Overview of Smart Grid Challenges in Sweden

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Abstract

Smart grids are advanced power grids that use modern hardware and software technologies to provide clean, safe, secure, reliable, efficient and sustainable energy. However, there are many challenges in the field of smart grids in terms of communication, reliability, interoperability, and big data that should be considered.

In this paper we present a brief overview of some of the challenges and solutions in the smart grids, focusing especially on the Swedish point of view. We discuss thirty articles, from 2006 until 2013, with the main interest on data-related challenges.

1 Introduction

A general power grid consists of three different operations: electricity generation, transmission, and distribution. In this grid, electricity is transmitted from a number of centralized power generators to a large number of users or customers. In the power grid, it is very critical to ensure high reliability, diversification of energy resources, high energy efficiency, low carbon emission, and reduced cost.

Smart grids are considered as the next generation of power grids which use distributed generation and widely automated network. According to the earlier works [20, 11, 13], smart grids are self-monitoring and can perform auto-balancing, detect overload, re-route power, and prevent outage with minimal human intervention. They employ multiple energy sources, including renewables, to ensure minimized environmental footprint. They can also be optimized based on customer demand and price. Moreover, smart grids are based on real time, two-way, and cyber-secured communication. Table 1 summarizes some of the differences between power grids and smart grids.

Power Grid	Smart Grid
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Throughout
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

Table 1: Power grid and smart grid comparison

Other generally accepted visions for the smart grid, according to Heckel [20], are:

> *Smart grid is an auto-balancing, self-monitoring power grid that accepts any source of fuel (coal, sun, wind) and transforms it into a consumer's end use (heat, light, warm water) with minimal human intervention.*
> *Smart grid will allow society to optimize the use of renewable energy sources and minimize our collective environmental footprint.*
> *Smart grid has the ability to sense when a part of its system is overloaded and reroute power to reduce that overload and prevent a potential outage situation.*
> *Smart grid enables real-time communication between consumer and utility allowing us to optimize a consumer's energy usage based on environmental and/or price preferences.*

The smart grid is a combination of infrastructural hardware and software systems which are employed in different layers. A general architecture according to the Smart Grid Coordination

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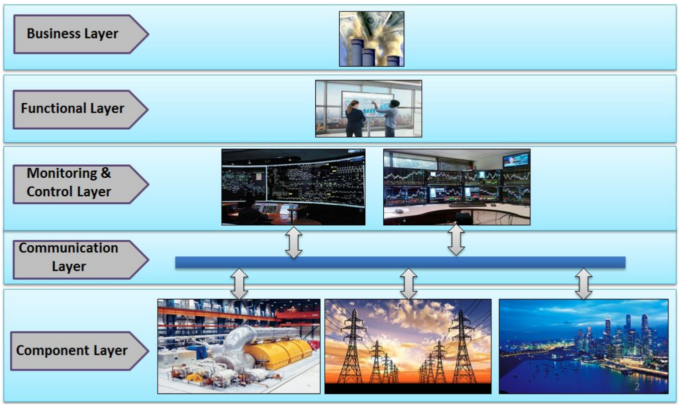

Figure 1: The five layered segmentation of smart grid

Group [17] divides the smart grid into five layers. These layers are described below and depicted in Fig.1.

The component layer consists of physical equipments distributed across generation, transmission lines and distribution sectors.
The communication layer describes the protocols and mechanisms used for exchanging information between components, and between the component layer and the monitoring and control layer.
The monitoring and Control layer, also called information layer, is responsible for visualization, monitoring and control of the information exchanged between functions and services.
The functional layer includes functions and services of the whole system including their relationship from the architectural point of view. In this layer, data mining process could be applied on the stored data to evaluate the characteristic of the smart grids and find suitable functions and services.
The business layer represents the business viewpoint and involves economic structure and policies as well as business models for the smart grid.

In this paper, a brief overview of some of the challenges and solutions in the smart grid in Sweden is presented. The main focus is on data-related challenges in the functional layer.

The data being collected contains a lot of useful information about the system and how effectively the various equipment is working. This information is available and can be used for many purposes such as fault detection, failure prediction, load forecasting, control, and system security. This is a new opportunity, especially interesting since mining available data to find problems is significantly cheaper than changing physical components or renovating the complete system.

The remaining of this paper is structured as follows. Section 2 discussed smart grid challenges and problems. Smart grid in Sweden is explained in section 3. Section 4 is devoted to an overview of articles which address a special challenge in the smart grid. Conclusion and future work are presented in section 5.

2 Smart Grid Challenges

By using advanced hardware and software technologies in different layer, the smart grid is capable of providing clean, safe, secure, reliable, efficient and sustainable energy for end users. However, several challenges must be addressed in order to make this a reality. In this paper, we focus on data-related challenges, namely communication, reliability, interoperability, and big data.

2.1 Communication

One of the challenges is related to the data communication system which consists of infrastructural design, type of protocols, and communication security [12]. Owing to the fact that, the industrial communication system sends and receives information from critical infrastructure, the security is a vital issue. In fact, having a safe, reliable, and at the same time a fast connectivity is essential.

S. Galli et al. in [15] addressed the role of power line communication (PLC) as a common protocol in smart grids. Jame A. Momoh in [30] discussed infrastructural challenges in the communication between components and the need for designing efficient and flexible power networks. The communication architectures in the smart grid, including the communication network compositions, technologies, functions, requirements, and research challenges were discussed by W. Wang in [46]. The security and privacy issue is put forward by P. McDaniel and S. McLaughlin in [28] where the long-haul communication system such as internet is considered as an extremely attractive target for malicious hackers.

2.2 Reliability

System reliability is another important issue in the field of smart grids. In this regard, aging of components and problems with system maintenance are very significant. Various problems often cause outages and breakouts in the grid and increase the maintenance duration. Fault detection, fault classification and weak-spot detection are some of the major tasks that belong in the reliability area.

The reliability of smart grids is discussed in [33] as a major focus area for the design and operation of modern grids. AK. Singh et al. in [43] regard the use of incorporating modern control as one of the important elements to increase the reliability of the smart grids.

Z. Yang et al, in [52] consider smart electricity meters as a key metering terminals for billing purposes and controlling for the distribution companies. They divide the functionality of smart meters into 8 models and discuss the reliability according to them. these models are: communication module, indicating module, power supplying module, controlling module, encrypting module, billing module, metering module and timing module.

2.3 Interoperability

Another issue is lack of available standards in smart grids. Many hardware and software providers design their own solutions, which may leads to a big challenge in term of devices and components interoperability. This is compounded by the fact that the power grid industry used to be very monolithic, and now it is facing the challenge of many more stakeholders and actors becoming active.

This problem is addressed by S. Rohjansand in [39]. For this purpose, some institutes focusing on smart grid standards and roadmaps such as NIST [26] and IEC [42] to establish a set of core standards for smart grids.

In this paper, the terms of interoperability in smart grid is addressed by three subjects: power quality, energy efficiency, and control and planning.

According to D. Boroyevich et al. in [6] the dynamics of electric energy generation, transmission, and distribution could be fully decoupled by using separate source converters, load converters, and power distribution converters. Therefore they discussed possible future ac and dc electronic power distribution system architectures, especially in the presence of renewable energy sources to solve such problems.

2.4 Big Data

Another challenge is related to the smart meters data. The smart meter is an advanced energy meter that collects information about energy consumption and then sends the information back to the control system for better monitoring and billing [51], [35]. In order to extract information from the data received from measurement devices, the data needs to be managed, organized, and analyzed.

As the industrial facilities were not designed (hardware and software) to handle a huge amount of data, data management and mining techniques are very important to obtain useful information. Furthermore, data mining results could be used for many purposes such as classification of customers for load forecasting which is very important in smart grids.

The data management issue is addressed by e.g. S. Dutta [11] where three different methodologies as *"data volume reduction"*, *"pattern identification"*, and *"spark-line display"* are proposed. Moreover, Z. Aung in [5] discussed two aspects of database systems: database management and data mining. Database management is related to data storage, transaction processing and querying. And data mining includes analysis of data in order to gain information and operate a suitable decision. In addition, M. Fozdar et al. in [14] and H. Mori in [32] present different data mining and AI techniques used in smart grid and power system.

3 Smart Grid in Sweden

The Swedish power grid has a good balance of energy production with hydro, nuclear, biomass and wind. The annual electricity consumption is about 140 TWh which is produced by more than 100 electricity suppliers[34].

From July 1, 2006 all the electricity companies had to install smart meters for customers above 63A. Since 2009, the smart meters should be installed for all customers (about 5.2 million). Indeed, 99 percent of all electricity meters have already been replaced by smart meters. The main challenge in this case is related to the lack of data handling systems in order to store and analyze data[34].

According to Söderbom in [41], some challenges from the view point of the "Swedish Coordination Council for Smart Grids" are: communication for smart grids, system architecture, energy efficiency, power quality, managing local generation, study of active demand, customer benefits of smart meters, vulnerability for IT threads in smart grids, and characteristic of loads.

Shorter outages and fewer outages are two challenges pointed in by Söderbom[41]. Outage longer than 24h are forbidden and customers are refunded after 12h outage. In order to handle this challenge, quicker outage detection, localization and fault repairing are essential. A service will be considered of *bad quality* if there are more than 11 outages per year. For this purpose, the areas that are likely to cause problems should be identified and repaired.

Halmstads Energi och Miljö AB(HEM) is one of the Swedish energy companies which operates in and around Halmstad [1]. In general, HEM offers:

Healthy eco-friendly and clever waste solutions

Locally produced electricity from hydropower

Practical, affordable and hassle-free heating

District cooling with minimal resource consumption and environmental impact

HEM was formed on 1 November 2006, by the merger of Renhållningsbolaget Company and Energiverken. Today, HEM serves over 45,000 customers in Halmstad with various services in waste management and energy (electricity and district heating).

In 2007, HEM declared 38,000 advanced electricity meters were enrolled to manage and reduce energy consumption by providing feedback to the customers [2]. Indeed, many smart meters are distributed all around Halmstad to monitor electricity consumption. Moreover, the power line carrier (PLC) is employed as a preferred protocol for the communication layer.

HEM, as a part of Sweden smart grid would like to reduce outages. At the moment the average power outage is about 20 minutes per customer per year. The aim is to reduce this to 10 minutes or less.

4 Overview

In this section we summarized thirty different articles, published from 2006, organized based on the previously identified smart grid challenges. In this regard, we have chosen the articles which are more related to the challenges in Sweden. *Smart grid*, *power grid*, *data mining*, and *challenges in smart grid* are some of the keywords used for literature search. Furthermore, we focused only on the data-related challenges and goals. In order to solve the challenges, different techniques are proposed which are mostly based on data mining and machine learning algorithms.These techniques could be categorized in three different topics: data-driven techniques, model-based techniques, and infrastructural solutions. In the data-driven techniques, the data is directly used in data mining or machine learning algorithms while in the model-based techniques a special model is used to extract information from the raw data. Furthermore, the infrastructural solutions describe a hardware or software designing in order to achieve effective results. By using these techniques on the collected data, many useful information could be extracted to solve challenges in smart grids.

In this section, we present a brief overview of the challenges discussed in part 2. In this case, data management and security are considered as communication challenges. Fault detection, fault classification, and weak-spot detection regarded as reliability issue. The interoperability challenge consists of power quality, energy efficiency, and control and planning. And for the big data we have classification of customers, load forecasting, and theft detection. The summary of the challenges addressed in the papers are indicated in Table 2. Consider that, some of the articles discuss more than a single challenge by their proposed techniques.

4.1 Communication

One of the challenges identified in previous section is related to the communication.

4.1.1 Data Management

Moslehi et al. in *"A reliability perspective of the smart grid"* [33]: A gridwide IT architectural framework is presented to meet the load management/demand response, and storage device challenges.

Bose in *"Smart Transmission Grid Applications and Their Supporting Infrastructure"* [7]: The requirements for an information infrastructure by considering the quantity and rate of data is proposed. In this work, the information within the substation, and between the substations and the control center are examined.

4.1.2 Security

Since the operation and control functions of a smart grid – in generation, transmission, and distribution – is transmitted through communication protocols, it is crucial to have strong security protection in place.

Wang et al. in *"Security framework for wireless communications in smart distribution grid"* [47]: A wireless communication architecture is proposed based on wireless mesh networks. Moreover, a new intrusion detection and response scheme, called smart tracking firewall, is developed.

Wei et al. in *"An integrated security system of protecting smart grid against cyber attacks"* [48]: A conceptual layered framework with three layers (power, automation, control, and security) for protecting power grid automation systems against cyber attacks are proposed.

4.2 Reliability

The second challenge identified in previous section is related to reliability.

4.2.1 Fault Detection

Calderaro et al. in *"Failure identification in smart grids based on petri net modeling"* [9]: A method based on Petri net model proposed for detect and identification of failures in data transmission and faults in the distribution network. The method captures the modeling details of the protection system and works by means of simple matrix operation.

Pang et al. in *"Multi-agent based fault location algorithm for smart distribution grid"* [36]: The design and implementation of a multi-agent technology is discussed for fault localization in smart distribution grids. The fault localization principle uses the characteristics of transient zero sequence current. Moreover, the proposed multi-agent system consists of control agent, database agent and node agent.

Zhou et al. in *"Smart Electricity Meter Reliability Prediction based on Accelerated Degradation Testing and Modeling"* [52]: Accelerated Degradation tests (ADTs) are conducted to predict smart meters reliability with respect to the billing function. In this work, six ADTs are conducted and consequently the test data used to fit degradation paths by linear regression models.

He et al. in *"Smart grid monitoring for intrusion and fault detection with new locally optimum testing procedure"* [19]: The Signal detection theory is employed to recognize failures by detecting changes in the system. In this regard, a discrete-time linear state space model employed to capture the dynamic time behavior of the system.

Authors [ref]	Goals
J Morais et al. in [31]	Fault Classification
V. Calderaro et al. in [9]	Fault Detection
Q. Pang et al. in [36]	Fault Detection
Y. Zhou et al. in [52]	Fault Detection - Weak-spot Detection
Q. He et al. in [19]	Fault Detection
P. Gross et al. in [16]	Weak-spot Detection
C Rudin et al. in [40]	Weak-spot Detection
C. Rao et al. in [38]	Weak-spot Detection
M. Chertkov et al. in [10]	Weak-spot Detection
Z Wenhui et al. in [49]	Weak-spot Detection
S. McLaughlin et al. in [29]	Energy Theft Detection
R. Mallik et al. in [27]	Load Forecasting
D. Ilic et al. in [22]	Energy Efficiency - Control and Planning - Classification of Customers - Load Forecasting
T. Kim et al. in [23]	Power Quality - Load Forecasting
H. Hongke et al. in [21]	Power Quality - Control and Planning
F. Li et al. in [25]	Data Management - Energy Efficiency - Control and Planning
Robert H. Lasseter in [24]	Energy Efficiency
IBM Software Group in [44]	Data Management - Control and Planning
D. Boroyevich et al. in [6]	Control and Planning
VC. Gungor et al. in [18]	Control and Planning
M. Pipattanasomporn et al. in [37]	Control and Planning
RE. Brown et al. in [8]	Control and Planning
PP. Varaiya et al. in [45]	Control and Planning
X. Wang et al. in [47]	Security
D. Wei et al. in [48]	Security
A. Albert et al. in [3]	Classification of Customers
TK. Wijaya et al. in [50]	Classification of Customers
A. Alber et al. in [4]	Classification of Customers
K. Moslehi et al. in [33]	Data Management
A. Bose et al. in [7]	Data Management

Table 2: Summary of different challenges addressed in the papers

4.2.2 Fault Classification

Morais et al. in *"An overview of data mining techniques applied to power systems*" [31]: The wavelets decomposition algorithm is enrolled as a pre-processor. This pre-processing or so called front end stage, converts sample data into feature. Then, decision trees, multilayer artificial neural network (ANN) trained with backpropagation, naive Bayes and K-nearest neighbor (KNN) techniques are used to classify time series that represent short-circuit faults in transmission lines. In this article, two type of fault classification systems as on-line and post-fault are discussed.

4.2.3 Weak Spot Detection

Gross et al. in *"Predicting electricity distribution feeder failures using machine learning susceptibility analysis"* [16]: A machine learning system known as Ranker for Open-Auto Maintenance Scheduling (ROAMS) developed for failure-susceptibility ranking. This ranking system evaluated by 13.8KV-27KV energy distribution feeder cables of New York city, Manhattan.

Rudin et al. in *"Machine learning for the New York city power grids"*[40]: A general process for transforming historical electrical grid data into models are introduced to predict the risk of failures for components. In this attempt, machine learning algorithms are used for prioritization of maintenance and repair work in cable sections, joints, terminators and transformers.

Rao et al. in *"Power line carrier (PLC) signal analysis of smart meter for outlier detection"* [38]: A method is proposed based on measuring strength of power line carrier communication signals. This method uses four metrics based on distribution of signal strength to identify outliers. Then, the proposed method is examined to analyze power line carrier signals from about 15,000 smart meters in residential building.

Chertkov et al. in *"Predicting Failures in Power Grids: The Case of Static Overloads"*

[10]: A standard static model is adapted to predict power grid weak points, and specifically to efficiently identify the most probable failure modes. The model is considered the grid as a graph with nodes representing loads, generators, and control equipment and edges representing power lines/links.

Wenhui et al. in *"State Assessment System of Power Transformer Equipment's Based on Data Mining and Fuzzy Theory"* [49]: The statistics-based association rule mining is used as data pre-processing method. Then, the fuzzy processing of electrical test data is conducted to use for generating assessment report and put forward suggestions on repairing of transformer equipments.

4.3 Interoperability

Another of the challenges identified in previous section is related to the interoperability.

4.3.1 Power Quality

Hongke et al. in *"Application and research of multidimensional data analysis in power quality"* [21]: A multi-dimensional data analysis from multiple perspectives is used to create a comprehensive and detailed understanding of the trends of power quality data. This information is used for operating in the power to makw scientific decision-making. In this case, they proposed the OLAP (On-Line Analytical Processing) which is a complex analysis technology based on massive data.

4.3.2 Energy Efficiency

Li et al. in *"Smart transmission grid: vision and framework"* [25]: As a roadmap for research and development, the future of smart transmission grids are considered as an integrated system. The smart grids defined as three components: smart control centers, smart transmission networks, and smart substations. Then, this new vision and its impact on CO2 emission reduction is presented.

Lasseter in *"Smart Distribution: Coupled Micro Grids"* [24]: This paper discuss using Microgrids and the benefits comes with this trend such as simplified implementation of smart grid functions in reliability, self-healing, and load control. Moreover, some vision of Microgrid are discussed; high power quality Microgrid with combined cooling heat and power, and multi-MW based Microgrid.

4.3.3 Control and Planning

IBM Software Group in *"Managing big data for smart grids and smart meters"* [44]: Techniques such as filtering and analyzing data using tailored analytics tools are proposed to process a variety of data. Then, IBM solutions for planning and decision-making in energy and utility industry are presented.

D. Boroyevich et al. in *"Future electronic power distribution systems – a contemplative view"* [6]: Possible future ac and dc electronic power distribution system architectures are proposed. In this case, some nanogrid structures such as AC Nanogrid, DC Nanogrid, and Intergrid are suggested. The proposed system architecture employed for power flow control, stability and system modeling.

Gungor et al. in *"Opportunities and Challenges of Wireless Sensor Networks in Smart Grid"* [18]: In order to measure background noise, a TinyOS application that samples RF energy is used. To measure the radio link quality, two useful radio hardware link-quality metrics are proposed. Furtheremore, wireless channel are modeled by using a log-normal shadowing path-loss model.

Pipattanasomporn et al. in *"Multi-Agent Systems in a Distributed Smart Grid: Design and Implementation"* [37]: The design and implementation of a multi-agent system that provides intelligence to a distributed smart grid is discussed. In this work, the open-source agent platform "Zeus" is used for the IDAPS (Intelligent Distributed Autonomous Power System) implementation because of its user-friendly features.

Brown et al. in *"Impact of Smart Grid on Distribution System Design"* [8]: Incorporating new technologies such as advanced metering, automation, communication, distributed generation, and distributed storage are discussed from the design perspective of smart grids.

Varaiya et al. in *"Smart operation of smart grid: Risk-limiting dispatch"* [45]: A new operating paradigm that uses real-time information of supply and demand obtained from hardware is proposed to limit the risk in operation of smart grid. The operating paradigm consists of basic probability model which uses observations, decisions, and constraints as key elements.

4.4 Big Data

The final challenge identified in previous section is related to the big data. The available data from smart meters contains a lot of useful information about customers, for example: demand response, variable pricing, consumer analytic, revenue protection and theft detection.

4.4.1 Classification of Customers

Albert et al. in *"You are how you consume: mining structure in smart meter data"* [3]:A new technique for clustering power demand distributions are proposed. The techniques is based on the two-sample Kolmogorov-Smirnoff test and evaluated during an 8-month experiment.

Wijaya et al. in *"Symbolic representation of smart meter data"* [50]: A symbolic representation of data is proposed to reduce smart meter data while maintaining its accuracy. In this case, various machine learning algorithms are employed.

Alber et al. in *"Smart Meter Driven Segmentation: What Your Consumption Says About You"* [4]: The time-dependent occupancy effects model on consumption is proposed based on Hidden Markov Models (HMM). Furthermore, spectral clustering is used to segment a collection of HMMs into classes of similar statistical properties. The proposed method is examined on about 1100 households of U.S.-based Google employees to group users according their consumption patterns.

4.4.2 Load Forcasting

Mallik et al. in *"Distributed data mining for sustainable smart grids"* [27]: The multivariate linear regression is employed to examine the problem of aggregation and prediction of power generation and consumption trends over a distributed smart grid. In order to verify the algorithm, it is implemented in distributed data mining toolkit developed by the DIAIDC research lab at UMBC.

Ilic et al. in *"Impact Assessment of Smart Meter Grouping on the Accuracy of Forecasting Algorithms"* [22]: A method based on statistical properties of the time series is proposed to predict consumers behavior. In this work, the exponential smoothing forecasting method is employed.

Kim et al. in *"Scheduling Power Consumption With Price Uncertainty"* [23]: The Markov decision process by using stochastic dynamic programming proposed in order to derive optimal policies and algorithms for finding price thresholds. These price thresholds are used for scheduling power consumption.

4.4.3 Energy Theft Detection

McLaughlin et al. in *"A Multi-Sensor Energy Theft Detection Framework for Advanced Metering Infrastructures"* [29]: An advanced metering infrastructure intrusion detection system is presented which uses information fusion to combine the sensors and consumption data from a smart meter. This leads a more accurate system to identify malicious energy theft attempts in advanced metering infrastructures.

5 Conclusion

This paper reviews several important challenges in smart grids from a Swedish perspective. The challenges related to communication, reliability, interoperability, and big data are discussed. Among the identified challenges, we only considered the data related challenges which can be solved by data mining and machine learning algorithms. These challenges include: data management, security, fault detection, fault classification, weak-spot detection, power quality, energy efficiency, control and planning, classification of faults, load forecasting, and theft detection.

Halmstads Energi och Miljö AB as a part of Sweden smart grid encounters some challenges especially in term of outage reduction. This overview gives a general perspective of the available challenges and solutions which can be employed in order to solve similar problems.

At the moment the average power outage is about 20 minutes per customer per year. The aim is to reduce this to 10 minutes or less. For this purpose, data collected from smart meters will be analyzed. Different data mining techniques will be investigated in order to be able to detect, localize and predict outages and consequently perform mitigating actions.

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