Processing Smart Meter Data Using IoT, Edge Computing, and Big Data Analytics

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Abstract

Smart meters have the potential for improving the accuracy of demand forecasts and the energy efficiency, also allowing for the reduction in energy consumption. Mostly the smart meter data is used for the measurement of energy usage at the consumer side that is then sent to the utility providers for billing purposes and demand planning. Internet of Things (IoT) is used to collect the data from smart meters and that data is used for the calculations and visualization for smart grid maintenance and future decisions. The number of smart meters are constantly increasing and so is the data from those meters. Gathering and performing analytics on such data is a hard computational task. In this study we have highlighted the role of IoT, edge computing and big data analytics focusing on how to speed up the information retrieval from the smart grid data and how that information can be used for multiple purposes, not only for billing purposes. A framework for more efficiently analysing data obtained from smart meters is presented, which utilises edge computing and big data analytics to process raw data to useful information.

Index Terms

Internet of Things, Big-data, Edge computing, Edge analytics, Advanced Metering Infrastructure, Smart meters

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I. Introduction

Smart metering is a method of digitizing the energy system through the use of smart meters, which allows businesses to track how much energy they use and modify their usage as needed. A smart meter is a computerized gadget that is intended to take the role of traditional electricity and gas meters. It can have a display panel that indicates the exact amount of energy used in real time. Installing a smart meter allows the user to control and reduce energy consumption, which eliminates projected expenses. It has the ability to submit meter readings to energy suppliers and gather data remotely. Smart cities can collect data from connected meters to gain insights into infrastructure, public services, and population. The most common problem for businesses installing smart meters is figuring out how to integrate them into their infrastructure and develop custom smart metering use cases.

From homes to towns and companies, the Internet of Things (IoT) promises to make the environment smarter and more connected. The number of IoT-connected devices is rapidly expanding and so is the demand for connectivity techniques to ensure that devices work, acquire, analyze, and manage data appropriately. As a result, connection must be adaptable to fulfill the network performance requirements of a diverse set of IoT use cases, device kinds, and applications. Communications protocols such as MQTT and HTTP are utilized for efficient connections and information sharing [1]. Using an IoT platform with data processing skills is the ideal approach to incorporate smart meters into its infrastructure, It can not only collect data from smart meters but also assist in creating a unique graphical dashboard [2].

Smart meters generate a large amount of data, which must be collected, saved and analyzed in order for companies to use the data for current maintenance and future business decisions. The energy consumption data, for example, if it is gathered every 15 minutes by the smart meter and stored in the billing centers. If a utility company installs one million smart meters, the annual energy consumption data collected from those smart meters is around 3 TB. This big data contains a large amount of information that is required by information-driven algorithms employed by utility firms for current and future organizational planning and strategy. [3].

Edge computing enables smart meter data to be collected faster, analytics to be applied locally, and information to be provided depending on the collected data. This data can be utilized for a variety of reasons, including energy consumption monitoring, demand side management, and energy conservation. According to [4], around 20.6 billion dollars has been spent on consumer-related data analytics from 2013 to 2020, indicating that smart meter data analytics is becoming increasingly significant for energy companies.Customers benefit from smart meters since they have access to and visibility of their energy usage, as well as adjustable pricing tariff rates and greater control over their energy use. The energy consumption can also be reduced because of the feed-back and suggestion from the smart meters data analytics [5].

This research mainly focuses on the data collection from the four phases of smart grid using smart meters and how that data is collected, processed, stored, and presented using the latest technologies like IoT, edge computing, big data and analytics. The rest of this contribution is organized as follows. Section II defines smart meter and in the same section we have explained its working, functionality, communication network and benefits of smart meter. Section III contains IoT and big data and the working of these two together. In section IV we present the framework that explains how IoT, edge computing and big data are working together to collect, process, store and present smart grid data.

II. Smart Meter

Smart metering is a technique of digitizing the energy system using smart meters that provides businesses a way to track how much energy they are using so that they can adjust the usage when required. A smart meter is an intelligent digital device that is designed to replace the traditional electricity and gas meter. It can be equipped with a display screen that shows the exact energy usage in real-time. Installing a smart meter helps you get rid of estimated bills by allowing you to control and reduce energy consumption. It comes with the functionality that allows sending meter readings to energy suppliers and gathering information remotely. Smart cities can leverage smart meters to collect data that provides insights on infrastructure, public services and population. The typical challenge for companies implementing smart meters is how to integrate them within their infrastructure and organize custom smart metering use cases. Here is when IoT comes into the picture.

A. Working of Smart Meter

The functionality and working of a smart meter depends on its use whether to measure electricity or gas affects etc..Embedded systems, or a combination of software and hardware, are used in IoT-enabled smart meters. According to [6] microcontrollers (Arduino UNO), sensors (ACS712-30 Amp Current Sensor), ESP12/NodeMCU, and Male-Female Wires are the primary components of smart meters. The ACS712 sensor measures the magnetic field surrounding a current-carrying conductor using the Hall-effect theory. It can measure both DC and AC, and it keeps the measuring unit and the load separate. Over the internet, an MQTT broker can be used to monitor energy usage. Smart meter readings are generated in real time 24 hours a day, seven days a week, and relayed to the network's edge, where edge computing can be used to execute business logic for the data collected by the meter. Electricity costs, for example, can be computed in real time. Electricity units have a threshold value that consumers can specify. If the meter surpasses the threshold amount chosen by the consumer, logic can be developed to turn it off automatically. The meter may switch on automatically if the user raises the threshold value. As a result, smart meters can be utilized to improve electricity conservation.

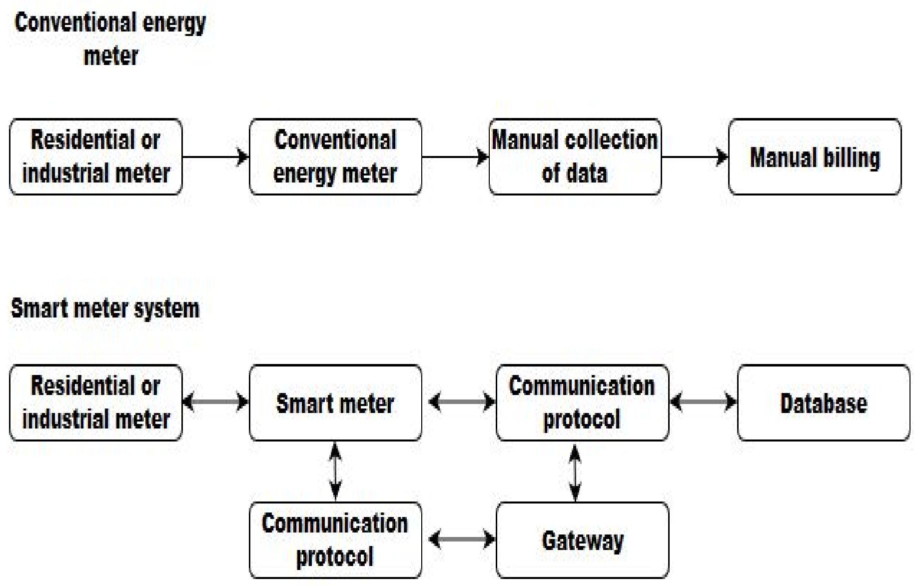

Fig. 1. Metering architecture of Conventional and Smart meter adopted from [7]

B. Functionality of Smart meter

Smart meters help to understand how to use energy more efficiently. Smart meters come with a built-in display (mobile app) that allows user to monitor energy usage while using gadgets. It allows users to view in real time energy usage whether the changes users made to save energy are actually working. In comparison to a traditional energy meter, a smart meter is a sophisticated energy meter that facilitates two-way communications. As a result, it may assess a consumer's energy consumption statistics and then transfer additional data to utility providers in order to support decentralized generation sources and energy storage devices, as well as bill the client appropriately.

Smart meters can also collect information about electricity prices and commands from utility companies and distribute it to customers. In fact, smart meters can read real-time energy consumption data from customers, such as voltage, frequency, and phase angle, and securely transfer that data to control centers [8]. Smart meters can collect information about the electricity consumption values of customer premises utilizing bidirectional data transmission. Smart meters capture data using a mix of parameters including a unique meter identifier, data timestamp, and electricity consumption figures. Smart meters can monitor and operate all home devices and appliances at the customer's premises remotely as well as locally based on the information. Furthermore, smart meters can use the home area network (HAN) to interact with other meters within their range in order to collect diagnostic information about appliances at the customer's location as well as the distribution grid. Furthermore, smart meters can be designed to bill just power consumed from the utility grid, ignoring power consumed from distributed generation sources or storage devices owned by customers. As a result, they can set maximum electricity consumption limits and remotely disconnect or reconnect power to any customer [9]. An architectural model of a traditional energy meter and a smart meter is shown in Figure 1. A smart meter system uses a variety of control devices and sensors to identify factors and circumstances in smart grid, and then sends the data to a control center or sends commands to the devices in the customer area. The utility companies can better manage power demand/response by collecting electricity consumption data from all of their customers' gadgets on a regular basis, and they can also provide useful information to customers about the most cost-effective ways to utilize their appliances. Smart meters can also be programmed to maintain a schedule for home device operation and control the operation of other appliances accordingly, such as lighting, heating water in a swimming pool, air conditioning, washing machines, and other appliances. Furthermore, utility firms can detect and identify electricity theft and unlawful usage by incorporating smart meters into the electricity grid, hence boosting power quality and distribution efficiency [7]. This shows that smart meters will be critical in the future for monitoring the performance and energy usage characteristics of loads on the electrical distribution grid.

TABLE I
SMART METER WITH SOME FUNCTIONALITIES IN MARKET ADOPTED FROM [10]

Functions	**Landis+Gyr**	**Sensus**	**Itron**	**GE**	**Corinex**	**Elster**	**Siemens**	**ABB**
Fraud detection	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Load Profile	Yes		Yes	Yes		Yes		Yes
Load Management		Yes	Yes	Yes		Yes		
IP Addressable	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
On demand	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Power quality monitoring	Yes	Yes	Yes					
Demand side management	Yes	Yes		Yes			Yes	
Remote connect		Yes			Yes			
Outage restoration		Yes		Yes				
Load profile	Yes		Yes	Yes		Yes		Yes

As a result, by combining the advantages of both small distributed power producers and large centralized generators, utility companies may deliver highly reliable, easily accessible, flexible, and cost-effective energy services to their customers via smart meters. Furthermore, demand side management approaches necessitate the collection of enormous amounts of data from smart meters in real time by these organizations. Table I shows some smart meters from various firms, along with their functions.

C. Communication Network in Smart Meter system

Several control devices, numerous sensors to identify parameters, and devices to convey data and command signals are all used in a smart meter system. Smart meters will play an important role in monitoring the performance and energy usage characteristics of loads on future electricity distribution systems. The frequent collection of energy consumption data from all customers allows utility companies to better manage electricity demand and advise customers on the most cost-effective ways to utilize their appliances. As a result, smart meters can be used to manage light, heat, air conditioning, and other appliances [9]. Smart meters can be programmed to keep track of when home appliances are turned on and off, and to manage the functioning of other equipment accordingly. Furthermore, smart meter integration aids utility firms in detecting unlawful usage and electricity theft in order to improve distribution efficiency and power quality [7].

The selection of a communication network and the design of communication devices are essential, as they must fulfill a number of difficult requirements. The use of a smart meter system necessitates a large volume of data transfer between the utility provider, smart meter, and networked household products. This information is important and confidential, and only a few people should have access to it. With these data constraints, security standards for transmitting, collecting, storing, and maintaining energy consumption data are developed. To ensure that data transfer within the network is secure, communication standards and guidelines were developed. This data must also provide a comprehensive information about the customer's energy use and the status of the grid without any potential manipulations or miscalculations. As a result, this information must be verified and should reflect information about the relevant target devices [11]. Fig. 2 depicts the generic architecture of a communication network capable of fulfilling all of the above-mentioned functions. The directionality of communication between devices on the customer's premises, the utility, neighboring smart meters, and other power system components is depicted in this diagram. In this diagram, transmission devices ensure proper transmission of generated energy, distribution control systems ensure fault monitoring and control, and communication devices such as protocol gateways, data collectors, and repeaters, as well as network operations, coordinate data and control signals between all devices in the communication network. A unique identifier is provided to a customer's smart meter or appliance which can be identified with it. Cryptographic approaches are used to protect the identities given to all components in general.

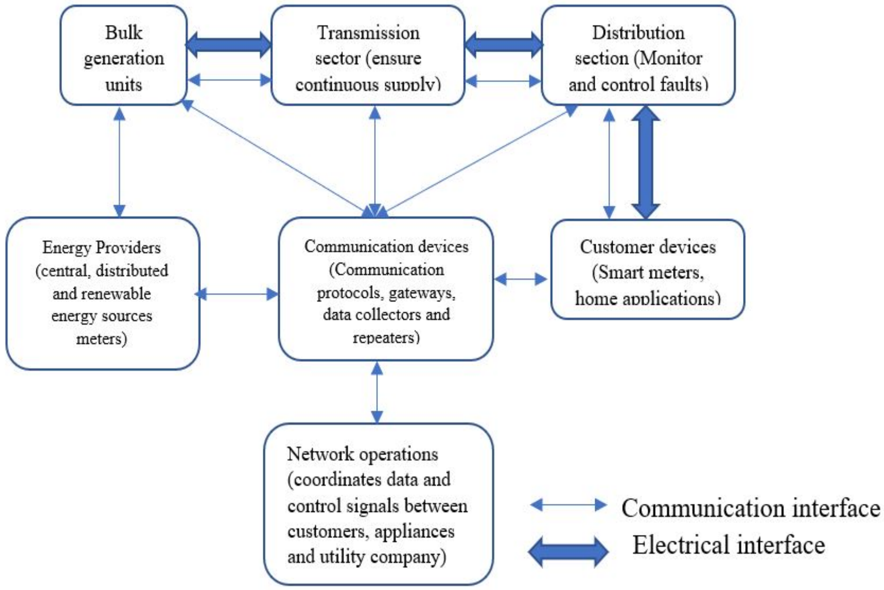

Fig. 2. The communication network in smart metering system adopted [7]

D. Benefits of smart meter

The main benefits of smart meters are the following [12], [13].

Convenience: The electrical department, unlike the manual procedure, will not require a representative to visit every home or building to take readings and generate bills. Readings from smart meters can be submitted to the electricity department automatically. There's no need to fumble around in the dark to find gas or energy meters.

Accuracy: Smart meters eliminate the need for estimated bills because usage data is provided to the electricity department in real time. Traditional energy billing necessitates a greater degree of guesswork. Also, when IoT intelligence is used to generate energy bills, there is no possibility for human error.

Control over energy consumption: Smart meters include a smart energy display that shows how much energy is generated by household appliances as well as how much it

TABLE II
BENEFITS OF SMART METER [12], [13]

Customer side benefits	**Utility side benefits**
Consumers get more information about their energy usage. This will provide energy efficiency gains for both the consumer and the industry	Demand peaks are reduced
Increased knowledge of quality of delivery and more detailed feedback on energy use	Remote controlling enables better management of billing and other consumer related issues
Bills are based on actual consumption	Automated and remote meter reading
Customer can adjust their habits to use more during off peak hours to lower electric bills	Electric systems are monitored more quickly
Power outages are reduced	Enabling more efficient use of power resources
Switching and moving are easily facilitated	Power outages are reduced
The necessity of bill estimation is reduced	Enabling dynamic pricing
No need to provide access to utility people for taking reading of meters located indoors	A voiding building of new power plants
Environmental Benefits	Optimizing income with existing resources
Smart Meters communicate directly with the utility, eliminating the need to put utility trucks out on the street	Increased information on low voltage network
Smart meters prevent the need for new power plants by contributing to the proper distribution of existing power usage, and as a result reduce pollution	Freeing up experienced staff for other high priority areas to better serve the customers
Smart meters indirectly reduce the emission of greenhouse gas from existing power plants	Operational costs are reduced

will cost. It aids in the tracking of the true cost of an energy bill before it is generated. It might also indicate when the least or most energy was consumed. Smart meters can assist in the discovery of new ways to save money by switching to energy-efficient appliances.

Safety from faulty appliances: Because smart meters include in-home display monitors that can reveal how much energy is being consumed at any specific time. A smart meter may also detect abrupt surges in usage that could indicate a malfunctioning appliance. Identifying such appliances can help assure safety while also reducing energy use.

Good Energy Habits: The installation of a smart meter aids in the adoption of excellent energy practices. Because in-home displays show how much energy has been consumed, they aid in the establishment of energy-saving objectives. It facilitates in the efficient use of energy and the elimination of waste. It helps to save energy resources by just using the energy that is required.

Environment Protection: Smart meters can also benefit the environment by reducing the need for new power plants or avoiding the use of less efficient power plants by allowing customers to reduce their energy consumption. It is highly costly to construct power facilities that are only needed for occasional peak demand. Through incentive schemes or energy-saving initiatives, customers' demand can be lowered. Peaker plants emit more greenhouse gases and produce more air pollution, thus avoiding them is better for the environment.

III. IoT and Big data

The recent research in smart grid has emerged new technologies like the Internet of Things (IoT) that are used to reduce the number of communication protocols, achieve better customer relation, and handle huge amount of data generated from the smart devices and presents the information in a good way from the stored data [1] . IoT is the high expansion point of the smart grid because of the data gathering, communication and promising future with the smart analytics. The energy-based data analytics from the user to the utility can highly improve the efficiency and reduce the congestions in the smart grid and improve the power supply reliability for the 100% renewable energy in future [14].

To make the IoT environment successful, some standards such as interoperability, compatibility, reliability, and operation effectiveness on the global scale must be followed. The rapid increase in the IoT devices can cause huge growth in data generation and results to big data. The generation of big data from smart grid by IoT makes the existing data-processing capacity ineffective and it is important to include the big data technologies to improve the data-processing capacity of IoT data [15]. The comprehensive sensing and processing abilities of IoT support many technologies in SG. Large number of IoT devices are connected in the SG that is generating huge amount of data and the data analytics becomes challenging. According to the International Data Corporation (IDC) report, big data market will reach to US$ 125 billion in 2019 which leads to requirements of the role of big data analytics. The big data analytics can be defined as the process by which the variety of IoT data are examined to find the trends, hidden patterns, unseen correlations and new information. This huge amount of data analysis and information gathering will provide benefits to the companies for current and future effective decisions and will also provide benefits to the individual users [16].

Big data is a growing topic in the research area and there is no any specific definition for it, however in simple terms big data can be define as the collection of structured, unstructured and semi structured data that can be generated by the social media, devices, sensors, software applications and digital devices that are continuously generating data [17]. The data collected in big data is so large that the normal conventional data processing software and techniques and not able to process such huge amount of data. Big data is characterized by the three main determinants, called as 3Vs of big data. These are volume, velocity and variety. The volume is the huge amount of data generated that make the datasets too large for the normal database technology. This type of data is measured in larger units of data like terabytes, petabytes, exabytes. Velocity is the speed with which the data is generated, processed and moves around in real time. Variety is the type of data (nature of data) that whether the data is structured data or unstructured data which can includes different types of data files [18].

These three characteristics of data determines that the stream of data is big data or not. For the processing of big data higher computing power is needed in relation with the business intelligence, natural language processing and machine learning.

A. Working of IoT and Big-data together

IoT and big data are the most needed technologies from the past few years and the organizations needs these two technologies to fulfil their business requirements and take effective decisions. Big data and IoT evolved independently but with the passage of time these two technologies becomes interrelated [16].Due to the advancement in digital technology and cloud computing, every passing day the generation of data is increased due to the increase in the number of digital equipment and sensors like smart phones, computers and smart meters etc. IoT is playing a promising role in connecting the devices together using a communication channel and share information with each and with the platform. The data generated from these devices are analyzed and is used for the current and future decision-making processes. The number of IoT connecting devices are increasing, it is estimated that the number of IoT devices will reach to 20 billion in 2020 [19] and may be 50 billion in 2020 [20] and will generate huge volume of data of about 40 Zeta bytes in 2020 [21]. Handling of massive amount of structured, unstructured and semi-structured data results in big data [22], because the current data-processing capacity of IoT is becoming ineffective, and there is a need to combine big data technologies to improve the development of IoT [15]. The massive amount of data needs high storage and high computing power and strong data analytics as the traditional databases systems are not able to store, process and analyze such a huge amount of data [23]. Cellular network like 5G has improved the large scale obtainment, communication and data processing in smart grid by providing good communication between energy providers and smart grid. 5G is providing the ability to collect high amount of data, speedup the data analysis process, take out information from the data quickly which is used to make better predictions and speedup the decision process [24].

B. Requirements of big data and analytics in IoT environment

The main idea of IoT is to connect heterogeneous object to the internet and collect data from those devices and analyze that data and make future decisions. From the past few years there has been dramatic improvements in the technology and business digitization, and the number of devices connected to IoT is increased and so is the data, there is need for the big data and analytics to IoT. Big data and analytics have high potential of taking out meaningful information from the huge amount of data and makes the decision processes very improved. The main requirements (functional and non-functional) of big data and analytics in IoT are explained below.

Connectivity: Connectivity in IoT is mostly ubiquitous with the heterogeneous objects in the network and many objects are connected to internet via sensors in a smart environment. The first and most important requirement of IoT is to provide a reliable connectivity for big data and analytics. The reliable connectivity will provide the big data and analytics the opportunity to efficiently combine and integrate the massive amount of machine generated sensor data. Using the advanced wireless networks like Wi-Fi and 4G/5G, many objects around us are able to connect to the high-computing and high performance infrastructure and facilitate the IoT services [25].

Storage: The number of IoT connected devices are increasing and so is the data generated by those devices, this has increased the storage of huge amount of heterogeneous data in a low-cost hardware on a real basis. The requirements of big data storage in IoT is to handle massive amount of unstructured data and provide low latency for analytics. Also, big data technology provides IoT an efficient data storage, processing and facilities to convert the massive amount of unstructured data into useful information which will provide a good foundation for better decision making. There are many sources of IoT data like sensors data, social media, smart phones etc. modeled in various ways and are using different communication protocols and interfaces. The IoT services are mostly based on machine-to-machine (M2M), communication protocols that are required to handle huge number of streams and is taking benefits directly from the cloud distributed storage and computing infrastructure [26].

Quality of services: The ability to provide guarantee of a specific level of performance to the data flow is called Quality of service (QoS). The QoS provided by the IoT is that the IoT network should be reliable and should provide the guarantee of an efficient transfer of data from the sources that generates the big date. The QoS in the IoT network is very important to big data and analytics [27]. There are many new networking technologies that can be used to create a reliable network so that there should be an IoT enabled real-time event transfer and improve the processing capabilities of big data.

Real time analytics: IoT is growing rapidly and is taking key steps to improve the streaming analytics and improve the timely decision processes. IoT is taking real-time communication of information concerning the objects that are connected to IoT. Big data and analytics in IoT will make the streaming process on the fast track and will take out the information in a quick possible time. Big data is using an operational database for the streaming data and on most of the streaming data from web-enabled objects big data analytics is performing real-time queries to get the information from it quickly and make decisions and interact with the concern devices and people in a real-time [28].

Benchmark: Due to the fast digitization of businesses, many organizations have started to shift their business online using IoT. Initially these businesses were running very smoothly and the organizations where happy from the progress, but with the growth in the business, many of these organizations are facing many challenges in storing an analyzing the huge amount of data connected through the IoT devices. Finding the solution of those challenges required some deep understanding of the problems. Bid data and analytics have got much attention from the academia and many organizations. Big data and analytics have found the solution of those challenges by using the big data and analytics platform. Benchmark plays an important role in this situation by allowing the organizations to compare the quality of the big data and analytics solutions [29].

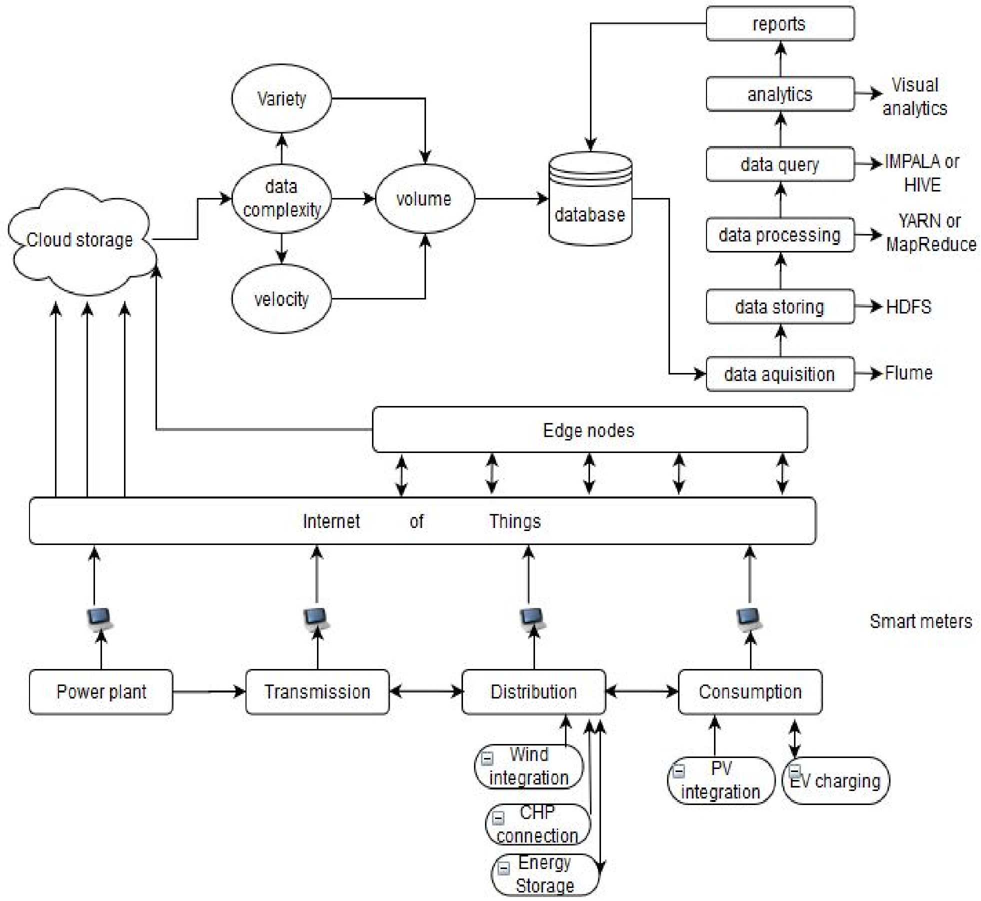

Fig. 3. Data collection from smart meter using IoT , edge computing and big data

IV. Working of IoT and big data in smart grid

Businesses are growing fast and so is the technologies. For the growth in the business, effective business decisions are very important which are possible by getting information from the collected business data. IoT is acting as the major source of getting data, according to the studies about ten billion devices will be connected to the IoT by 2020.

These devices gather, analyze, share, and transmit data in real time. It is estimated that these devices will generate around 4.4 trillion GB of data in 2020 [30]. Handling such a massive amount of data is the point where the IoT needs big data, because analytics in big data is the key source to analyze the IoT connected devices generated data and improve decision making. The relation of IoT,edge computing, big data in smart grid is shown in Figure 3.

The life-cycle of the smart grid data starting from data generation to data analytics. The streaming data is generated from hundreds or more of smart meters with a specific time scale. The data generated may belongs to generation side, transmissions side, distribution side or customers side. The data can be generated from power plants, wind farms, solar panels, hydro, nuclear, residential homes, electric vehicles, commercial buildings, factories etc., the data can also be generate from the environment like weather, humidity, temperature, pressure etc. data generated from many sources increase the reliability of the grid. The data generated may be like how much power is generated, how much is transmitted in transmissions lines, how much is distributed to customers etc. and how much is utilized by the customers , as smart grid is bi-directional, so how much is provided by the customers to the grid. some of the data can be collected from the social media. The generated data from those smart meters etc. are transmitted to the IoT gateway (platform) using the IoT devices like sensors, actuators through the network technologies 3G/4G/5G, ZigBee, wi-fi, bluetooth, wired communication etc [31], and then some of the data is send to edge nodes for local analytics and the rest of the data is stored in the cloud storage. From the cloud storage the data after processing is provided to the big data analytics technology like Hadoop. The Hadoop analytics applies the required analytics process on the data and provide the information from that data to the dashboard and API management.

The data collected from smart grid using smart meters and other devices contains structured, semi structured and unstructured that which is not possible for the conventional databases to handle such data [32].Such huge amount of data needs high storage, fast analysis and large queries to get information from that data and make the decision process faster using dashboard for presentation of information . This is due to this reason that the processing of smart grid data needs IoT, edge computing and big data analytics for the calculations on smart grid data.

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