Preface

In many countries, the electricity sector is undergoing a profound change—the biggest in its 100 year history. The conjunction of some major drivers—such as the need to decarbonize the power industry—and megatrends towards more distributed, renewable systems, is forcing massive change in the industry. Concurrently, the need to expand electrification to an additional 1 billion people in India, Africa, and parts of Asia combined with the convergence of digital technology, and new distributed power generation technologies has opened up new ways of providing power to local communities and industry.

For many developed economies, the conventional power system has been centralized, with large remote thermal power stations located close to fuel sources, such as coal, providing power to major loads that might be hundreds of kilometers away, through long distance high-voltage transmission lines. This has worked well for the last 50–60 years, providing low cost, reliable power for industry, commerce, and residential use. In conjunction with this physical system, electricity markets have evolved to provide a means to apportion costs and revenues to the participants—i.e., generators, transmission and distribution service providers, retailers, and customers. This market structure ensures a level of competition, whereby low-cost generators are favored. In contrast, the networks are a natural monopoly, requiring regulation. The very long life of the generation and distribution assets requires a long payback time—often 40 years or more. This system is not easily or quickly changed, as investment decisions, construction approvals, and payback times are predicated on long operational life.

All this is now changing, and with a pace that is unprecedented in the industry. Local generation, energy storage, tariff reform, new technology, and new business models are rapidly emerging and disrupting the conventional industry.

This type of industry-wide disruption has been seen in other industries, such as telephony, music delivery, newspapers, and many more. While it is largely technology driven, there is a strong element of consumer acceptance, whether for convenience, cost, or other driver.

From a technology perspective, two of the strong drivers for change in the electricity industry are low-cost photovoltaic (PV) power generation and, increasingly, battery energy storage. While the cumulative global installed PV capacity was less than 10 GW in 2007, it increased by tenfold to 100 GW by 2012 and surpassed 200 GW in early 2015. As a result of this increase in production scale and also the shift of global production to China, PV costs have decreased dramatically in the last 5 years, with system prices dropping from $7/W to $4/W and below. For countries like Australia, this cost reduction coincided with large electricity price increases, and government subsidies, providing an attractive alternative for many customers. Indeed at the time of writing (2015), Australia installed over 4700 MW of rooftop PV in 5 years—the equivalent of many coal-fired base load power stations. Consumers that installed PV generation have been able to reduce their grid consumption, and consequently their electricity charges, which have largely been based on kWh consumed. This has impacted the revenues of both generators and networks.

Consumers are generally comfortable and pleased with the performance of PV systems. With lower system costs, the average size of installed systems (in Australia for example) has grown from $\sim$1.5 to over 4.5 kW in 2015. This now presents a new challenge to many consumers (and utilities!). Consumers can generate more power than they require during daylight hours. This power can be exported in most cases, with some payment received (a "feed-in" tariff). This payment however will be very much less than what consumers will be charged for power as they move into the evening peak periods—if they are on a time-of-use tariff. Even if they are on a flat tariff, the payment for their export will be much less than their unit power cost, which includes network and other charges. Consequently, for many consumers, or precisely prosumers, with PV generation, there is a genuine interest in being able to store their excess generation for use after the sun goes down. This is the driver for on-site battery storage in many jurisdictions. Therefore, we are moving towards "nanogrids" that are standalone hybrid generation system with energy storage to not only supply power to its local load, but also trade its shortfall or surplus energy with the available grid nearby.

Under "ideal" conditions, the combination of PV and batteries could provide for all power requirements for many consumers. Indeed there is a sizable group of consumers in Australia that are pursuing this possibility—going "off-grid."

From an engineering perspective, the use of PV generation and battery storage is relatively straightforward. Modern battery systems—lithium ion in particular—provide good round trip efficiency, with low footprint and acceptable lifetime. The challenge is largely financial. Is it more costly to be self-sufficient than to be grid dependent? Today, for most consumers, e.g. in Australia, complete independence from the grid is still largely more costly (see Chap. 7). While a significant fraction of local generation and storage may be economically beneficial, our analysis shows that it is extremely costly to achieve self-sufficiency while retaining the same level of load and reliability. This will obviously change with tariff structure and technology costs, and the breakeven point will be different for each customer. However, the downward trend in technology costs will bring this point closer and closer.

Large-scale grid-disconnection is a possibility, though there is a high degree of uncertainty if, and when this might occur.

While the uptake of PV and storage for individual homes will be followed with interest, there is a more interesting and challenging future that may evolve—that of integrated, communicating, and cooperative community energy networks (CCEN). These are groups of homes, and other consumers, that are able to generate, store, and exchange energy within their community. For small groups, such as 10–30 homes, this CCEN consists of homes (nanogrids) that may generate some or all of their power, store some of their power, but also exchange power with other members of the community that may lack storage or generation, or have load profiles that are not easily met with PV generation alone. These cooperative nanogrids can maintain a grid connection, either with every home, or with a single connection point. There will be a mechanism to price power, either dynamically or statically, and a means to settle accounts as a community and with individual members. Of course there are significant regulatory and other challenges (social, legal, behavioral, and physical) but some communities are already exploring these possibilities.

Combining these nanogrids with use of electric vehicles, and the cooperative, communicating nanogrid becomes a very complex system to optimize. For utilities, planners, and policy makers there will be a plethora of questions, such as

Can a network of nanogrids provide benefits to the macrogrid?

What effect will time-of-use tariffs have on nanogrids?

How does capital and operating costs influence technology choice?

What would be the optimum mix of generation and storage for a given community?

Should or will grid-disconnection be an option?

How will the local weather affect operation?

It is hoped that this book will provide a useful basis for developing solutions to many of these and other questions.

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