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Research Article

Artificial Intelligence and Big Data applications in smart energy systems

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Abstract

A thorough examination on the usage ofbig data and Artificial Intelligence (AI) in electrical power grid, as offered bythe advent of smart grid, next generation power system is performed in this study. The heart of this new grid system is the Internet of Things (IoT) that provides connectivity which remains the essential part of Smart Grid (SG). Ahuge data volume that requiressystemslarger than the traditional methods for decision-making and accurate analysis is introduced by this connectivity and requisite relentless communication. Effective load forecasting, economical and key data acquisition technique is delivered by IoT integrated SG system. In order to obtain these primeadvantages,Machine Learning (ML),AI and big data analysistechniques plays a crucial role. IoT devices along with their data emerge as the main target, wherein cyber security turns out to be a serious issue in SG's complex connected system, owing to which the smart power grid's development and utilization is quite prevalent and popular at present. In the case of digital power network in SG, prominent technical supportis delivered bybig data and artificial intelligence applications.Big data and AI have emerged as a commanding technique utilized in smart grid for driving it into new generation energy networks and power systems, in spite of the issues faced by the smart grid using such applications.

Keywords:Smart grid, artificial intelligence, IoT (Internet of Things), neural network, Demand Side Management (DSM), data analytics.

1. INTRODUCTION

An enormous amount of data is collected in nearly each and every facet of lives, due to the wireless transmission's fast progress, network communication technology, smart mobile devices, sensor technology including cloud computing. Furthermore, owing to progressively intricate forms and constructions, the data size is increasing swiftly. It is expected that a volume

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of1.8ZBdata that is generatedandsimulatedin2011globally wouldsurgeby50times within the year 2025 as per the research reports published by International Data Corporation(IDC).

Energy systems is undergoing digitization alongside growing infiltration in information technologies development in energy field, due to the data consumption produced causing an enormous amount of energy creation[1]. Traditional energy industry scenario is getting altered due to the big data inventions and discoveries. System reliability and stability, management of renewable energy, environmental issues, energy efficiency, service improvement challenges in operational efficiency, consumer engagement and effective cost control are some of the challenges met by the energy sector presently [2-6].
Big data analytics related to energy offer fresh prospects by accomplishing management of smart energy for effectively addressing these challenges. Smart grid which includes distributed generation resources, inventive storage solutions, vibrant power distribution, balanced electricity consumption, effective power transmission etc. are few of the activities recommended for attaining clean power generation objectives [7–11]. Data collection and energy transmission simultaneously is accomplished in smart grid as they are conceptualized and made to incorporate energy flow and information flow by introducing the concept of "information flow".

The topics of smart grid have much-admired and important consideration in the field of research and experiment, since the electrical power system's travel towards next-generation smart grid (SG) method is quite assured [12-13]. For the purpose of allowing power flow and two way communication which can improve reliability, efficiency and security of the power system, SG is utilized in digital and information communication technologies assimilation in conjunction with power grid systems [14-16].

The ideal pattern of generation, transmission and distribution calculation including data storage of power system is smart grid solutions target. The Distributed Energy Resource (DER) along with smart micro grid is a prospective solution to the rising concern related to environment along with effective distribution and generation and [17]. It is said that for global power system planning, supplementary benefits can be brought by distributed smart micro grid [18]. In order to create power grid automated and intellectual, SG could be made with the combination of advanced systems, processes and technologies [19].

The direction of power system development is provided by smart grid, wherein it's a traditional power grid and modern information system amalgamation. Reduced interaction, low energy efficiency, challenging stability analysis and security are some of the difficulties that could be resolved by smart grid. Optimization and prediction are mainly challenges in the power system. For power generation, energy grid balancing and energy usage testing, AI can deliver unique solutions.

2. LITERATURE SURVEY

Smart grid encompasses data from generation, transmission, distribution of electricity and its consumption process, as energy and information together is captured in an intellectual system, wherein it has a rich source of information. Electricity meters, distribution stations, switch stations comprising other information like regional economic data, meteorological including marketing are some of the electrical information data involved by key an et al. [20].

Teng et al. has stated that external data, measurement data including business data are three categories into which the aforesaid data sources can be organized [21].Sagiroglu et al. stated the systems historicalas well as current status is specified through smart meters and sensors installed, by which power system's maximum operation parameters are determined. The external data such as social events, festivals and weather conditions have an effect on the planning and operation in power system; however smart meters are incapable of measuring it. Promotion tactics and competitors conducts are the business information largely comprised[22-23].

Sagiroglu et al. has illustrated the customers and utility company (or DSO) energy related information in smart grid are delivered by the data that is obtained, accrued and communicated using smart meters. The amount of smart meter readings in the case of big utility company related to residential customer's energy consumption is envisaged to surge to 220 million per day from 24 million a year 2016 [22].

Baimel et al. has comprised the three types of networks such as Wide Area Networks (WAN), Neighborhood Area Network (NAN) and Home Area Network (HAN) in smart grid's communication infrastructure. When dealing with the electromagnetic problem, the technology of wireless communication enables data centre in collecting requisite measurement data through smart meters at economic cost and with easy connections [24].

Fan et al. has stated that the foundation for uncovering relevant information and assisting in making assessments and conclusion is provided by data analysis, big data processing system's supreme crucial step [25-26]. Similarly, Roya et al. is oblique that accumulation of data obtained from different sources in aproficientmanner having a cohesive vision is targeted by data integration techniques [27].

The category like unsupervised or supervised learning based upon whether labels are stringed with datasets every item are the most commonly used machine learning algorithms or data mining. For the purpose of determining data attributes and corresponding values or categories relationship, the supervised learning algorithms and data analytics is viable for education centered on the data given. Di Zhua and Zhang have identified the probable groups amongst all items and model of data analytics is typically planned and developed for those that does not contain labels [28].

Siryani et al. has managed and regulated the operation and maintenance activities by comparing real-time data vs historical data is accomplished by extracting valuable information from the past, which is the data analytics 'foremost practice in smart grid system [29].

3. SMART ENERGY PLANNING

The energy design incorporation with spatial planning and urban planning is essential for energy planning resulting in 'smart' urban solutions. A preparation method involving different disciplines that comprises of building and infrastructure design, spatial and energy systems design, mobility planning and ecological impacts evaluation is required for new inhabitants occupancy design including prevailing city quarters renovation. Accordingly, deploying inventive and creative methods are required for accomplishing those. The discussion on providing renewable energy to urban areas has been the focal point of discussion related to electricity supply in urban areas. The main smart city development features have been the incorporation of both solar thermal energy and industrial waste heat in supply systems including heat storage and integration. For permitting a comprehensive energy system design and complete ecological assessment, the following methods and tools are applied to the energy plan structure.

In order to improve energy technology network, entire energy demands are required as vital preliminary information for the area explored. To ponder on city quarter level, the building requires an additional downscale level that is very crucial. Energy demand levels endorsed by Indian Energy Standards (IES) have to be appraised to continuously reduce entire building’s energy consumption. For example with measurements of energy efficacy like retrofit buildings having improved insulation, developments pertinent to optimizing buildings energy is obtained.

In order to assist city patrons in discovering ideal and safe supply of energy in future, the approaches adopted evidently focus on the significance and requisite for emerging thoughts and approaches. This paper also deliberates a method that is commonly valid to the range of spatial planning processes, even though it is apprehensive of the difficulties given by these concepts.

Building Energy Management System (BEMS) centered on AI and Big Data methodologies

Energy demand’s future trend via past data is predicted by AI-based method. It consist a process encompassing the key four steps and they are a) Collection of data, b) Pre-processing of data, c) Model training procedures, d) Model testing

The characteristics of big data are involved with 5V namely Volume, Value, Veracity, Velocity and Variety which involved in the smart grid have been considered by various researches.

4. CHECKLIST REQUIRED FOR IMPLEMENTATION

TECHNICAL NECESSITIES 	**Hardware** • Collect large amounts of high-quality and granular data using smart grids and smart meters
	Software • AI technology specific software that is utilized in a certain system. • If data is not stored locally, cloud platform may be used. • Huge granular data quantities for training models.
	Human Expertise • In power industry, particularly VRE integration, data scientists capable of developing machine-learning algorithms and continually improving models may be used. • Stakeholders in the renewable energy industry who can comprehend digital technologies and collaborate with data scientists to incorporate VRE into power systems using AI approaches. (For example, power system operators collaborating with data scientists or ICT specialists for obtaining proficiency about the power industry)

REQUIRED POLICIES	• Examine the AI effect on occupations, encourage retraining to avoid job loss, and generate new work possibilities. • Make data open to public so that anybody may utilize or build digital technology. • Consumers, particularly prosumers, should be informed and empowered to engage in demand-side management initiatives. • Empowering for AI application investment in research and development.
REGULATORY NECESSITIES	• Create motivations and encouragement for customers to engage as data suppliers in pilot projects by outlining data privacy guidelines. • Cyber security protocols to be outlined. • Interoperability of big data protocols to be detailed out. • To see that algorithms conform to current power sector regulations, or adjust as needed.
ROLES AND ACCOUNTABILITIES OF STAKEHOLDERS	**System operators:** Increasing collaboration amongst distribution and transmission system operators, while implementing a novel approach to system operation; taking into consideration of distribution system operators changing role. **DER owners/operators** (e.g. aggregators): To contribute as data providers in trial projects. **ICT companies:** Cultivate customized AI solutions for combining VRE into the power system in collaboration with different actors of power energy field (e.g., system operators).

5. RESEARCH and METHODOLOGY

In Figure1, a process model on smart energy management focused on big data for attaining management of smart energy centered on analytics of big data is proposed. In this model, seven key stages are encompassed in smart energy management activities concentrated on big data.

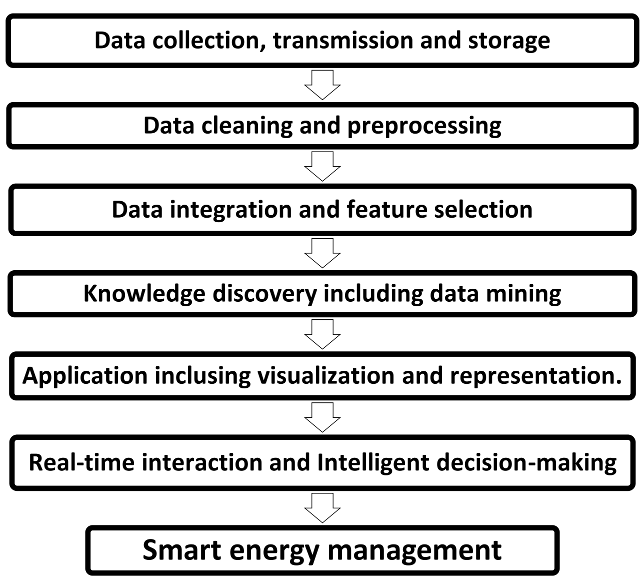

Figure 1 - Big data driven smart energy management process model.

Data collection, cleaning, preprocessing, integration, transmission, storage including choosing features are all important steps in big data mining process model. The essential step and smart energy management's core content centered on big data is data mining and knowledge discovery. Control and decision making all the way through the energy system is reinforced in subsequent to the knowledge obtained from the source where energy big data is exemplified, visualized and made functional.

Better insights are obtained by improving existing business processes to augment operational efficiency and productivity, find out new trends and patterns. Moreover, it determines hidden values from energy big data via several process, progressive data acquisition, analysis and visualization methods. Hence, this proposed method has illustrated the complete process of decision making with assistance of big data and AI technique in Smart Grid Management (SGM) is shown in figure 2.

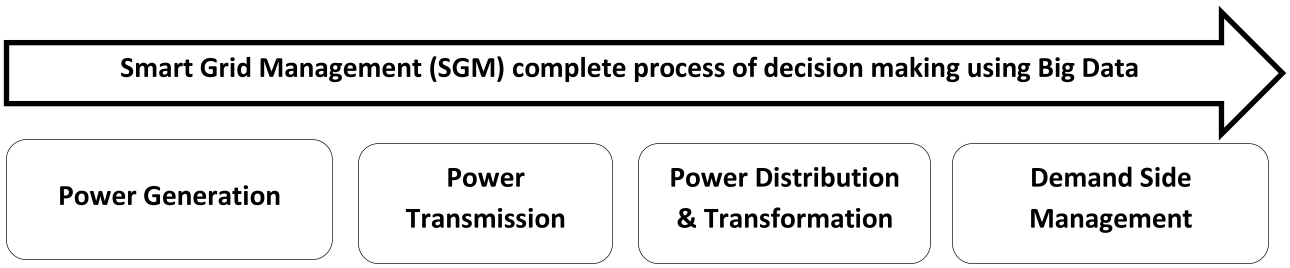

Figure 2 - Smart grid management entire process decision support of big data

Implementing smart energy method using AI and big data including its process involved.

a) Power Generation

Exceptional dynamic response and outstanding operational mode flexibility is meant as Smart Power Generation. The main aspect of these plants in power system optimization is that they are able to function in multiple modes, to dynamic system balancing from proficient base load power production. By utilizing AI and Big Data techniques, smart Power Generation is attained with ease.

b) Power Transmission

The grid is made smart by the digital technology deploying Big Data and AI by transmission lines sensing, wherein collaborative communication amid utility and its clienteles is permitted.

c) Power Distribution and Transformation

The transformers, wires and switches that link the utility substation and customers by utilizing Big Data, AI and ML are Smart Grid features that are applied to utility distribution System, commonly termed as "Distribution intelligence". The power distribution system's one part is a power line which passes via publics' courtyards.

The current grid conversion into an efficient and proficient "smart grid" is the contemporary modernization wave in the power industry. The forthcoming power grid would be self-healing, further robust, enhanced environmentally friendly aspects, provide greater power quality, provide additional choices and more efficient and effective for catering all kinds of generation of customers by captivatingthe advantages ofmodern technologies in signal processing, control, sensing, computer and networking, communications, manufacturing, power engineering, ML, DL, Big Data, AI etc.

d) Demand Side Management (DSM)

The preparation, execution and observing utility actiontargeted at influencing power usage of customer is termed“demand side management” (DSM). Utility’s load magnitude and time pattern is altered consequential to it. Inspiring users to change energy use to normal hours and to less power consumption at peak times or demand curve leveling is the foremost objective.

6. RESULTS and DISCUSSIONS

Big data and AI driven smart energy management research status

Asset management, collaborative operations and DSM, micro gridand renewable energy management and also power generation side management are mainly the four aspects in environment of smart grid. In the case of smart grid environment, big data analytics focused smart control and decision making assistance is made.

Planning and power generation centered on big data analytics can be augmented. In power generation, the two most significant decision making processes are Economic Load Dispatch(ELD) and power generation planning. Energy production efficacy could be immensely enriched and production costs might be prominently decreased by attaining benefit from advanced analytics using big data techniques including extensively collected big data related to energy.

Modern energy systems imperative part is renewable energy, wherein the renewable energy power generation is integrated by micro grid, an encouraging distributed power generation model. Solar power and wind power are two power generation systems in main renewable energy. Owing to weather conditions, their outputs are largely impacted.

In the field of micro-grid management and renewable energy, big data analytics performs a key role. For developing power output and energy efficiency, weather data, GIS data, combination of consumption data and energy production data can support in renewable power generation devices site selection.

7. AI AND BIG DATA ANALYTICS APPLICATIONS IN SMART GRID

In smart grid system, general categorization pertaining to applications using AI and Big Data is a) Analysis, b) Monitoring, c) Forecasting and d) Prevention and Detection

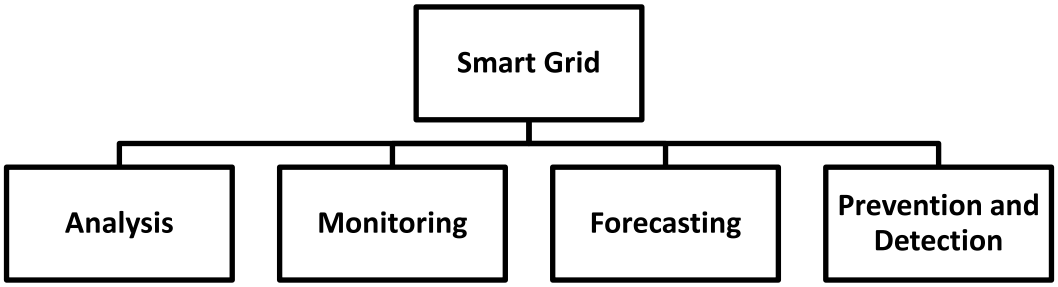

Figure 4 – Flowchart of AI and big data analytics applications.

7.1 Analysis

7.1.1 Analysis of transient stability

A serious problem diligently associated to power system's secured operation is transient stability. It is observed that there is a decontrolled market force power grid for functioning to the nearby safe operating parameters, renewable energy sources mounting permeation and growing electricity requirement.

7.1.2 Analysis of consumer electricity consumption behavior

Machine learning's grouping and recognition capabilities in AI are used to detect aberrant power usage, assess user power consumption pattern and also to perform non-invasive load monitoring.

7.1.3 Topology identification

Using information layers in smart grid to address the issues posed by renewable energy sources (RES) in distribution network is an efficient and worthy way to proceed. Advanced sensors and gadgets are used to measure, monitor, communicate, and manage smart grids, making the complicated network comprehensible and noticeable.

7.2 Monitoring

7.2.1. Predictive maintenance/condition based maintenance

The smart grid concept centered on distribution level's operation and system dependability is termed as Distribution Automation (DA). For the purpose of enhancing customer satisfaction, to isolate and localize distribution system faults with a condensed restoration time are few capabilities of a successful DA.

7.2.2. Electric device state estimation/health monitoring

A power transformer failure can result in disastrous shutdowns in power system since it is such an important component for conversion of electrical energy. As a result, research into power transformer life-cycle management based on precise estimates is attracting a lot of attention in the quest for a more stable and dependable power system.

7.2.3. Power quality monitoring

The waveform and voltage frequency, power system's magnitude and current, that is greatly linked to power grid safe operation including the consumers satisfaction is termed as Electric power quality (PQ), that is viewed as a global concern. The unbalanced situations and harmonic misrepresentations often occur in power grid due to irregular and loads and generators.

7.3 Forecasting

7.3.1 Load forecasting, Load profiling and Load disaggregation

The power grid daily operations most essential part is power grid **load forecasting** that ensures power output and loads are harmonized concurrently. The estimate in the grid's power demand is known as power load forecasting.

The electric consumption's characteristic behavior is defined by **Load profiling**, which is generally denoted in time for capital planning, demand-side management and load forecasting.

Load disaggregation also termed as Non-Intrusive Load Monitoring (NILM) is targeting towards individual appliances energy consumption, wherein domestic level's entire load profiles is separated.

7.3.2 Renewable energy forecasting

Renewable energy power generation is gaining more prominence; however there would be an effect on grid stability due to its sporadic and unstable nature. In power system's efficient, cost-effective and steady functioning, renewable energy output's precise projectionist very critical.

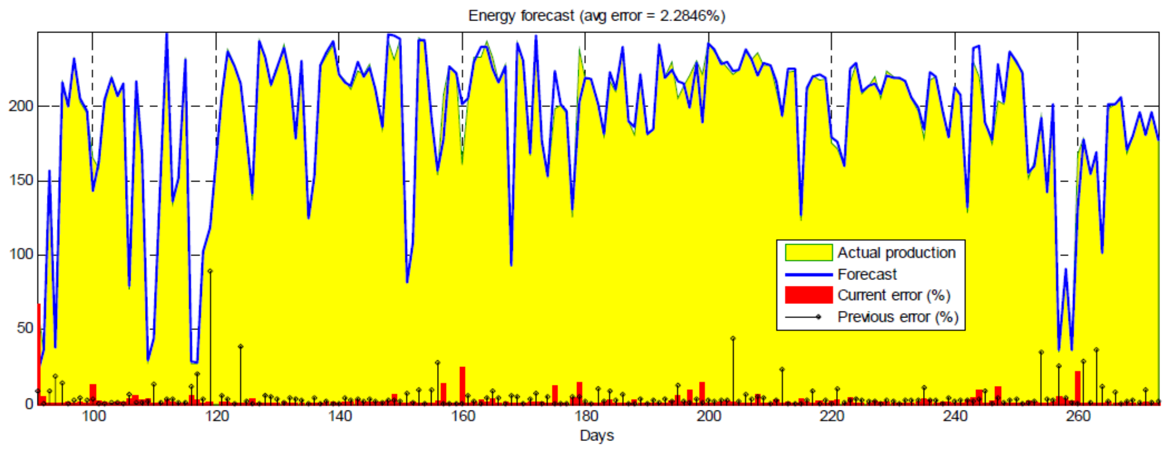

Figure 5 -Comparison of current error and previous error with actual production and forecast.

The results of the forecasting over a six-month's time frame and comparison with actual measured data are shown in Figure 5.

7.4 Prevention and Detection

7.4.1 Non-technical loss detection

One of the main concerns that have plagued power system utilities for many years, the non-cooperative game model that has been made functional in advanced metrological infrastructure for non-technical loss screening for micro distribution systems is the non-technical loss, probably caused by electric burglary or accounting mistakes.

7.4.2 Power network security protection

Dynamic control, real-time observation and information service are comprised in smart grid complex method. Power system would face increased dangers as a result of the deep information flow interaction. Solid concealment and extensive incubation period are some of the features of network attacks of power system. The secondary system can be destroyed to target the physical power grid, even if the primary equipment is not directly affected.

7.4.3 Fault detection and diagnosis

Flexible power equipment is the equipment based on the technology of power electronics. A significant role in fault expansion, rapidly isolating faults and evading equipment damage in power system is played by flexible equipment protection and fault diagnosis, which acts as a secured line for assuring well-being of the equipment.

8. CONCLUSION

This article evaluated and addressed AI and big data in smart grids, inclusive of accompanying state-of-the-art analytic methodologies. Building energy use is monitored, collected, controlled, evaluated, and managed using big data and AI. Electrical market, smart meters placed at power system, social media, meteorological information system, GIS and other various sources are from where the data comprising possibly significant information is collected. To link conventional power system physical factors to external factors in order to uncover possible regulatory and scientific concerns are the goal of modern ICT technology in the power system. The load/output forecasting, operation and maintenance, protection including fault detection and location are outlined in the article that is almost engaged in every element of smart grid. In future, data analytics application possessing a safe and supreme performance is going to be critical in societal welfare including the interests of power corporations. Smart grid necessitates collaboration among specialists from many domains including best designs strategic visions, since smart grids deployed using data analytics is a broad and sophisticated topic including ICT technologies, mathematics, algorithms, electrical engineering, computer science& applications etc.

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