Internet of Things Enabled Smart Grid for Optimized Asset Utilization

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***Abstract*—**Smart Grid with Internet of Things (IoT) has been used to increase efficiency of power system by reducing power loss, forecasting energy demand, optimizing distribution process and reducing blackout time. It has enabled bi-directional energy and information flow between service provider and consumer. Owing to this, power generation, transmission, distribution and utilization systems have become more consumer friendly, efficient and smart. In the present experimental study, asset utilization using IoT enable smart grid with time division multiple access technique has been investigated. For information flow home area network has been considered in star and mesh topology. Two user has been able to share common asset using wireless transceiver system. This has optimized the asset utilization with enhanced efficiency of the system with reduced operational cost.

Keywords— *Internet of Things, Smart Grid, Multiple Access, Smart Metering, Home Area Network.*

I. INTRODUCTION

IoT has been defined as things connected with internet which has the power of sensing, communicating and computing capabilities as depicted in Fig. 1.

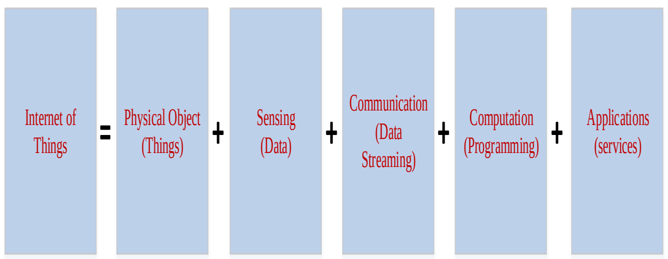

Figure 1. Definition of Internet of Things

It consists of an embedded device in the form of a sensor loaded with operating systems having communication capabilities. It delivers reliable services with minimum latency and initial cost [1]. Things in IoT have become intelligent and smart and even without any human intervention, it can see, hear, communicate to each other, share information and coordinate decisions among themselves [2].

IoT enabled Smart Grid (SG) has become an essential technique to deliver secure electricity supplies to the consumer with low cost and higher efficiency [3]. Its use has not only resolved the issues of energy wastage, fulfill enhanced energy demand but also improved reliability and security issues. The conventional uni-directional energy flow between service provider and consumer has become things of the past. With the emergence of IoT enabled smart grid, bi-directional energy and information flow between service provider and consumer have been made possible. It has made power generation, transmission, distribution and utilization systems more consumer friendly, efficient and smart [4]. It supports bi-directional flow of electricity and information as shown in Fig. 2.

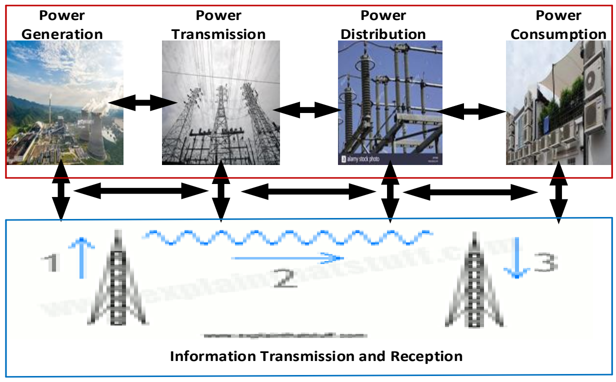

Figure 2. Bi-Directional flow of Electricity and Information

It prevents blackouts, reduced carbon emission, integrated renewable generation sources, fulfilled the requirements of new types of electrical loads, etc. Fig. 3 shows the IoT architecture for smart grid applications.

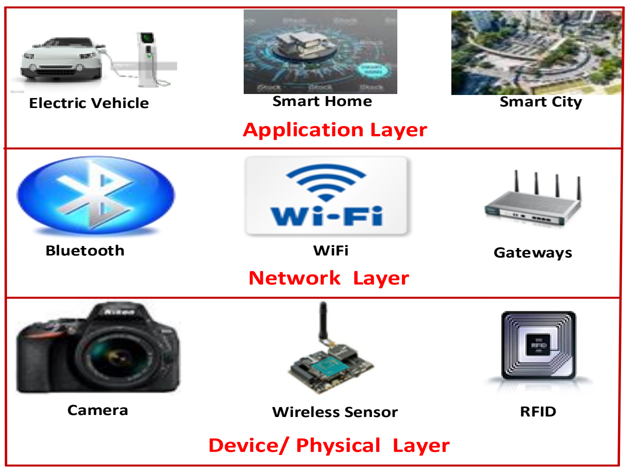

Figure 3. IoT Architecture in Smart Grid Applications

The essential components of SG consists of smart meter, facility for phasor measurement, capability of real time information transfer and distributed power generation capability [5]. Power generated by the consumer from non-conventional energy sources such as roof top solar panels, etc. can also be connected to the main grid. In this case, consumer not only consumes power but is also involved in power generation [6].

IoT has no fixed architecture or topology and numbers of layers can vary as per requirement, where as the number of layers are fixed in conventional internet protocol. For example, ISO OSI model has seven layer architecture whereas TCP/IP follows five layer architecture. IoT may have a very robust and simple architecture with only three layers: device/physical, network and application layer as shown in figure 3 or it may contain even four, five, six or seven layers, depending upon the user requirement [7].

II. Role of IoT in Application of Smart Grid

Role of IoT in smart grid is to monitor power generation unit, transmission line, distribution line, energy consumption, energy storage, power theft, etc. on real time basis. It should be used as a self-diagnostic tool in the case of power breakdowns. Apart from charging of electric vehicle batteries, it can also be used in monitoring of battery status, vehicle identification, location monitoring, etc. [8]. Power is also generated by consumers with the help renewable energy sources like, roof-top solar panels. When the power generated is more than the consumption level, extra power generated can be connected to the main grid and power consumption billing information generated and communicated [9]. In order to enhance the efficiency of smart grid, wireless sensor network with IoT could be deployed to monitor weather information to forecast the actual power requirement in different weather conditions.

IoT can be employed to manage user power consumption pattern in order to minimize the utilization (billing) cost. Sensors employed at consumer location can collect data for energy requirement and send to the generation unit and to smart meters for billing information [10]. It can collect real time information from consumers regarding peak demand requirement to balance the demand supply ratio and to maintain smooth power supply. It can employ smart storage devices and feed power to main grid making bi-directional electricity flow. It should be used to secure the future of electric supply in an unpredictable power consumption pattern exhibited by consumers. Last but not the least, it should be able to increase efficiency, reduce losses, forecast energy demand, optimize distribution process and connect energy generated through renewable sources from house hold to the main grid [11].

III. Communication Technologies for Smart Grid

There are various communication technologies available for smart grid application using IoT and this gives flexibility to the consumer to choose depending upon their requirement and suitability. Mainly there are two types of communication technology available for smart grid applications. First one is the wired technology using guided media and another one is wireless technology under unguided media category. In the case of guided media, there is no signal interference and data can be transmitted through Power line communication (PLC) system using power line cable itself. But its initial cost of installation is comparatively high. In the case of unguided media, wireless communication is very popular owing to low cost, can be easily available in difficult terrain. But it is subjected to information security, signal fading and interference, which is otherwise not the case in wired communication. Information flow between sensors and home appliances, smart meters and IoT devices can be achieved either through PLC or wireless communication technology. Similarly, data flow between control center and smart meters can be achieved either with the help of internet or with cellular phones [12].

ZigBee, 6LowPAN, Z-Wave and LoRaWAN are some of the communication technologies mainly used with unguided (wireless) media for the smart grid applications. Frequency bands used for ZigBee technology are 868 MHz, 915 MHz. It also operates in industrial, scientific and medicine (ISM) band in 2.4 GHz frequency range with 16 channels of 5 MHz bandwidth. It can be operated within the coverage area of 10-100 meters with 250 Kbps of data rate. ZigBee is considered as a good choice in the home area network for smart grid applications owing to very low operational cost, low bandwidth requirement, mobility, robustness, and simplicity. But ZigBee also suffers from demerit like signal interference, high latency, low processing capabilities and low memory power.

IPv6 over Low-power Wireless Personal Area Networks (6LowPAN) is an IP based communication technology used to carry IPv6 packets within link layer frames defined under IEEE 802.15.4 standard. 6LowPAN is an ideal communication technology for smart grid application like smart metering and home automation under home area network. It consumes less power and is very robust and can be applied on various communication platforms. But 6LowPAN suffers from low data transmission rate and small operating range hence it is not suitable for neighbor area network (NAN) and wide area network (WAN) and can only be employed in home area network (HAN).

Z-Wave is a short range, low power wireless communication technology for IoT enabled smart grid applications. It can be operated within 30 meters of range with 100 Kbps data rate at 1 GHz frequency band. Its signal quality does not get affected by interference with devices like ZigBee and Bluetooth working in the 2.4 GHz of ISM band. It has high reliability and low latency and can support up to 232 devices without compromising on the signal quality. But Z-Wave also suffers from low data rate transmission, short range application and cannot be employed for NAN and WAN applications [13].

For application in NAN, WAN and wide area network coverage, LoRaWAN is used. It is a Low Power Wide Area Network (LPWAN) communication technology used for IoT enabled smart applications with wireless battery operated device. Apart from mobility it provides interoperability, localization services and secured bi-directional communication. It has 2-5 km coverage range in urban area and can be extended up to 15 Km in suburban area and supports up to 50 Kbps of data rate. At the cost of peak data rate, LoRaWAN is suitable for long range communication with very low power consumption and does not suffer from signal interference [14].

Apart from above mentioned IoT-based wireless communication technologies, there are some non IoT-based wireless communication technologies, such as cellular communication, Wimax (worldwide interoperability for microwave access), Bluetooth, wireless mesh, digital microwave technology and mobile broadband wireless access etc. Cellular communication is mainly suitable in smart grid application because of its low cost of implementation as existing infrastructure of cellular communication network can be used. The available cellular communication technologies can be utilized for smart grid services like smart metering, fault location, self-healing and other information requirements. Because of its ubiquitous presence, larger bandwidth, high data transmission rate, enhanced data security, cost effectiveness in maintenance and deployment, it is mainly preferred for smart grid applications. But cellular communication may be a risky choice for the application which requires uninterrupted and continuous communications for mission critical applications of smart grid. It suffers from congestion and performance deterioration as the network is shared among large number of GSM user and it cannot be deployed for guaranteed service as in the case of wired communication [15].

Wimax is mainly used for achieving goal of worldwide interoperability for microwave access based on IEEE 802.16 standard. It has the maximum coverage area of 48 Km with 70 Mbps of data transmission rate. It operates in the 2.3 GHz, 2.5 GHz and 3.5 GHz frequency bands for mobile communication whereas 3.5 GHz and 5.8 GHz frequency bands are used for fixed communication operation. It uses both licensed and unlicensed spectrum for providing the services. The 5.8 GHz spectrum band is unlicensed while 2.3 GHz, 2.5 GHz and 3.5 GHz are licensed bands. For smart grid applications it is mainly used in HAN network for fault-detection, self-healing, metering and real-time pricing. But its hardware cost is high and performance quality degrades with increase in distance.

Bluetooth is used for short range communication, consumes less power and follows IEEE 802.15.1 standard. It operates in ISM band at 2.4 - 2.4835 GHz frequency and supports data rate up to 721 Kbps. It supports point-to-point and point to multipoint communication with maximum coverage area of 100 meters. Bluetooth is manly suitable for HAN topology due to low power consumption and it can be easily deployed for online monitoring of substations [16]. But it suffers from signal interference, short range coverage and low data rate transfer capabilities.

In wireless mesh network smart devices are equipped with radio modules which routes metering data through neighboring meters. Individual meter works as a relay unit for transferring data to the electric network access point and finally to the user. It mainly consists of a combination of wireless nodes in which new nodes can join the network and act as router. It has the self-healing characteristic and provides alternative route in case any node leaves the network. It is preferred for smart grid applications due to its cost effectiveness, self-configurable, self-organizing, self-healing and high scalability properties. But wireless mesh network also suffers from signal fading and interference as in the case of other wireless communication systems. It may not be preferable for deployment in rural area owing to low meter density and may suffer from cross-talk problem due to multi-level switching [17].

Digital Microwave Technology provides coverage area of 60 Km with maximum data rate of 155 Mbps. It operates in the 2-40 GHz of licensed frequency band and provides high bandwidth and long distance coverage. It can be used in smart grid application for point-to-point communication. But its signal quality is affected due to multipath fading and interference. Mobile Broadband Wireless Access operates in 3.5 GHz licensed frequency band and follows IEEE 802.20 standard. It has up to 20 Mbps data rate transmission capability and can be employed in smart grid application using NAN and WAN topology for broadband communication. It has advantage of high bandwidth, high mobility and low latency [18]. But it suffers from high implementation cost due to unavailability of dedicated communication infrastructure.

Similarly, under guided media (wired) communication technology, digital subscriber line (DSL) optical communication, and powerline communication (PLC) etc. are used. Digital subscriber line is a wired transmission technology that uses telephone network wires for transmitting high speed data. It has low installation cost, high bandwidth, high data rate transmission capability and cost effectiveness which makes it a popular choice for smart metering and data transmission application in IoT enable smart grid services. DSL has major disadvantage of higher maintenance cost mainly in high density populated urban area. Its operation is not reliable mainly in monsoon season hence cannot be used for applications where high reliability is required [19].

Using optical fiber optical communication technologies are widely used as communication backbone in smart grid for connecting substations with control centers and providing services to consumer. It is becoming more popular because of its interoperability with existing IP-based networks using Ethernet Passive Optical Network (EPON). Optical communication technology has advantages of long distance and high data rate (Gbps) transmission capability, not affected by radio and electromagnetic interference, low power loss and less number of repeaters required. But it suffers from huge initial deployment cost, difficult to upgrade and cannot be used for metering application. Powerline communication (PLC) can be directly connected with meters using existing powerlines and can transmit data up to 3 Mbps rate. Its main advantage is low installation cost due to use of existing powerline infrastructure and is therefore cost effective. It is used in HAN topology and mostly suitable for urban area. PLC has disadvantage of poor signal quality due to interference caused by many IoT devices connected with the powerline, noisy and difficult for channel modelling [20].

Although wired technology are somewhat costlier than wireless technology form the installation point of view but it offers secured communication with high data rate transmission capability. Whereas wireless communication technology suffers from information security and low bandwidth capability. Depending upon the operational requirement user can choose among various communication technologies available [21].

IV. Smart Grid Essential Features

Smart Grid should have the feature of providing quality power to the consumer. The power supplied should not have fluctuations in terms of voltage and frequency, it should be stable both in the case of on load and off load conditions. It should be able to optimize utilization of assets by sharing of electrical infrastructure (loads) on the principle of time division multiple accessing. In turn this will enhance the asset utilization efficiency apart from reducing operational costs. Operating efficiency should also get optimized with employment of sensors, actuators and information capability by sharing real time information regarding power theft, power consumption pattern, etc. [22].

It should include consumer information as a vital source in demand forecasting, determination of tariff rates, reduction in reactive (inductive) loads and improvement in power factor. It should also have self-healing feature in the case of disturbances caused and should be able to operate efficiently without blackout in the case of physical and cyber-attacks. With the introduction of e-bikes and e-vehicles a new segment of market is emerging in the power sector which should be catered efficiently using capabilities of smart grid.

V. Optimization of Asset Utilization

In the present study electrical assets (loads) have been shared on time division multiple access basis by two consumer using the concept of IoT. Fig. 4 depicts the Arduino Uno board used in the present study

Figure 4. Arduino Uno Board

Electrical loads like, air compressor, water pump (motor), etc. have been operated remotely by two consumer using wireless remote transmitter, Arduino development board, receiver, switching circuit, control circuits, electrical meters, relay units, air compressor, display devices etc. have been used in the present investigations [23]. The computer code has been written in C++ language using IDE for Arduino board. Individual user has been able to switch on the desired load remotely and the electricity consumption has been recorded in his personal electric meter as shown in Fig. 5.

Figure 5. Electrical Meters used

Motor running status along with other relevant information have been displayed on the display device (monitor/mobile) to all users to make an intelligent decision regarding when to use the common resources [24]. Computer code for remote operation and message display is shown in Fig. 6.

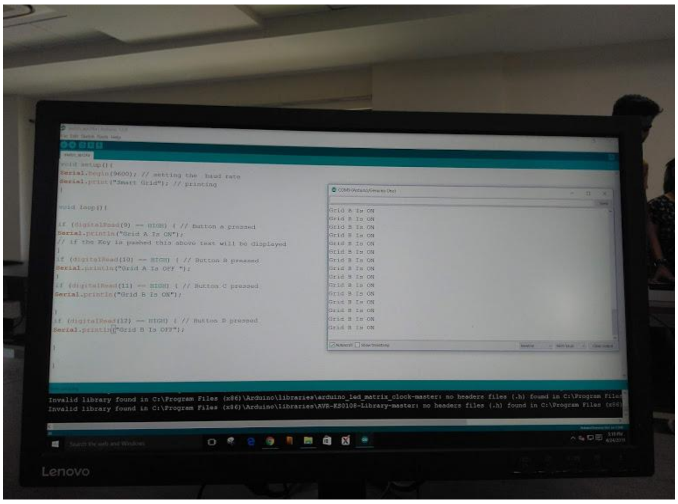

Figure 6. Computer code for remote operation and message display

Home Area Network has been considered as communication technology for various functions and it may have mesh or star topology configuration. For information transfer it may use Bluetooth, ZigBee, WiFi or powerline communication (PLC) depending upon the operating environmental conditions. This has enabled remote meter reading and automatic metering infrastructure and has improved the reliability in collection of real time electricity consumption information. This application has reduced the infrastructure cost owing to multiple user access on time shared basis and enhanced the efficiency of the system [25].

Fig. 7 shows the transmitter and receiver unit used in the study.

Figure 7. Transmitter and receiver unit

A wireless transmitter capable of operating from a distance of 50 meters have been used to transmit information sent by the consumer for switching on the (electrical asset) load. This transmitter has provision for four different consumer but in this experiment, it has been used for only two consumers. The signal received is processed by the receiver unit. Fig. 8 shows the switching circuit which has been used to switch on the desired load as decided by the consumer after processing the data received by the receiver unit.

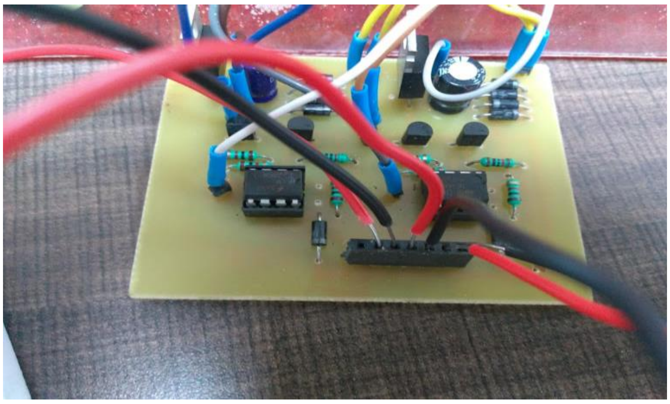

Figure 8. Switching Circuit

Control relays for Load transferring used in the study has been reflected in Fig. 9. It consist of two units of step down transformer and 12 volts relay, each one for different user. It connects the electrical load as decided by switching unit.

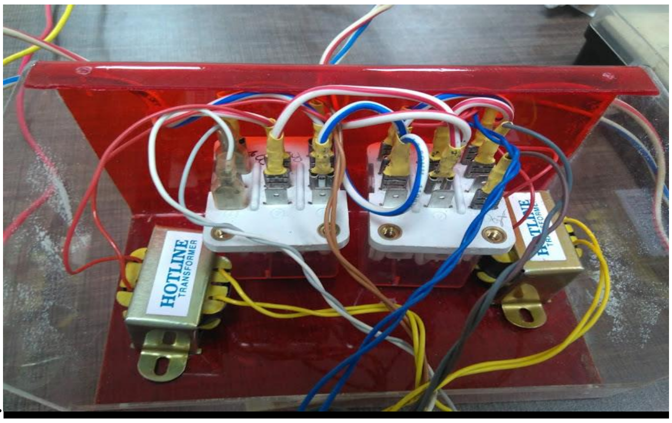

Figure 9. Control relays used

The electrical load (asset) used in the study is an air compressor as shown in Fig. 10. It operates with single phase 230 volt 50 Hz power supply.

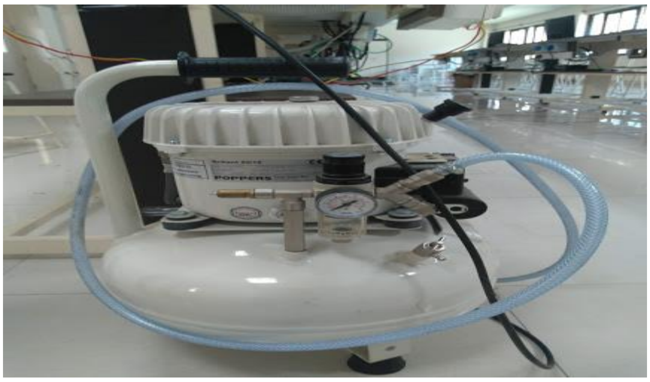

Figure 10. Air Compressor as electrical load

Fig. 11 depicts the complete experimental setup for optimized asset utilization using IoT enabled smart grid. The load can be switched on by two user independently from a distance of 50 meters using wireless transmitter.

Figure 11. Air Compressor as electrical load

VI. CONCLUSIONS

In conventional power system the energy flow is uni-directional and suffers from poor operational efficiency, higher operating cost, blackouts and power theft, etc. Whereas, IoT enabled smart grid makes energy and information flow bi-directional between service provider and consumer. This makes power generation, transmission, distribution and utilization system more consumer friendly, efficient, smart apart from increasing its efficiency and reducing cost. In this paper, asset utilization using time division multiple accessing technique has been studied. This has resulted in increased operational efficiency with reduced cost.

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