Integration of Fog and IoT model for the future Smart grid

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***Abstract*- A modern power grid with smart devices, smart houses, smart meter, smart vehicle and transmission lines connected through a network constitute smart grid. Unlike the traditional structure of power grid, a smart grid provides transparency between the customer and distributor and having a property of self-healing and self-monitoring. In this paper, an integrated approach of fog and IOT is presented as a backbone for smart grid structure. Wherein the micro-grid concept is proposed with fog to extend the feature to the end users and efficient load balancing and power consumption technique are being introduced. Private data of smart meter is secured by the use of RSA algorithm at the fog server. Further, smart street light is integrated with fog server for efficient load balancing.**

Keywords - Smart grid, Microgrid, Smart meters, Street Lights, Fog computing, IoT, Cloud computing, RSA algorithm.

I. INTRODUCTION

The existing power grid has remained the same for about a century. There is an inverse relationship between the existing power grid and demand for electricity. The power grid is aging and the demand for electricity is increasing. The inefficient power distribution network is very complicated and cannot fulfill the rising needs of the 21st century. There have been several issues with the existing power grid system. The major issues are network traffic which results in a congested network and safety-related issues which often result in major blackouts[1].The response time is more due to mechanical switches and less automation, one-way communication, decreasing supply of fossil fuels etc. are major factors leading to blackouts. Fossil fuels are scarce and cannot meet the growing demands of electricity, In addition to this, the traditional distribution of energy by the power grid is often not efficient in the distribution as well as there is no opportunity to manage and direct the consumption of energy[2].

Traditionally there is a power plant which produces electricity, mainly through large diesel engines, coal, oil, steam etc. Further, this AC produced by the power plant reaches the transmission substation which has a large step-up transformer to produce a voltage for long distance transmission. The ground wires in this majorly attract lightning. This then reaches the power distribution grid having a step-down transformer and a bus to split the power in multiple directions. Then, there are regulator banks to regulate the voltage and finally, the power reaches the respective destinations. There is a lot of scope for innovation at every step of this power grid. It is not easy to modify or change the entire power grid because it is neither cost-effective nor practically feasible and there is an urgent need to bridge environment between smart grid and technologies like fog, cloud and IoT [3].But to meet the future demands, the power grid can be made smart by the integration of technology and turn the existing power grid into a smart grid.

"Smart grid" is referred to as the future generation network for electricity distribution which includes automation at all major levels of the power grid. The traditional power grid is electro-mechanical, one way, centralized management, hierarchal in nature, limited control and fewer sensors etc.[3],[4]. The smart grid is a digital way of communication with a two-way flow. It is composed of sensors over a distributed network. It is self-adaptive, self- healing and can adapt to blackouts too. In A smart grid, effective load balancing can be achieved and the flow of electricity is where it is required at a particular time [3],[4],[5]. The flow is dynamic and based on the need of area. Smart meters in the grid can give real-time electricity usage of the user to the authorities as well as to the user. Also, it is seen that in existing power grid one-third of power is used from the power generated and rest is wasted, therefore a virtual power plant or microgrid is used to feed that power back to the plant so that it is utilized fully[6].In, other words smart grid is the 21st-century grid to meet the demands of renewable energy and efficient power distribution.

The paper is detailed as follows: The introduction is followed by the literature survey. The proposed model is discussed next with the aspects of smart grid, smart meters, smart street lights followed by sensors with the concept of fog and IoT. Then, the merits of the system are discussed.

II. LITERATURE SURVEY

Various papers on smart grid and projects which are discussed below:

Feyza Yildirim okay et al.[3] proposed a system with smart meters which is a 3-tier architecture and based on fog computing's integration to smart grid. The system is based on integrating the concepts of fog computing to the grid which is basically extending cloud to the edge users.

Vehbi C. Gungor et al.[1] in their paper discussed major issues in smart grid technologies focusing on information and communication technology primarily. This paper explains various technologies like Zigbee, wireless mesh, cellular networks etc. their usage and integration with the smart grid.

Li Li, Hu Xiaoguang, Chen Ke et al.[7] in their paper discussed the importance of smart grid and Internet of Things. It described the development of smart grid in USA, Japan, Europe, and China. Also, the applications of wireless sensor networks in the context of IoT and smart grid is explained, that how WSN would be a better choice for IoT and smart grid.

Albert moldering et al.[8] gives a three-step control method to manage the distribution of energy, storage demands, and sideload with various new technologies. The main tasks like peak shaving and virtual power plant formation can be achieved without harming the residents. A better match for demand and supply is met is this proposed model.

A.R. Al-Ali et al.[9] presented the concept of IoT in the smart grid. In this paper, each device in IoT is considered and can be accessed using the Internet. IPv6 is used as the underlying backbone of the communication. A smart grid model in the context of IoT is proposed with devices and objects with their communication and control.

III. SMART GRID

The smart electric grid can be described with a network of smart devices, objects, sensors along transmission lines etc. to meet the growing electricity demands of the future[3].In a smart grid, the main feature is the bidirectional flow of both information and electricity, information from utility to the customer. Fig .1. shows a block diagram of a smart grid architecture. A smart grid consists of networks of home, neighborhood, business, smart meters, electrically chargeable vehicles, central station, substations with automation systems etc. The 'grid' is called a 'smart grid' when all of its phases are automated and provide a sustainable, reliable, efficient source of electricity. Micro-grid is a concept of a mini-grid to aid the power grid or often act as an autonomous unit away from centralization concept[10].Another feature is AMI i.e. Advanced metering Infrastructure which does the task of collection and delivery of information about the consumption of electricity read by smart meters[1], [3].The data generated by smart meters is both public and private.

The main features of a smart grid are discussed below[2]:

- It is digital and is connected to a network rather than a hierarchal structure.
- It has sensors throughout the system and transmission lines.
- It allows a two-way flow of information and electricity and the generation is distributed in nature.
- It is self-monitoring and self-healing.
- The smart grid can operate in islanding mode and adaptive mode which makes it less prone to failures and blackouts.

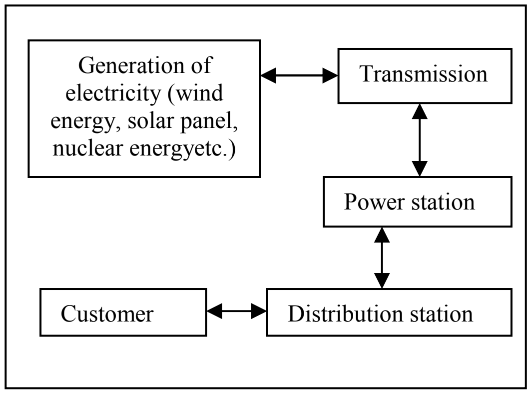

Fig.1. Smart grid showing bi-directional flow

Various technologies like Fog computing, Internet of Things, cloud computing and sensors technology will aid to the developments in the grid. The sensors can be deployed throughout the power grid and transmission lines for efficient monitoring, controlling and working on the power grid. A centralized cloud is present as the central station for managing the entire network of the grid which include local network areas, power grid stations, and others.

Cloud computing is defined as a shared pool of configurable resources where the resources are on demand and provides services to the customers as infrastructure, platform, software etc. [3], [11].The smart meters collect data and through the internet can be sent over cloud where it can be accessed by the users and service providers as well. The data includes both public and private data of the users, hence data privacy is a must. This can be achieved by localized fog on the edge of the network, which can manage the private data of the user securely and rest of the public data can be sent to the cloud.

Fog computing is described by Cisco which is simply extending the services of the cloud to edge users. Fog can be called as the integration of Mobile edge computing(MEC) and Mobile cloud computing(MCC)[3],[11]. MEC provides edge users the ability to develop applications without latency and MCC provides the facilities of storage and processing by moving them from devices which are mobile. Fog is advantageous over cloud as:

- It is locally based as compared to the cloud and is real-time scalable, i.e. the addition or deletion of nodes or networks does not affect the system.
- It is fault tolerant and ensures private data privacy as it is on the edge.
- Geo-distribution of fog over the various networks and steps of smart grid ensures service provision with reduced latency.

Internet of Things is the technological advancements in which with the help of unique identification and sensing technique, the devices can be monitored, controlled and operated for efficient management. The major advantage of IoT is that various heterogeneous devices called things can be connected to the internet. This is an important technology helping in smart grid evolvement.

In this paper, we will describe a model having microgrid, fog computing to extend its features to the edge users on the smart grid based on the cloud for efficient load balancing, power consumption, and data monitoring. It integrates the micro-grid architecture, fog computing, IoT and sensor concepts to the smart grid.

IV. PROPOSED MODEL

The proposed model is as shown in Fig.2. The proposed model is divided into various aspects. First, a micro-grid is connected to the main grid at PCC, then smart micro-grid works in coexistence with the power grid and provides power according to the real-time consumption of the user. Further, smart meters are implemented to read the electricity consumption of the users and information is saved and processed on a local fog. Thus, a fog-based model is implemented to manage the local area networks and street lights, which are also powered by the smart grid. Thus, mainly Fog, IoT is used in form of sensors, smart vehicles, and smart meters to develop more features in a smart grid.

A. Smart Micro-grid in Smart grid

A Microgrid is distributed energy systems which are interconnected and can operate autonomously as well as a part of the main electricity grid [2],[10].Fig.3. shows the physical layout of a smart micro-grid. A smart micro-grid is connected to the main grid through PCC or point of common coupling. The micro-grid is somewhat like a power grid but with a difference that it can operate in islanded mode. It can coexist with the power grid as well as operate in the mode where it is not connected to the power grid and is acting independently. It does the task of feeding the unused energy back to the grid as well as meeting local demands when the main grid has a downtime or is operational due to some reasons.

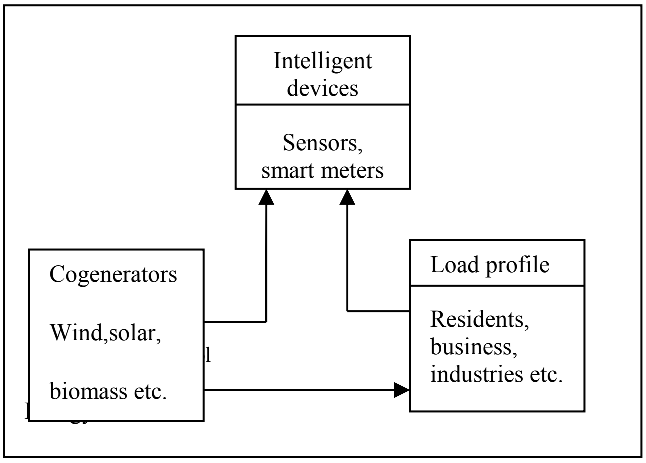

Fig.3. Topology of a Smart micro-grid

It has its own power plants for this purpose called cogenerators which use renewable energy resources, or some even have thermal power plants which can recover the heat in the power plant itself by various methods. It can address a variety of loads like residential, business etc. and has smart meters and sensors to measure, monitor and control the distribution of energy and ensure its efficient utilization. The micro-grid which do not have PCC can operate independently in islanded mode.

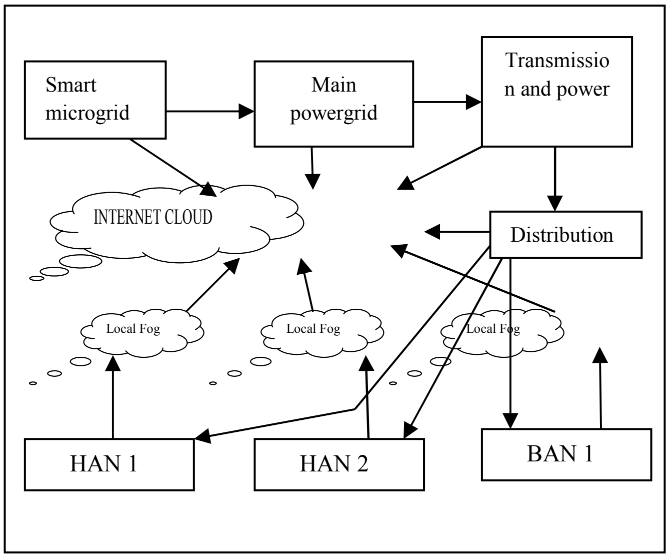

Fig.2. Proposed Model

The steps of a smart grid can be automated and linked to IoT with the help of sensors[12]. A smart grid sensor has four parts:

- A transducer to generate electrical signals based on power line voltage,

- A microcomputer to store and process the output of the sensor,
- A transceiver to send and receive commands and signals, and,
- A power source to derive sensor.

These sensors can be installed among the power transmission lines for real-time energy distribution efficient load balancing etc. These sensors can sense the transmission line to adjust real-time power, manage the real-time data generated and control the power distribution in various regions by analyzing that data.

B. Smart meters

Further, when the distribution of power takes place to home area networks, business area networks etc. All these networks are connected to each other through wireless networks or Wi-Fi or Zigbee etc. Each of these networks has smart meters, plug-in charge vehicles etc. and can communicate with each other over the interconnected network.

There are four types of communication in this model as follows[3]:

- Among various smart devices
- Between fog server (or cloud server) and smart devices
- Among the various fog servers
- Between cloud servers and fog servers

Fig.4. shows the tiers with their communication structure. The first tier is the smart grid tier is based on communication amongst various devices like sensors, smart meters, electronic vehicles etc. It is responsible for communication amongst these devices for various services like a business, location-based purpose, billing, monitoring etc.

The smart device to fog server communication can be explained as, let say for example an owner of the electric vehicle which is chargeable by the grid [3],[13], is charging his vehicle from another power outlet which is not belonging to the owner but in the same local fog range, then the fog should be able to communicate with the power outlet and the reading of the charging should be measured in owner's smart meter by fog. The power outlet sends the power reading and the ID of the owner to the fog and fog adds up the reading corresponding to the reading of the owner.

Further, the smart devices along the power grids, transmission and distribution lines communicate directly to the central cloud server for monitoring and control of power distribution and transmission. The fog server to fog server communication can be explained through another example. Let say, the two smart meters which are not belonging to the same fog server need to communicate with each other. The owner crosses his fog range and reaches in the range of another fog server where he needs to charge his vehicle. Now, the reading cannot be directly recorded into the meter of the owner. This requires communication between fog servers. The owner charges his vehicle and had an ID corresponding to his vehicle. The smart meter records the reading and transmits it to its fog sever, the fog server communicates with the other fog server through the internet and delivers it to the desired fog server. Here, the server of the local fog can further communicate with the cloud server to give real-time energy consumption of a particular user and distribute the energy to the customers accordingly. The smart houses, business area etc. are powered by solar panels which is a renewable energy resource and can be stored and kept for further use in capacitors or storage units.

Further, data generated by smart meters is of two types: public and private [3]. The public data includes the total consumption and total production. The private data include data about the user and its various appliances. Let say there are 'n' etc. appliances in a household like television, AC, refrigerator The smart houses are capable of producing electricity and storing it for their use, therefore the total production energy is given by $P_i=P_1+P_2$, where P_1 is the energy produced by grid and P_2 is the energy produced by the solar panel. Let the 'n' devices consume C_1 from the power grid directly or the microgrid and C_2 from the own energy production. The consumption read by the smart meter is the aggregation of C_1 and C_2 i.e. the total consumption $Ci= C_1+ C_2$. The bill is therefore generated for only the consumed reading C_1 by the grid and not by the solar panel. All the data of total consumption and production is categorized under public data. The private data includes the private information of the owner as well as the information on appliances and their consumption. Let the consumption be $c_1,c_2......c_n$, which is added to the total readings of C_1 and C_2 based on the consumption of the type of source which produces electricity. Fig.5. shows the smart meter with types of data it collects. The smart meters read the data and encrypt the private data using RSA algorithm.

RSA is the standard public key encryption algorithm used for sending data over the internet [14]. It is an asymmetric key encryption algorithm, in which user encrypts data with his public key and the decryption is done by the private key at the receiving side. The vice versa of the above scenario can also be done. The KEY_{PU} is the sender's public key for data encryption, and KEY_{PR} is used for decryption. The public key is shared and the private key is kept secret. The keys are generated, distributed and then used for encryption and decryption. This encryption takes place at fog server and is done by the user, the decryption happens at the central cloud server with the private key.

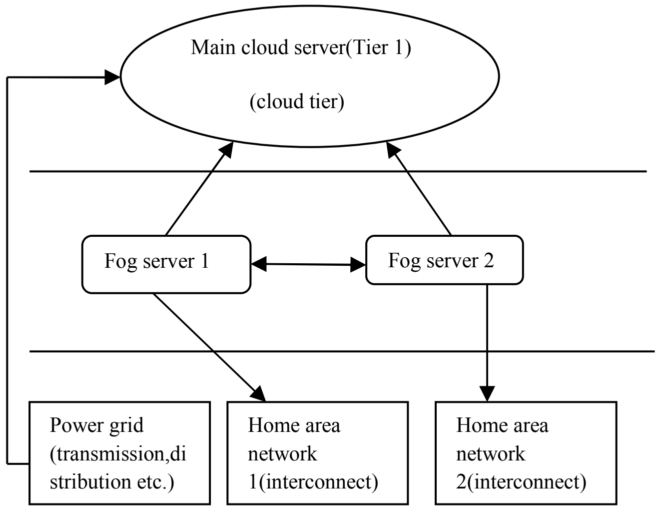

Fig.4. Hierarchal communication structure with various tiers

At fog level, the fog aggregates this data and sends to cloud and at the highest tier, the cloud does the task of aggregation and data storage. The data from the power grid or micro-grid having information can also transmit to the cloud securely. Thus, customers will be able to access their real-time consumptions, bills; history with other details and the cloud server can be regularly informed about the grid functioning, downtime if any or even switch the micro grid's mode from connected to islanding depending on the requirements.

C. Smart streetlights

Street lights are another part of smart grid which can be monitored and given power or energy according to various parameters like area, density, population, the requirement of lights and others. The street lights can be linked to a local fog which is connected to the cloud server. The street lights can be turned on automatically by sensing the time of the day when they are needed or by automatically programming them to be turned on for a particular time. The area which has a large number of street lights but less population, only a few street lights can be powered in that area. When the electricity is required by the power grid the bidirectional flow of the smart grid helps in taking electricity from the smart houses, devices, appliances, street lights etc. the important residential areas can be powered by microgrid in islanded mode thus providing electricity to those localities. Hence, it can be called as a win-win situation for both customers and power grid.

V. MERITS OF THE PROPOSED SYSTEM

The proposed model is based on Fog, IoT, and wireless sensor networks. The major merit of the system is its power of coexistence with the existing power grid. The smart grid can exist in parallel with the current grid and offer a much better electrical energy distribution and production. The micro-grid at the PCC of the power grid helps in shoving the energy back to the grid which is unutilized and also helps in the grid during failure or downtime. The islanded mode of the micro-grid helps the power distribution and continuous power supply to the areas in which grid is currently not functioning. Also, can help in load balancing by providing power to the areas when required i.e. a stable operation.

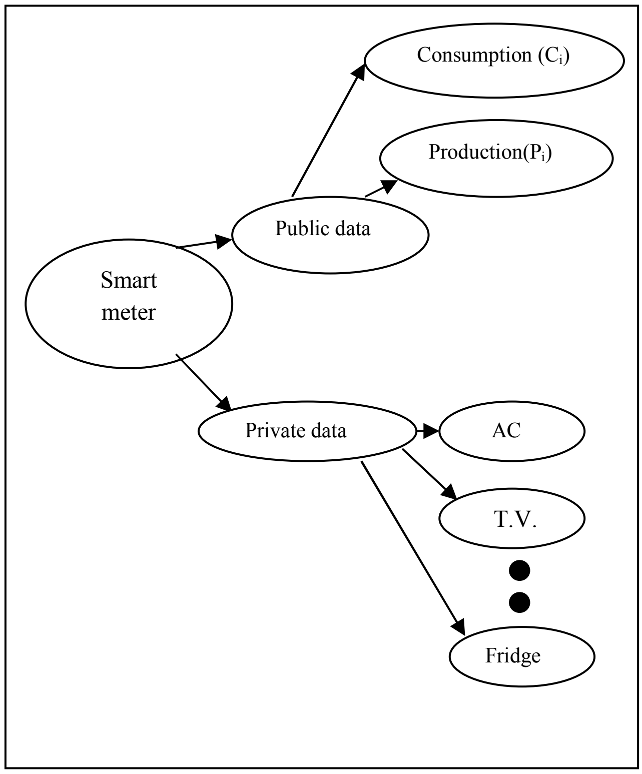

Fig.5. Smart meter readings of data types

Also, it doesn't let the energy go unused or waste, it shoves it back to the power grid for generation of electricity. Further, the sensors along the transmission line and various automation at different power grid levels make it easier to detect the real-time flow of electricity, its distribution in various areas, can detect downtime and failures efficiently and enable the micro-grid support system in that scenario without latency.

Along with this, the smart devices like Plug-in vehicles, smart meters, smart houses etc. which are related to IoT provide digitization in the majority of things. The level of privacy and isolation is increased along with increased connectivity i.e. there is major independence than dependence in these devices and the entire system

Cloud central servers act as the central monitoring unit which can look after the entire power grid working. This can control, monitor and effectively distribute the working real-time. Cloud is feasible for centralized communication and where latency is not a major factor, but Fog is an extended version of the cloud for the edge users which increases the proximity, privacy and reduces latency. The fog servers locally help in the management of local area networks at a faster speed and simultaneously updating the data on the cloud corresponding to the user and fog ensures the privacy of user data. The encryption of private data on fog ensures user data security, confidentiality, and integrity. Fog provides a good locality with a better-distributed communication network over the grid.

VI. CONCLUSION

The paper describes the smart grid with its various features. The main advantage of the smart grid is its power of co-existence with the existing power grid. It is difficult to change the entire architecture of power grid, therefore it is necessary that any system developed should be in integration and coexistence of the current system. The proposed model covers various features of smart grid which may add up to it to enhance its working. Micro-grids, smart meters, street lights and sensors increase the automation, digitization and other aspects of the power grid. Fog servers and cloud manage the data both locally and centrally providing isolation and proximity to customers. In future, all the aspects of the grid can be automated using various systems and controlled together through central management or control system. Also, various new devices which are 'smart' can be added to the smart grid which can enhance its capability and efficiency.

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