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IoT Architecture for Smart Grids

Hossein Shahinzadeh
IEEE Member, Department of Electrical Engineering
Amirkabir University of Technology (Tehran Polytechnic)
Tehran, Iran
h.s.shahinzadeh@ieee.org

Jalal Moradi
Young Researchers and Elite Club
Khomeinishahr Branch, Islamic Azad University
Esfahan, Iran
sj.moradi@iaukhsh.ac.ir

Gevork B. Gharehpetian
Prof., Department of Electrical Engineering
Amirkabir University of Technology
Tehran, Iran
grptian@aut.ac.ir

Hamed Nafisi
Department of Electrical Engineering
Amirkabir University of Technology
Tehran, Iran
nafisi@aut.ac.ir

Mehrdad Abedi
Prof., Department of Electrical Engineering
Amirkabir University of Technology
Tehran, Iran
abedi@aut.ac.ir

***Abstract*— The tremendous advances in information and communications technology (ICT), as well as the embedded systems, have been led to the emergence of the novel concept of the internet of things (IoT). Enjoying IoT-based technologies, many objects and components can be connected to each other through the internet or other modern communicational platforms. Embedded systems which are computing machines for special purposes like those utilized in high-tech devices, smart buildings, aircraft, and vehicles including advanced controllers, sensors, and meters with the ability of information exchange using IT infrastructures. The phrase "internet", in this context, does not exclusively refer to the World Wide Web rather than any type of server-based or peer-to-peer networks. In this study, the application of IoT in smart grids is addressed. Hence, at first, an introduction to the necessity of deployment of IoT in smart grids is presented. Afterwards, the applications of IoT in three levels of generation, transmission, and distribution is proposed. The generation level is composed of applications of IoT in renewable energy resources, wind and solar in particular, thermal generation, and energy storage facilities. The deployment of IoT in transmission level deals with congestion management in power system and guarantees the security of the system. In the distribution level, the implications of IoT in active distribution networks, smart cities, microgrids, smart buildings, and industrial sector are evaluated.**

Keywords*— *Internet of things (IoT), Internet of energy (IoE), Renewable energy, Active distribution networks, Smart grid 2.0.

I. Introduction

Internet of things (IoT) refers to an informatics network which connects various objects and elements of a system to each other using advanced ICT and advanced embedded systems including digitalized sensors, meters, and controllers. In this regard, IoT has the fame of the third revolution in information technology. Internet of energy (IoE) represents an upgrade of IoT which deals with the combination of ICT and energy ecosystem. In this study, the deployment of IoT in the smart grid's components will be discussed. Smart grid denotes an electricity supply network that uses digital communications technology to detect and react to local changes in usage. IoT in smart grids refers to the ability of all components in a smart grid to share information through any kind of wired or wireless network. IoT is regarded as an indispensable part of the implementation of smart grids and materializing smart cities and smart buildings schemes [1].

Regard to the presence of a large diversity of devices, equipment, energy forms and their corresponding inherent behavior, variability of some parameters in energy field, and unpredictable or chaotic nature of some phenomena, it is necessary to transfer and analyze a big amount of data in near real-time and to make decision with a brief delay. The data should be quickly and securely shared with corresponding destinations and the required actions must be taken automatically. Thus, the solution is to equip components with IoT-oriented technologies to take advantages of information technology in the form of networks. IoT-based devices are those that equipped with electric boards encompassing microcontrollers and microprocessors with the ability of share of information which can be sensors, meters or controllers. Besides, the correctness and validation of information must be ensured which may be threatened by deliberate cyber-attacks or unintentional interruptions (disturbances). Nowadays, a new concept is propounded that is called the second generation of smart grids (smart grid 2.0) and refers to the next design of smart grids which will be implemented from 2020 [2]. This concept has meaningful distinctions with the current smart grid concept. In smart grid 2.0, the interactions between supply-sides and demand-side will be mounted utilizing advanced smart metering infrastructures, the share of energy and its correlated information between competent players using informatics infrastructure, and the plug & play capability, which denotes the ability to deliver energy even by small-scale generation resources (e.g. V2Gs). Plug & play capability indicates that a demand-side electricity source is able to inject power to the grid as easy as plugging in a plug into an outlet. Such consumers that are able to play the role of power providers are called "prosumers" [3]. Currently, the ability of connection or disconnection of distributed generation at each desired moment is not possible.

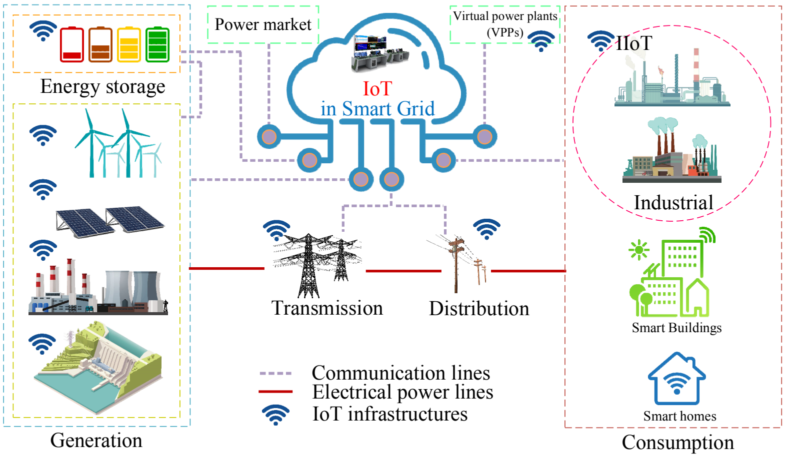

Figure 1. The paradigm of IoT in smart electrical grids

However, in smart grid 2.0, a wider range of equipment will be in control which procures more flexibility for power grids. Thus, in the future power grids, an abundant number of utilities including their components will be monitored by the grid operator. The control of such a massive number of elements cannot be viable without improving the smartness of grids and employment of big data analytical techniques. It is claimed that more than 50% of total demand will be controlled by real-time controllers in smart grid 2.0. In such an environment, the performance of electricity markets will be improved. All market players can participate in market trades and monitor its transactions and power exchanges using an internet-based interface in peer to peer (P2P) mode, in which the vendors and purchasers are specified. In the first generation of smart grids, the serious attention has been paid on the development of fundamental prerequisites such as the installation of advanced metering infrastructures (AMIs) in local distribution networks. However, by enjoying IoT interfaces, the concept of smart grid will be more globalized in a wider level and will be propelled toward a worldwide pervasiveness known as macro-level. The smart grid 2.0 will be able to keep working after any unwanted contingency automatically and effectively so that the infected zone immediately begin to be supplied using self-healing schemes, which highly relies on real-time data gathering and analysis. In addition, appropriate programming interfaces (APIs) will be used as a platform to show information for P2P and third-party access. The more deployment of microgrids, electrification, digitalization, decentralization of generation resources, and energy sharing are some features of future grids.

All technical requirements for modernization of power system are categorized into four layers including data analysis layer (encompassing data visualization, AMI-provided data analysis, small-scale distributed energy resources analysis, equipment's data analysis), application layer (equipment's supervision, data acquisition and management, and distributed energy resource management system (DERMS)), communication and control layer (including AMI connection network, internet-protocol-aided networks, supervisory control and data acquisition (SCADA), bidirectional wired or wireless communication protocols such as WiFi, Zigbee, HomePlug, GPRS, WiMAX, LTE, power line carrier (PLC), Lease Line, and 5G wireless communication which features high bandwidth accessibility), and physical equipment in grid edge layer (including smart AMIs, supervisory and monitoring equipment, storage equipment, voltage control equipment, protection equipment, modern sensors, and switches of the power grid) [4].

II. IoT in the generation level

The management of generation resources used to be controlled using local controlling devices. The system operator has low controllability for remote control and many actions must be carried out by sending commands or instructions to be performed by a local operator. In addition, power system generation asset management is becoming more sophisticated than ever before due to some reasons. First, the penetration of renewable energy resources, as a huge source of uncertainty, is mounting in power systems. In near future, the pervasiveness of electric vehicles will be in widespread use that impacts on power system generation scheduling. Third, the participation of loads as demand response resources is increasing which is highly corresponded with the uncertain hourly electricity prices. The electricity price is also correlated with many items such as power market structure, and instantaneous fuel price. In addition, demand-side medium-scale or small-scale distributed generation (DG) will have extensive prevalence in the near future which is referred to as virtual power plants sources-or micro) (VPPs) (in microgrids. The operator must deal with such a high level of uncertainty and volatility in addition to prevailing constraints of the grid which can be led to the imposition of load shedding or curtailment in some cases. In order to prevent such measures and to retain the security, stability, reliability, and environmental sustainability of the power system, IoT technology can facilitate tackling the problems and challenges. In IoT-aided smart grids, all fluctuations and generations in both demand and supply sides can be automatically and accurately be monitored and the operator will be able to have more elaborated supervisory on the grid. The IoT technologies in generation level deal with the integration of a couple of energy resources such as coal, oil, gas, nuclear, hydro as well as renewable energy sources such as wind, solar, geothermal, and marine-based energies in order to improve the performance of the generation sector and maintain the dynamic and static security of power system. In addition, energy storage utilities can be utilized to redress imbalances caused by various sources of uncertainty which can be influenced by IoT infrastructures.

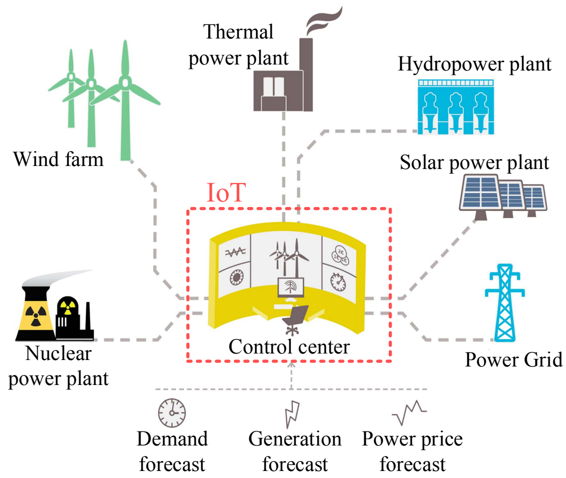

Figure 2. Real-time generation monitoring from an IoT-based control center

So far, the concept of IoT has been focused mainly on demand-side with less attention given to supply-side. Deployment of IoT in this level can be led to a further stage of efficiency and performance due to a higher level of controllability and observability which brings tremendous benefits for power systems.

A. Renewable energy resources

1) **IoT and wind energy**

Wind technologies are evolving rapidly in term of efficiency and scale. The energy experts have ambitious futuristic deployment targets for the wind energy sector. The main obstacle encountering the development of wind energy corresponds with the natural intermittency of these resources. Hence, if the wind units have large penetration in meeting the demand, severe imbalances may threaten the security of the system. Thus, the real-time operation can prepare the rest of the power system to compensate the volatilities without suffering sharp ramp rates. In addition, better collaborative operation with energy storage facilities can be maintained only when real-time data exchange is available between wind units and energy storage unit [5].

In addition, IoT technologies along with ICT infrastructures make the wind farm owners able to conduct accurate predictive maintenance schedules, which prevent incurring huge detriments. Such a schedule can be conducted using machine learning and data mining techniques. For example, the on-time maintenance can reduce the levelized cost of energy (LCoE) index for wind assets which denotes the net present value of the unit-cost of power over the turbines' lifetime [6]. The necessity of IoT in the exploitation of wind energy is that the data corresponded with wind turbines and wind farm should be immediately collected and immediately analyzed. At the current time, the barriers of data transfer delay for offshore wind farms and limited bandwidth to send information to remote locations are two concerning issues that must be overcome. Therefore, if the critical data can be collected and analyzed in real-time, the decision-making process (such as shutting down a turbine in order to avoid cascading damages) can be done faster or can be automated. Deployment of IoT systems in the wind sector highlights the need for more comprehensive strategies for cost-effective, secure, and safe frameworks for design and operation of wind farms, as well as installation and maintenance of turbines [7].

A wind turbine consists of some principal components such as tower and foundation structure, yaw system, blades, rotor hub, pitch system, drive shaft, high-speed shaft, brake system, gearbox, generator (usually doubly-fed induction generator (DFIG)), power converter, wind sensor, nacelle, transformer and the central controller. The controller layer contains plenty of sensors and actuators. The sensors can report the state of health and performance of each intrinsic component. The control system governs and manipulates the components utilizing a set of actuators. The sensors are classified into five layers of environmental (wind speed, humidity, lighting, icing), mechanical (positions, speeds, angles, stresses, strain), electrical (voltages, currents, power factors, frequencies, faults), temperature (bearings, oils, windings, electronic components), and fluid sensors (pressure, levels, flow). The controller receives the sensors' data and sends electric, hydraulic, and mechanical commands and instructions using power amplifiers. The instructions will be performed using a gearbox control system, pitch angle control system, linkage control system, motors, magnets, switches, positioning pistons, fans, and heaters. Hence, the cyber-physical devices should be integrated to connect the physical layer of the wind turbines to the cyber layer using a network infrastructure. The cyber layer consists of network, condition-monitoring system, and SCADA. Network denotes a reliable connection for communication of data and control signals between controller and subsystems as well as the connection of intelligent machines and deeply embedded devices in a wind farm. The main role of the network is to facilitate the real-time transfer of data and control signals between the supervisory center, controller, actuators, sensors, and data storage stations. The design of communication network highly depends on local condition, especially for offshore wind farms [8]. Each turbine must be equipped with a remote terminal unit (RTU) to be able to connect to a local area network (LAN). The LAN network is connected to the condition-monitoring system (CMS) in both turbine level and wind farm level along with a SCADA system to enable control over wind turbine and facilitate earlier fault identification to prevent chain reaction and cascading failures of wind turbines in a wind farm caused by voltage dip. Thus CMS retain the stability using fault ride through (FRT), under-voltage ride through (UVRT) or low voltage ride through (LVRT) schemes. These systems share the data with a central data center incorporating a cloud-based wide area network (WAN). All turbines of a wind farm are equipped with the IoT-based embedded systems and distributed intelligence devices enjoying wireless sensor networks (WSN), and they have machine-to-machine (M2M) communication with a cloud-based network which transfers the data according to internet-enabled and open communication standards to the servers and can be managed and monitored by unified computer-aided interfaces or mobile human machine interfaces (HMIs). It is alleged that the IoT-based controlling system has a higher cost than currently conventional SCADA systems but it is more capable of diagnosis because of higher information frequency and higher sampling rate. In order to perform a unified monitoring and information exchange, the IEC61400-25 standard has been established, in which the extensibility, diagnostics, autonomy, and standardization of the data exchange gateway is improved [9].

2) **IoT and solar energy**

After the 1973 oil embargo and the 1979 energy crisis, the exploitation of non-fossil-based energy resources assumed more attention. The global warming and environmental issues implied that renewable energy resources must have higher penetration in the provision of the world's energy demand. Solar energy has the largest potential for power generation from renewable energy. Hence, this source is contemplated as a major contributor to future clean power systems. Solar energy refers to radiant heat and light of the sun, and it can be harnessed by incorporation of ever-evolving photovoltaic (PV) technologies. PVs can be installed dispersedly as distributed generation (decentralized), solar parks (centralized), or concentrated solar power (CSP) systems.

A photovoltaic system basically consists of solar panels (photovoltaic arrays), wiring, switches, mounting system, and inventers. These accessories can be accompanied by a battery storage unit (battery bank). Modern PV systems enjoy newer technologies for the more efficient extraction of solar power such as maximum power point tracker (MPPT) controlling scheme, GPS solar tracker, solar irradiance sensors, anemometer, and some other task-specific accessories. Contrary to the conventional PV systems, concentrator photovoltaics (CPV) are equipped with optical lenses and curved mirrors that help to focus irradiance onto a tiny but remarkably efficient multi-junction solar cell [10]. Moreover, a cooling system usually is embedded in CPVs to improve efficiency. CPV and CSP are suited best for regions with high mean irradiance (such as Sunbelt region in the U.S. or Golden Banana region in Europe). The conventional PV systems can also be used for end-user distributed generation such as rooftop-mounted or building-integrated solar production because it has sensibly cheaper capital cost per kW. Currently, a large contribution of PV systems is grid-connected rather than stand-alone. The output power of PV systems mainly relies on ambient temperature and sunlight radiation intensity. It is noteworthy that the performance of the PV system can highly be exacerbated by shading and dirt which can be led to a drastic drop in output power. In addition, in higher temperatures, the efficiency of the PV system deteriorates. The MPPT system tilts the panel either directly in front of the sun or the brightest area of the sky when it is partly clouded. The presence of a storage facility is indispensable because the solar power must be stored whenever it is available and the storage should deliver the stored energy when it is needed.

IoT refers to coordination of analogous things that have solitary identifiers, mechanical machines, objects, digital machines, and computing devices. This coordination assists in conveying the data and information across the network by removing the gap between the operational technologies and information technology (IT) without the need for computer-to-human interactions, or human-to-human interactions. IoT can help to share all data gathered from the PV sensors in real-time and have remote controllability on the operation of solar units for breakdown and fault detection as well as predictive and preventive maintenances. In addition, the grid-scale coordination of uncertain solar production and energy storage facilities requires real-time communication that can be maintained by IoT infrastructure. Uncertainties are correlated mostly with the solar resource evaluation and the PV system performance. Approximately, the sources of uncertainties are typically 4% related to year-to-year climate variability, 3% for estimation of irradiation in the array's plane, 3% for power rating of modules, 5% for solar resource estimation, 2% for losses due to dirt and soiling, 1.5% for losses due to snow, and 5% for other possible sources of error.

Monitoring of arrays' performance is an extremely important matter which affects the profitability of the PV unit as well as the reliability of PV unit. Identification and appropriate reaction to the losses due to various reasons are critical in terms of revenue and O&M efficiency. The measure of monitoring of arrays' performance can be conducted through contractual agreements between the PV owner, the PV system builder, and the utility (grid's operator) which ensured the purchase of the energy produced [11].

Solar radiation intensity is fluctuating and time-varying and highly depends on the weather. Thus, the generation in constant level is not possible. This matter indirectly affects the functioning of other components of the system like battery state of charge and power converter voltage levels. In addition, environmental conditions (such as cloud or rain), dust accumulation, existence of snow on the PV panel, and the impact of surface coating (e.g. hydrophilic or hydrophobic) on soiling result in poor performance of the PV system and will result in loss of part of generation or may cause failures and breakdowns. Paying attention to this fact that PV systems are either as close as a rooftop-mounted PV system or as far away as a solar park in the desert, the monitoring of all PV panels to prevent losses and failures is quite difficult for humans, because frequent visit of the PV plant site and maintaining the record of operational data is needed, which is a quite tedious job when the PV plant is located in faraway places. It takes a lot of time to address these failures by human and sometimes it is not easily recognizable. Hence, a continuous real-time monitoring system is needed to be equipped along with the PV panels, so that it should monitor the PV system parameters and store the required data in a cloud-based platform. The stored data can be used to have a better perception of the PV system performance and the reasons for poor performance. Thus, the use of IoT technologies allows making troubleshooting and conducting on-time maintenance [12].

B. *IoT and thermal generation*

Thermal power plants are a fundamental part of all power systems at present. These types of units ensure the reliability and resiliency of the grid's operation. However, in future power systems, it is tried to replace conventional thermal power plants with renewable resources due to environmental concerns. They also operate in low efficiency and low level of flexibility. Gas-fired units are also considered as expensive generating units at present. These matters imply that IoT will probably have the least deployment in this section compared with other parts of electrical grids such as renewable generation, distribution, or demand-side. However, the role of IoT can be important in two facets. The first is that the output state of generators, the state of transformers and tap-changers, along with the injected power to each branch must be exactly be shown to the central operation and control center of the system. Thus, the IoT infrastructure can ease the access to such real-time data. Besides, the conventional steam power plants have a variety of elements and components. The state of health of each one must be automatically be recorded and monitored by the power plant engineers using advanced IoT-based sensors to conduct preventive maintenance schedules and overhauls which alleviates the risk of unplanned outages.

C. *IoT and energy storage facilities*

Electricity markets are moving progressively toward a smart environment enabling the collaboration of several providers and customers for an intelligent and autonomous generation. The reason is that the penetration of renewable resources has had an incremental trend in recent decades which increases the level of uncertainty in operation of the grid. Energy storage technologies help to increase the dispatchability of uncertain renewable resources by redressing the imbalances. However, incorporation of IoT and process of the enormous body of data impose high complexity but boost the performance in levels of autonomy. A sensible balance must be always between complexity and performance (usefulness). The application of energy storage units can be divided into categories of bulk energy time-shifting, frequency regulation in small-scale, frequency stability in large-scale and power reliability (reserve capacity) [13]-[16]. So far, different energy storage technologies are developed for various applications. Pumped-hydro energy storage (PHES) [17], and compressed air energy storage (CAES) [18] are the two most successful technologies for bulk energy time-shifting purpose. Besides, some emerging types of energy storage are introduced such as the advanced rail energy storage (ARES) [19], the underwater compressed air energy storage (UWCAES) [20], the liquid air energy storage (LAES) [21], ocean renewable energy storage (ORES) [22, 23], and the blue battery in green power islands [24], which are tested as prototype or in pilot scale and can work in large-scale applications. Different kinds of batteries, flywheel, and fuel cell can also be used in small-scale applications such as frequency regulation and power quality. Energy storage units play a pivotal role in enhancing the flexibility of power systems and guaranteeing the reliable operation. The main obstacle to more deployment of renewable energy resources is their uncertain and intermittent nature. The risk of these uncertainties can be mitigated by utilization of energy storage facilities. Hence, real-time coordination between these units is required to prevent undesired curtailments due to excess generation possibility or detriments due to deficiencies. IoT infrastructure can actualize this condition to facilitate the collaborative operation of wind farms or solar parks with grid-scale energy storage facilities, which can boost the profitability of both types of units. The impact of IoT for improvement of application of small-scale energy storage units, such as batteries, for deployment in microgrids for frequency stabilization is discussed in section IV.B.

III. IoT in transmission level

Transmission level is the connector between the generation level and distribution level. This level is a critical part of power systems which ensures a reliable supply of demand. The integration of IoT in transmission level is so important in two aspects. The first is the implication of IoT in the improvement of congestion management and the second is the impact of IoT on maintaining system security. The IoT-equipped intelligent electronic devices (IEDs) can be installed in the transmission sector to inform the operator of the electrical state of the lines such as losses disturbances. Phasor measurement units (PMU) can determine the magnitude and angle of voltage and current at a specific point of the line taking advantage of GPS system for time synchronization. This device can also distinguish the frequency. A commercial version of PMU is able to report measurements with a high temporal resolution of about 30-60 measurements per second. This matter makes the power system engineers enable to analyze dynamic events in the power system. Such a fast and accurate measurement is not possible with traditional SCADA that report one measurement every 2 or 4 seconds. The wide-area protection schemes can be implemented using PMU in collaboration with protective relays [25]. The invention of micro-synchronous PMUs with non-GPS reference time calibration can report 120 samples per second that help to prevent catastrophic black-outs. PMUs can provide data to show active and reactive power passing through the line in a high degree of precision, which improves system visibility. This matter results in smart and preventative control actions and strategies. The monitoring of real-time power flowing through the lines enables the operator to manage congestion automatically in congested power systems or locally congested areas, particularly in emergencies and contingencies. Hence, the maneuverability of the operator can be increased [26].

Furthermore, overhead lines are vulnerable to natural disasters. Harsh wind and fierce snowy condition lead to galloping and icing of lines that cause exertion of asymmetric pulling force to lines which may be led to leaning of towers. These factors cause damages to overhead lines which mount the risk of the operation. In addition, the transmission system is scattered in a vast area of land where can be remote and difficult to maintenance and monitor. The incorporation of IoT can alleviate the damages caused by such natural phenomena. The appropriate data must be acquired from advanced sensing devices which are installed on the line's conductor of towers. The data must be sent to the sync node device and thereafter must be sent to the central controlling center through an optical fiber system or wireless communication ways. The IoT devices, which can be embedded in transmission grid, are sync node device, tower deviation sensor, meteorological sensors (temperature and humidity sensors), wind speed sensor, conductor acceleration sensor, sag sensor, current leakage sensor. These devices can help to have enhanced real-time monitoring on the conductor, insulations, and towers.

IV. IoT in distribution level

The prerequisite of a smart distribution grid is that all critical points of the distribution network must be equipped with IoT infrastructures. The installation of AMIs is the first stage toward the implementation of a smart distribution grid from consumers' point of view. The communications network is counted as one of the most crucial parts in AMI systems. It provides a bidirectional, consistent, and secure connection between the servers and data collectors, counters, customers and beneficiary companies. This communication infrastructure can be implemented differently with respect to local condition, and investment budget. Incorporation of IoT in distribution layer yields tangible benefits such as online supervision on consumption pattern of consumers, intelligent control of generation and consumption of energy, detection of problems in low-voltage transmission lines, the capability to implement emergency demand response programs, the ability to implementation of self-healing schemes, the power loss management, and the remote monitoring and control during unplanned disasters etc. In addition, the data gathered from all feeders and buses must be digitalized and shared through local ICT-based networks to make the distribution operator able to have rigorous monitoring and supervision on the distribution grid. Furthermore, in order to improve the reliability of the grid, the self-healing process is one of the vital and indispensable schemes of distribution grid in the future. Self-healing schemes must occur in real-time to restore the appropriate and desired functionality as quickly as possible [27].

A. IoT in active distribution networks

Active distribution network refers to a distribution grid which enjoys the presence of medium-scale or small-scale distributed energy resources (DERs) such as diesel generator, gas units, wind and solar units, micro-turbines as well as energy storage facilities such as batteries, flywheel, and fuel cell. These generating sources are also referred to as virtual power plants (VPPs). In addition, some of these generating units can be used in the form of combined heat and power (CHP) utilities. In such a situation, a lot of microsources (small-scale generation resources) are involved which can affect the generation schedule in large-scale. This matter will have more implication on the system in the next decades. As an instance, the California power system is struggling with a huge penetration of solar energy in demand-side which has caused duck curve phenomenon. The more efficient exploitation of renewable resources along with the economical operation of fuel-fired resources in such distribution networks must be managed by local distribution network operator which have a connector role between demand-side and supply-side. In this regard, the instantaneous generation of renewable resources must be provided for the operator using IoT-based AMIs and proper controlling action must be carried out automatically based on predefined settings [28].

B. IoT in microgrids

A microgrid represents a small-scale set of loads which are localized on a specific feeder of distribution network and is capable of meeting some or all of its demand through small-scale generation sources (microsources) such as small-scale wind turbines, photovoltaic panels, micro-turbines, diesel generator, or gas turbines, some of which may be integrated using combined heat and power scheme [29]. In addition, in order to store the surplus generation of small-scale renewable resources when there is a lower level of demand, an energy storage facility can be utilized. Battery units are the most prevalent type of storage for such purposes to maintain the frequency stability of the microgrid. However, utilization of fuel cell, micro-CAES, and flywheel units are implemented in some cases. The design of microgrids can have an isolated (off-grid or stand-alone) structure, especially for remote areas, or connected (to the main grid) structure. The connected mode is also known as collaborative mode, and the isolated mode is also called independent mode, islanding mode, or off-grid mode. The microgrid can sell the excess generation of internal resources to the grid in collaborative operation with an upstream network. The cooperative operation of microsources and storage facilities are proposed as hybrid schemes is some studies. Besides, the paradigm of interconnected microgrids for mitigation of reliance on the main grid is also presented by some researchers. However, the current microgrids are suffering from three concerning issues which are microgrid's efficiency, power quality, and security of interconnected microgrids. The incorporation of IoT can help to resolve these problems, which can be led to more prevalence of microgrid scheme which is desired by the power system operators.

The energy management in a microgrid must be conducted independently from the main grid. The upstream grid has no control and no observability on microsources. The forecasts of uncertain microsources must be carried out by the microgrid operator. The created imbalances must be redressed by the internal storage unit. However, with respect to this fact that such schemes have limited capabilities in term of resiliency, the microgrid's operator has to impose unplanned load shedding or undesired curtailment. For connected microgrid's, the incorporation of IoT improves the level of observability and controllability of the main grid's operator on microgrids components and can take the characteristics of all microsources into account for the whole system generation. This matter will be led to the improvement of power system performance as well as more penetration of renewable energy resources. In addition, the microgrid's operator can conduct better storage-renewable collaboration to increase the profitability of the microgrid corresponded with real-time prices of the electricity market. In addition, real-time monitoring helps the controlling schemes to procure better power quality. In addition, when two or more microgrids are connected to each other, they can affect reciprocal stability due to scale incompatibility. Hence, any sever imbalance in one of them can threaten the security of other ones. In this regard, a real-time frequency and voltage stability controlling schemes must be incorporated to serve the demand uninterruptedly. This matter necessitates the utilization of internet-based environment taking advantages of IoT infrastructure. The data must be acquired from all sensors to inform the real-time state of critical parameters to the controlling devices. The data must be processed using cloud computing and the proper action must be determined according to pre-specified instructions.

To sum up, by the implementation of IoT infrastructure, the data corresponded with all microgrid's internal components and microsources can be shared with the upstream grid's operator, which is not done at present. This matter helps the main grid operator to have monitoring and controllability (maneuverability) on microsources and elements in a microgrid. In addition, the microgrid's operator can leverage renewable resources and earn more profit by the accurate coordination of storage unit with generation sources. Besides, IoT-oriented technologies make the operator able to maintain the security of interconnected microgrids.

C. IoT in smart cities, buildings, and homes

Smart city refers to an urban area that takes advantages of different types of IoT sensors and ICT infrastructures to share information which is employed to manage resources and assets efficiently. This information encompasses data collected from citizens, devices, and assets. The data must be analyzed to monitor and control transportation systems (traffic), electricity generation microsources, water supply networks and waste management, as well as affairs corresponded with different energy consumption in a city. In particular, the incorporation of IoT for managing energy consumption in smart cities is targeted. The smart cities are made up of smart public places and smart buildings. For example, the lighting system of the roads can be supplied using hybrid systems which can be monitored and controlled using an IoT-based environment and it can be supported by the main-grid when real-time generation is not adequate. From a distribution operator point of view, the incorporation of parking lots for electrical vehicles (EVs) is also important, particularly for EVs with the vehicle-to-grid capability (V2G). The pervasiveness of EVs has had an accelerating trend during the last decade and will have a boom in the future. This matter considerably affects the operation of distribution systems. Furthermore, the modeling of EVs behavior is extremely sophisticated due to its highly stochastic nature. They may charge or discharge their batteries whenever they want. Hence, if the EVs are able to connect to a cloud-based controlling server when they are at a specific region, they can inform the operator about their charging or discharging decisions. In addition, the capability of real-time control over them can be accessible through parking lots' control systems. This implication of V2Gs in power systems will be a controversial issue in near future. Hence, the power system's operators would rather take advantages of IoT infrastructures to not be obliged to resort to undesired measures such load shedding and curtailment which may be led to paying detriments to the loads or unsatisfactory of customers.

Smart buildings and smart homes are an important component of smart grids. Residential and commercial consumers constitute a considerable share of loads in term of quantity. The behavior of each individual load is important for the operators because their overall implications are not negligible. Thus, many innovative devices are invented to help reducing electrical consumption as well as improving the efficiencies while the required energy of a building is maintained. Even though the incorporation of IoT in the construction of a building incurs more costs, it procures tangible benefits which are noteworthy. The usage of IoT in buildings and homes offers innovative solutions to revolutionize traditional buildings and achieve a more efficient, comfortable, sustainable, and safer environment [30]. In this study, the incorporation of IoT from the energy point of view is investigated. Smart metering infrastructure is one of the fundamental parts of smart buildings. The real-time electricity and gas price must be acquired for energy management center to adjust the generation and consumption accordingly. All energy-related equipment and devices must be equipped with IoT technologies to send and receive real-time signals. A wireless platform can effectively create an access point for all devices to share information in a cloud data center [31]. In addition, some devices can have accessibility to LTE and 5G protocols to enable the owner's and controller's to have a remote control using mobile HMIs. The HVAC system can effectively be adjusted based on the data gathered from occupancy sensors and temperature sensors. This matter reduces energy waste considerably. The lighting system can also be controlled automatically or optionally. The charging and discharging schemes of V2Gs in parking can also be programmed and controlled using IoT connectivity gateways to absorb or deliver power from or to the grid. The utilization of a CHP scheme can improve the efficiency of the energy management system of the building considerably [32]. The most optimum time for generation of CHP unit must be determined by the energy management system of the building, with respect to the concept of energy hub, which includes the electricity and gas prices, provided by AMIs, into account. In addition, Zigbee protocol can be used to enable smart control of modern devices and appliances which can automatically connect to the AMIs. For instance, a dishwasher can start at midnight automatically with regard to the price of electricity. The storage unit can deliver their excess power to the grid at peak based on the load pattern of the building and its capacity. The V2Gs can be charged automatically at midnight based-on real-time electricity price monitoring and can sell its excess stored energy to the main grid at peaks. Thus an intelligent cloud computing environment with a wide bandwidth and high-speed communication infrastructure is needed which can be materialized by IoT technologies and development of ICT.

In the past, the demand pattern was considered to be as a random process which was governed only by statistical rules. Hence, the power industry experts and planners had to employ very sophisticated methods to adapt the generation to consumption in real-time. This lack of control on demand incurred exorbitant costs because the grid dimension was designed for peak transmission. This matter indicates that a considerable generation capacity must be constructed to be committed only a few hours within a year. Hence, the idea of promotion of demand to reduce their consumption using penalties or incentives was conceived. This idea was flourished and was led to the concept of demand response (DR). The customers were promoted to sign a voluntary or mandatory contract known which was representing a certain type of demand response program (DRP). DRPs are classified into time-based rate programs (TBR) and incentive-based programs (IBP). TBR refers to the model of electricity pricing which provokes a reaction by the consumer due to instantaneous price. TBR is segregated into three kinds of real-time pricing (RTP), time of use program (TOU), and critical peak pricing (CPP). These programs incline the end-users to show sensitive reaction corresponded with the instantaneous price of electricity [33]. IBP is divided into three types of voluntary programs (including emergency demand response programs (EDRP) and direct load control (DLC)), mandatory programs (including interruptible/curtailable (I/C) services and capacity market program (CAP) and), and market clearing programs (including ancillary services market (A/S) and demand bidding/buyback (DB)) [34]. Demand response resources (DRRs) are contemplated as a virtual demand-side power plant, from the operator point of view. Nowadays, the operators tend to enable more dependable DRRs instead of calling an expensive unit at peak hours. The demand response concept was conceived after the advent of power markets and emersion of restructured power systems. Restructuring and deregulation of power systems was a revolution in power systems. However, integration of AMIs equipped with IoT connectivity technologies can be the significant advance toward another transition. Currently, the world is experiencing a change toward more pervasiveness of internet on everyday life. Aside from the automatic demand response for household appliances or devices, which are explained above, some DRPs may be performed by the end-users spontaneously. Hence, by incorporation of IoT-based communication infrastructure, the end-users are able to have more convenient control over many devices and equipment using computer-based interfaces or HMIs such as mobiles and tablets.

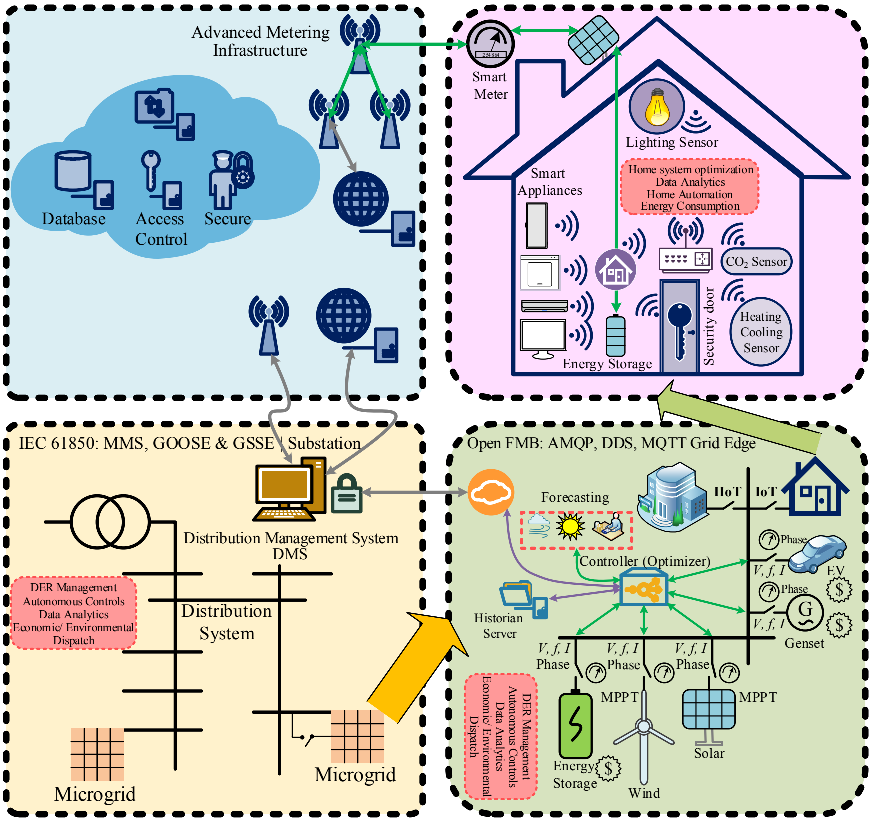

Figure 3. Different layers of integration of IoT in distribution level

D. Industrial internet of things (IIoT)

Industrial consumption accounts for a substantial part of electrical consumption. The industries are classified as sensitive loads which demand more reliable electricity supply than residential, commercial, or agricultural consumptions. In addition, the industries require better quality of power in terms of voltage regulation, frequency stabilization, and harmonics. On the other hand, various types of loads such as power-electronic-based devices, induction machines, synchronous motors are vastly used in this sector. In this regard, the power management in this section has paramount importance. Furthermore, the interaction of industrial loads with wholesale or retail power markets has assumed special attention by the owners. In order to manage all mentioned concerns, the IIoT concept has been introduced to overcome these hurdles. Hence, in recent years, the new phrase of "Industry 4.0" has been coined by researchers, and it denotes the 4th industrial revolution. The first revolution refers to mechanization using water and steam power. The second revolution corresponds with mass production and the invention of electricity. The third revolutions imply the incorporation of automation systems in the industries. The 4th revolution is defined as the use of internet in industries which is also called IIoT. The 4th industrial generation corresponds with the IoT, cloud computing, cyber-physical systems, and cognitive computing. A fascinating insight into sustainable technology for future energy on the way to post-fossil societies is proposed which is known as "Energy 4.0". This terminology refers to the era of digitalization of theenergy sector which represents the deployment of IoT infrastructure in the energy sector. The key principles of IIoT are interconnection, information transparency, technical assistance, and decentralized decisions. Incorporation of IIoT (including big data acquisition for sensor data harnessing, data mining, M2M communication, IoT-based automation) enhances the manufacturing process and improves performance.

V. Conclusion

In this study, the deployment of the IoT in various parts of smart grids was investigated. The study was categorized into three sections. The first section dealt with the implication of IoT in the generation layer. In this layer, the necessity of new innovation corresponded with wind and solar renewable resources as well as thermal plants and energy storage facilities were comprehensively explained. The IoT helps to increase the controllability and observability of the system from an operator point of view. Thereby, the flexibility of generation schedule will be increased. In addition, renewable energy sources can have better real-time collaboration with storage facilities which boosts the profitability of both types of generating units. Besides, IoT helps to conduct better preventive maintenance and fault detection in the generation section. The second section corresponds with the transmission layer. In this layer, the incorporation of IoT improves the observability of lines which results in better monitoring of the transmission grid. This matter results in a more secure operation along with better congestion management in emergencies through automatic IoT-equipped controllers. The third layer dealt with distribution level. In this section, the role of IoT in active distribution networks, microgrids, smart cities, smart buildings and smart homes in addition to industrial digitalization (IIoT) was investigated.

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