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Supply chain intelligence for electricity markets: A smart grid perspective

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Abstract Smart grid technologies are bringing innovations in electrical power industries, affecting all parts of the electricity supply chain, and leading to changes in market structure, business models and services. In this paper we introduce a model of business intelligence for a smart grid supply chain. The model is developed in order to provide electricity markets with the necessary data flows and information important for the decision making process. The proposed model offers a way to efficiently leverage the new metering architecture and the new capabilities of the grid to reap immediate business value from the huge amounts of disparate data in emerging smart grids. The model was evaluated for the Serbian electricity market in the electric power transmission company Public Enterprise "Elektromreža Srbije". The results show that business intelligence solutions can contribute to a more effective management of smart grids, in order to ensure that companies achieve sustainability in the increasingly competitive electricity markets, while still providing the high quality services to end users.

Keywords Smart grids · Business intelligence · Electricity supply chain · Key performance indicators · Electricity markets

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1 Introduction

The energy sector is one of the largest industrial sectors in the modern economy. It accelerates the economic growth and sustainable development. Nowadays, the electricity industry is facing increasing pressure from consumers, businesses, and governments to provide new ways to increase energy efficiency (Corbett 2013). The changes are highly influenced by the development of smart grid technologies (Farhangi 2010; IEEE Smart Grid 2014).

As electricity companies move to deploy and operate smart grids, they face the problem of adapting the grid with respect to consumer needs (IEA 2011). In order to succeed in a dynamic business environment, electricity market operators need to expand the access to the operational data, and acquire intelligence from that data (Pfenninger et al. 2014). Therefore, the introduction of smart grid technologies leads to the consequent changes in companies' information systems and increased requirements for real time analytics (Gungor et al. 2011). Business intelligence (hereinafter: BI) and knowledge management infrastructure have already been recognized as a necessity for large energy systems that adopt smart grid technologies (Arends and Hendriks 2014; Popovic et al. 2015a; Venkat and Saadat 2009).

In this research, the authors set out to explore how the decision making process in smart grids can be improved with business intelligence concepts. The main goal is to design a business intelligence system that enables the monitoring of key performance indicators (hereinafter: KPI) across the electricity supply chain, as well as advanced data analysis. The main contribution of the paper is reflected in the development and evaluation of a business intelligence model for analysis of electricity supply and demand from the perspective of the entire electricity supply chain. The research context is the electric power transmission company Public Enterprise "Elektromreža Srbije" (hereinafter: PE EMS). PE EMS is a part of electricity supply chain responsible for transmission of electricity and the management of the Serbian electricity market and is the national transmission system and market operator.

The rest of the paper is organized as follows: in the second section we give a literature review on the concepts of smart grids with the focus on business intelligence for electricity markets. In the third section we present a model of supply chain intelligence for smart grids. Section four presents a case study with the details on the implementation of a business intelligence system in Public Enterprise "Elektromreža Srbije". The fifth section provides a description of the implementation procedure, results of the analysis of the Serbian electricity market – balance responsibility, transmission network delivery quality indicators, and allocation of cross-border capacity. Finally, results were discussed and conclusions were made.

2 Theoretical background

The importance of smart grid concepts for electricity distribution is discussed by many authors (Bećirović et al. 2014; Joy et al. 2013). Smart grid is a complete information architecture and infrastructure system that covers the entire electricity value chain: power generation, transmission, distribution and electricity networks (Li et al. 2013). It enables the optimization of electricity delivery and bidirectional communication between the system operator and grid users. Consumers in the smart grid are provided with possibilities to adapt their energy consumption with respect to their needs, preferences, environmental concerns, or other characteristics (Giordano and Fulli 2012).

Today's electric grids use a variety of different monitoring and controlling applications to detect anomalies on the grid (Popovic et al. 2015a). Advanced data analytics and forecasting is also possible, and allows electricity companies to predict future issues more precisely (Erdinc et al. 2015; McLoughlin et al., 2015; Popovic et al. 2015b; Vardakas et al. 2015). Therefore, BI technologies can bring new value and empower electricity companies with better decision making process (Argotte et al. 2009).

Electricity markets are becoming dynamic. The opening of electricity markets worldwide forces power companies to seek for a more granular understanding of the market and to act competitively. In order to achieve this, they need to predict future outcomes, recognize patterns and trends, and detect exceptions. These types of problems can be solved using BI models and solutions (Mejía-Lavalle and Argotte-Ramos 2009). Further benefits of BI include cost reduction, optimization of business processes across the supply chain and increase in profit.

There are several applications of BI in electricity markets today. The most frequent application is for speeding up the reporting process, and integrating information from various sources. More advanced applications include the support for trading on the wholesale electricity markets (Sueyoshi and Tadiparthi 2008; Sancho et al. 2008), analysis of electricity market data quality and the integration of electricity market system based on the smart grid paradigm (Rahimi and Ipakchi 2010). Sueyoshi and Tadiparthi (2008) developed their own decision support system for analyzing dynamic price change in smart grids. The proposed solution includes features for modeling and simulation of wholesale electricity market. However, it does not integate data from the smart grid supply chain. Another useful tool was designed by Sancho et al. (2008). The authors developed a decision support tool based on behavior of the competitors in the electricity market. This solution was proven to be applicable for a specific problem, however, no details are given on the possibility for its integration into a smart grid information system. Rahimi and Ipakchi (2010) considered smart grid from a wider perspective, and dealt with distributed generation, demand response, and energy storage. In addition, Ipakchi (2007)analysed aspects of information systems in smart grid environment and the problem of integration of information in smart grids. He defined data assets in a smart grid and gave a view on interoperability aspects.

Performance measurement is a topic of keen interests in the e-business intelligence literature and can be defined as the practice of measuring process parameters and results achieved by a business unit or organization (Bremser and Chung 2005). Several different frameworks for combining measures of performances were developed by various authors, whose aim was to help organizations answer the question of what to measure. The most commonly adopted and used framework is the Balanced Scorecard, which consists of four perspectives (Kaplan and Norton 1996): the customer perspective, the internal business process perspective, the financial perspective, and the learning and growth perspective. Bremser and Chung (2005) point out that Balanced Scorecard needs to be expanded with two additional dimensions: constituencies and e-business models.

A data warehouse is a basis for decision support and business intelligence systems (Alhyasat and Al-Dalahmeh 2013). The data warehouse technology has been developed with the goal to extract the data from heterogeneous data sources into a single entity optimized for analysis purposes. Throughout the years, numerous data modeling techniques have been discussed and used for building a data warehouse (Sen and Sinha 2005). These methodologies usually include similar activities, such as analysis of business requirements, data modeling, architecture modeling, implementation, and deployment (Kimball et al. 1998). Data warehouse design requires a high level of domain expertise, as well as knowledge and experience in data and architecture design (Stefanović and Stefanović 2011).

Using a data warehouse and business intelligence is one way for an enterprise to collect and analyze performance measurement data. For modeling performance management, business objectives should be translated into KPIs. These indicators enable the organization to compare the most important aspects of the process against a target that they define. KPIs are widely used in companies for performance measurements on all levels of management (Masayna et al. 2007). Managing performance involves the process of choosing indicators or metrics of critical success factors as well as definition of criteria and areas of measurement, which can aggregate subcriteria and indicators (Ferreira et al. 2011).

Taking into account the quantity of data in a smart grid, as well as the rising need for real-time analytics, it is expected that the future BI systems for smart grids need to be based on big data technologies (Diamantoulakis et al. 2015). The full implementation of big data analytics in smart grids is expected to lead to new knowledge on power utilization habits, energy consumption patterns, energy market pricing and bidding, management and control of the grid, etc. (Min et al. 2014).

3 A model of supply chain intelligence for smart grids

Electricity supply chain includes companies that operate in the fields of generation, transmission, distribution, and consumption of electric energy. As the smart grid develops, the new business models arise, new companies appear on the market and the supply chain becomes more complex. Therefore, smart grid companies need new supply chain intelligence systems that integrate business elements, concepts, tools, and smart grid technologies. These supply chain intelligence systems are expected to unify business processes, KPIs, data warehouse and business intelligence through a specialized web portal (Fig. 1). The portal should be designed to leverage proactive performance management and foster optimizations (Stefanović and Stefanović 2011) with mechanisms for reporting and analytics, and services that connect users, information, processes, and systems within a smart grid. The BI portal is a complex web site that integrates numerous information and services, and provides access to various applications. In the context of smart grid, the BI portal allows access to many resources and services such as daily reports, plans, forecasts, etc. The portal allows access to information and services depending on the access level of the specific user. Some of the portal data may be freely avalable to a wider public, such as data on network capacity, auctions, etc.

The goal of a supply chain intelligence model for smart grids is to provide the main capabilities required for a successful supply chain management including the planning, monitoring, analyzing and prediction of states and events (Stefanović et al. 2011). Supply chain intelligence system should provide a consistent and timely view of the data and the tools which allow decision makers to explore large quantities of data. Advanced data mining techniques can be used for demand forecasting, inventory prediction, customer segmentation, risk management, etc. (Stefanović et al. 2009). A vital part of a smart grid management is performance monitoring. Smart grid performance measurement is driven by metrics and supported by business intelligence.

3.1 Smart grid supply chain

The basic concept of the smart grid supply chain and its effect on the electricity market stakeholders are outlined together with the conceptual model described by National Institute for Standards and Technology (National Institute for Standards and Technology NIST 2012). This model shows interconnected communications across the smart grid and provides a framework for identifying actors, communication networks, interactions and their potential capabilities (IEEE Smart Grid 2014).

Figure 2 shows the conceptual diagram for smart grid supply chain which is based and adapted from the NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 2.0 (2012). The elements of a smart grid supply chain determine the necessity for business intelligence tools and techniques. The main participants in a smart grid supply chain are:

- Electricity producers produce electricity from various forms of energy. The main purpose of electricity generation is the transmission and distribution of the electricity to the end users. Intelligence in this domain is necessary in order to achieve smart generation and load balancing.
- The transmission and distribution of the electricity to the customers are enabled through markets and operators. In these domains BI is primarily required to support the monitoring and control of the network. BI systems in these domains are specifically required to support the distributed generation processes, where beside bulk generation, electricity may be generated by customers.
- Residential, commercial and industrial customers are the end users of electricity. They also have a possibility to produce and distribute energy if they possess an electricity source, such as solar panel or a windmill, and therefore

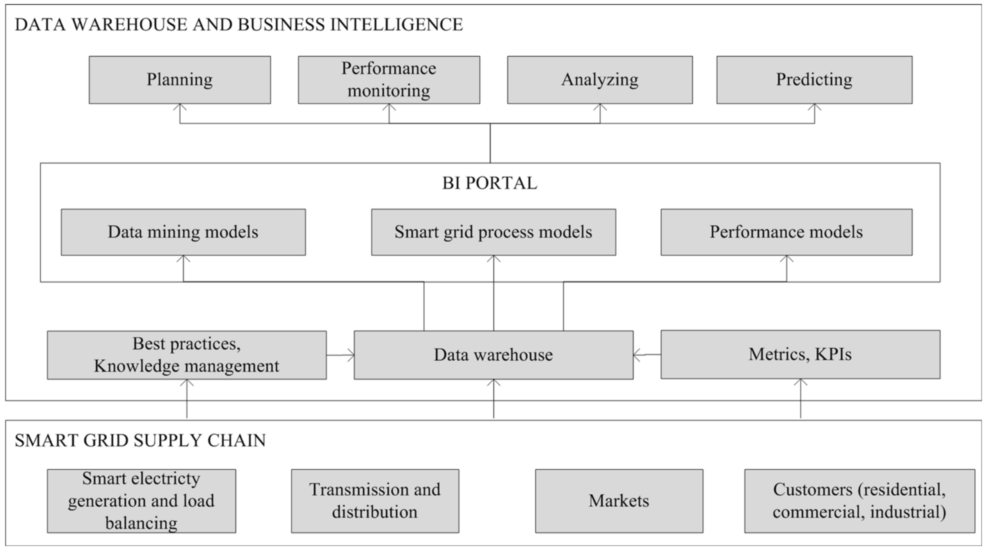


Fig. 1 Supply chain intelligence model for smart grids

influence the retail market competition (Bae et al. 2014). For the measure of power consumption customers use smart meters that enable remote reading and real-time reporting. Customers may require anvanced analytics in order to manage their consumption and distributed generation adequatly.

- Markets manage electricity wholesaling, retailing and trading. In this processes they are connected with service providers, operators and customers. In this field, BI is required to support all the market processes, including pricing, auctions, etc.
- Service providers provide customer management, billing, and installation and maintenance. They are connected with markets, operators and customers. BI is necessary for service providers in order to provide proactive customer service or keep lower maintenance costs.
- Operators are the managers of the movement of the electricity. They set network design and construct networks; they manage network operations, security, logistics, etc. Numerous strategic decisions related to smart grid development are made here, therefore, adequate decision support system are necessary. These systems should provide advances analytics features, such as data mining, optimizations, simulations, and others.

Smart grid information networks demand appropriate communication architecture based on network technologies such

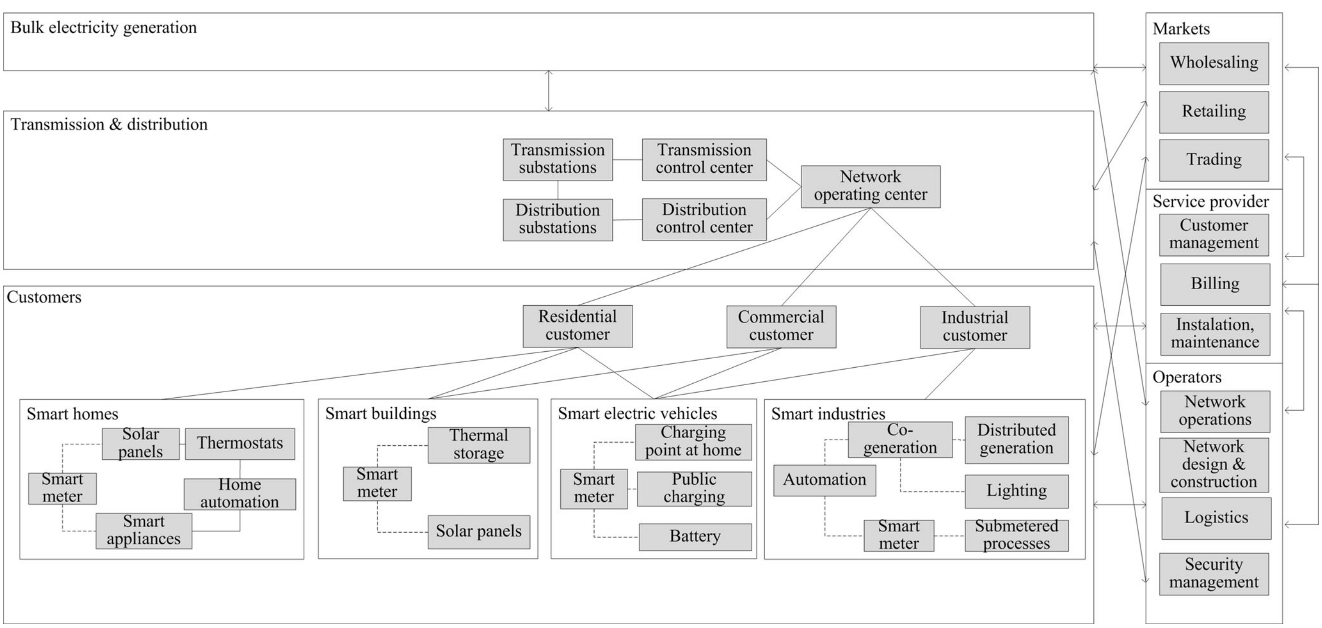


Fig. 2 Conceptual diagram for smart grid supply chain

as wide area networks, field area networks and home area networks (National Institute for Standards and Technology NIST 2012). These networks should enable data flow and information management between customers, electric power public enterprises and service providers. Then, business intelligence tools and techniques can provide features for visualization and decision support. In addition, integration with external data sources, such as weather data or geographic information, can be performed. Dashboards, scorecards, maps, charts and other visualization tools are used to present data in an intuitive way that supports the presentation of information for a more efficient planning of the network (Personal et al. 2014).

3.2 Data warehouse and business intelligence

Customer service and relationship management are becoming more important for electricity utilities operating in deregulated markets (Werner and Hermansson 2002). Successful relationship management relies on enormous amounts of information stored in a data warehouse. The data warehouse needs to be flexible and scalable enough to support effective data mining and capable to handle the huge amount of data inflow from the power network. The data warehousing for smart grids should allow market participants to have the ability to forecast future conditions by looking at the history (Xu 2005). Electricity utilities that integrate and analyze data from smart grid can gain insights into their grid operations and assets, in order to take proactive rather than reactive actions. This approach may lead to increased profitability, higher customer satisfaction and loyalty, and enhanced interaction with stakeholders. Advanced analytics for smart meters and measurement systems will offer high reliability and quality of delivered electric energy, better consumption management, and reduction of technical and commercial losses (AERS 2014).

There is an endless amount of information that needs to be integrated into utility and end-user information systems, including weather predictions, geospatial information, real-time bid-ask data for energy markets, and many others (Leeds 2009). As smart grid technologies push more data with increasing speed and volume, many energy and utility companies have realized that they cannot continue to operate in the same fashion, and have committed to rapid adoption of new technologies to help meet these changing demands (Nechifora et al. 2015). In this ever changing environment, electricity utilities are turning more towards the benefits provided by business intelligence and advanced analytics to support data-driven decision making and planning. The main challenge in the area of smart grid data analytics is the how to transform the huge amounts of smart grid data into valuable intelligence (Hedin and Wheelock 2010).

When electricity utilities implement a smart grid they will immediately face a huge amount of data generated by an enormous amount of sensors and devices. Smarter and faster decisions are possible only if the data is interpreted accurately and timely, which can only be done if the data is optimized in a centralized data warehouse.

Electricity utilities need a real-time business intelligence system to integrate various data sources, extract and display KPIs, leverage existing investments, improve scalability and security, and save resources and costs. Advanced analytics can help solve business problems in the areas of (Accenture 2011):

- Meter data analytics/usage and consumption analytics - data gathered from smart meters and various types of analytics can provide a better understanding of customer segmentation, behavior and how pricing changes affect the demand.
- Customer management analytics - the customer data enables market analysis and advanced segmentation based on energy consumption patterns, interactive communication, and monitoring of customer behavior. The data warehouse and BI can be used to find patterns that point to common characteristics of the customers, which would in turn allow for a more direct way of marketing. Predictive models could be drawn for a more in depth comparison of various product development plans.
- Asset management analytics - asset utilization can be optimized and load balancing performed if relevant data is available in real time.
- Operational decision support analytics draws information from a multitude of sources and offers real time decision support, allowing decisions to be made on a reactive, rather than a proactive basis.
- Enterprise performance management analytics measures performance of the business. KPIs are used to measure achievements against goals or benchmark with other transmission operators.

Smart grid analytics provides information on the performance of the energy ecosystem with the goal to avoid power failures and facilitate decision making. Some energy companies are still focused on smart metering infrastructure, but there are those who are looking to gain strategic value from other customer technologies that stream data from a variety of devices. This means that smart grid data analytics is the process of collecting, aggregating, inspecting, cleaning, interpreting, visualizing and modeling smart grid data from smart meters and other smart grid devices, also including data mining, which focuses on modeling and knowledge discovery for predictive analytical purposes (Hedin and Wheelock 2010).

Smart grid technologies, including the tools for intelligent network management and performance monitoring have spurred a worldwide demand for further research on how advanced analytics can help electricity utilities to better track grid operations. According to Li et al. (2013), traditional energy management database systems, emphasize the monitoring activities, while lacking the ability to aggregate data, analyze them and create advanced reports. And for this reason the solution presented in this paper was designed in a way to provide an in-depth view of data in various levels of aggregation by drilling up or down through the observed hierarchies.

Figure 3 shows a smart grid taxonomy adapted from Accenture (2011)Technical analytics and business intelligence are emphasized as critical for transforming raw data into useful information necessary for operational decision making.

As the taxonomy shows, creating actionable intelligence is an important aspect of analytics. A key consideration in overcoming the challenges of the smart grid data is the effective use of the adequate analytical techniques and tools that would transform the data into comprehensible reports, via the definition of suitable metrics and KPIs. KPIs carefully designed for the electricity network, enable measuring and monitoring the progress of development of smart grid. These KPIs can serve multiple purposes, within the energy companies or at the regulatory level. For example, KPIs can be used for monitoring the operative or strategic goals of an organization, or for assessing the development of smart grid on a regional, national or international level (Dupont et al. 2010).

4 Implementation and results

The business intelligence system for electricity market was evaluated within the Public Enterprise "Elektromreža Srbije", a Serbian transmission system and electricity market operator. Some of the core activities of the company are power transmission, system operation and organization of the electricity market. The business intelligence system was designed upon the model presented in the previous section and supports the business processes taking place in the Electricity Market division of the enterprise. The system was designed to be able to easily adapt as the grid modernizes and adopts the smart grid concepts, in particular related to communication and real-time metering.

Business intelligence requirements of smart grid enterprises are often related to monitoring and forecasting energy consumption (Zhaolin 2012). Tracking trends and comparing the performance is not a straightforward process, and requires an adequate methodological approach. In order to design and evaluate a system for business intelligence for the Serbian grid, its main phases and requirements need to be identified. The steps shown in Fig. 4 are conducted as integrated components of an iterative process, where business value is derived from analytics driven by smart grid information.

The proposed method can be implemented in smart grid adopting as well as smart grid compliant grids in order to offer support for the analysis of large amounts of data. This approach can improve upon the existing way of doing business, by offering a more efficient and structured perspective on the provided data and allow for data analysis which is critical for those who are looking to implement an open market together with real time pricing.

A huge amount of data can be generated from metering, monitoring and other smart grid processes. The data is often located in different internal or external systems. To cope with this the smart grid must support advanced information management which includes data collecting and modeling, and information integration and analysis (Fang et al. 2012).

The collected heterogeneous data is stored in a data warehouse after extract, transform and load (ETL) processes. The challenge is to design an adequate dimensional model for the reporting of data relating to the development and administration of the electricity market. In addition, the designed data infrastructure supports collecting disparate data that originates from multiple vendors' devices. BI system provides the capability for information integration across the applications like DAMAS, SRAAMD, SCADA and other systems.

Figure 5 illustrates the proposed framework of BI, which supports data integration needed for the functioning of the electricity supply chain processes. The newly integrated data can be used by future applications to provide new interpretations of data. The proposed BI framework aims to increase the performance and reliability of current processes through improved data and supply chain data flows. Additionally, a workbench can be used for creating customized analytics in a self-service model.

4.1 Defining business requirements

In the phase of defining business requirements, interviews with system users were conducted, and functional and non-functional requirements identified. This includes specification of reports, data flows, KPIs, measurements, etc. For this phase, ASAP for Business Warehouse (BW) approach was used (Lukić 2014; Musil 2012; SAP AG and SAP America, Inc 2006). ASAP methodology framework provides users with various development strategies. The standard ASAP methodology is structured into the following phases (SAP AG 2014): project preparation, business blueprint, realization, final preparation, and go-live support. ASAP for BW is based on the same concepts, but it is focused on the configuration of BW to work with the structure already in place.

For identification of the process KPIs that have significant influence on the business results, Balanced Scorecard (BSC) framework proposed by Bremser and Chung (2005) was adopted. KPIs based on the best transmission system operator practice and company's practice cover the full scope of the important activities. Table 1 presents measurable indicators with its unit and calculation formulas. These indicators were

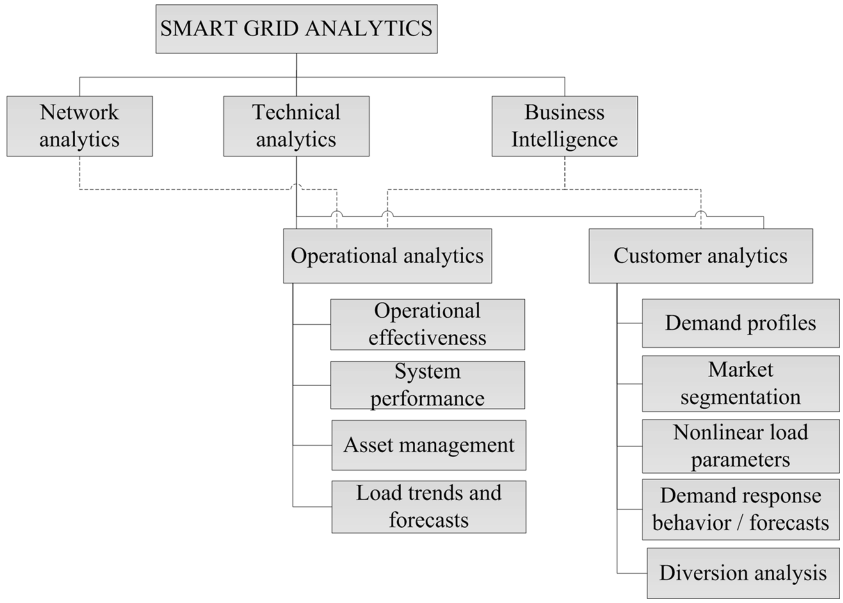


Fig. 3 Smart grid analytics taxonomy (Accenture 2011)

chosen in order to allow for insights into energy saving and power efficiency.

The proposed methodological approach for developing a business intelligence system in a smart grid links the KPIs to the principal characteristics of the smart grid. For this purpose a set of KPIs for monitoring electricity market as a smart grid domain has been defined. From the perspective of energy saving and power efficiency, the benefits of the proposed model have been identified in the following main domains: efficiency of power consumption, maximization of metering data, demand-side management, electricity market organization and administration in a more transparent and effective way, improvement of market functions and customer services, and improvement of transmission system stability.

In PE EMS the focus was on the improvement of the processes taking place in the Electricity Market division of the enterprise, and the processes were chosen so as to provide an in-depth perspective of the market. The implemented business intelligence model currently supports the following process groups: Cross-border Capacity Auctions, Balance Responsibility, and Balancing Mechanism.

4.2 Data modeling, integration and report design

Phases of data modeling and integration and report design were carried out according to the method proposed in (Kimball et al. 2008; Lukić 2014). Designing a data warehouse and business intelligence system is an iterative process. New subject areas are loaded into the warehouse in every iteration. The main data model elements were identified by analyzing the database entity-relationship schema, and the attributes, facts, dimensions and hierarchies were imported in the data repository.

Internal sources of data are operational databases which are used by comprehensive information system for the system for Auctions of cross-border transfer capacities - DAMAS and system for remote acquisition and accounting of metering data - SRAAMD. External data sources include the data from customers, energy traders, other TSOs, as well as DSOs operating on the territory of Republic of Serbia which provide the metered data for the BRPs on both the distribution and transmission level. Generally, BI systems do not cause major changes in business processes and procedures. In our environment rules for certain data collection from external sources were changed in order to allow that set of data to BI system.

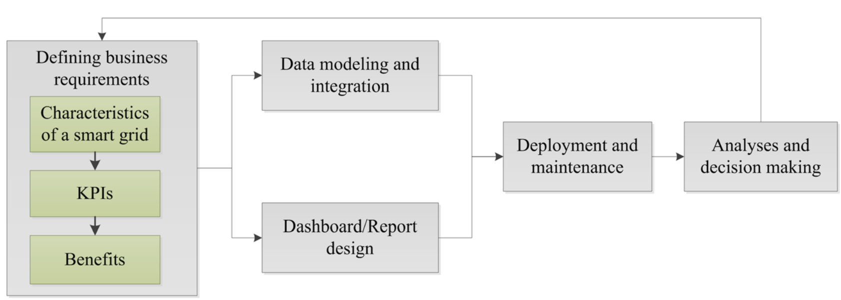


Fig. 4 Phases in developing the business intelligence system in a smart grid

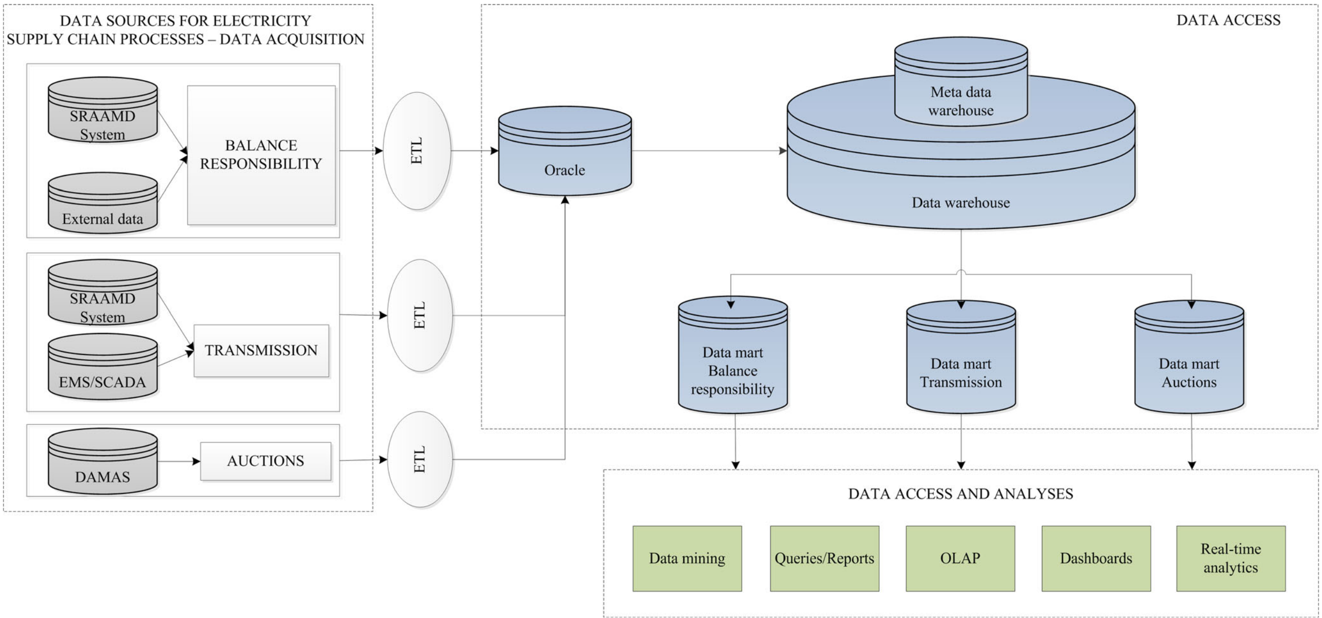


Fig. 5 The proposed business intelligence framework

The intention is to expand the data model to include data from SCADA/EMS system and other systems in order to provide advanced analysis on the transmission level.

The data is presented to the users in a highly visualized manner, in a single dashboard built with Business Objects Dashboards 4.0 tool (SAP AG 2013). The created dashboard encompasses the measure of performance in the related field, analysis of reasons behind gaps that may occur and description of the possible corrective and preventive actions.

The analysis that can be built in a more flexible and detailed way, allowing for drilling up and down through data are given in the Table 2:

4.3 Deployment and maintenance

Effective utilization of the developed business intelligence system is possible only after adequate deployment and with permanent maintenance.

Final preparations include stress tests, end-user training, and performance tests. Preliminary results provide data for fine tuning and improving the support for end-users across the enterprise. In addition, administrative procedures are established. During the application of the developed solution, new requirements are gathered and used to improve the solution and provide better information to the decision makers.

4.4 Analysis and decision making

In 2008, Cross-border Transmission Capacity Allocation in Serbia was changed to work on market principles. Electricity market in Serbia has opened in 2013. Market processes have many parameters which must be measured and monitored in order to analyze and derive certain conclusions about market trends and to draft market reports. According to them EMS will be able to adjust market rules based on the data derived from the behavior of market participants.

For the purpose of evaluation of the developed solution, three cases of analysis were selected: 1)Analysis of the electricity market; 2)Transmission network delivery quality indicators; 3)Allocation of cross-border capacity. The cases were selected in order to demonstrate the role of business intelligence across the electricity supply chain.

4.4.1 Analyses of the electricity market – balance responsibility

The electricity retail represents the sale of energy from an energy provider to a consumer. In the beginning of 2013. all end customers connected to electricity transmission system were obliged to purchase electricity in the open retail market (AERS 2014). As it is shown in Fig. 6, from 01.01.2014. 43 % of total consumption was supplied on the free market.

It can be observed that from 01.01.2013. 26 consumers connected to transmission network have lost right to public supply and are forced to find supplier on the free market. They represent 9 % of total consumption.

From 01.01.2014. 18 % of distribution level end-user customers was not eligible for public supply (as with 9 % of consumption in the transmission network makes 27 % of total consumption). Losses in transmission and distribution

Table 1 Some of the indicators for monitoring in electricity supply chain

Indicator/Definition	Unit	Calculation	
ELECTRICITY MARKET - BALANCE RESPONSIBILITY			
Balancing group deviation (OBOS)	MWh	$OBOS_{BOS,oi} = UPP_{BOS,oi} + UOP_{BOS,oi} - BEN_{BOS,oi}$ $BEN_{BOS,oi} = [BES_{BOS,oi} + BET_{BOS,oi} + BETS_{BOS,oi}]$ where (PE EMS 2014): UPP - total nominated balancing group position; UOP - total metered balancing group position; BEN - total engaged balancing energy of the balancing group; BET - balancing energy as result of tertiary regulation engagement for system balancing; BES - balancing energy as result of secondary regulation engagement; BETS - balancing energy as result of tertiary regulation engagement for ensuring the secure power system operation; BOS - index designating BRP (hereinafter: BRP) in charge of that balancing group; oi - index designating accounting interval.	
Acceptable Imbalance of Balance Group (POB)		Value of acceptable imbalance of the balancing group (POB) is determined for each day and is equal to (PE EMS 2014):	
		MAX (1 MWh; 3 % of maximal scheduled hourly consumption from the balancing group's daily schedule)	In case that the balancing group is associated with minimum one Withdrawal/Injection points (hereinafter: WIP point) and that BRP has the role of Consumption Responsible Party and has no role of Production Responsible Party.
		MAX (1 MWh; 1,5 % of maximal scheduled hourly production from the balancing group's daily schedule)	In case that the balancing group is associated with minimum one WIP point and that BRP has the role of Production Responsible Party and has not the role of the consumption Responsible Party.
		MAX (1 MWh; 1 MWh and sumarized value of 3 % of Maximal scheduled hourly consumption and 1.5 % Maximal scheduled hourly production from the balancing group's daily schedule)	In case that BRP has the role of Consumption Responsible Party and the role of Production Responsible Party.
		0 MWh	In the case when BRP has the role of Trade Responsible Party.
Imbalance settlement price (ISP)	EUR	Settlement price can be maximum of 1.5 times greater than the maximum price for the engaged balancing energy in regulation upward in that accounting interval.	
TRANSMISSION (ENS, PF, AIT, BNR, UONSI, TL)			
Energy not supplied (ENS)	MWh	$ENS = \sum_{i=1}^{F} IP\ (MW)\ {*}T\ (h)$ IP - Interruption power (in MW) T - Duration of interruption (in hours) F - Total number of Interruptions during the reported period	
Power failure (PF)	MW	–	
Average Interruption Time (AIT)	min	$AIT = \frac{8760{*}60{*}ENS}{AED}\ [MWh]$ ENS - Energy not supplied AED - Annual Energy Demand	
The number and duration of voltage reduction (BNR)	hh:mm:ss	–	
Unplanned disconnection of the network of systemic importance (UONSI)	–	–	
Percentage of the transmission losses in relation to the total of injected energy on the Serbian transmission system (TL)	%	$TL = \frac{TEI-TEW}{TEI} {*}100$ TEI - Total energy injection TEW - Total energy withdrawal	

Table 1 (continued)

Indicator/Definition	Unit	Calculation
AUCTIONS FOR TRANSMISSION CAPACITY ALLOCATION (YMA, DA)		
Available Transfer Capacity (ATC)	MW	joint: *ATC = NTC – AAC* split: *ATC = 0.5*NTC – AAC* *NTC = TTC – TRM* NTC - Net Transfer Capacity AAC - Already Allocated Capacity TTC - Total Transfer Capacity TRM - Transmission Reliability Margin
Total Requested Capacity (TRC)	MW	Total requested transfer capacity of all Auction Participants
Congestion scale: total demanded/total allocated capacity	–	If the total required capacity exceeds ATC then Yes, otherwise No
No. of participants in auctions	–	Number of participants who submitted auction bids for that auction
Number of Bids	–	Total number of auction bids
Auction Price (marginal price)	EUR/ MWh	The price of the last accepted auction bid during one auction

network, as well as power consumption accounted for about 16 % of total consumption.

As of 1.1.2014 the market has been opened to the customers whose facilities are connected to the medium and low voltage distribution network and has limited the public supply to only the households and small consumers. This has resulted in the forming of new balance groups in December of 2013. Retail market opening represents a major step forward towards full market opening. Further harmonization of the underlying balancing energy market should be a priority issue. By the end of year 2014, a total of 44 participants in the electricity market signed the Contract on Balancing Responsibility and became Balance Responsible Party (AERS 2014). Figure 7 shows a structure with a number of BRPs in the regulation area of PE EMS. Each consumer belongs to exactly one BRP. Based on the composition of the balancing group (hereinafter: BG), PE EMS awards to the BRPs the role for the purpose of application of daily schedules.

Changing the composition of the balance group is a process in which more market participants are directly or indirectly involved. Due to this fact, intended or unintended errors that might occur during this process can seriously affect the functioning of the electricity market. By analyzing historical trends, analysts have a greater chance of making more accurate predictions about possible outcomes of decisions in the electricity market. One of the most important analysis is the impact analysis of the end-customers supply on the applied concept of balance responsibility.

In accordance with the Calendar of Calculation and Payment at the electricity market and in keeping with the Electricity Market Rules, PE EMS is obliged to perform the calculation of the monthly fee for deviation of the balancing group in the accounting period and to submit it to BRP. The balance responsibility of the participants in the electricity market for each settlement interval,

Table 2 List of designed reports

Area	List of reports
Electricity market - balance responsibility	- Calculation and analysis of the imbalance settlement price for specified accounting intervals; - Calculation of weighted price and average imbalance settlement price; - Review of the composition of the balancing group (the number of Withdrawal/Injection points, approved power, nominal power); - Calculation of the Balance Responsible Party Imbalance Settlement; - Calculation and analysis of acceptable Imbalance per BRP according to Serbian Market Code in combination of calculated financial fee for BRP Imbalance.
Transmission	- A trend analysis of a few KPIs for quality of electricity supply.
Auctions for cross-border capacity allocation	- A trend analysis of the value of cross-border transmission capacity available to the market for various accounting periods as well as in all or some borders; - An analysis of ratio between required and allocated capacity which might be observed from different time perspective or the viewpoint of a different borders as well as by all participants in the auctions; - A trend analysis of achieved prices at auctions per borders (directions); - Congestion management.

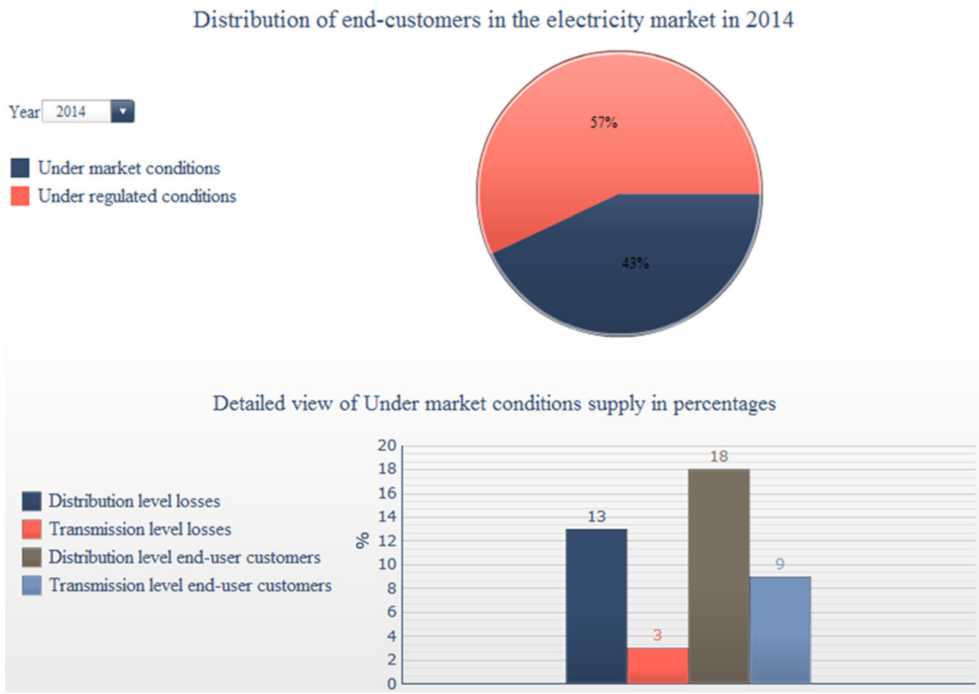


Fig. 6 Opening up of the electricity market in Serbia

represents an obligation to undertake financial responsibility towards transmission system operator for all deviations caused by unbalanced daily schedule after closing of intraday nomination process. In order to prevent manipulation of the electricity market, and to prevent the emergence of large deviations of balancing groups, which could affect the efficient operation of power systems and cause problems in the supply of electricity to end customers, EMS has introduced the concept of acceptable deviations of balancing groups (POB). POB is determined by the composition of the balance group (Janković et al. 2013). Depending on the composition of the balancing group, BRP may be responsible for the application of plans of production, consumption and trade blocks of electricity. Based on the calculation of the monthly fee, in case of a positive imbalance of the balance group PE EMS will pay to the BRP, otherwise BRP will pay PE EMS. In the case of late payment or non-payment, insolvency of the market participant is transmitted to other participants as well as to PE EMS, and thereby endangers the functioning of the electricity market and security of supply to end customers (Janković 2014).

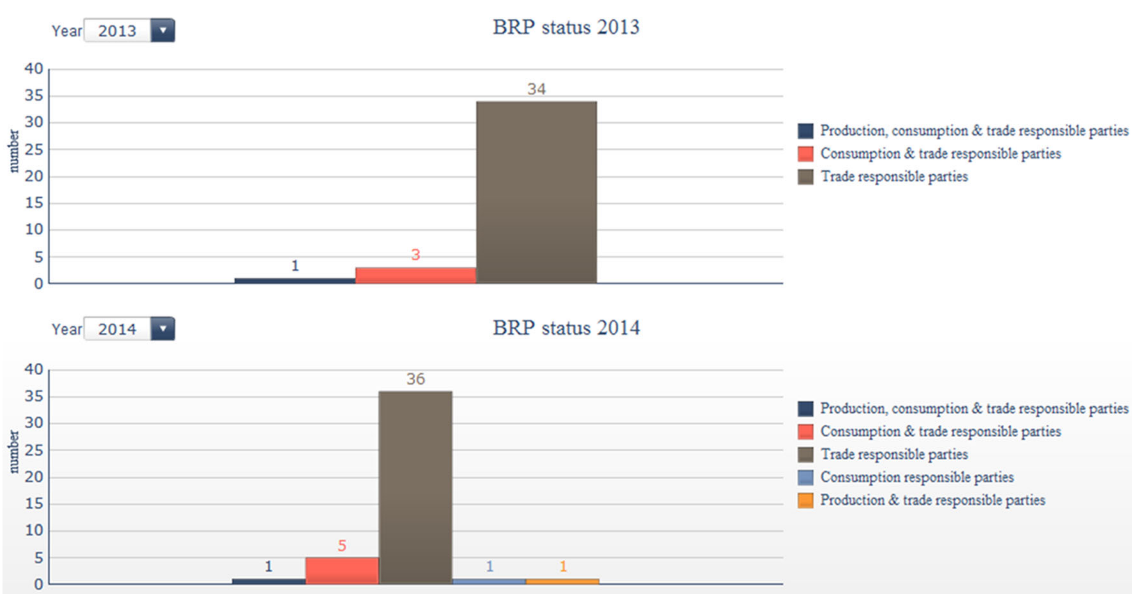


Fig. 7 Structure with a number of Balance Responsible Parties in the regulation area of PE EMS

4.4.2 Transmission network delivery quality indicators

Interruptions to the power supply can occur for many unexpected reasons, such as natural hazards, or even sabotage. However, many of them are consequences of faults in the electricity network. Indicators of discontinuity of delivery in the transmission network which are monitored and calculated are shown in Fig. 7.

Summarizing these data leads to the conclusion that the number of power failures and cases of undelivered electricity was drastically reduced in the period from 2011 to 2013. It resulted from the investments in transmission grid maintenance and development as well as from the upgrade of transmission system operation and permanent investments in education of the operating personnel.

During 2013 monthly data about energy not supplied as a consequence of events in the transmission network were systematically recorded and analyzed. The structure of this data on a monthly basis in 2013 is also shown in Fig. 8. Looking at the pie chart, we can see the trend of EMS responsibilities regarding undelivered electricity due to unplanned events for selected year. EMS is responsible for 46 % of unserved energy, while the other users of the transmission system are responsible for 39 %. Based on the given values, one can notice that 14 % of unserved energy belong to the events in which EMS could not influence or force majeure (transient failures, lightning strikes...), while other causes account for about 1 %. Based on these indicators, PE EMS analyzes the significant operating events in transmission network in order to determine the causes of the disorder and proposes measures to prevent repetition of similar events. The performed analysis can be further combined with the smart grid and used for more precise grid management resulting in reduced equipment failures.

4.4.3 Allocation of cross-border capacity

PE EMS performs the Allocation Procedure for allocation of rights for use of cross border transfer capacities on yearly, monthly, and weekly basis. In order to harmonize with the operators of neighboring transmission system, PE EMS determines the values of cross-border transfer capacities. The cross-border transfer capacity on the interconnections is allocated by the auction operator of the neighboring transmission system (Rules for allocation of available cross-border transfer capacities on borders of JP EMS control area from 01.01.2015 until 31.12.2015, 2015), according to the current agreements with the operators of the neighboring countries and Auction Rules in the form of commercial transfer rights for each country.

PE EMS is responsible for calculation, allocation and use of cross-border transmission capacities on all borders of the control area of the Republic of Serbia. In 2013, PE EMS organized monthly auctions for the allocation of 50 % of available capacity for each month, on all the above given borders and in all directions. In 2013, Transelectrica organized long-term (annual and monthly) and intraday (first come-first served) auctions for the allocation of 100 % of the available capacity on the Serbian-Romanian border, while PE EMS allocated the available capacity on daily level (Daily Auction Rules 2013; AERS 2014). Figure 9 indicates average monthly amounts of net cross-border transmission capacities (NTC) on the Serbian-Romanian border in both directions for 2013. The figure also shows the trends in the three selected performance indicators defined in Table 1 for a three-year period.

The number of participants as well as the other general data on joint annual auctions for 2013 on the Serbian-Romanian border is given in Fig. 9. Based on the given values, one can notice that on the Serbian-Romania border, in 2013 there were congestions in both directions.

There is a general concern by the market participants for reaching the correct business decisions when the operating schedule of the transmission line is involved or the contribution to the Available Transmission Capacity (ATC) (Xu 2005). The dashboard is related to yearly and monthly auctions for the allocation of transmission capacities at the border of the control areas of PE EMS and can be used to monitor the behavior of the competitors in the market, as one of the many different scenarios.

The company analyses the results of the yearly and monthly auctions, take actions, and set goals for the coming years in order to achieve performance improvements, and through them increase the overall efficiency of auction sales. Number of participants as well as the other general data on annual auctions may vary depending on the previously selected neighboring country and the year. With this data, the dashboard is readily usable by decision makers for market analysis and grid analytics to monitor the flow of energy along the grid as well as to monitor behavior of Serbian Market area in relation with interconnection and not just regular parameters of Serbian Electricity Market. In addition, when international benchmarks are available, comparisons will be made.

5 Discussion

Various reports have shown that the existing management information systems cannot meet current needs of participants in the electricity industry. It is difficult to obtain the decision-making information to compete in the market or to create policies (Zhaolin 2012). The challenge to promote the operation and management capacity of electric power enterprises implies the construction of an integral business intelligence platform designed for KPI management, analysis, and forecasts. In addition, numerous studies have proved that intelligence across the whole electricity supply chain is necessary for the effective

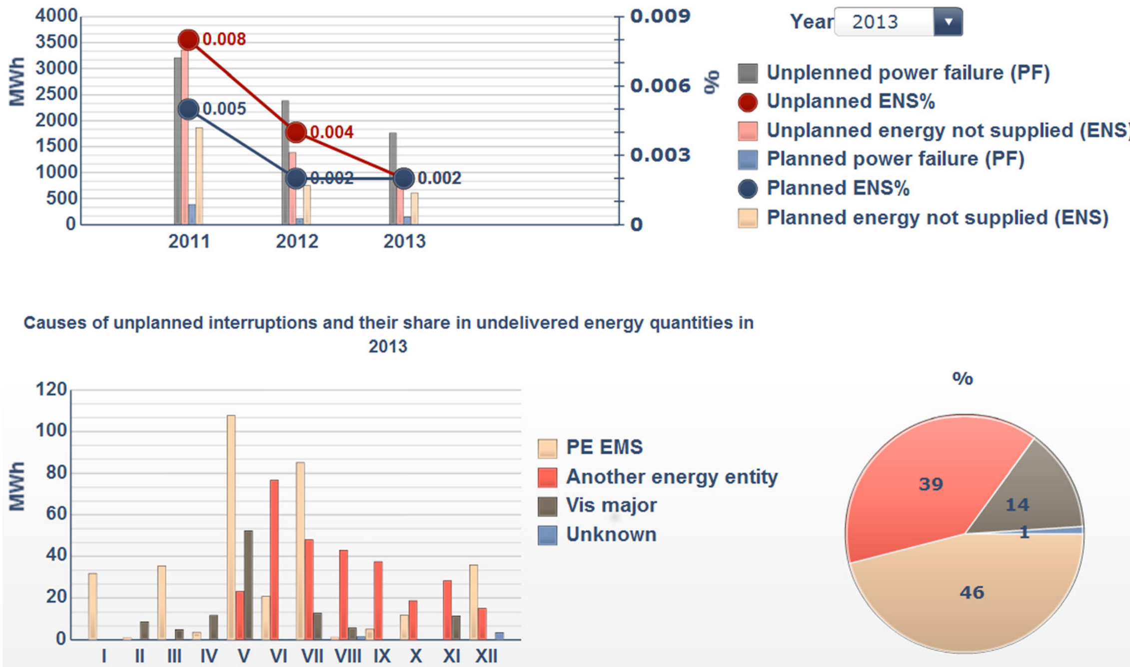
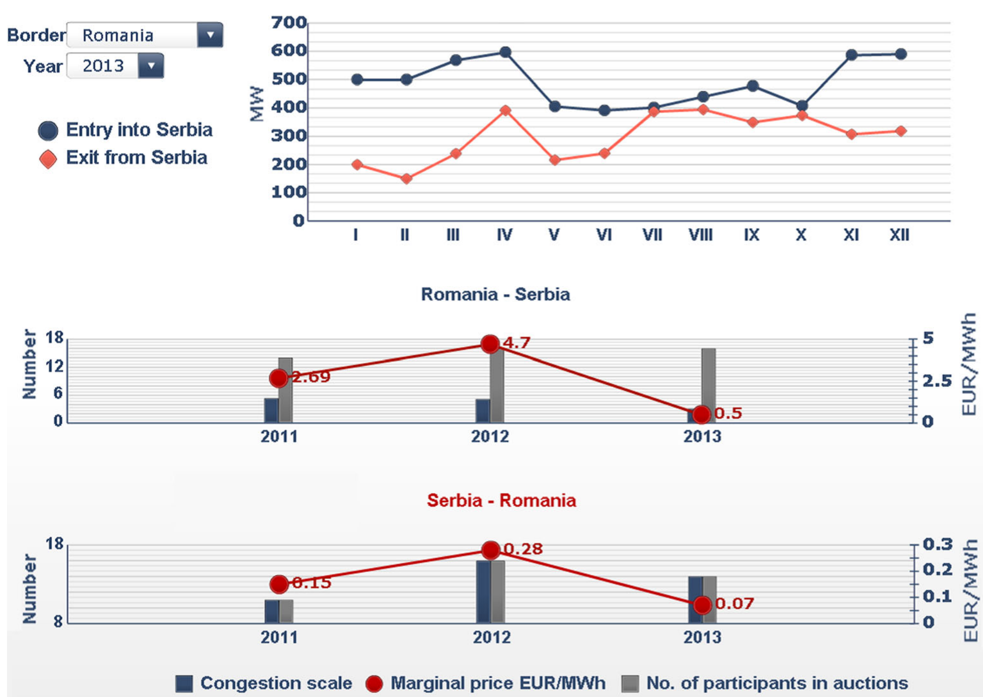


Fig. 8 Indicators of discontinuity in delivery within the transmission network in the period 2011–2013

coordination of business activities (Stefanović and Stefanović 2011; Zhaolin 2012). Supply chain intelligence can effectively integrate large data volumes and support a variety of difficult and challenging electricity market issues such as prediction, pattern recognition, modeling, and others. In this complex scenario, supply chain intelligence approach can be an important solution due to its essential characteristic to manage large data sets intelligently and automaticaly (Argotte et al. 2009). However, the electricity industry, has not yet harnessed all the potentials of business intelligence (Argotte et al. 2009; Mejía-Lavalle and Argotte-Ramos 2009).

This study proposes a framework for enhancing decision making in smart grids by presenting a business intelligence model that enables the monitoring of electricity supply chain KPIs in the field of energy transmission and the electricity market. The main advanatge of the proposed model is the focus on the entire smart grid

Fig. 9 General data on joint monthly auctions for the allocation of 100 % of available cross-border transmission capacities on Serbian-Romanian border in 2013



supply chain. The data is acquired from the transmission grid, distribution grid, end users and the electricity market, in order to offer a centralized view of the whole supply chain. The main contribution of the paper is reflected in the development and evaluation of a business intelligence system for analysis of electricity supply and demand from the perspective of a transmission system and market operator in a smart grid. The research has opened up perspectives for studies on business intelligence for smart grid adopting markets with the growing trend of small resolution data aquisition that strives towards real-time, and the KPIs which could easly be adopted and modified during the transition process. The BI system is well suited to adapting to the quickly changing needs and the evolution of the grid that is still taking place, and can be expanded to the processes that support whole electricity supply chain.

Smart grid technologies and applications are expected to determine the future of electricity industry and create a platform for new innovative business models, the so called "Energy Internet" (Sua and Huang 2014). Therefore, energy companies will have to be significantly modernized if they wish to become adaptive to end-users' needs and more competitive in deregulated markets (Ghanem and Mander 2014; Lund 2014). This has an effect from both economic and technical points of view. From the economic point of view, it is very critical to consider the impact of the smart grid for an efficient and well-structured commercialized electricity industry. The benefits of smart grid will be maximized only through integration of technological developments into global energy sustainability strategies (Koliba et al. 2014). These benefits should be valuable for both companies and customers (Babic 2013). Consequently, from the technical point of view, this paper provides valuable insight into the business intelligence technology to solve business problems that are characteristic for smart grid organizations. As the electric grid and electricity markets become more trans-active, distributed, and bidirectional, the challenge of implementing business intelligence grows. Supply chain intelligence should be available for every link in the chain (Leeds 2009).

The difficulty of data integration across the electricity supply chain lies in the multitude of different organizations that operate within it. Each of these organizations functions in the separate part of the supply chain and uses various systems for data collection and storage. This variety of systems greatly influences the difficulty of integration into a single system, due to diversity of data formats, types and granularity. Another challenge in the implementation of the proposed model was the lack of standard in the communication between supply chain participants. For the processes of balance responsibility for electricity market there was a need to collect the data from both the energy producers, consumers and traders. Data was collected from end customers, distribution grids and the transmission grid. Large parts of the data were of the different granularity. The main problem with the grids that are still adopting the smart grid concepts is the lack of interoperability standards. As the modernization process continues the interoperability problems are expected to reduce.

PE EMS is currently in the process of modernization and the integrated data with the BI solution can offer insights into the development of the grid and the benefits of modernization, as well as help take the first steps towards a full fledged deregulated open market. The work presented in this paper is oriented toward making an impact in practice, and can contribute to the introduction of business intelligence in all parts of electricity supply chain. The business intelligence system described in this paper provides the necessary tools for efficient energy management and monitoring in smart grids and allows the combining of data from different sources. The designed dashboards aggregate data in the desired granularity in order to analyze supply and demand on the wholesale electricity market and provide efficient energy management and monitoring for more adequate decisions in the constantly changing electricity market. Combining performance indicators capability with alerts when performance differs from expectations allows managing performance in a very proactive way (Personal et al. 2014). By analyzing historical trends and emerging patterns across the organization, management has a greater chance of making more accurate predictions about possible outcomes of their decisions in a highly competitive market (Peters et al. 2013).

The application and use of performance metrics and performance data is widespread in the electricity industry (EPRI 2003). Existing reporting systems based on performance indicators, with emphasis on electricity data monitoring, lack the ability to create data aggregation and do not support the analysis of electricity data to deliver reports and actionable information (Li et al. 2013). Having this in mind, the dashboard created for the purpose of this study provides aggregated data that meet user requirements related to the efficient management and monitoring of the chosen parameters, allowing customized views for employees at various levels of management. The proposed approach would free up employees from the mechanics of manipulating data and chart creation, and extend the application of their knowledge to the identification and analysis of market trends, anomalies and potential behavioral issues.

Finally, the authors acknowledge some drawbacks of the presented research. There is a lack of information that would offer an estimation of the benefits that a company would achieve through the full implementation of the business intelligence system based on the proposed approach. Although the present implementation of the proposed model does not explicitly include big data concepts, the developed model is flexible and will support big data implementations across the grid. The retail market is still difficult to analyze because it is concentrated in the hands of one operator, we have tried to fill this gap by highlighting the main performance indicators on which competition is expected to have a relevant impact. Further, the intelligence system for smart grid participants should include the data on renewable energy and distributed generation.

6 Conclusions

In this paper, a business intelligence model for the opening electricity market was proposed. The designed model takes advantage of the new metering infrastructure and the vast amounts of data that originates throughout the electricity supply chain. The proposed approach was evaluated in the system for electricity market analysis of an electric power company, where it proved to be adequate. Furthermore, the approach presents an important part of the process of building a business intelligence system for the rapidly modernizing grids such as the Serbian grid and may foster further investments in smart grid technologies. The organizations that can gain the most from the implementation of the proposed model are TSOs of countries that are still adopting smart grid concepts and wish to utilize the vast amounts of newly generated data. Supply chain intelligence can help smart grids to provide reliability, operating efficiency, resiliency to threats, energy security, and sustainability of the production and distribution of electricity. From the transmission system operator perspective, besides the need of interconnection, the well-managed smart grid will be able to foster the single European market by offering cross-border balancing mechanisms and new possibilities for congestion management.

The future work of this research will take several directions. A more detailed analysis of the project's results will be one of the main objectives, which will serve to leverage the proposed approach by making future development more flexible, more responsive and more agile. The system of continuous data collection should be completed and improved upon to be able to work in near real-time resolutions. More efficient applications for management of the enormous amounts of exponentially increasing physical system data need to be found. What remains to be done is to allow for real-time analytics in the smart grid and to enable a more efficient analysis of retail-based measurements in order to impact the decision making process. Further, future research will be directed towards the incorporation of advanced simulation, artificial intelligence and advanced data mining models.

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