Towards an internet of energy

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***Abstract*--The current model of centralized electricity generation, transmission and distribution is under pressure to change for a variety of reasons; environmental concerns are driving a shift away from large coal-fired generation systems to increasing adoption of renewable energy sources, which tend to be distributed and not always available on demand, and hence requiring distributed storage support. Moreover, to support electric vehicles, energy needs to be provided as a service to consumers independent of location, rather than a product delivered and billed to a fixed location. In this work, we compare and contrast modern internet and energy networks and services, identifying key functionalities and the main technical challenges to be faced in transforming the electricity distribution system to a flexible yet reliable and robust platform for the exchange of electrical energy.**

***Index Terms*—Distributed networks, energy router, internet of energy, smart grids.**

I. Introduction

HISTORICALLY, the majority of energy (82% in 2011) has been generated from fossil fuels [1]. However, widespread use of fossil fuels is having negative environmental impacts. A sustainable way to deal with this problem is to replace fossil fuels with renewable energy sources. Consequently, there is a growing worldwide focus on renewable energy systems to both replace fossil fuels and meet future demand for electricity. The International Energy Agency estimated that 22% of the world's energy was generated from renewable sources in 2013, and is expected to grow to about 26% by 2020 [2].

There are some major challenges associated with the large-scale adoption of renewable energy systems, which typically require complex control of diverse and distributed energy sources and storage to meet demand [3]. The concept of a "smart grid", i.e. an intelligent electricity distribution infrastructure relying heavily on reliable high-speed communication networks for monitoring and control. The Internet of Energy (IoE) or energy internet can be viewed as an extension of the smart grid concept. The term was coined by Jeremy Rifkin in his book "Third Industrial Revolution" in 2008 [4], and refers to an internet-style solution for electricity based on bidirectional information and power flow [5].

The IoE concept is attracting significant attention within universities, companies and government sectors. For example, in Europe the ARTEMIS IoE project had 38 partner companies across 10 European countries developing IoE technologies with a focus on electric mobility infrastructure and smart grid communications [6]. In the US, the Future Renewable Electric Energy Delivery and Management (FREEDM) Center funded by the National Science Foundation has created a new electricity delivery infrastructure with key features being "plug-and-play" capability, an open-standard communication operating system, etc. [3]. In 2008 Germany launched the "E-Energy" project with the aim of motivating the development of highly efficient ICT-based energy systems [7]. In 2015 China established the Global Energy Internet and Interconnection (GEI) project as an extension of the Chinese Smart Grid to integrate renewable energy using information communicated via the Internet [8]. In Japan the Digital Grid Consortium (DGC), established in 2011, has proposed the concept of the Digital Grid using an asynchronous, addressable digital grid router capable of sending discrete energy packets over existing transmission lines to any location using an IP address. In the DGC model the large synchronous grid is divided into smaller standalone cell grids connecting digital grid routers asynchronously [9].

The IoE represents a paradigm shift of today's grid systems from centralized power generation and one-directional power flow into more secure, reliable, efficient, flexible and sustainable energy networks. Like the internet networks, the goal of the IoE is to provide a robust system for exchange of energy between prosumers. To achieve this will require widespread intelligent monitoring and control, via the internet, of distributed and intermittent energy production and storage.

In this paper, we focus on the architecture of the IoE, highlighting the similarities and differences between a future IoE and the current internet. We also touch briefly on issues such as security, changing business models, etc. The paper is organized as follows: Section II describes the expected architecture of IoE, Section III discusses the key functions and technologies required to realize an IoE, and Section IV highlights the similarities and differences between the IoE and internet. The main challenges to realizing an IoE are discussed in Section V, with conclusions presented in Section VI.

II. Architecture of the Internet of Energy

As shown in Fig. 1, the IoE will allow energy exchange between a wide variety of sources and loads, including renewable energy sources, distributed energy storage, plug-in

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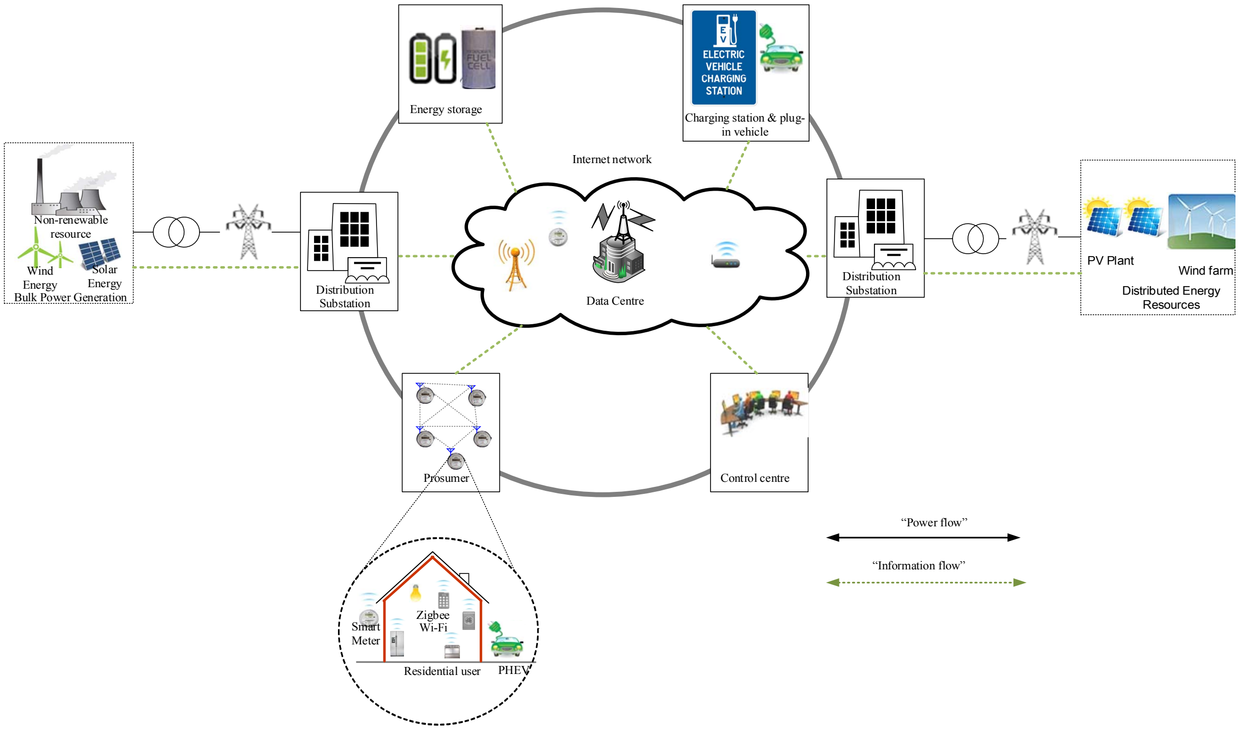

Fig. 1. Overall architecture of IoE.

electric vehicles, domestic and industrial "prosumers", etc. The energy network will be monitored and managed via the internet. In principle, peer-to-peer exchange of both information and energy may occur in this system, though some level of central or hierarchical control, may also be required. The general principle is that energy is directed from the source(s) to the load(s), similar to the routing of information in the internet.

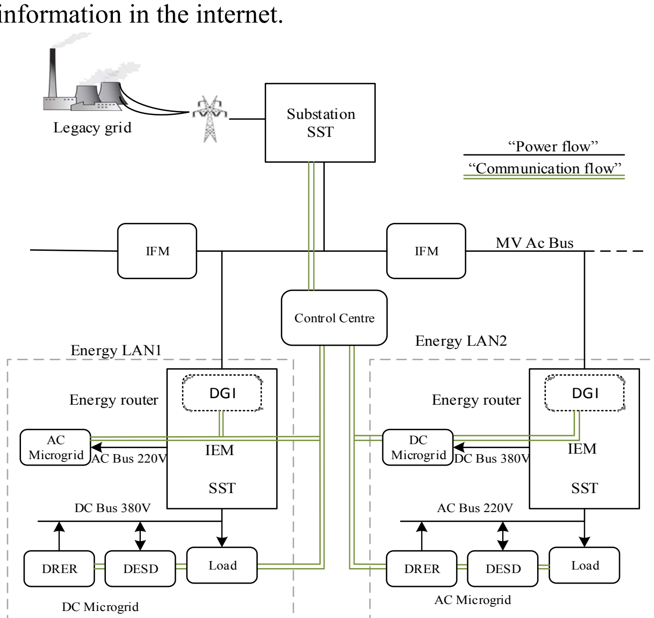

Fig. 2. FREEDM system: key elements [3].

Various detailed architectures have been proposed for the IoE. For example, FREEDM system has published a roadmap for achieving an automated and flexible electricity distribution system, or energy internet, as shown in Fig. 2 [3][10]. Key enabling technologies in this system are the "energy router" or intelligent energy management (IEM) unit, the plug-and-play interface, and a distributed grid intelligence (DGI). An intelligent fault management unit (IFM) isolates the energy LAN if an electrical fault occurs or islanding is required. The IEM and IFM must communicate via a reliable and secure communication network. The energy router is capable of AC and DC supply, and contains a Distributed Grid Intelligence unit (DGI).

III. Key Technologies

A. Energy Router

The energy router is a key element of IoE. Its functions are to process information, dispatch electricity, and convert voltage. Its role is to improve reliability, efficiency, and safety of the power system, and to optimize energy usage by balancing supply and demand. It has the capability to receive, process, and transmit grid status information regarding current generation capacity, and current demand. It is expected that energy routers will be placed at various points around the energy network, similar to the transformer in the today's grid. The energy router is still largely a concept and has yet to fully realized. Significant research towards realization has been reported in [3], in which a prototype single-phase 20 kVA solid state transformer (SST) based on 6.5 kV 25 A silicon IGBT is described.

The energy router is responsible for communicating with a large number of distributed sources and loads, and for local balancing of supply and demand. When the local supply is higher than the local consumption then the energy router transfers the surplus energy into the grid. The energy router also communicates with other routers for wider balancing of supply and demand on a wider scale [11].

The energy router consists of three modules: solid-state transformer, distributed grid intelligent control and communication unit. The solid-state transformer is essentially a power electronics based voltage converter. The distributed grid intelligent control unit is an open standard based operating system, which optimizes energy generation and distribution within microgrid to which it is connected. The communication module is responsible for communicating within and between energy routers.

B. Storage Devices

The storage system in the energy internet makes the grid efficient by providing quality of energy, reliable supply, and stable grid operation. The energy storages are useful when the grid is under stress and cannot alone balance the supply and demand in its peak demand. In that case, the battery along with grid can supply the power simultaneously thereby smoothing the supply of electricity to prevent a possible blackout. It also can solve the problem of a voltage surge, sag, and transient power outages. The storage can be installed by the utility company as a backup supply in distributed side or it can also be stored by the consumer as a battery backup in the electric vehicle. The customer can charge the battery in their electrical vehicle in the off-pick hour and they can sell the power to grid in its peak demand maximizing the economic benefit.

Since the nature of renewable is intermittence. The PV does not produce power at night and wind power could not supply power when there is no wind. So, when the solar or wind is on working condition providing excess power then this power can be stored in the large storage and utilize it when the distributed power generation devices is not delivering power. Therefore, it increases the robustness of the grid by improving the stability of grid operation. The commonly used storage devices are the battery, super capacitor, fuel cell, flywheel, compressed air, and pumped hydro.

C. Distributed Renewable Energy Sources

The IoE consist of various interconnected renewable energy resources with the legacy grid to make the energy clean and green. The price of these renewable sources is decreasing by the introduction of advanced technology so there is increasing global growth of these sources each year. The integration of theses renewables requires the appropriate power converter topologies, control and modulation technique to meet grid requirement, fulfil grid code and to avoid instability and synchronization problem. However, use of power electronics converter inject harmonics at the point of common coupling (PCC) due to its nonlinear behavior [12].

There are various forms of renewables such as hydroelectric, wind, solar, geothermal, biomass etc. where solar and the wind is having a top priority of the new form of renewables.

Wind source: The wind power system uses the wind source to tap the wind energy through the wind turbine to produce electricity. The output power is determined by the size of the wind turbine and wind speed. A large number of wind farm across the windy area decrease the investment cost and also the cost of generated power is less due to an economy of scale. A wind turbine, creates clean, cost-effective sustainable energy, is the best alternative to fossil fuel.

Solar power: The solar energy is a ubiquitous and abundant source of energy in the earth. When solar radiation strikes the PV cell, which is made up of semiconductor materials, the electricity is generated using photovoltaic effect. PV cells are interconnected forming PV panel to produce bulk power generation (typically 5-200 Watt). The solar power system is robust since it involves no moving parts; have longer life span and low maintenance requirement. However, the efficiency of commercially available PV panel is about 15-20%, so the power produced by it should not be wasted.

In the last decade, the solar energy technology is less expensive and more efficient making the solar as an attractive solution for the renewable energy source being harmless to environment and renewable. In [13], the paper tells that in early 2014 the total global PV capacity overtook 150 gigawatts (GW) and estimated that its share will reach 600 GW (16% of global electricity consumption) by 2050. The report shows that it avoid 4 gigatonnes (Gt) of CO2 emissions per year. Also, the cost of PV will reduce by 25% by 2020, 45% by 2030, and 65% by 2050.

Renewable sources such as wind and solar are the sustainable and growing source for the electrical power, which play the significant role to facilitate the IoE. They form the power station that can supply power to the load connected within their sector. These sources are variable in nature and however, add complexity to normal grid operation.

D. Plug-and-play Interface

Just like the computer detects the plug-and-play device automatically such as USB hardware and allow it to communicate with the computer, the plug-and-play interface of IoE facilities the connection of renewables, storages or the loads. Using plug-and-play interface it is easier to connect distributed generations and storages. The plug-and-play interface can have different interface type (AC/DC) since either AC or DC micro grid can connect through its interface. It also contains open-standard-based communication interface that help to recognized immediately when any storage or generating device connected with the system.

When the renewable source plugged into the system and ready to give the power, it sends the energy generation request message to the energy router. The energy router checks the local power demand (including current load demand and energy capacity of DESD) then energy router grants the access to the renewable to start producing power. Similarly, when there is no more generation of renewable such as PV at night or wind power when there is no wind flowing, they send the service stop signal to the energy router and disconnects from the grid. The energy router then sends a message to DESD to supply the power.

E. Electric Vehicle Integration

There is increasing interest in EVs, as indicated by the number of electric vehicles on the road is growing every year. Electric vehicles may be a significant source or load on the grid, and therefore have the potential to either support the electricity grid, or not, depending on their state of charge, etc. For vehicles with vehicle-to-grid (V2G) capability, EV's can support the grid by supplying power during time of peak demand, thereby improving power quality, reliability, and efficiency. Intelligent EV energy management systems are therefore required to facilitate integration of EV's into the IoE [14].

IV. Energy Internet vs Internet

The IoE will have comparable structure and functionalities to todays distributed computing and the internet infrastructures. It will consist of distributed generation and energy storage resources with plug-and-play capability that make it analogous with the internet system shown in Fig. 3. This section discusses the similarities and differences between these two systems.

A. Similarities

i. Structural Similarities

Both the IoE and internet have three structural parts comprised of generation, transmission, and distribution.

In the power system, distributed renewable/nonrenewable sources are similar to the various internet servers; the electric transmission line is comparable to long-haul transmission cable for the internet (e.g., microwave link, satellite link, coaxial cable, optical cable, submarine cable etc.); and the local distribution grid company is analogous to the internet service providers (ISPs). Just as the specified ISPs control the internet usage of its customer with its own control facilities, the local distribution company is responsible for energy management and controlling of its associated customers. The users of both internet network and energy network have dual roles. The internet user can send or receive the information over the internet and grid user can sell or buy the energy to the grid. Moreover, both have bidirectional flow capabilities i.e. energy in IoE and information flow in the internet network.

Storage is crucial in both systems. In the grid, batteries, hydrogen storage, supercapacitor, flywheel, compressed air, may be used to provide the storage whereas buffer in an information router, cache memory corresponds the storage of information.

ii. Functional Similarities

The energy router is functionally similar to the information router as it is capable of routing, controlling, and coordinating power flows. It should recognize any plug-in device connected to the energy LAN automatically from its plug-and-play interface. These plug-and-play interfaces should have similar functionalities in both systems, as shown in Fig. 2. The internet consists of plug-and-play interface such as RJ45, Ethernet, and USB so as the IoE where load/distributed resources (AC or DC) can connect or disconnect through DC or AC bus. On the internet, all devices are able to interact with each other and the same holds true for the IoE. Information-dependent intelligent devices communicate each other through their communication interface utilizing the open standard protocol.

Both types of router embody various degrees of control. The IoE has many control nodes from some central core to the distributed intelligent peripheral nodes similar to the internet. The core network has a strict control and there is distributed control within distribution systems where sectoring is done for the ease and efficient control of various distributed prosumers. In addition, there is the lightly controlled environment within home or buildings [15].

Table I summarizes the analogies, where relevant, between the internet and the internet of energy.

B. Differences

In the internet, point-to-point flow of information between any two nodes is possible. However, this is difficult to accomplish in a power system, in which direct peer-to-peer transfer is limited to local- feeders (local area networks). Furthermore, in the internet, information is constantly being created, replicated and stored, not necessarily "consumed". This raises one important difference - one cannot replicate energy – supply must be balanced by demand.

Authentication and security are critical to both; however, there is some difference in their requirements and deployment. In the internet, a common security solution can be deployed whereas in the IoE a variety of security requirements are needed. It is difficult to develop network-based or host-based security solution.

TABLE I

Similarities of Internet with IoE

Function	IoE	Internet
Storage	Batteries, ultra-capacitors etc.	Buffers, short term or long-term memory.
Transmission	Transmission lines(HVAC/HVDC)	Transmission cables(optical fiber, microwave)
Generations	Renewable and non-renewable distributed generations	Servers (e.g. Web Servers, application servers)
Distribution company	Utilities	Internet Service Providers (ISP)
Distribution network	Energy LAN	LAN
Switching	Energy router	Information router
Source/sink	Prosumers	Clients
Sectoring/Clustering	Segmented grid (cells)	Internet network under ISPs
Plug-and-play interface	Plug-and-play port in Energy router with DC and AC bidirectional port	RJ45, Ethernet etc.

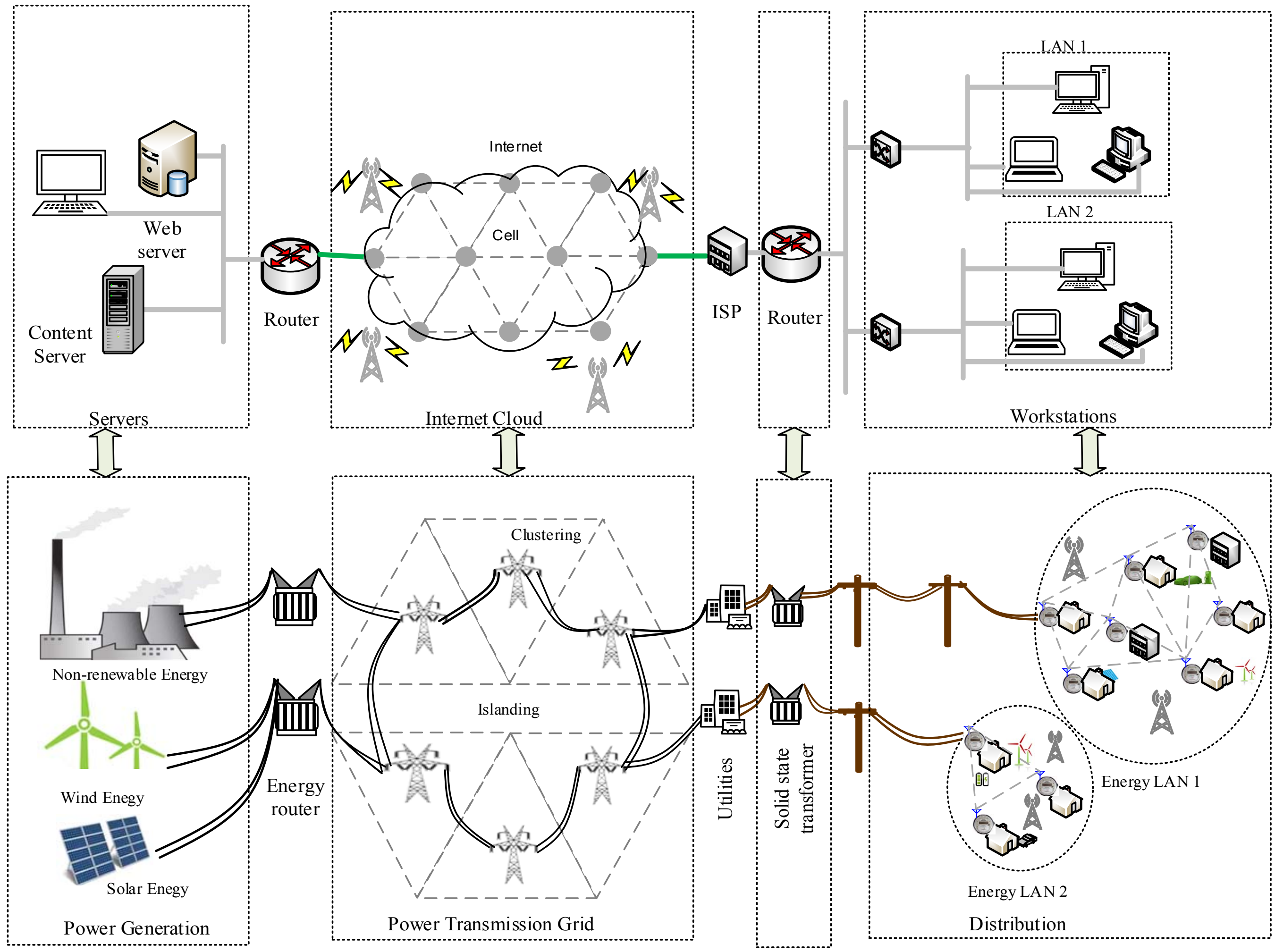

Fig. 3. Analogy between the internet of energy and the internet.

V. CHALLENGES

Here we consider the three main challenges foreseen in moving towards an internet of energy

A. *Technical Challenges*

The IoE will be a complex network integrating embedded systems such as smart grid, sensors etc. and involving decentralized monitoring and control. The integration with distributed renewables and management of huge data sets from various communicating devices and the real-time monitoring and controlling of the vast resources brings the complexity to the system. Moreover, the intermittent nature of renewable generation and the variability of loads makes achieving a robust intelligent power management system quite challenging [3]. Whilst storage assists with maintaining system stability, challenges remain with ensuring continuous supply for critical loads, e.g. using demand-side management through energy pricing [5]. Another challenge will be to regulate voltage and frequency on the grid to within strict standards. Standards being developed for networking smart grid components (e.g. IEC 61850, and IEEE standard including C37.1, 1379, 1547, and 1646[16]) are themselves quite complex.

B. *Privacy and Security Challenges*

Utilizing the internet for smart-grid communications saves on infrastructure, but also raises a significant threat with respect to security - the debate continues regarding the relative merits and costs. The three high-level cyber security objectives for performance are: i) timely and reliable access to and use of information, ii) the integrity of communicated information, and iii) confidentiality of personal privacy and proprietary information [17].

There have been some serious cases of cyberattacks on the grid. The most dangerous malware attack was in Iran's nuclear power plant (Bushehr nuclear plant) attacking SCADA system, which was used to monitor and control an electrical network [18]. Attacks targeting generation equipment or distribution and control stations could result in catastrophic damage such as black out or infrastructure destruction.

The ideal IoE supports peer-to-peer connections so if a hacker breaks into any node they could attack any point in the network, breach customer confidentiality and their electricity usage, etc. The key security mechanism that is necessary to establish a secure, reliable and sustainable smart grid system are authentication, integrity protection, and encryption [19].

C. Business Model Challenges

Conventional grid business models are based on large centralized generators and utility companies with large market share from generation to the consumer premises. For both technical and business reasons the current system does not easily accommodate a large proportion of distributed renewable generation or energy storage [9], and neither does it allow billing to follow the consumer. New business models are therefore required to provide a more open market, and to allow for peer-to-peer based energy exchanges. Deregulation and transformation of today's energy market are a key challenge for achieving future service-oriented energy market [20].

VI. Conclusion

The future electricity grid will depend on the internet for monitoring and control of distributed energy resources, but will also resemble the internet, i.e. with many prosumers connected by a network. Consequently, there is much to be learned from the internet industry in transitioning to an IoE. Similarities and differences between the IoE and the telecommunications internet have been highlighted, and some of the many challenges to be faced in developing the IoE have been discussed. For an ideal internet of energy to be realized will require substantial changes to electricity infrastructure, business models, and regulations.

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