Business Intelligence applied to Electric Power Markets

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Abstract. Today, there is the need for establishing a strong relationship between Business Intelligence (BI) and Electric Power or Energy Markets (EM). This is crucial because of enormous and increasing data volumes generated and stored day by day in the EM. The data volume turns impossible to obtain clear data understanding through human analysis or with traditional tools. BI can be the solution. In this sense, we present a comprehensive survey related with the BI applications for the EM, in order to show trends and useful methods for tackling down every day EM challenges. We outline how BI approach can effectively support a variety of difficult and challenging EM issues like prediction, pattern recognition, modeling and others. An extensive bibliography is also included.

1 Introduction

Electric Power Markets or simply Energy Markets are the consequence of the de-regulation of electricity. In these markets, power suppliers and consumers are free to negotiate the terms of their contracts, e.g., energy prices, power quantities and contract durations in several auctions structures. Several issues have to be considered and analyzed before taking actions. There are physical, economical and political restrictions that have to be considered together (Bhatnagar & Rao, 2005). Although enormous data volumes related with this process are stored day-by-day, and hour-by-hour, it is impossible (through human analysis or with traditional technology) to obtain knowledge from this data, in order to take wise decisions.

In this complex scenario, BI approach can be an important solution due to its intrinsic way to manage very large data sets in an intelligent and automatic fashion.

We survey recent applications of BI for the EM, seeking for the most relevant, important or characteristic state of art works. This survey can help to detect diverse EM problems and its BI solutions, and can be a useful guide for EM decision- makers from countries with de-regulated electricity schemas, or from countries next to participate in this global environment. In addition, our survey can be helpful to detect and create new and innovative solution proposals.

To address these topics, in Section 2 we offer an abstract about what BI is. In Section 3, we describe the EM dynamics and the essential problems. Next, in Section 4 we survey works that combine EM problems with BI solutions. Finally, we conclude and discuss future work challenges in Section 5. An extensive reference Section is also included.

2 Business Intelligence

Nowadays, huge corporations are seeking to know more about their business processes. They usually have enormous and valuable data repositories, but they do not know what to do with these data. It is common to hear the phrase: “worse than have too little (or any) data, is to have many data and not knowing what to do with it” (Richeldi, 1999).

BI can be a useful approach to meet the challenge. BI is focused on transform data into knowledge (or intelligence) to improve corporation central process. At the end, BI is a discipline formed with tools emerged from Artificial Intelligence and Database technology, which main purpose is to give people the information or knowledge that they need to do their jobs.

The term BI was coined by Howard Dresner about twenty years ago (McKay, 2008), to describe an emerging discipline concerned with the discovery of information (that was not known before) in a corporation. BI includes disciplines and tools like:

- Data Warehouses (Gill, 1996.),
- On Line Analytical Processing (OLAP) and related methods (MOLAP, ROLAP, etc.) (Brackett, 1996).
- Knowledge Discovery in Databases (KDD) and Data Mining (Piatetsky-Shapiro, 1991),
- Artificial Intelligence areas and algorithms like, for example, Machine Learning, Intelligent Multi-Agents Systems, Artificial Neural Networks, Fuzzy Logic, Case Base Reasoning, Pattern Recognition, Genetic Algorithms, etc. (Turban, Aronson, Liang & Sharda, 2005),
- Statistical analysis,
- And, in general, any algorithm, tool or method that serve to transform data into knowledge.

It is predicted that, in the near future, BI will become a need of all huge corporation (McKay, 2008).

3 Electric Power Markets

The electrical power industry around the world has been continuously de-regulated and re-constructed from a centralized monopoly schema to a competitive market structure. This transformation is taking place since the last century.

Today, there is many people and governments that agree in the fact that in most cases the competitive market is a more proper mechanism for energy supply to free the customer’s choices, improve overall social welfare (Wu & Varaiya, 1999) and allows markets to operate more efficiently and cost effectively.

The Energy Market is a very dynamic and inter-related system. In the open market, power companies and consumers submit their generation or consumption bids and corresponding prices to the market operator, who will then use a market-clearing tool to clear the market. The clearing process is normally based on a single round auction to determine the spot price for the corresponding time interval (Xu, Dong, & Liu, 1996).

Nevertheless, not only power companies and consumers participate in the EM, governments take active participation too. There are continued reasons for governments to remain involved in EM: long-term uncertainties, the fact that markets do not always take account of environmental and social objectives (including safety and health concerns), the continued monopoly nature of natural-gas and electricity transmission grids and the global nature of some problems such as climate change. All these examples are reasons for a continuing government regulation.

Additionally, when market prices do not fully reflect environmental and social costs, consumers' choices are distorted. Sending an appropriate market signal to encourage environmentally, rational energy use may be accomplished through a variety of economic facts, from direct taxes to tradable permits, including by reducing consumption and changing its composition in favor of more environmentally friendly goods and services. The government policies will need to take into account particular and national circumstances.

There is EM technical factors and restrictions too. For instance, unlike other commodities, the electricity cannot be stored and power system stability requires consistent balance between supply and demand. Therefore, besides this factor, there are many physical and technical constraints for the transmission and delivery of energy. Moreover, unpredictable and uncontrollable contingencies in power system increase the complexities. As such, EM exhibits a high volatile nature and is probably the most volatile market.

All these circumstances create a complex multi-disciplinary challenge. Broadly speaking, we can say that EM face problems related to issues that concern prediction, pattern recognition, modeling and other areas.

For instance, *forecasting* problems in EM are: Short-Term Load Forecasting, Electricity Market Price Forecasting, or Power System Transient Stability Prediction.

In the *pattern recognition* area, we can find problems like: Operation Patterns, Energy Consumers Characterization or Consumer-Supplier Analysis.

About *modeling*, we can talk about the need of monitoring or training systems.

Finally, BI can contribute to *analyze* EM data quality or be part of an integrated EM system.

4 Business Intelligence and Electric Power Markets Related Work

Our survey on *EM problems-BI solutions* found papers from very different countries, but almost sharing the same information needs. For instance, according to our survey, we found papers from: USA (17%), Australia (13%), Spain (13%), China (9%), Portugal (7%), Brazil (6%), Greece (4%), Italy (4%), Japan (4%), and others countries with almost 2%, like Germany, Argentina, Canada, Russia, Iraq, UK, Colombia, Taiwan, Belgium, Switzerland, Ireland, Netherlands and Singapore. Surprisingly, we cannot found anything directly written from some Mexico's research institution.

Related to the BI algorithms, techniques, methods or disciplines applied to solve different problems from the EM scenario, we observed that there is a great diversity, as Table 1 shows.

Table 1. BI algorithms / disciplines applied to EM problems.

Algorithm / Discipline	**Reference**
Artificial Neural Networks	(Sun, Lu, & He, 2005), (Xu *et al.*, 1996), (Sheble, 2000), (Sánchez-Ubeda, Muñoz, & Villar, 2005), (Andrade, Camargo, & Teive, 2007), (Richeldi, 1999)
Bagging	(Xu, He, Wang, & Xu, 2004)
Clustering	(Sánchez-Ubeda, Peco, Raymont, Gomez, Banales, & Hernandez, 2001), (Wu, Wu, Wang, & Ye, 2006), (Ramos, 2008)
Data Warehouse	(Richeldi, 1999)
Fuzzy logic	(Widjaja & Mielczarski, 1999), (Andrade *et al.*, 2007), (Samper & Vargas, 2007)
Genetic algorithms	(Srinivasan, Woo, Rachmawati, & Wei, 2006), (Sheble, 2000)
Induction and Decision Trees, Learning Classifier Systems (C4.5, J48)	(Lobato, Ugedo, Rouco, & Echavarren, 2006), (Sánchez-Ubeda *et al.*, 2001), (Voumvoulakis, Gavoyiannis, & Hatziargyriou, 2006), (Li, Runger, & Tuv, 2006), (Kitayama, Matsubara, & Izui, 2002), (Sánchez-Ubeda *et al.*, 2005), (Troncoso, Riquelme, Gómez, Martínez & Riquelme, 2007), (Bagnall, 2004)
InformationEntropy Theory	(Sun *et al.*, 2005)
Information Gap Theory	(Cheong, Sheble, & Berleant, 2006)
Intelligent Agents and Multi Agents Frameworks	(Praca, Ramos, Vale, & Cordeiro, 2003), (Geoff, Cohen, Dodier, Platt, & Palmer, 2006), (Herrera, 2006), (Da Silva Lima & De Andrade Freitas, 2006), (Kok & Kamphuis, 2005), (Fujii, Okamura, Inagaki, & Yamaji, 2004), (Karbovskii, Lukatskii, Fedorova, & Shapot, 2002), (Debs, Hansen, Yu-Chi, Hirsch, & Szot, 2003), (Praca, 2008)
K-Nearest Neighbor	(Herrera, 2006)
Knowledge Discovery in Databases	(Rico, Flores, Sotomane, & Calderon, 2004), (Athanasopoulou, Chatziathanasiou, Komminou, & Petkani, 2006), (Cruz, Carrillo, & Pinzón, 2007), (Yokoyama, 2008)
Multivariate Adaptive Regression Splines	(Zeripour, Bhattacharya & Canizares, 2006)
Naive Bayes	(Zhao, Li, & Wong, 2005), (Lu, Dong, & Li, 2005), (Zhao, Dong, Li, & Wong, 2007)
Support Vector Machines	(Troncoso *et al.*, 2007), (Zhao *et al.*, 2005), (Zhao *et al.*, 2007), (Xu *et al.*, 1996), (Xu *et al.*, 2004), (Dongjie, Peng, Renmu, & Tao, 2004)
Time Series Data Mining - Discrete Fourier Transform	(Wu *et al.*, 2006), (Zhenfyou, Qingquan, & Zhibing, 2003), (Vucetic, Tomsovic, & Obradovic, 2001), (Bhatnagar *et al.*, 2005)
Wavelet Transforms	(Xu *et al.*, 1996), (Zhenfyou *et al.*, 2003), (Cannataro, Curci, & Giglio, 2001)

Attending the application type, we grouped our findings in four broad categories: prediction, pattern recognition, modeling and others, as we show in Table 2. In the next sub-sections, we addressed these topics.

Table 2. BI´s EM applications by year.

Year	Prediction			Pattern recognition			Modeling			Others	
	Price	Demand	Transient	Operation	Characterization of Customers	Analysis of supply and demand	Simulation with agents	Model behavior	Simulation / Monitoring	Data Quality	Integrated systems
2008				(Yokoyama, 2008)	(Ramos, 2008)		(Praca, 2008)				
2007	(Zhao *et al.*, 2007)					(Andrade *et al.*, 2007), (Frezzi, Garcés & Haubrich, 2007), (Samper *et al.*,2007)			(Cruz *et al.*, 2007)		
2006	(Zeri-pour *et al.*, 2006)	(Herrera, 2006), (Lobato *et al.*, 2006)		(Bougard, et.al, 2006), (Voumvou-lakis *et al.*, 2006), (Li *et al.*, 2006)	(Nizar, Dong & Zhao, 2006), (Ramos, Vale, Santana & Rodrigues, 2006), (Verdu, Garcia, Senabre, Marin & Garcia, 2006)		(Da Silva Lima *et al.*, 2006), (Geoff *et al.*, 2006)	(Sriniva-san *et al.*, 2006), (Cheong *et al.*, 2006)	(Athanaso-poulou*et al.*, 2006)	(Wirth, 2006)	
2005	(Lu *et al.*, 2005), (Zhao *et al.*, 2005)	(Sun *et al.*, 2005)				(Bhatnagar *et al.*, 2005), (Sánchez-Úbeda *et al.*, 2005)	(Kok *et al.*, 2005)				(Muñoz San Roque & Sánchez-Ubeda, 2004), (Taft, 2005)
2004		(Rico *et al.*, 2004)	(Xu *et al.*, 2004), (Dongjie *et al.*, 2004)	(Peng, Chien & Tseng, 2004)			(Bagnall, 2004), (Fujii *et al.*, 2004)				(Cherian & Ambrosio, 2004)
2003		(Zhenf-you *et al.*, 2003)			(Duarte, Rodrigues, Figueiredo, Vale & Cordeiro, 2003)		(Praca *et al.*, 2003)	(Debs *et al.*, 2003)			(Felden & Chamoni, 2003)
2002					(Kitayama *et al.*, 2002)			(Karbov-skii *et al.*, 2002)			
2001				(Sánchez-Ubeda *et al.*, 2001)		(Vucetic *et al.*, 2001)				(Canna-taro *et al.*, 2001)	
2000					(Alcocer, Chiesara & Galiasso, 2000)			(Sheble, 2000)			

4.1 Prediction

Deregulation in EM brings demand and electricity prices uncertainty, placing higher requirements on forecasting; commonly for estimating load and prices levels more accurately.

Forecasting is essential to support the decision making for an appropriate scheduling and planning in the operation of power systems and for developing bidding strategies or negotiation skills in the EMs. It is being considered as a helpful tool for consumers and producers.

There have been several research projects around the world involving forecasting of EM prices, electricity demand and transient stability; taking into account that lower operation cost and higher reliability of electricity supply is the main operation goal. Next, we present the most representative research works.

4.1.1 Electricity Price Forecast

There are many research works on electricity market price forecasting. However, most of them are focused on the expected price analysis rather than price spikes forecasting. A price spike is an abnormal market-clearing price at certain time and is significantly different from the price at previous time. In Australia, two methods (*Support Vector Machines* and *Naive Bayes*) are chosen to be the spike occurrence predictors (Zhao *et al.*, 2007). Forecasting price spikes can improve the market participants' ability to take advantage of them and their risk management.

4.1.2 Electricity Demand Forecast

In the Australian Electricity Market, there are some projects where the bidding behavior is analyzed based on the prediction of electricity demand using an application of *Fuzzy sets* to generate a rule-base that is basically the system-demand profile in the forms of linguistic variables (i.e. midnight peak, morning valley, morning peak, afternoon valley, evening peak and evening valley). These variables are tolerant to imprecision and easier to understand.

The rules extracted are in the form of: "*IF Season is AUTUMN AND Type of Day is WORKING DAY and Time of the Day is MORNING PEAK THEN System Demand is SLIGHTLY HIGH*". At last, three trends of system demand are analyzed: daily, weekly and yearly (Widjaja *et al.*, 1999).

4.1.3 Transient Stability Forecast

In the deregulated power industry, the increasing number of power marketers and independent power generators increases the variability of power flow patterns in the transmission system, thereby reducing the ability of transmission planners and operators to predict the critical operating conditions and limits. Consequently, the small signal stability problem becomes more complex. And the existing standard methods and tools for small-signal stability are not able to perform security analysis in the claimed response time required for online use.

In (Dongjie *et al.*, 2004) they propose a novel approach for power system small signal stability analysis and control which combines the state-of-the-art small signal analysis tools, data mining, and the synchronized phase measurement techniques.

4.2 Pattern Recognition

During the process of data analysis is looking to find patterns from which to draw a series of rules and/or identify factors that facilitate the understanding of market behavior of electric power, detection of flaws or any other aspect of interest.

4.2.1 Operation

In (Peng *et al.*, 2004) the historical data of distribution feeder faults of Taiwan Power Company was used for validation and this study aims to use rough set theory as a data-mining tool to derive useful patterns and rules for distribution feeder faulty equipment diagnosis and fault location. More recently, Yokoyama (2008) presents the most advanced technologies and the newest issues related to reliable and stable operations of power markets and systems in the competitive environment.

4.2.2 Characterization of Customers

In (Kitayama *et al.*, 2002) they mention that the electric power industry is an industry that had allowed local monopolies to date in the background of economies of scale, so it was unnecessary for electric power utilities to deeply understand customers. However, in order to effectively oppose new companies in liberalized sector, it is necessary for these utilities to recognize preferred customers based on customer profiles. It presents a concept of customer load profile analysis based on Customer Relationship Management (CRM) concept and applications of data mining techniques. A more recent approach is described by (Ramos, 2008): the proposed framework includes several steps, starting from the pre-processing data, application of data mining algorithms, classification model, and finally, the interpretation of the discovered knowledge. To validate this framework, a case study, which includes real databases, is used.

4.2.3 Analysis of Supply and Demand

In (Andrade *et al.*, 2007) the dynamic behavior and non-linear demand in relation to the parameters that determine, as: calendar, climate, economy and energy intensity, increase the complexity of constructing models of analysis of the demand. Each see more companies and institutions that are part of the electricity sector in Brazil collect data for the consumption of electricity and the variables for different segments of the industry in new and useful knowledge about the behavior of that demand. They use Neuro-Fuzzy (neural network combined with fuzzy logic) as a technique.

4.3 Modeling

One area of concern in other countries has been displaying the future behavior of the market for electric power in liberalized markets, for which projects have been developed for simulation and modeling of the behavior of market power by using different techniques. Below are the work related documents.

4.3.1 Simulation with Agents

To study electricity markets behavior and evolution Praca *et al.* (2003) propose a multi-agent simulator where agents represent several entities that can be found in electricity markets, such as generators, consumers, market operators and network operators, but also entities that are emerging with the advent of liberalization, such as traders.

The simulator probes the possible effects of market rules and conditions by simulating the strategic behavior of participants. In this paper, a special attention is devoted to the strategic decision processes of Seller, Buyer and Trader agents, in order to gain advantage facing the new emerging competitive market. A more recent studio is presented in (Praca, 2008).

4.3.2 Model Behavior

One project of Model behavior is in (Srinivasan *et al.*, 2006), it presents an evolutionary algorithm to develop cooperative strategies for power buyers in a deregulated electrical power market. Cooperative strategies are evolved through the collaboration of the buyer with other buyers defined by the different group memberships.

The paper explores how buyers can lower their costs by using the algorithm that evolves their group sizes and memberships. The algorithm interfaces with Power World Simulator to include in the technical aspect of a power system network, particularly the effects of the network constraints on the power flow. Simulation tests on an IEEE 14-bus transmission network are conducted and power buyer strategies are observed and analyzed.

4.3.3 Simulation / Monitoring

The project in (Athanasopoulou *et al.*, 2006) describes research into the application of data mining algorithms for deriving new control monitoring patterns that can improve the plant's performance.

It proposes the use of a knowledge engineering methodology, named CommonKADS, as a tool for completing the knowledge discovery in databases phases that precede data mining. The application of data mining classification algorithms resulted in new control monitoring rules, which improve performance without demanding installation of new equipment.

The derived rules can also be used to trace a possible malfunction of a measurement instrument and even more to replace the recording values with those resulting from the data mining algorithms.

4.4 Others

There is other alternative solutions to implement the BI approach to electric power markets where the authors have developed other projects such as: building data warehouses for OLAP analysis, development of integrated systems or quality assessment data. Below are some works where they have addressed these other topics.

4.4.1 Data Quality

The project in (Cannataro *et al.*, 2001) presents a priority-based data transmission protocol for sending large volumes of data (data cubes) over congested networks, which allows the incremental implementation of OLAP applications. A wavelet-based lossy compression algorithm that is the core of the transmission protocol is also presented.

4.4.2 Integrated Systems

The project in (Muñoz San Roque *et al.*, 2004) describes the environment SGO, an information system to perform best deals in liberalized electricity markets. The SGO is based on a client-server architecture, and contains a comprehensive set of tools designed and developed to facilitate all tasks related to the preparation of tenders of the Spanish electricity market: identification of resources from generation to generation offerings, generating reporting results, characterization of the conduct of competition, and analysis and optimization of bidding strategies.

5 Conclusions and Future Work

We present a comprehensive survey related with the BI solutions for the EM problems, in order to show trends and useful methods for tackling down every day EM challenges. We think that it is fundamental for the EM and the computer science communities to know how is the BI´s level of applicability to define present and future research work.

In these sense, this paper is an effort to bring attention from electric power industry, in particular the EM community, about the outmost relevance for applying the BI approach and its methods, because those methods have been designed to overcome the limitations that traditional approaches and methods have.

We highlight the novelty of our paper because, to the best of our knowledge, we didn’t find any state-of-the-art BI for EM published work. Furthermore, because we cannot found anything directly written from research institutions of several countries, we claim that there are many opportunities in these countries to work and contribute in this field.

Additionally, we observed a great variety of BI´s methods applied to the EM problems. Broadly speaking, we detect four principal areas of interest: prediction, pattern recognition, modeling and other areas like integrated systems and data quality projects; but we point out that there are still open research topics for EM to explore and apply, like change point detection algorithms, associative rules, feature selection methods and variable inter-relations studios.

All these are material for future work. A final contribution of this paper is an alphabetical list of bibliographic references to be used as a source for researches interested in solving EM problems using the BI approach.

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