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Systematic Review of Smart Grid Analytics

Ashu Bhardwaj
(Student)
Department of Computer Engineering
Punjabi University
Patiala, Punjab, India

Williamjeet Singh
(Assistant Professor)
Department of Computer Engineering
Punjabi University
Patiala, Punjab, India

Abstract: Smart grids will require real-time reaction and make distribution decision very fast in order to cover unexpected demand peaks and renewable generation peaks. A smart grid should require little consumer participation. Traditionally large imbalance is the ratio of electricity consumption and electricity generation results in wasting of large quantities of electricity generated in states where generation exceeds consumption significantly. The difference between the generation and consumption is the result of system loss, uncounted loads, and lack of centralized control. The amount of available storage capacity could be not enough in order to record all the digital information generated in the world and this could turn into main triggers for a paradigm shift to Smart Grid. This systematic review focuses on electricity data analytics technologies used in previous studies. The existing work is classified into different categories. Furthermore, the paper highlights the challenges arising due to the advent of big data.

Keywords: Big data analytics; Electricity; Smart Grid; Challenges; Technologies; Techniques

I. INTRODUCTION

Smart Grid designed to revise the existing grid to intelligently and efficiently take action to available power generation, power transmission, and consumer demand. The main idea is the need to react instantly to meaningful changes in data and the need to detect complex patterns over time because changes take place over the time [14]. The electricity is mostly generated from natural resources, such as coal, gas, nuclear, petroleum, oil, and renewable energy. The consumption sectors can be detailed in terms of commercial, industrial, residential and other user communities. The difference between the generation and consumption is recognized to system losses, uncounted loads, and the lack of centralized control. The power generation provides two types of information: the amount of energy consumed and the quantity to be imported. Therefore, forecasting power generation might provide vague information about power demand; hence increase the quantity to be imported from neighboring countries. It is significant to discover the possibility of centralized power management and to find out the allocation of natural resources. The prediction is challenging due to the accuracy constraint, and it becomes unmanageable when data sets are massive in volume and have excessive noise and high volatility [16].

A. Smart meter:

The smart meter gathers data locally and transfers via a Local Area Network (LAN) to a data collection point. There are two key categories of data collected, namely usage data and event data. Usage data deals to the actual electricity usage measured in Kilo Watt Hours (KWH) and this is read and transmitted at regular intervals; for example, every 15 minutes to half an hour according to the deployment. The event information captured and relayed by smart meters includes real-time device status, power quality information and meter status information which could be used to improve the business processes of the utility. There data processing carried out at local collection points and their function shifts data to the utilities' central collection center via a Wide Area Network [13].

B. Function of smart meter:

A meter is called smart or intelligent because it can compute the electricity usage, remotely control the consumption of electricity and remotely switch off the supply when required. It could be a visual, real-time display showing electricity consumption and interrelated information. These functions are based on the hardware, networking and smart grid aspects of smart meters. The data collected helps to predict future needs and trends of demand management, network tariff optimization, and asset maintenance requirements. Smart meters can allow consumers to directly review their electricity usage, and adjust their usage to decrease energy cost [8].

C. Motivation and objectives:

This study explains the existing big data analytics in the smart grid and the different application area that is used in different aspects of doing the analysis. This analysis is compulsory to make it possible to know which categories of big data analytics under smart grid areas and tools have been covered in past research period (from 2012 to 2016) and helps to identify gaps the results may help the researchers to get an overview of the status of big data analytics in smart grid. This paper is structured as follows. Section 2 describes the research methodology used in this study. Section 3 gives the classification of big data analytics in electricity papers considering the following criteria: (1) Technology (2) Challenges (3) Techniques (4) Characteristics of today's grid and smart grid.

II. RESEARCH METHODOLOGY

The research methodology is consisting of different stages. The first stage involves exploring of mechanism related to smart grid data analytics. The second stage is concerned with establishing a classification scheme described in Section 3. The third stage involves the review of application area and

tools. Some research questions are arises and their solution are describes in Table 1.

Table I. List of research questions with answer.

Question	***Answer***
RQ.1: What are the technologies used in smart grid analytics?	See the section 3.1 technology.
RQ.2: What are the challenges occurs in smart grid analytics?	See section 3.2 shows various challenges.
RQ.3: What are the techniques used in smart grid analytics?	See section 3.3 techniques
RQ4: What is the difference between today's grid and smart grid?	See the section 3.4 presents characteristics of today's grid and smart grid.

*A. **Search strategies and screening*:**

Search strategies and screening process follow the following steps:

1) Sources of information

For general and broad exposure to the literature, a broad view is necessary. To enhance the chance of significant articles, a set of appropriate databases must be chosen. For this review, the major databases of electronic journals are searched.

1) IEEE Xplore 2) ACM Digital Library 3) Springer
4) Science Direct 5) Wiley-Interscience

2) Study Selection:

The search engine in the above electronic database hits number of studies, articles. Research papers published by journals, conference proceedings, and workshops are thought to be worthy and reliable. Keyword based selection of search is employed to select the most related works. The works irrelevant to electricity data analytics are discarded. The criteria used for exclusion of a research paper include unpublished papers, other than English papers, Text-books, Master and Doctoral dissertations, non-peer-reviewed papers. In result shows the distribution of paper from 2012 to 2016. Table 2 shows the defined search strategy and number of results obtained. From the returned studies, firstly irrelevant studies are excluded on the basis of title. Certain studies could not be estimated from the title, and then their abstract is considered. If even abstract is not evident then after reading the full text of papers, irrelevant studies are excluded. In some library search when the huge amount of studies returned then apply some advanced search.

Table II. Search selection criteria

Sr. no	**E-resources**	**SR**	**Excluded**			**Keyword used**
			BOT	**BOA**	**BOF**	
1.	ieeexplore.ieee.org	20	-	7	1	Electricity data analytics+ Challenges
2.	www.acm.org	18	14	2	-	Electricity data analytics+ Challenges
3.	www.sciencedirect.com	144	112	24	1	Electricity data analytics+ Challenges
4.	www.springer.com	240	235	4	-	Electricity data analytics+ Challenges
5.	www.interscience.wiley.com	320	313	6	-	Electricity data analytics+ Challenges

SR= Studies returned BOT= Based on title BOA= Based on abstract
BOF= Based on full text

B. Establishing a Classification Scheme

Classification is done on the basis of selected keywords. Keywords with the filter applied to it so that in particular field papers are comes. The selection process output in 23 papers selected from 5 different digital libraries as on 15th April 2017, 7.30 pm (IST). Each paper is carefully assessed and classified. The selected research papers are classified according to the criteria established in section 3 of this article.

C. Distribution of paper

The results of the classification offer important guidelines for future research on electricity data analytics. Literature related to electricity data analytics has increased enormously in the last 5 years; papers from 2012 to 2016 are reviewed. The distribution of reviewed papers over the years is depicted in Table 3.

Table III. Distribution of papers over the past five years from 2012 to 2016

Year / E-resources	2016	2015	2014	2013	2012
IEEE	5	5	-	1	1
ACM	-	-	1	-	1
Science direct	1	6	-	-	-
Springer	-	-	-	-	1
Wiley	-	-	1	-	-

III. CLASSIFICATION METHOD

The research papers are classified by taking into consideration the following ways: (1) Technology used in smart grid data analytics (2) Classification based on challenges involved in smart grid data analytics (3) Techniques used in smart grid analytics (4) Classification based on characteristics of today's grid and smart grid .

*A. **Technology used in smart grid analytics:*** On basis of papers analyzed technologies returned from the study are shown in Table 4.

Table IV. Description of technologies along with features

Technologies	Description	Features
Hadoop [10,11,16,17,22]	-open source platform for handling Big Data. -handles parallel computation	-scalable, fault tolerant Virtual Grid operating system architecture for data storage and processing. -works with structured and unstructured data. - handling the velocity and heterogeneity of data
NoSQL [5,18]	-Database design that implements a key-value store, document store, column store or graph format for data. -It is an alternative to the Structured Query Language (SQL) database. -It especially targets large sets of distributed data.	-NoSQL database is used by cheap off-the-shelf servers and this cheap server's scale to handle more data. -A cluster of servers can be used to hold a single large database.
Postgre SQL [23]	-open source object-relational database system. -Requires very minimum maintained efforts because of its stability.	-Supports text, images, sounds, and video format. -Programming interfaces for C / C++, Java, Perl, Python, Ruby. - Run on Linux, Unix, and Windows.

Spark [18,19,22]	-An open-source and cluster computing framework. -An engine for large-scale data processing.	-High Speed due to reducing the number of read/write operations to disk. -Support multiple languages like Java, Scala, or Python.

B. Classification based on challenges involved in smart grid analytics:

Challenges of using big data analytics in Smart Grid are the third section in which challenges classified according to the papers. In Smart Grid, numerous research challenges exist, among which best decision-making mechanism used to provide better results.

Privacy: The power consumption information from the household within micro-grids creates a large amount of time series data that are privacy-sensitive. Research results have shown that energy consumption patterns can be used to leak private information about the activities and behavior of the inhabitants of a household [9]

Reliability: The smart grid has a higher requirement for the reliability of data. The data cleaning method may not eliminate the unpredictability of data [12]. Smart Grid reliability measured as continuous delivery of high-quality electrical energy without any block-out.

Transparency: To achieve real benefits of analytics outcomes it is essential to gain consumer's acceptance and support for smart meters. A key requirement for such acceptance is transparency of the process which is currently being addressed by government regulators as well as utilities. The availability of easy to understand and visual displays of information is also an important need. Making smart meter data and analytics outcomes available on the web and on mobile devices will make such information more readily available and also updates communicated to consumers in near real-time [8].

Availability: A large volumes of data collected in steady streams as well as other ad-hoc occurrences such as power outages and from many regions and localities, makes it essential to have an integrated view of company data and alignment of data across disparate operational groups and lines of business [13].

Security: Replacing false information in the AMI can replace the control from administrator to any wrong hands. Development of viruses, malware's, firmware, malignant codes etc. could break the security barriers. Hence it is essential to track such activities and update the firmware capable of resisting such cyber-attacks. For a consumer, the potential threats and implications would be unknown [8, 9, 15, 21].

C. Techniques used in smart grid analytics:

The Techniques identifies relationships and patterns within the data sets that can be generalized to a set of rules, the analytics model, and is used for prediction. List of various techniques is shown in Table 5.

Table V. Description of techniques comes in Smart Grid Analytics

Technique	Description
Clustering [3,5,6,7,8,13,17]	-Clustering is an unsupervised learning technique which is used to set identical instances on the basis of features. -In clustering their no use of training set and labels. -Statistical concepts are used, and datasets are split into subsets with similar features.
Outlier detection [6]	-This method used to search for data items in a dataset that do not match a projected pattern or expected behavior. -It can help find extraordinary occurrences that could indicate fraudulent actions, flawed procedures or areas where a certain theory is invalid.
Regression [3,7,12,14]	-A Statistical technique that takes a numerical dataset and develops a mathematical formula that fits the data. -It defines the dependency between variables and predicts one or more continuous numeric variables.
Neural network [11,16,17,23]	-It is a set of connected input/output units and each connection has a weight present with it. -It is non-linear, predictive models that learn through training. -It is used to reviewing records to identify fraud and fraud-like actions.
Association rule [12]	-Detect relationships or associations between specific values of categorical variables in large data sets. -Association rule is "unsupervised" approach and its accuracy is subjective.

D. Classification based on characteristics of today's grid and smart grid:

Today's grids represent a complex system of systems with intense interactions between them and require the collection of large amounts of data from a variety of sources to improve the energy ecosystem operation [4]. Smart grid provides recording consumption of electricity or a decision support tool to support energy usage by users. It includes easier processing of billing, automated meter reading and data processing, detection of energy losses (possible fraud) and early warning of blackouts, fast detection of disturbances in energy supply, possible real-time pricing schemes, and demand-response for energy saving and efficient use of energy generated.[8]. Classification is done on basis of characteristics and it showed in Table 6.

Table VI. Differences based on characterstics of Today's grid and Smart grid

Characteristics	Today's Grid	Smart Grid
Active consumer participation	Consumer are unaware and do not participate	Informed, involved consumers demand response and distributed energy resources
New products, services, and market	Limited, poorly integrated wholesale markets; limited opportunities for consumers	Mature, well integrated wholesale markets; growth of new electricity markets for consumers
Type of communication	One-way and local two-way communication	Global/integrated two-way communication
Provision of power quality for the digital economy	Focus on outages slow response to power quality issues	Power quality a priority with a variety of quality/price options, rapid resolution of issues
Accommodation of all generation and storage options	Dominated by central generation and many obstacles exist for distributed energy resources interconnection	Many distributed energy resources with plug and play convenience focus on renewable resources.
Type of restoration	Manual restoration Automated	self-healing
Type of checking	Check equipment manually	Monitor equipment remotely
Optimization of assets and operates efficiently	Little integration of operational data with asset management business process silos	Greatly expanded data acquisition of grid parameters; focus on prevention, minimizing impact to consumers
Resiliency against cyber attack and natural disasters	Vulnerable to malicious acts of terror and natural disasters, slow	Resilient to cyber attack and natural disasters; rapid restoration

	response	capabilities
Anticipating responses to system disturbances	Responds to prevent further damage; focus on protecting assets following a fault	Automatically detects and responds to problems; focus on prevention, minimizing impact to consumers

IV. SOURCES OF DATA GENERATED AND TYPE OF CONSUMERS:

A. Sources of data generated from Smart grid:

In electricity field to apply analytics it requires data which is generated from various sources describes following.

1) 1. Power generation oriented data

In power plants, electricity is generated from different sources like water, coal, wind, nuclear etc. Wireless sensors are employed effortlessly over wind farms to take out the data about the dynamic state behavior of the wind turbines. A coal-based power plant fault analysis and diagnosis system doing calculate load pave the way for power plants, to plan for their future needs. This helps for utility industries to save money.

2) 2. Power Transmission Distribution data

Once the power has been produced, it is fed to a step-up transformer and intensified into a high voltage, and is transmitted to several substations. At each substation, the high voltage electricity is reconstructed to a low state, which is best matched for real-time consumption. This is done with a step-down transformer. Further, it is distributed to the consumers for utilization. Distributed control system (DCS) and supervisory control and data acquisition (SCADA) are monitoring subsystems used for monitoring the grid activities. The data collected from these sources can be utilized to analyze power system state estimation, a real-time stability determination and commence the significant sequence of action. Power system state estimation is used to ensure the stableness of the grid and prevent blackouts

3) 3. Power Consumption data:

The distributed electricity will be consumed by consumers from various zones like Residential, Commercial, Industrial, Transportation, and governmental services, etc. Smart meters are equipped with customer endpoints, which sense and broadcast utilization data to the service providers at regular interval of period.

4) 4. Others:

- **Sensor data**: Sensors produce different types of data (Heterogeneous), which are then collected at the utility data centers. The amount of data collected from all the different connected components and sensors in a very short time interval is huge [8].
- **Power quality data**: It is used in fault analysis to help improve reliability. Both pre-fault and post-fault analyses are considered as effective techniques of using power quality to improve the reliability of a distribution network [21].
- **External data:** A fusion of various data sources such as weather, geography with consumption can provide useful information for predicting power usage [8].

B. Various types of Consumers come in Smart Grid:

1) Type of Consumers:

Availability of vast volumes of data which could be used to profile and understand customers, their needs and behaviors enable better service provision and building stronger loyalty. Various consumers' types come and it lists in Table 6.

Table VII. List of various consumers along with description and benefits

Type	Description	Benefits
Domestic sector [11,16,21]	It includes individual and multi-family housing. A major use of electricity in this sector for appliances, electronics, lighting, water and space heating. Electricity demand in the domestic sector tends to be the hike due to increased air conditioning use at hot summer afternoons.	-Directly view electricity usage. -Monitor appliances use and consumption leading to awareness and better electricity usage planning.
Commer-cial sector [11,16, 21]	It includes government facilities, equipment, and other public and private organizations. A major use of electricity is for lighting, heating, ventilation, and air conditioning. Electricity demand tends to be highest during working business hours and it decreases significantly on nights and weekends.	-Directly view electricity usage -Offer the Load control feature
Industrial sector [11, 16]	In this phase electricity is used for processing, producing, or assembling goods, and also including such various industries as manufacturing, mining, agriculture, and construction.	-Cut down peak usages -load control feature offer -Maintain the power factor to get the incentives according to the government scheme.
Transport ation sector [19]	Some vehicles use electricity and include battery-powered electric cars and plug-in hybrid electric cars that accumulate power from the grid when they charge their batteries; various types of vehicles' come in this categories like electric vans, trucks, buses, electric rail, and trolley systems that are constantly connected to the electric power grid.	-Whenever demand from other sectors is high then feed power back into the grid, which means the vehicles' batteries are in that case become storage capacity for the grid.

V. SUMMARIES OF RESEARCH PAPERS:

The summary of research paper includes that paper in which electricity data analytics application areas defined in Table 7.

Table VIII. Summary of research papers along with application area and tool used

Application Area	Objective	Tool Used	Research Gap
Smart Meter Data [1,3,8,13,18]	To forecast average electricity load for every hour on daily basis.	S [18] NS [18]	-Forecast model performance only good for some hours of the day as compared to other duration. -Required to improve short term load for household power consumption from the smart meter.
Monitoring of Wind Farm [5]	Planning in advance for necessary maintenance actions that performed during low wind and low electricity demand period.	NS	-false positive alarms are the challenge. -Can' not detect failures during other "lower temperature" operating regimes.

Fraud Detection [7]	Based on customer profiling select suspicious customers for inspections on electricity theft.	H, NS	-Identifies potential data sources and make data accessible. -Improves analytics model to distil information. -Solutions and methodology need to validated in practice
Power Distribution System[10]	Apply on Big Data Analytics in Power Distribution System to overcome the obstacles.	H	Still data privacy and protection issue not solved
Electricity Generation Forecasting [11,16]	Predict the amount of power required at a rate closer to the power consumption.	H [11, 16]	It requires to first trained dataset completely
Smart grid [2,9,12,15,17,20, 19,21]	Design an effective demand response event by analyzing its consumers' house level consumption data and external context data.	H[17, 19,20] S [19,20]	Additional computational overhead comes due to unbalanced against the value added by the use of empirical, purely data-driven approach.
Fault analysis of transmission line[23]	Design fully automated substation data integration and fault analysis for power system transmission lines.	PS	Privacy challenge occurs.

S= Spark NS=NoSql H=Hadoop PS= Postgre Sql

VI. DISCUSSION:

This systematic study is derived from 23 publications. 10 papers are published in journals and rest of papers is published in conference and workshops. Table 7 shows the summary of researches in electricity data analytics. A large number of the study shows Hadoop tool is used followed by NoSQL. A large number of studies depict that tool used for analytics is largely depended upon the situation, objective, and processing need.

VII. CONCLUSION:

Big Data analytics is an active area in the smart grid field. The result of this work had done help new users to understand the role of analytics in Electricity field. This study helps to understand the available technologies, challenges, list out various data originated sources and consumer types. Smart grid demands real-time processing capabilities to fulfill consumer need, short term predictions and determine renewable energy generation peaks. One of the major application areas in smart grid is smart meter analytics. Analysis of data and its predictive nature results in a better perception of plans to be implemented in future. The government has invested huge amounts in smart meter deployment to achieving wide economic, social and environmental benefits.

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