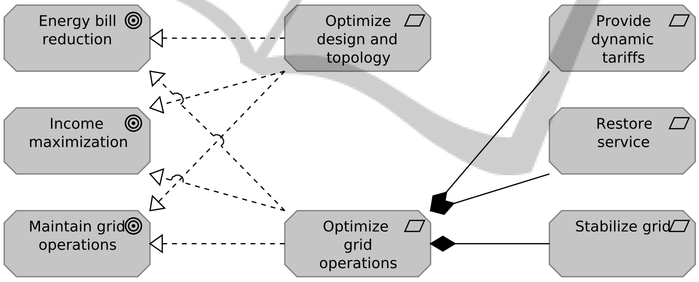

Figure 2: Goal realisation.

and assure their safety.

Another aspect of AI which finds applications here is inference. Real-time inference is needed to provide context aware control and early malfunction detection. It also includes automatic state interpretations providing advices and serving as analytics platform, thus supporting operators and engineers at the control center, at DSO, or applications to other parties. One of important themes here is so-called non-technical loss identification, which is regards energy theft.

Multiple optimization methods and concepts find applications here as well. Especially multidimensional, multicriteria and multivariant algorithms. They can be used both for power grid design or control.

Last but not least there is a need for historic data analysis. It allows to make either control, design or business decisions based on insufficient data, thus approximating or filling gaps with the interpreted historical ones. It is not only “foreseeing” the future but also fulfilling gaps in data streams representing states of the entire grid system overload, lost communication etc.

The commercial type of outcomes regards actual products and services that could be offered directly to the involved parties. Besides new grid control algorithms which needs to be tightly integrated with DMS systems, or methods for grid design, being products for DSOs, the most prominent one would be establishing and providing dynamic tariffs. It would be a result of multicriteria analysis using researched earlier domains, since there are different goals of the involved stakeholders. Thus dynamic tariffs can improve maintaining grid operations, maximizing sales profits and minimizing energy bills of the end customers.

The didactic category of the outcomes is not subject of this paper however it should be noted here since the project is developed by AGH University. As a result all other outcomes: research results, algorithms, methodologies, tolls can find a way to be integrated with curricula.

4 ARCHITECTURE

The proposed concept is based on three main components. These are: an aDMS (Advanced Distribution Management System), a Power Data Warehouse, and the Simulation System (see Fig. 3: Distribution Management System, Data Warehouse, Simulation respectively). It is assumed that the aDMS works in a redundant mode, based on two instances: the actual aDMS, managing the distribution of energy and a shadow instance, also called the *shadow environment*. The shadow instance is not connected to physical devices. Its role is to verify the energy management process under varying (real or simulated) circumstances and parameters. These include raw telemetric data from field devices, raw simulated data, simulated and real decisions made by the operators and engineers as well as structural modifications to the managed network. This approach allows, on one hand, efficient management of power, and on the other – optimization of the network operation based on any criteria, including simulation-based implementation of the assumed management process and network structure changes.

Using an ETL (Extraction-Transformation-Loading) process, the data warehouse collects information regarding the network operation from the aDMS. This allows for its further analysis using BI (Business Intelligence) methods and extraction of results and conclusions which can serve as input to the simulation environment. Simulations allow for verification of the aDMS operation and implementation of arbitrarily complex optimization processes, based on multiple criteria. Separation of the simulation system from the aDMS makes it independent from technological and conceptual limitations of current aDMS systems and makes its performance less critical. Performed analyses do not affect the management of the actual network, and therefore cannot destabilize it. It must be noted that while the simulation system uses information about the network structure from the 'production' aDMS instance, the generated operation parameters are submitted to the shadow instance.

aDMS systems extend classical SCADA solutions by assuring appropriate scalability and integration with the power grid operator's business processes. They usually have a modular structure, which typically includes the following components: SCADA, NMS (Network Management Systems), OMS (Outage Management Systems), FDIR (Fault Detection, Isolation and Recovery) and VVC (Volt-Var Control). The SCADA module is responsible for communication with local SCADA systems and directly with field devices; it acquires telemetric data and assures efficient remote control. The NMS module provides network management features, offering an operator's interface (including e.g. schematic and geographic visualization, an event log, notifications, event reactions, etc.) and cooperating with the SCADA module by allowing for appropriate control of the entire managed network. The OMS module allows for maintenance planning and scheduling and manages fault notifications and handling. It often integrates data from smart meters, allowing for automatic detection of disconnected grid segments. The above modules constitute a DMS-class system. By further developing its functionality, an aDMS (Advanced DMS) system can be created. This is usually achieved by integrating additional modules, responsible for network operation optimization, such as FDIR and VVC. The FDIR module allows for automatic isolation of faults and provides automatic switching (or recommendations for the operator) to minimize losses, e.g. the number of affected customers. VVC stabilizes network voltages and power distribution. Such modules often use additional helper modules which perform power flow calculations on a given network structure or simulate its behavior. aDMS systems are also often equipped with modules which allow field crews to directly interact with the system, which gives them information about the current network status and provides means of reporting diagnostic and repair actions.

Simulation of power grids is perform both within aDMS-class systems and by means of external tools. Simulations are usually performed on three logical levels: device, network and comprehensive simulation. Device-level simulation involves replacement of real field device input and output data with simulated information. This allows for simulation of the DMS system behavior as well as its reaction to generated events. Solutions such as SimSCADA can be used for this purpose. Network-level simulation goes a step further, offering input and output data in conjunction with the grid topology. This allows for generation of events involving groups of devices as they interact within the network. Often, such simulations also allow for generation of events which, under normal circumstances, are the decisions of the NMS or the system operator. SimNet is a ready-to-use solution of this class. Finally, comprehensive simulations involve all possible significant grid components as well as factors which affect them: end devices, network parameters and topology, source and load character-

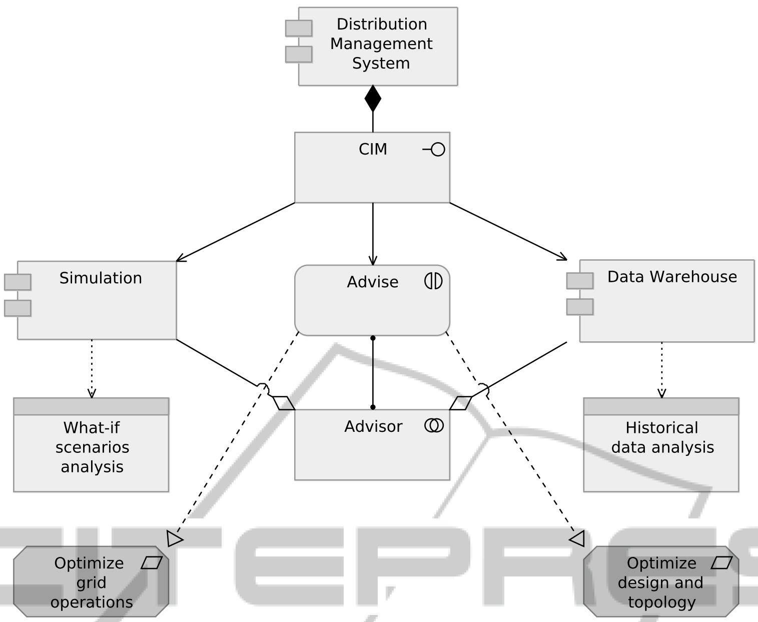

Figure 3: Architecture and requirements realisation.

istics and weather conditions. One of the solutions which can be used in such scenario is GridLAB-D, described further in this section.

Data warehouses allow for central storage and analysis of business data. They usually store data from long time spans which can be used to obtain new information, significant for the business operation. Therefore, a data warehouse provides a unified data store oriented around business entities, which is: integrated (as it contains data from different subsystems), time-variant (as they contain data from various periods) and non-volatile (as the data is loaded incrementally from transactional systems). Data warehouse solutions are provided by, among others, Oracle, IBM, SAS and Microsoft. These solutions often use proprietary or open software components for data acquisition, discovery and analysis, including relational databases (Oracle, DB2, SQL Server, PostgreSQL, Informix), non-relational data stores (HBase, MongoDB, Cassandra) and AI-based solutions (classification, machine learning, statistical analysis, decision-support systems, etc.).

GridLAB-D, developed by the Pacific Northwest National Laboratory and supported by the US Department of Energy, is an advanced, open-source power system simulation tool based on the BSD license. This system is one of the leading grid simulation tools, which provides accurate results thanks to precise models. Thanks to GridLAB openness, it is possible to modify any of its components, which is often necessary to adjust it to local conditions and requirements.

GridLAB-D is a modular system: besides the "central" power flow simulation module, it has dedicated modules for precise simulation of loads (including residential and commercial customers), distributed generation, weather, energy market components, reliability testing (including metrics such as SAIFI or SAIDI), power storage or electric vehicle charging.

However, while the system has been widely used in the USA (as the project was started by the US Department of Energy) and Australia (e.g. within the Smart Grid, Smart City project[3]), its use in Europe was very limited. Therefore, it is crucial to verify how each component complies to the characteristics of European (and Polish) power grids and the local regulations. Evaluation of each module will provide the information whether it needs to be modified and to what extent – from adjusting parameters to algorithm and model modifications. This process will be performed by the University's software and power grid staff, as well as external experts.

The foreseen changes include customization of the modules for proper operation with voltages and phase configurations used in Europe and better coherence with real devices and installations. For instance, the *residential* module includes predefined load schemes for houses and apartments and algorithms to multiply the instances with set parameter variations, which allows for easy and scalable simulation of loads gener-

[3]http://www.smartgridsmartcity.com.au

ated e.g. by newly-built housing estates. However, its characteristics are typical for American households, with deep penetration of air conditioning systems, different thermal insulation parameters and heating solutions as well as different characteristics of the appliances themselves. It is a similar case with the *commeracial* module, which simulates loads originating from commercial and office buildings.

Practically all modules are predicted to require modifications. GridLAB-D's supported weather data formats are vastly popular in the USA, but less so in Europe; data formats and conversion workflows need to be established. Models for DG devices (PV, wind turbines, heat pumps) need to be customized to better match European devices. Quality metrics used by Polish and European utilities need to be implemented and configured; also, for economics-related simulations, the energy trading schemes may need to be adjusted to local characteristics.

The above components cooperate (see Fig. 3) to form an Advice which in turn can be used by the aDMS. Providing the Advice fulfills requirements: Optimize grid operations and Optimize design and topology, which in turn realize the goals (see Fig. 2).

5 CONCLUSIONS

The Green AGH Campus project is based on state-of-the-art solutions and methods to ensure it is on the cutting edge of distribution grid management research. The concept, based on three components (aDMS, Power Data Warehouse, Simulation), is an innovative approach which allows for better exploitation of data and detection of knowledge (rules, patterns) regarding grid operations. Because AGH University is not a TSO or DSO, but a research-oriented scientific institution, the potential for improvement and experimental verification of results is much bigger than in case of industrial, production systems.

One possible criticism may address the fact the system will be initially deployed on the university campus power network, which is of a significantly smaller scale than the intended application. However, all components are assessed with regard to their scalability, and tight integration of simulation solutions allows to perform experiments on models of larger, real-life distribution grids.

Finally, one of the important aspects of the Green AGH Campus projects is the possibility to develop a range of services, from operation parameter optimization to strategic investment planning, which can be offered to operators on the Polish and European markets.

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