

Chapter 1

eIoT as a Solution to Energy-Management Change Drivers



The electric power grid was developed on the architectural assumption of centralized generation being delivered to passive distributed loads irrespective of the cost implication [33]. However, several new energy-management change drivers have emerged to uproot this status quo. These drivers include a rising demand for electricity [34–36], the emergence of renewable energy resources [37–40], the emergence of electrified transportation [41, 42], deregulation of power markets [43, 44], and innovations in smart grid technology [45, 46]. Responding to these drivers requires new and integrated technical solutions for energy management.

The internet of things (IoT) for energy applications, herein called the “energy internet of things” (eIoT), has been proposed as one such energy-management solution, illustrated in Fig. 1.1. eIoT is a leading and overarching perspective where all devices that consume electricity are internet-enabled and consequently can coordinate their energy consumption with the rest of the grid in real time or near real time. eIoT technologies must, therefore, be adopted within the context of these emerging energy-management change drivers.

1.1 Energy-Management Change Drivers

Several change drivers are causing a fundamental shift in energy-management practices in the electric power grid. These change drivers include:

- Growing demand for electricity,
- Emergence of renewable energy resources,
- Emergence of electrified transportation,
- Deregulation of electric power markets,
- Innovations in smart grid technology.

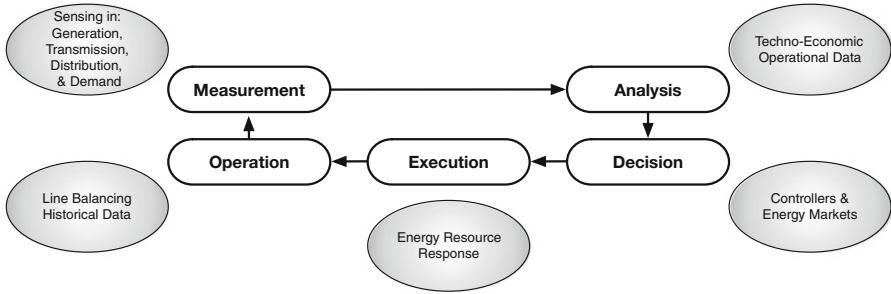


Fig. 1.1 A closed-loop framework for electrical power system management

1.1.1 Growing Demand for Electricity

The first of these drivers is the rising global demand for electricity which follows a larger global trend where the demand for all types of energy in developing countries is growing. The International Energy Agency's (IEA) 2016 World Energy Outlook Report projects the growth of Total Primary Energy Demand from 1161 million tons of oil equivalent (Mtoe) in 2014 to between 1705–2017Mtoe in 2025 and 2528–4049Mtoe in 2040 [48]. During that time, global electricity consumption is projected to increase by around 2% per year [48]. Demand for electricity in industrializing economies outpaces renewable electricity generation so that displacement does not occur, but energy generation from all available sources continues to grow [48].

Meanwhile, in developed countries, electricity demand will continue to grow. Although in recent years electricity demand has been nearly flat in many developed countries, electric load growth is expected to return in order to support fuel-switching and other decarbonization trends [49, 50]. Figure 1.2 shows that most of the energy growth will occur in developing countries that are outside the Organization for Economic Cooperation and Development (OECD) countries. Furthermore, during that time, renewable generation growth will increase more quickly than demand and is expected to replace fossil-fuel generation [48]. As a result, any advancement made to accommodate renewable energy in countries with existing infrastructure will have a profound impact on the world's decarbonization efforts.

1.1.2 The Emergence of Renewable Energy Resources

The growth and widespread adoption of renewable energy resources is expected to significantly alter the generation mix. This widespread adoption is encouraged by advanced research, state-of-the-art technologies, and favorable legislation that

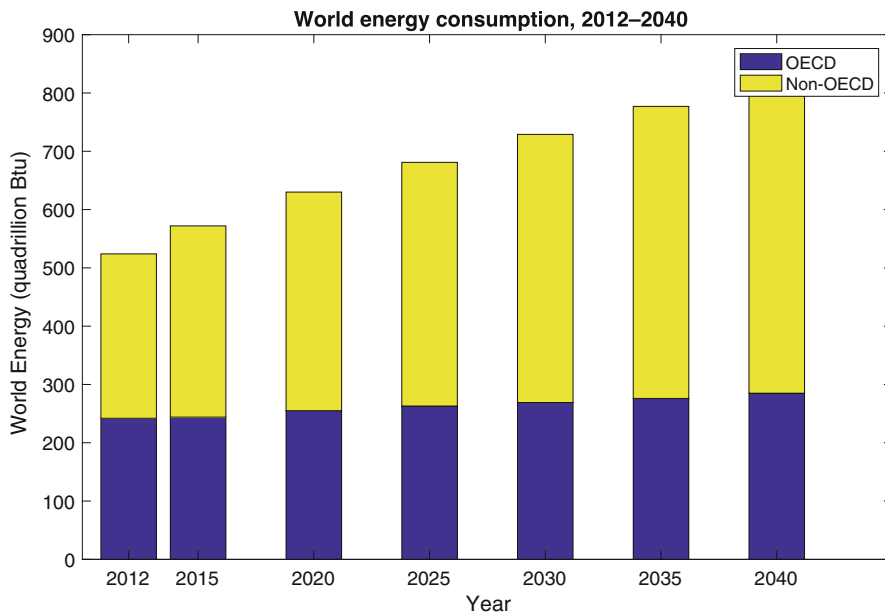


Fig. 1.2 World energy growth between 2015 and 2040 [1]

continue to improve renewable energy resources. These factors have advanced wind and solar technologies, and have pushed them to become more efficient and cost-effective as compared to thermal generation. Research in new wind turbine designs has resulted in improved turbine efficiency and wind power output [51–53]. With these improvements, the cost of wind generation is set to decrease significantly. In fact, the IEA projects that the average costs for wind generation will decline by 15% for onshore wind and by one third for offshore wind between 2017 and 2022 [54].

Further research in solar cell technologies has also led to much higher conversion efficiencies for solar cells. For example, the efficiencies of commercial mono- and poly-crystalline solar modules increased from 12–14% in 2006 to 16–18% in 2016, while that of high-efficiency N-type modules reached an efficiency of over 21% [54]. In addition, generation costs for utility photovoltaic (PV) solar are expected to fall by one-quarter over the period 2017–2022 [54, 55].

Similarly, the growing amount of new legislation and regulations favoring generation and supply of clean energy has forced the evolution of the electricity supply infrastructure and operations to support renewable energy sources. Favorable policies have not only helped lower the cost of investment in these technologies but they have also created competitive market environments for solar and wind projects [54]. Two developed countries and the European Union (EU), in particular, display how renewable energy policy is setting a precedent for countries where the energy infrastructure has yet to reach maturation. Favorable legislation in China and the United States (USA) has played a key role in promoting the widespread adoption

of renewable energy resources [56]. These legislations and a commitment towards decarbonization have encouraged investments in renewable energy resources for both small-scale consumers and large-scale energy developers.

Legislation initiatives in China have made a strong impact on the growth of the country's renewable energy capacity [57]. China is projected to add up to 1300 gigawatts (GW) of generation by 2040, which more than doubles its combined growth of fossil fuel and nuclear power capacity [48]. In part to cut back air pollution, China has set 5-year plans to reach 2020 renewable energy targets [56]. As of 2017, China had surpassed its solar PV target and is estimated to meet its wind target by 2020 [54, 56]. These targets have helped China achieve over 40% of global renewable capacity growth by 2016 [54]. By the end of 2015, China's cumulative installed wind capacity was 180.4 GW with 30.5 GW alone being installed in 2015 [58]. Despite these installations, China still faces many challenges towards the growth of renewable energy resources such as the uneven distribution of capacity and unmatched economic growth [58]. China remains the world's largest solar cell producer and consumer [59], a position it has held since 2009. As of December of 2015, China's installed PV capacity was 43.18 GW accounting for 14.9% of the global solar PV capacity [58]. Solar PV installations are expected to continue growing with one study predicting the total installed capacity of 200 GW by 2030 [58].

Developments in wind and solar in China are supported by either a national feed-in tariff (FIT) program or direct subsidies that are meant to encourage the deployment of these resources [58, 59]. Overall, China's central government has guided participation by developers and financial stakeholders to foster large-scale investment in renewable energy [60]. Soon, due to an increase in energy subsidies and integration costs, China is expected to adjust its policies to a quota system with green certificates [54]. Going forward, however, it is still unclear how this shift in legislation will affect the country's overall renewable energy growth and decarbonization efforts. That said, there are still many challenges facing the growth of renewable energy resources, such as uneven distribution of capacity and unmatched economic growth. For example, inner Mongolia has 28% of the over installed wind capacity despite having a low demand of just 6.78% [58]. While areas like Zhejiang, Fujian, and Guangdong province that have a higher population density and contribute 20.5% of the consumer load only have 4.7% of the installed capacity [58]. These disparities in capacity distribution present operational challenges that may influence future renewable legislation in China.

The USA experienced fast growth in wind and solar technologies primarily due to: (1) renewable energy portfolio standards (RPS), (2) state-level policies supporting distributed solar PV and electric vehicles (EVs), and (3) federal tax credits for wind and solar industries [54]. As of 2015, the tax credit for wind producers was 2.3 cents per kilowatt-hour, and solar power developers still receive tax credits for 30% of the value of their investment [61]. Both tax credits are set to expire in 2020, but a 2016 tax bill proposition began phasing out wind credits starting in 2017 [62, 63] and completely terminated solar credits. As per the new tax bill, on the production tax credit (PTC) is gradually phased down for wind and is expired for other technologies such as solar, biomass, and geothermal, for projects beginning

construction after December 2016. The PTC will be subject to a 20% step-down in 2017, 40% in 2018, and 60% in 2019 [63, 64]. A similar phase-out schedule applies to the wind energy investment tax credit (ITC), where the allowable tax credit is 30% of expenditures in 2016, 24% in 2017, 18% in 2018, and 12% in 2019 [63, 65]. Although the future of federal tax credits is uncertain, the USA is the second-largest growth market for renewable energy generation sources after China [54].

Most of these changes are happening at the state level with states such as California and New York taking a lead on decarbonization efforts. For several states, the goal is to reach 40% decarbonization (50% for California) by 2030 and 80% by 2050 [66–68]. Decarbonization efforts have focused largely on increasing the renewable energy capacity and energy efficiency improvements, but, lately, these efforts are shifting to include electrified transportation and electric indoor heating [67, 68]. Recently, new regulation by the Federal Energy Regulatory Commission (FERC) has allowed the participation of distributed energy resources in electricity wholesale markets [69]. This regulation will not only improve the deployment of DERs but will also enable the creation of market structures that are more inclusive for DERs.

In the EU, there is a strong interest in wind energy. However, investment has lagged behind due to the lack of support for investments by non-member states [70]. Progress in the deployment of wind technologies is contingent upon the creation of a favorable policy framework that helps bridge this gap in investment [70]. In 2009, the 2009/28/EC Directive to promote the use of renewable energy was adopted by the European Parliament and the Council of Ministers. The directive promoted the development of renewable energy sources as one of the main objectives of the EU energy policy [71]. It also set mandatory national targets that would ensure at least a 20% renewable energy share in total energy consumption by 2020 [70, 71]. By June 2010, each member state was required to have a national plan that defined the technology mix scenario, the trajectory to be followed, and the measures and reforms necessary to overcome barriers and to enable the development of renewable energy [70]. Wind energy was a main component in these national energy plans with an estimated 209.6 GW of wind capacity to be installed by 2020 within the EU [70]. This accounted for 43.1% of the expected renewable energy technologies installed by 2020 [70]. Nevertheless, the EU remains on track to meet their goal of reaching 20% renewable generation by 2020 [72].

A recent report by the renewable energy agency shows that the EU has been able to cut its associated greenhouse gas (GHG) emissions by fossil-fuel generation by about one-tenth [72]. The share of the renewable energy in the total energy consumed in the EU was reported to be 17% in 2016 from the 16.7% reported in 2015 [72]. These numbers show that the EU is likely to still meet its 2020 decarbonization target. However, the stability of the policy framework still remains a potential barrier to meeting this goal for wind energy investors [70]. In future frameworks, policies must address cooperation among nations within and outside of the EU membership [71]. Furthermore, cooperation between countries in renewable energy development projects is imperative for the EU in terms of technical exchanges, economic ties, and political relationships [71].

1.1.3 The Emergence of Electrified Transportation

Third, the new load from electric vehicles requires fundamental upgrades to the electricity infrastructure. New advancements in EV batteries and fast charging technology have led to reduced costs of electric vehicles. A recent review puts the costs per kWh of an electric vehicle battery pack at \$500 [73]. This cost is estimated to be even lower (\approx \$300) for vehicle manufacturers [73]. Although this cost needs to fall to below \$150/kWh for electric vehicles to be as price competitive as gasoline vehicles, these lower costs have made electric vehicles much more accessible and affordable [73].

In addition to improved technologies, many countries have adopted electric vehicle mandates to promote EVs and reduce the CO₂ emissions of their transportation system. Countries including China, the UK, France, India, and Norway have national legislation to encourage the sale and production of EVs [74]. As a result, car makers are responding with large monetary investments into electrifying their fleets [75]. Although many countries will not establish similar policies, these large mandates are set to contribute to a competitive environment for EVs internationally. Consequently, the falling costs of vehicles will affect the US consumers and encourage the integration of EV infrastructure into the US electricity grid.

In the USA, federal income tax credits and state-level cash incentives are available to consumers who purchase electric vehicles [76]. For example, a federal income tax credit of \$7500 is available for vehicles delivered before the end of 2018 and over 13 states offer cash incentives to consumers [76]. In addition to cash incentives, other non-cash incentives such as carpool lanes and free municipal parking are offered by some states to EV owners [76]. These incentives have largely contributed towards the widespread adoption of EVs.

The future fleet of EVs requires a large load of energy that the current electricity system does not produce or support. Most EVs require around 0.2–0.3 kWh of charging power per mile of driving [3]. A plug-in vehicle of 1.4 kW more than doubles the average evening load of a household, and fast chargers, at 6.6 kW or higher, will significantly alter the load pattern of the consumer [3].

On an energy basis, the electrification of transport will have a substantial impact on the current capacity of the electric power grid. One study estimates that with a 100% electrification of transport by 2050, the total electricity demand will increase by 2100 TWh [77]. This represents 56% of the 2015 electricity sales [77]. Consider Fig. 1.3. In 2016, the USA consumed 27.9 quads (quadrillions, or $\text{Btu} \times 10^{15}$) of energy whereas the electric power grid only delivered 12.6 quads of useful electricity. Such a figure suggests that the electric power grid will require significant upgrades in order to accommodate a large-scale electrification of transportation. Furthermore, electrified transportation has the potential to complicate power system operations—in balancing, line congestion, or voltage control [78, 79].

Figure 1.4 shows the potential impact of plug-in electric vehicles on residential customers' electrical load. Beyond the need for higher rated electrical panels in the home, several plug-in vehicles could overload distribution circuits and transformers

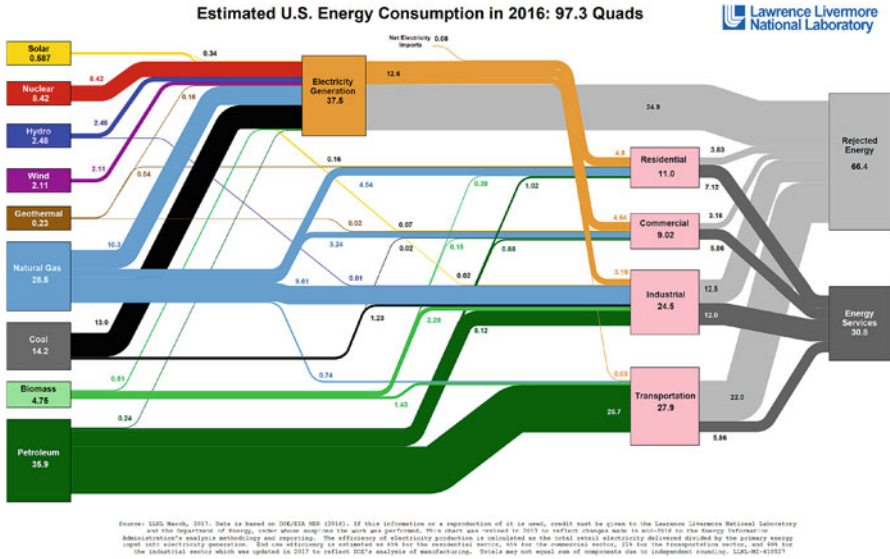


Fig. 1.3 Sankey diagram of American energy system in 2016 [2]

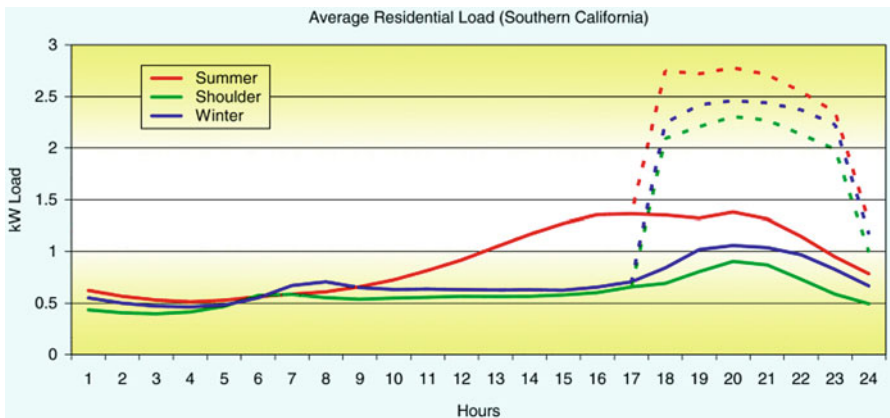


Fig. 1.4 Plug-in EVs as a new and significant component of residential consumer load [3]

that normally operate close to their limits [3]. With normal demand variations, several plug-in vehicles may overload a 25- or 50-kVA secondary transformer on a single-phase lateral [3]. EV loads can also create unbalanced conditions on distribution system feeders [3]. Therefore, advanced control strategies for charging EVs such as coordinated charging [80, 81], vehicle-to-grid stabilization [79, 82–86], and charging queue management [87, 88] have been proposed to stabilize electric vehicles’ charging schedules. These works have determined that a holistic approach to studying electric vehicles is necessary given the coupling with the electricity sector [31, 89–91]. Electrified transportation is discussed further in Sect. 3.1.5.7.

1.1.4 Deregulation of Electric Power Markets

Fourth, during the deregulation trend of the 1990s, American power markets were restructured so as to become more diversified and competitive [44, 92–95]. Figure 1.5 shows a transition from a fully regulated (monopolistic) electric power system to one that is fully deregulated [96]. Debundling generation, transmission, and distribution was intended to lower customer rates and improve the quality of service [44]. Utility activities in resource production have also become deregulated, thus opening resource trading on wholesale markets by non-traditional parties [97]. Presently, energy retailers interact directly with customers, and in countries with high regulation, the distribution network operator takes on the role of a service aggregator [97].

More recently, there has been steady progress towards the development of deregulated markets in the distribution system as well [98, 99]. Data services present in physical transmission and distribution are typically unregulated, and IoT can facilitate supply-chain management as well as demand-side market participation [97]. As a result, companies that offer aggregation services may play a larger role in selling distributed power at both the local and wholesale level.

Continuing on the trend towards deregulation, transactive energy (TE) has been proposed as a means of managing generation and demand through the use of time-dependent economic constructs while giving adequate consideration to reliability [100]. In many ways, it is considered a new “smart grid” approach to synthesize measurements, devices, and market information into an emerging fair market for the electricity grid [101]. This market requires real-time data, interconnection among systems, and judicial transparency of information and market operations [101].

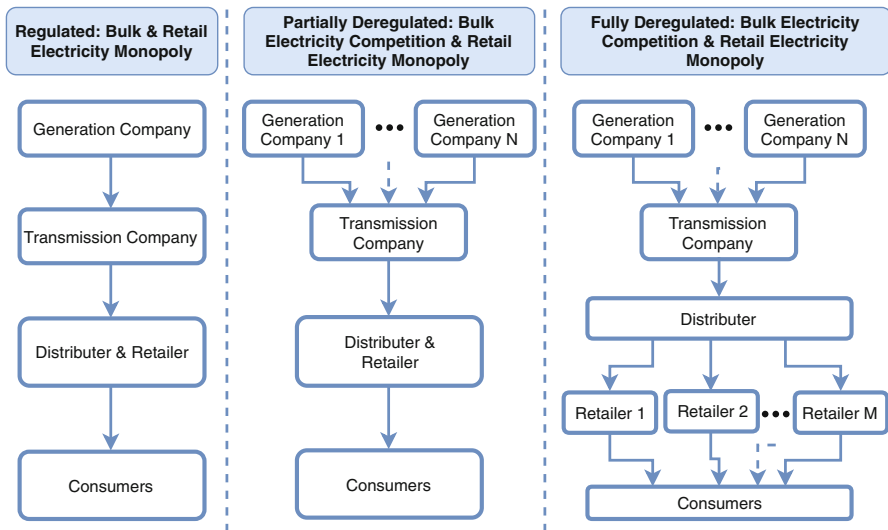


Fig. 1.5 Types of regulated and deregulated environments

TE approaches can establish distributed energy resources (DERs) in energy markets, and further liberate consumer choice in power services. However, techniques for measurement, market surveillance, and market contract enforcement are necessary for expanding the number of market participants [101], which easily exemplifies how market complexity can increase rapidly. TE, which is discussed at length in Chap. 4, is perhaps one of the most compelling use cases for eIoT.

1.1.5 Innovations in Smart Grid Technology

In recent years, the electric power system has seen a steady stream of new “smart” technology innovations [102–104]. Although these innovations enable new functions and services, they also increase the operational complexity of the grid [105–107]. A *smart grid* is commonly defined as a power system that allows two-way communication and two-way flow of power [106] through advanced control and decision-making functionality. It supports decentralized energy generation where power is injected from the grid periphery back into the larger electrical power system. This brings about many opportunities in distributed generation (DG), distributed energy resources (DER), demand response (DR) as well as TE. These technological innovations are quickly transforming the structure and function of the electric power grid. Consequently, pricing mechanisms and regulatory bodies must keep pace with this rapid technological transformation by creating appropriate framework adjustments and legislation to standardize the grid’s development [46, 106].

1.2 The Need for a Technical Solution

Responding to these five energy-management change drivers presents new reliability challenges to the overall operation of the power grid. In grid operations, balancing and frequency control are affected by renewable energy generation (for example, wind and solar PV). Due to the variability of renewable energy generation, grid operators must now dispatch to a real-time load profile that is significantly different from the daily load profile. Consequently, the grid operators may have to adjust their balancing operations to accommodate this new requirement on the system. For example, high penetration rates of solar PV bring about what is often called a “duck curve” (shown in Fig. 1.6), which exhibits a very sharp ramp during the early evening hours when solar PV generation is fading away [4].

During this time, dispatchable generation must respond quickly to the evening load peak in the absence of solar PV generation. Solar PV and wind generation, as variable energy resources, also exhibit forecast errors that are significantly greater than the forecast errors for load [108, 109]. This is partly due to operators having many more decades of experience forecasting load than wind and solar PV generation. The larger forecast errors further complicate balancing operations.

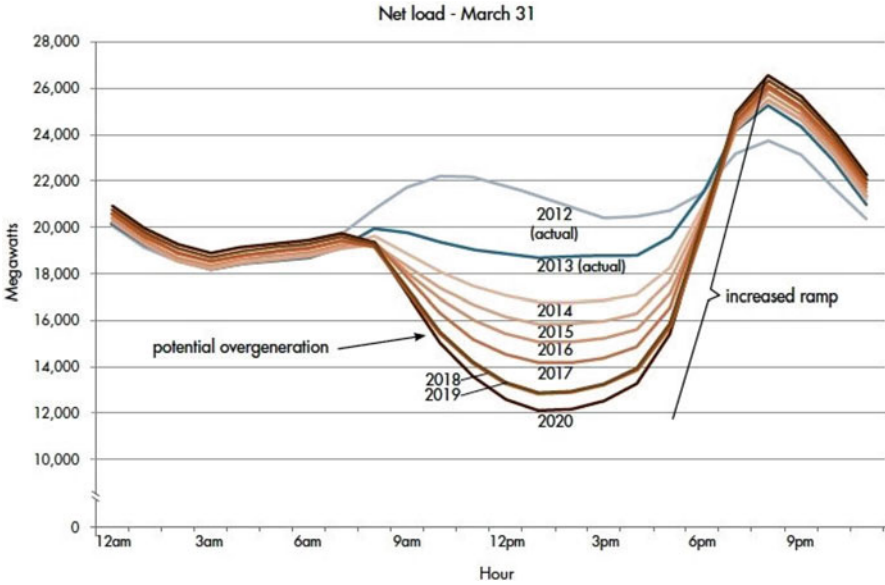


Fig. 1.6 The California ISO duck curve [4]

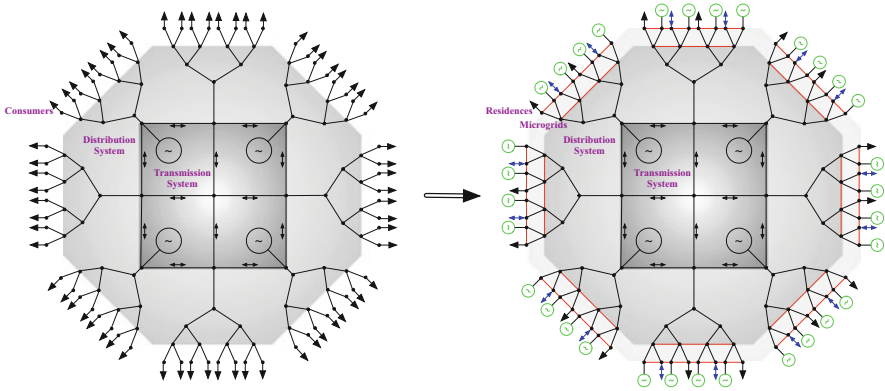


Fig. 1.7 A conceptual transition from a traditional electric power grid to a future smart grid

In addition to these challenges in balancing operations, much renewable energy is integrated as distributed generation at the periphery of the electric power system (see Fig. 1.7). Currently, the electric distribution system is designed for one-way flow of power out to consumers [33, 110]. The presence of distributed generation creates the potential for two-way power flow in the distribution system. Consequently, the distribution system’s protection equipment must be redesigned to accommodate two-way flow of power [111].

Furthermore, the widespread integration of DG on a radial topology has the potential to exceed transformer ratings [112, 113] and/or exceed line flow limits in this backward direction. Hence, when adding two-way power flow from variable energy resources, voltage limits, phase balances, and load balancing are threatened [114].

Finally, the distribution system was designed for a monotonically decreasing voltage profile from generation down to the load. The presence of distributed generation at the grid periphery can cause over-voltages as power flows upstream towards the transmission system. These structural changes to the physical grid bring about new dynamics at multiple timescales. Within seconds to minutes, ancillary services like frequency regulation must resolve minor disturbances and short-term ramping effects. Hourly balancing uses forecasts to meet loads at peak and off-peak demand which creates the daily shapes of energy consumption.

In the long-term, seasonal patterns affect renewable energy generation, the consumption of natural gas, and end-user power consumption. Naturally, these many structural and behavioral changes require technical solutions that are responsive at multiple timescales and can be applied to the grid periphery. Furthermore, these technical solutions will need to be supported by appropriately designed technology, policies, and regulations.

1.3 eIoT as an Energy-Management Solution

This work advocates the “energy internet of things” (eIoT) as a promising technical solution to the challenges presented above. The eIoT is one application of the internet of things (IoT). The IoT term was first used in 1999 by Kevin Ashton [115] and later became an integral part [116] of a global research consortium called the Auto ID Centre [116] that included the Massachusetts Institute of Technology (MIT), the University of Cambridge, ETH Zurich, Fudan University, Keio University, and Korea Advanced Institute of Science and Technology (KAIST). It is a technology that has expanded the use of communication technologies namely; over the internet, from user-to-user interaction to device-to-device interaction [117]. The adoption of the IoT has been supported by business efforts, such as the establishment of the Internet Protocol for Smart Objects (IPSO) Alliance in 2008, and technological advancements, such as the launch of Internet Protocol version 6 (IPv6) in 2011 [117]. Internet technologies with IoT have enabled growth in industry, especially in home automation and supply chains [117]. As a way to connect humans, computers, and devices, IoT presents itself as a key enabling technology of new energy-management approaches.

From the beginning, decentralized supply-chain management was an integral part of the IoT vision [5–13, 118]. The idea of was that the IoT provided unprecedented visibility of shop floor and supply-chain operations. Each piece of raw material, work in progress, or final product could be on tracked in near real time through the control loop captured by Fig. 1.8. When this information is relayed to manufacturing

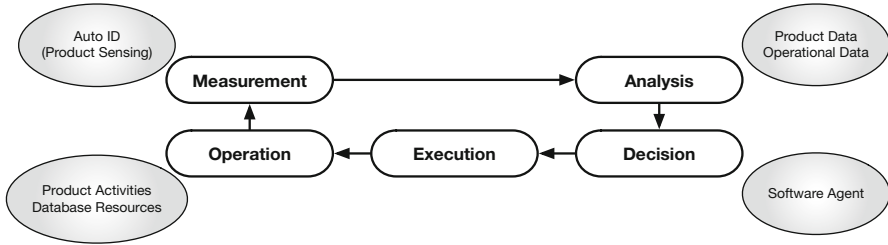


Fig. 1.8 A closed-loop control framework for production systems with intelligent products [5–13]

execution systems and enterprise information systems, it could be used to support reactive and proactive decision-making on how to best manage production systems and their associated supply chains.

Next-generation production systems [119–121] such as Industrie 4.0 advocated for the concept of “intelligent products” [8, 122, 123] that used “product agents” [124–131] that negotiated in real time with supply-chain resources to make it to their final customer. The presence of an embedded product sensor (e.g., a radio-frequency identification (RFID) tag) enabled this new paradigm in industrial control systems.

eIoT emerges when the vision of IoT described above is applied to “energy things.” In other words, it forms a “digital energy network” [132] where IoT technology is integrated into the smart grid as a full supply chain that includes centralized generation, transmission, distribution, DERs, and customer premises. IoT enables opportunities for smart grid applications such as DG, DER, DR as well as TE. The distributed nature of these technologies makes them ill-suited for the hierarchical and centralized systems as is typically found in conventional bulk power systems.

The decentralization of the energy system requires device-to-device connectivity so as to achieve distributed energy management. Eventually, the number of devices (things) that connect to the periphery of the power system is expected to grow significantly. In the consumer market, the number of things that use electricity is far greater than the number of things connected to the internet. However, the number of internet-connected devices is rapidly increasing [133]. As electric loads become dynamic and responsive, it is imperative that the increasing number of “things” that connect to the grid are managed through faster, real-time communications and control.

When the concept of decentralized IoT-based supply-chain management is applied to “energy things,” it has the potential to become a powerful energy-management solution that not only reaches the grid periphery but also addresses dynamics at multiple timescales. IoT can manage end-point devices with real-time communications and control, and achieves monitoring, tracking, management, and location identification through protocol-based communications and data exchanges [133]. Smart devices (RFID tags, sensors, actuators, etc.) connect via communication networks (cellular networks, ZigBee, WiFi, etc.) to decision-making entities and actuators [133]. The process forms an IoT-enabled control loop that can be

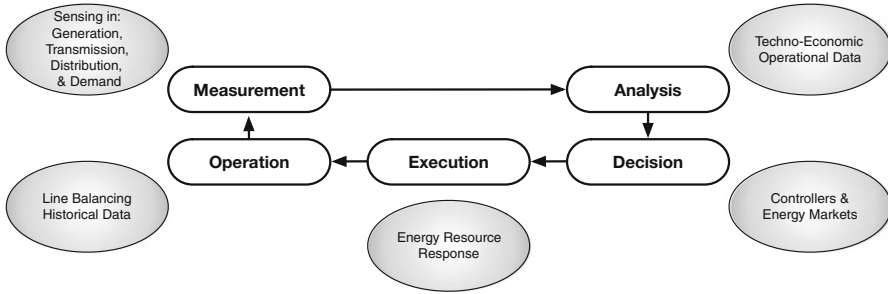


Fig. 1.9 A closed-loop framework for electrical power system management

used to monitor the equipment state of devices, collect information for analysis, and control the smart grid for a variety of applications [133] (Fig. 1.9). For example, TE is the realization of a control loop interacting with market information, two-way communication networks, and real-time pricing mechanisms that incentivize the generation and consumption of electricity.

With the emergence of IoT, the technical development of the grid's infrastructure, the changing role of the grid's stakeholders, and the energy market development can all be advanced with real-time data. The ability to connect devices, create market signals, and influence generation and consumer behavior within an overarching energy-management framework is known as the *energy internet of things* (eIoT).

1.4 Scope and Perspective

The goal of this work is to provide a broad perspective of the implications of eIoT on the management and control of the electricity grid. This book offers a formal definition of the IoT within the context of the electricity supply and distribution control loop. It presents the growing demand for advanced and internet-enabled sensing and actuation devices for the generation and transmission system layers as well the distribution system layer. More importantly, it presents the changing roles of existing grid stakeholders as well as the gap in energy-management solutions that could potentially be filled by new stakeholders. Specifically, it recognizes a closer working relationship that may emerge through collaborations with telecommunication companies as new communication networks are adopted. Additionally, the book shows a convergence of cyber, physical, and economic frameworks as more eIoT devices seek to function and collaborate effectively. Finally, this work presents the role of TE as a core application of the eIoT control loop. Two TE use cases are presented to illustrate the changing nature of consumer interactions with utilities. This brings up the issue of how utilities are going to address the growing penetration of eIoT and DERs. Overall, the book presents the challenges, opportunities, and the

transformative implications of eIoT on all the layers of the electricity supply and demand value chain.

1.5 Book Outline

To that end, the rest of this document is structured as follows:

Chapter 2 address the activation of the grid periphery.

- Section 2.1 recognizes that DERs will transform the nature of energy management at the grid periphery.
- Section 2.2 discusses some of the challenges presented by this transformation.
- Section 2.3 finally presents eIoT as a scalable energy-management solution for the activation of the grid periphery.

Chapter 3 focuses broadly on the development of eIoT within the energy infrastructure. This development is discussed in the context of a control loop.

- Section 3.1 presents the sensing and actuation in the transmission and distribution levels of the power grid. This section is discussed in four main categories:
 - Section 3.1.2 discusses sensing and actuation of primary variables in the transmission layer.
 - Section 3.1.3 addresses the sensing and actuation of secondary variables required for the reliable supply of solar, wind, and natural gas resources.
 - Section 3.1.4 introduces the sensing and actuation of primary variables in the distribution system focusing on key devices such as the smart meter.
 - Section 3.1.5 discusses sensing and actuation of secondary variables within the demand side, recognizing the role of automation, smart home devices, real-time demand-side data, and the challenge of integrating plug-in-electric vehicles.
- Section 3.2 presents the communication layer of the control loop recognizing that the current communication structure must evolve to deal with the heterogeneity of sensing and actuation devices. This evolution will occur within all layers of the energy system's jurisdictions.
 - Section 3.2 addresses the communication network for grid operators and utilities.
 - The shift from current grid communication networks to telecommunication networks is discussed in Sect. 3.2.3.
 - Section 3.2.4 addresses the growing demand for local area networks on the consumer side.
- Section 3.3 presents the need for distributed control algorithms to deal with the growing heterogeneity and number of control points in the electricity grid. This

section examines the evolution of control algorithms and applications within multi-agent systems studies, game-theory approaches, and microgrid control.

- Section 3.4 discusses the changing architectural needs for the electricity grid and the need for standardization of cyber-physical/economic frameworks to enable interoperability of technologies.
- Section 3.5 examines the social implications of eIoT deployment both from the perspective of privacy concerns and eIoT cyber-security.

Chapter 4 presents TE as an overarching application of the eIoT control loop.

- Section 4.1 presents a broad definition of TE and offers a review of some of the current applications of the TE framework.
- Section 4.2 explores potential transformative impacts of TE in the energy system management. These impacts are summarized in two plausible eIoT use cases as potential transactive energy applications.
- Section 4.3 discusses the implications of eIoT for the future of electric utilities especially in North America, and finally,
- Section 4.4 considers the implications of eIoT for industrial, commercial, and residential consumers.

The book is concluded in Chap. 5 with a high-level discussion of the three main eIoT transformations in Sect. 5.1 and two major challenges and opportunities in Sect. 5.2. This chapter broadly reflects on the implications of eIoT advancement on the future of the electricity grid.

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