Electricity Markets and Regulation

Alex Cruickshank and Yannick Phulpin

The operation of markets and regulations is difficult to predict for 2050 because:

- *There is no uniform starting point between countries and markets; and*
- *The political and social structures of communities differ, which impacts the development of the grid, from a markets and regulation perspective, toward 2050.*

That said, the current markets are discussed in terms of liberalization, cross-zonal and temporal integration, and integration of DER. These categories are further broken down by management of risk, price and cost efficiency, and ability of trading to occur outside of the formal markets.

The extension of the current approach, option 1, where the current overall structure is retained but increasing interconnection between systems, even between continents allows a broader market to develop. The highly interconnected system will allow transfers of energy from areas with good renewable resources, such as hydro and stable low emission resources, such as nuclear, to balance the increased amounts of intermittent, renewable energy and distributed energy. A major development in this option is the integration of existing markets as is currently occurring in Europe and could be expected more in other regions. These are significant changes, which will require new pricing techniques for network and markets. We note that the concepts for these developments are already beginning to occur in advanced markets and that monopoly markets will have increased customer participation under this option.

Option 2, with a reliance on distributed markets and grid structures, is a radical change from the current design and requires the development of complete trading and settlement at the local grid level with net trading between the local grids. The

On behalf of CIGRE Study Committee C5

A. Cruickshank (✉)
Oakley Greenwood Pty Ltd, Margate, Australia
e-mail: acruickshank@oakleygreenwood.com.au

Y. Phulpin
EDF, Saint-Denis, France

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use of distributed and local sources of energy rather than reliance on centralized supply is a complete change to market structures and the management of risk, where end users will directly support a significant share of the investments. An approach is included in the chapter. We note that option 2 is less likely than option 1, even with the long lead time of this book, where the social and political structures support and encourage monopoly or government provision of electricity.

This limitation and the nature of market development that currently occurs mean that there is likely to be a variety of market and regulatory forms in 2050, both in the remaining vertical structures and in the operation of the distributed structures.

1 Introduction

This chapter is to examine potential market designs and operations and the regulatory environment for the two potential future states of electricity provision in 2050 described in Chapter "Introduction and Overview":

- A highly connected grid with globalized grid provision of electricity and a high proportion of renewable energy; and
- A system dominated by loosely connected microgrids, which are largely self-contained and contain a large proportion of renewable energy.

This chapter deals with the potential market arrangements for the two future states and related regulatory issues.

While the underlying physics and technologies of the grid will impact the form of the markets and regulation that is required, this chapter does not deal with:

- The economics of system development, which is covered in Chapter "Power System Development and Economics" (SC C1);
- Market and system operation, which is covered in Chapter "Power System Operation and Control" (SC C2);
- The technical aspects of distributed energy resources (DER), which are covered in Chapter "Active Distributed Systems and Distributed Energy Resources" (SC C6); nor
- The information systems and requirements, which are covered in Chapter "Information Systems and Telecommunications" (SC D2).

In addition, other chapters have described the advances in energy market equipment and technology, including the increase in distributed and intermittent, the impact of this increase and the more general advances in the engineering and technical aspects of electricity. While the pace of technical advances can vary, the direction is generally forward (cheaper, better, faster) with occasional leaps as new technologies are developed.

The development of markets and regulation does not always "improve"[1] the electricity service from an end-customer perspective, while there is generally move forward as technology, particularly communication, monitoring, and measurement tools improve. By forward, we mean toward open markets, innovation, and competitive supply. Community faith in markets as a means of reliable supply can, however, reverse. This can lead to an increase in political intervention or substantial reduction in market freedoms. The trade-off between reliable supply, open markets, least cost, and safe supply is not always straightforward.

The recent World Energy Outlook 2018 [12] reports:

> While fully regulated markets with vertically integrated utilities tended to face over-investment, leading to excess capacity, market upheaval was apparent in countries that rely on competitive markets (competition drives about 54% of the world's electricity consumption, it notes). Several jurisdictions—for example, in Colombia, France, and the UK—that rely on markets to attract investment are shifting from markets where energy is the only source of revenue toward the inclusion of a firm or dispatchable capacity product. In the changing business environment, U.S. vertically integrated utilities for the most part kept hybrid generation-retail models, though competitive generators are also moving in that direction.

With increasing availability of technology and increasing retail prices for energy, there is a movement to more distributed supply of energy, increasing self-reliance on the provision and management of energy and a desire to trade locally with or without central supply. While some consider leaving the grid, the need for backup and efficient outcomes generally requires a level of interconnection. This means that we need to consider markets and also non-market actions of connected parties.[2]

Energy markets are in place to optimize the price paid for secure supply of energy. When the security of supply is low or reduced for some reason, communities generally expect more government or regulatory intervention. When supply is highly secure, the question of price dominates, and markets become more competitive.

1.1 Optimizing Energy Supply

At all levels, the efficient provision of electricity is the aim of all forms of electricity supply systems, whether liberalized or not. The question of efficiency, in terms of the prices paid by customers and their ability to respond to those prices, is central to consideration of the future of the grid.

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[1]The term "improve" is used for want of a better word. The key requirements of a market are the reliable supply of electricity at minimal cost, while ensuring the safety of the community and the industry theory, competitive markets are seen as the solution by economists but in practice, governments and communities may not always seek the best outcome but rather a good outcome.

[2]For example, one response to high prices is the fitting of LED lights or other energy use reduction, which is economically efficient. Another response is the adoption of PV generation, which can, in the absence of correct charging (see [9]), reduce costs to an individual connection while increasing costs overall.

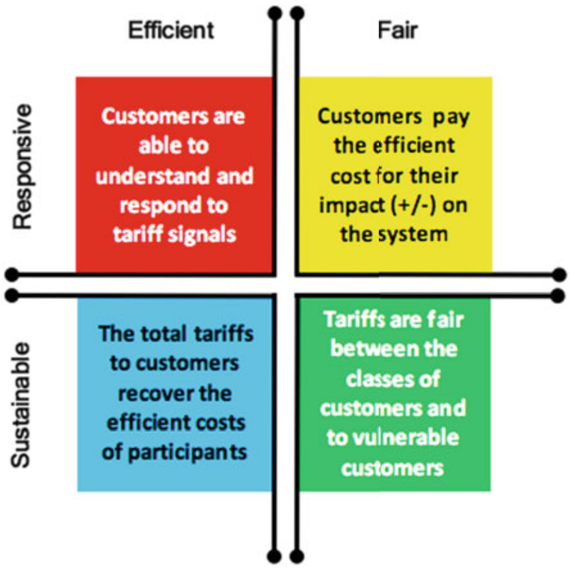

Fig. 1 Efficient prices from TB 747

When Working Group C5.16 examined retail pricing, discussed in Sect. 2.2 below, they prefaced their technical brochure (29) with a discussion of the efficiency of the entire grid in its supply to end use customers.

The working group noted that efficient supply systems had been described by many authors, for example, Bonbright [20], Simshauser [21], and Farugui [22]. The working group summarized the discussion into Fig. 1, noting that the essential features of efficient supply are that:

- Efficient costs of the entire system are developed and fully recovered for a sustainable and efficient system;
- Tariffs should be fair between customer classes, noting the need to support vulnerable customers, so that system was sustainable and fair;
- All customers should pay or be paid the total efficient cost of the impact of their connection and use of electricity for a fair allocation of system costs and to allow customers to gauge their impact when they make decisions; and
- Customers should be aware of their impacts and be able to be rewarded if they act to minimize their impact, when compared to other costs, allowing efficient use of energy.[3]

The technical brochure noted that efficient tariff, according to the literature cited above would comprise four elements:

- A **fixed charge** to recover costs that were nor specifically related to the actions of customers but that were efficiently occurred, e.g., systems costs;

[3]This is the subject of a review by Oakley Greenwood on economic integration of DER [24].

- **Demand charges** to recover costs that were incurred due to the need for fixed assets to generate and transfer the capacity required by customers;
- **Variable costs**, possibly time of use based, to recover costs that were related to the energy consumed at a site; and
- **Policy levies** to recover the imposts of regulators and governments for environmental, social, and other policy reasons.

The technical brochure noted that few tariff regimes clearly delineate these four elements at the small customer level with commercial and industrial customers having more efficient tariffs. Some, particularly European tariffs, contained a measure of demand in the fixed charges, which allowed some measure of efficient recovery.

1.2 Markets to Be Considered

There are two levels of markets to be considered:

- Wholesale—the dispatch of supply to meet demand. These markets dispatch large-scale (usually >10 MW) generation and other electricity supply sources to meet the net operational demand.
  The role of the market and system control is to set the price of electricity that is consistent with an optimal dispatch of energy while ensuring system security. They are also a driver for many investment decisions. The role is both economic and operational; and
- Retail—the trading of energy to and increasingly between customers. Traditionally, the role of retail supply has been to break up wholesale supply to the smaller packages for supply to customers. Beyond supply-cost recovery, retail contracts also aim at delivering economic signals that end users can assess to take efficient investment and operational decisions. Increasingly, smaller-scale distributed generation[4] resources are providing supply within the distribution network and are part of the retail market.
  Some markets are developing for direct sales between customers or to purchase supply from customers. The retail supply is therefore a combination of energy purchased via wholesale markets and from customers with the intent of optimal pricing and efficient supply. This is best summarized:

> From a regulatory perspective, retail models should ensure affordability and sustainability while maintaining reliability of electricity supply; they should enable customers' empowerment, energy transition policies encouraging higher integration of Distributed Energy Resources (DER) or energy efficiency and better access to the market to new actors such as aggregators, local authorities and consumers. Bialecki et al. [1]

The role of markets is also influenced by community expectations for services. Electricity has become an essential service, which means that its reliable supply is

[4] Larger generation, although within the distribution network, may be settled in the wholesale market.

considered to be part of a developed community and the lack of supply, whether at the personal level or for a community, is considered a serious problem.[5]

Note that not all countries or regions within countries use markets for electricity, optimizing dispatch using other criteria and ensuring reliable supply. Working group C5.17, which was investigating capacity remuneration, found that 5 of the 31 markets they surveyed (16%) were not liberalized,[6] that is open to competition for supply.[7] The World Energy Outlook 2018 [12] reported that 46% of regional electricity supplies are not liberalized, suggesting that countries and markets reporting to CIGRE surveys are not always representative of energy supply systems generally.

Working groups C5.16 [9] and C5.19 [5], which were examining retail pricing and demand response found that 85% and 73% (respectively) of surveyed markets had retailer choice for their customers. These figures relate to primarily liberalized markets, where supply competition is also available. While WG C5.16 reported on all of the EU countries and some other markets, markets not covered by CIGRE membership were not included.

We note that environmental policies are tending to increase the imposts on the electricity bills, again leading to higher priced energy for consumers. The imposts can be in the form of obligations to use specific technologies, such as low emissions, but also can restrict the technologies, such as restrictions on the use of nuclear or coal technologies.

1.3 Causes of Market Development

As noted above, the development of markets and regulations in electricity are therefore governed not only by changes in available technology but also by government policies, community expectations, and social factors. Working group C5.20 examined market changes and their drivers and noted that, while environment and technology influence the changes, the market operator and governments actually tend to make the changes, not consumers and participants, who provide the pressure for the changes.

They noted in their conclusions[8]:

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[5]For example, in Australia, a recent rapid increase in prices combined with a lowering of market reliability has resulted in the threatened reintroduction of price regulation in some states and the introduction of reliability obligations on market participants—a retreat from the pure economic market to a more centrally planned market.

[6]TB 647 [4], page 6. “Not liberalized” includes multiple vertical monopolies service areas within a country or region as well as single monopolies and government owned suppliers.

[7]While all but two members of the EU have liberalized markets and there are some liberalized markets in Asia, North America and South America, many countries retain monopoly suppliers. Only markets and countries that are members of CIGRE respond to these surveys and, therefore, the sample will contain a larger proportion of liberalized markets.

[8]Based on the conclusions in the executive summary of Technical Brochure 709 [7].

- Although one objective of markets is to disaggregate decision making and allocate risks away from central parties to where the risks can be better handled, it appears major changes are driven by central authorities;
- Consultation is very valuable in ensuring development of workable rules but can also be a barrier to reform if market actors are faced with repeated calls for input;
- Consumers will ultimately hold governments and their agencies responsible for poor electric reliability, insecure power system operation and affordability. Therefore, governments and their agencies are likely to be conservative by promoting change, perhaps ahead of other actors (e.g., generators/retailers) who are not held directly accountable; and
- It is inevitable that major change is complex and that the changes in physical or financial operation can lead to unintended outcomes. The Working Group sees merit in designing markets for typical conditions (which of course may change) and protecting against extremes rather than designing for worst case but providing no mechanism to respond to extreme conditions.

The current developments in the grid, with accelerated increases in renewable and intermittent generation due to environmental policies, are leading to higher prices (including levies related with the achievement of policy targets) and reduced grid resilience leading to reduced confidence in pure markets[9] where they currently exist to address the energy transition challenges. This will be noted in the description of the current state of affairs in markets and regulation but not in the description of the end states described under the two scenarios.

The need and volume of subsidies and regulations promoting some technologies and restricting others is usually transitionary and not an issue for the long term. Nevertheless, it is not always clear how these developments will progress where they are subject to political processes[10] rather than economic factors.

This chapter therefore notes political and social influences but assumes that economic drivers and the advances in technology will be the primary factors for consideration for the grid of the future.

[9]Note that this chapter, while noting the impacts of environmental policies and legislation, including Anthropomorphic Global Warming (or Human Caused Climate Change), will not address this issue directly. This is the role of Study Committee C3 Power System Environmental Performance and is included in Chapter "Power System Environmental Performance".

[10]For example, while most developed countries have signed the Paris Accord on emissions reductions, the USA a large emitter and a developed country has not. It is, however, significantly reducing its emissions due to the structural shift to gas fired generation, driven by low cost sources as well as significant state level actions on renewables. In addition, other countries, such as France and Australia that are both signatories to the Accord, are facing difficulties at the social/political level from implementing the necessary reforms. The outcomes of the Accord are also heavily influenced by other countries emissions reductions, particularly high emitters that are not signatories.

1.4 The Structure of This Chapter

In this chapter, we will examine the current issues with the change to the mix of supply types, including an increase in embedded supply and demand response. Other chapters will cover the issues of technical integration of new technologies. We outline the current market and regulatory states at a general level and examine what market and regulatory features are required to achieve the two end states postulated in this book based on general reviews, such as the Australian Future Grid Forum.[11]

1.5 Sources of Information

This chapter contains original ideas from members of SC C5, but sections and data have been drawn from relevant papers to the CIGRE Session in 2018 and technical brochures developed by recent working groups. These technical brochures are listed in the bibliography, and specific references will be noted in the text, including the relevant working groups.

2 Current Markets and Regulatory Approaches

There are a number of criteria to compare the potential future of the grid to the current grid operations. For markets and regulation, this is complicated as there are a number of forms in countries and regions. Key characteristics are:

- Monopoly or liberalized wholesale market;
  - Form of the market and management of risk;
  - Mechanisms for ensuring capacity;
  - Integration of renewables; and
  - Efficiency of pricing;
- Retail competition and the form of the retail competition;
  - Form of the retail markets, including “beyond the meter”[12];
  - Efficiency of pricing and management of risk; and

[11] The Future Grid Forum [15] examined the future market and grid in Australia using four potential end states (discussed later), two of which are similar to the potential end states in this book. Other countries have also conducted similar reviews, each considering, like this book, how technical, industry and political changes will impact the future of the electrical system.

[12] Beyond the meter operations refers to trading within unregulated networks, known as embedded networks in Australia and private networks in some countries. The increasing role of these networks as effective microgrids is being increasingly reported, for example [1, 2].

  - Integration of distributed energy resources, including demand response and the used of storage (DER).

- Interconnection and trading between markets and countries.

These factors are discussed in the following parts of this section as well as in the discussion of the two options. They are also referred to in the discussions of country developments but less directly.

2.1 Markets and Reliability of Supply

Where market exists,[13] they have the role of ensuring resources are available to operate and efficiently dispatched to optimize and maintain the grid. How markets do this varies depending on their forms and future markets, whether centralized or distributed will need to meet these requirements.

For this chapter, we will define markets by:

- How the pool or balancing market is operated and settled;
- Whether capacity is remunerated separately; and
- How ancillary[14] services are provided.

2.1.1 Market Balancing and Settlement

Gross Dispatch and Settlement

In the Australian NEM, all energy is traded via the wholesale market and the market operator dispatches and settles all of the energy traded. This approach is sometimes referred to as a "gross" market as the gross value of the energy traded is transacted via the market operator.

In this market, all generators offer their plant to the market and are dispatched by the market operator. Each retailer is then required to pay the market operator the full value of the energy purchased during a trading period (in the NEM it is a week). The market operator, having collected the monies from the retailers, pays the generators for the energy dispatched.

As large amounts are potentially owed by retailers at the end of each trading period, there are prudential arrangements to ensure that there will be sufficient funds

[13]As discussed in Sect. 1.1, half of the energy systems do not have markets. In these systems planning and the development of capacity is done by the grid operator or government. This chapter will assume that the forms of market in 2050 are mostly competitive.

[14]Frequency control, system restart, voltage support services. These can also be referred to as spinning reserve and other terms. The concept of system strength is being is being incorporated as well.

to pay the generators and defined approaches to manage participant risk [10] and retailer default [11].

In this form of market, participants establish financial contracts between themselves to manage their risk exposures. These contracts may be directly established between participants, termed “over the counter contracts (OTC)” or traded via an exchange such as the Australian Stock Exchange (ASX) or the European Energy Exchange (EEX). These arrangements are discussed in TB 667 [10].

Net Dispatch and Settlement

Other markets, like PJM[15] and the GB balancing market,[16] only trade balancing amounts. In these markets, participants establish physical contracts for supply between themselves and supply the grid operator with generation and demand schedules for each trading day. Prior to the delivery period, the grid operator sums the various generation and schedules as the basis for dispatch and then adjusts the generators, including some that only participate in balancing, to meet demand in real time.

Retailers pay the net difference between their lodged schedules and their actual demand on the day, and generators are paid the net difference between their lodged schedules and their generation on the day. Note that the settlement amounts for each party can be positive or negative.

As the amounts transacted by the market operator are dramatically smaller than in gross settled markets, the prudential arrangements are often less formal in net markets. Technical brochure 667 describes these arrangements in more detail.

In net markets, participants often do not contract to cover their exposures to the balancing market as they can be quite small[17] since the bulk of the energy value is traded bilaterally. If they do want to manage their exposures, they use the same tools, OTC and exchange products, that are used in gross markets.

2.1.2 Remuneration of Capacity in Markets

Markets can be also described in terms of how they remunerate capacity. This was the subject of technical brochure 647 [4], which found that, while there were energy-only markets, like the Australian NEM and ERCOT, and long-standing markets with separate capacity remuneration, like PJM, markets in Europe that had been focusing on energy and balancing reserve were now starting to separately remunerate capacity.

A general characterization is that markets that evolved, like PJM, where existing entities start sharing reserves and that morphs into a market, tend to have separate

[15]PJM is a transmission interconnection based market for seven states in the North Eastern part of the United States of America. It is centered on Pennsylvania, New Jersey and Maryland.

[16]There are some differences between the markets. Some, like PJM, dispatch all generators on the day based on a common price established in a day-ahead market. In the GB market, generators opt to participate in the balancing market, which has a separate price.

[17]There are examples of parties in net markets only operating in the balancing market. In these cases, they would utilize contracts to manage their risks.

capacity remuneration. Markets that are designed, like the Australian NEM and the UK market, tended to be energy only. This was based on:

> … under ideal conditions, electricity spot markets provide efficient outcomes in both the short and the long term, meaning that they lead to optimal investment in generation capacity, both in terms of volume and generation technology portfolio. This theory stands; the question is whether it applies in practice, or whether real market conditions deviate too much from the ideal situation. The belief that unregulated markets in electricity generation can produce an optimal outcome in the long term used to be widely shared …—TB 647 page 16 [4]

The increase in the withdrawal of thermal resources due to high levels of renewable generation penetration, and price caps in some markets, has led to general adoption of separate capacity remuneration schemes in Australia, the UK and some European countries as the proportion of reliable, dispatchable plant has decreased. This trend can be expected to continue. In addition, if the trading group size reduces, as option 2 suggests, the need to explicitly fund capacity increases.

2.1.3 Ancillary Services

To maintain reliable supply, there are a number of services that are required by the electricity system that need to be funded via the market. These will have been discussed in Chapter "Power System Operation and Control", particularly the increasing requirements for services that maintain the strength of the system, which used to be provided routinely by synchronous plant.

Funding these services is an essential component of markets. Where possible, these services are incorporated into markets and purchased in conjunction with capacity and energy, ether in parallel with these open offer markets or separately via tenders. Some services, however, are not capable of market provision and have to be purchased through regulatory requirements.

It is beyond the scope of this chapter to deal with the range of ancillary services other than to note that the range of services required is changing due to the increase in intermittent and asynchronous resources in the grid and that all of the services will need to be funded. Chapters "Power System Development and Economics" and "Active Distributed Systems and Distributed Energy Resources" will cover the changing nature of ancillary services provision.

For this chapter, we will assume that the necessary range of services will be defined, and that funding of those services will be part of the market design.

2.2 Retail Contestability and Pricing

Many working groups in market areas note that full retail contestability is not universal. As discussed in the introduction, 46% of markets are not liberalized and

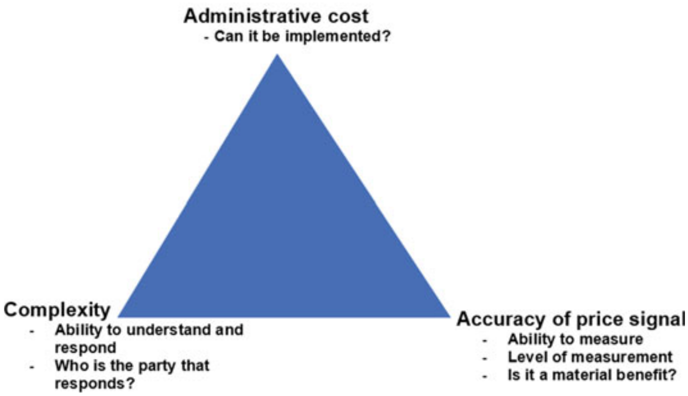

Fig. 2 Tariff trade-offs for customer pricing [24]

of the 54% not all are fully liberalized. Liberalized markets may still have non-competitive prices, but where they do, the combination of efficient wholesale pricing and competitive retail prices should yield the most efficient price for customers.

Working group C5.16 [9] looked at retail pricing, particularly small customer pricing, noting that it was often inefficient. This was independent of the liberalization of the market, although competition for customers should drive efficient prices.

A key consideration is that efficient pricing should provide the optimal use of any system and that efficient tariffs should empower customers to make the best use of the grid and to invest appropriately so that they are part of optimizing the system as whole.[18]

In establishing prices, however, there is almost always a range of potential price signals that could be used to facilitate more efficient outcomes, but these have to be adjusted to meet the circumstances and customer size [24] (Fig. 2).

Generally, developing efficient pricing structures involves making trade-offs between efficiency and:

- **Complexity**. Are the tariffs and rules too complex for the customer to be able to understand them and respond?
- **Accuracy**. Is the tariff element able to be measured so that the tariff is accurate? and
- **Administratively feasible**. Can the tariff be efficiently levied or is the cost of recovery greater that the pricing benefit achieved?

The trade-offs are impacted by the size of the customer. Industrial customers tend to have staff to manage their costs, and suppliers are likely to be able to cope with complexity. In addition, they will normally have higher level metering, and the profit margins on their supply would support more complex tariffs.

[18] Paraphrased from Farugui "Bonbright Revisited" [23].

Smaller customers are increasingly being targeted by intermediaries and aggregators [2], who build up portfolios of customers so that better pricing options are available. The does not necessarily mean the use of microgrids, but microgrids may assist in better pricing.

The key point for retailers, intermediaries, and end use customers is that the efficient cost needs to be available at the retail level and be couched in form that allows empowered customers to interact efficiently with the grid.

2.3 Distributed Energy Resources

Distributed energy resource (DER); PV generation, standby plants, co-generation, storage and responsive loads are increasingly part of electricity systems as their costs reduce, the unit sizes match smaller loads, and integration tools become available.

DER from industrial and larger commercial sites has always been available and incorporated into the electricity market to a greater or lesser degree. The key factors causing their increased penetration now include:

- Reduced prices, allowing them to be cost effective as part of a customer energy package;
- Smaller unit sizes that allow their integration into customer sites, often without export to the grid and the complications that entails;
- Better control systems that allow more efficient control of DER as part of site operation; and
- Renewable energy subsidies.

Not all of these factors are present for all installations. A key factor for many sites is the subsidies for both the capital costs and the prices paid for renewable generation and, in many cases, responsive loads.

Regulation of these installations has so far lagged behind the installations and many countries are reporting issues, particularly with high penetrations of PV generation, as most of the current inverters are not controllable.

These issues are, however, being addressed technically (with better inverters) and through improved pricing. As mentioned in the previous section, improved pricing could cause better decision making for PV installation. The issue of subsidies (see next section) needs to be addressed, however, before efficient integration can occur.

Working group C5.19 [5] examined the regulatory issues with DER and noted that some countries were effectively integrating DER. The key factors were the use of specialized resources (aggregators or demand-response providers) and fitting the type of demand response to the relevant market.

It was noted that uncontrolled DER did not increase economic welfare in general after a defined point (that differed for each market) but that controlled DER can add significant value.

2.4 Market Distortions

In Sect. 2.1.2, above, we noted that energy-only markets are very efficient in developing and remunerating capacity, *under theoretical conditions*. We also noted that some markets are abandoning the concept of energy-only markets due to real-world impacts of increased variability in supplies, lower rates of capacity formation, and higher investor risks related to political intervention.

2.4.1 Price Caps

One of the well-known market distortions to efficient markets is price capping. To work effectively, energy markets need to allow the price to range freely from the value that will cause unnecessary generation to depart (or load to increase) to the value that will cause investment in generation (or load reduction). Price caps and floors restrict the range of prices causing the need for additional mechanisms for managing capacity.

In theory, the maximum price in markets should be unlimited, but at least the value at which energy users will voluntarily stop using energy. In Australia, this is known as the Value of Customer Reliability (VCR) and in other countries the Value of Lost Load (VoLL). In practice, this is rarely achieved as the risk for market participants can be too high, leading to some restrictions.

Working group C5.23 [12] examined this issue. They noted that the market arrangements, discussed above in Sect. 2.1, were a key factor as well as participant structure issues, such as vertical integration and ownership of the assets. A summary of the findings is on page 6 of their technical brochure (TB 753 [12]):

> It was found that for the vast majority of countries and regions surveyed, market price caps are implemented for market power mitigation and to protect load from supply resources being able to raise the price in situations when they have market power. Very few markets set caps that reflect the VoLL to the customer, nor do they even have any information of what the VoLL is for their region.
>
> Current trends across all countries and regions are that market price caps are rising over time. In addition, price caps in Europe are converging toward common values with the recent Agency for the Cooperation of Energy Regulators (ACER) decision No. 04/2017 for single day-ahead coupling (SDAC).[19] It is likely that these trends will continue as wholesale electricity markets continue to evolve and regulators and government authorities become more assured with their operations.

That being said, the working group noted examples of regulators and governments using modeling and other tools to ensure reliable supply and that this was included in decision making for price caps.

[19] Single day-ahead coupling (SDAC) is a coordinated electricity price setting and cross-zonal capacity allocation mechanism, which simultaneously matches orders from the day-ahead markets per bidding zone, respecting cross-zonal capacity and allocation constraints between bidding zones.

2.4.2 Subsidies

A large, emerging issue, driven currently by environmental policies, is the impact of subsidies on investments in other competitive assets. While government and other subsidies are not new as various industries have been subsidized for job creation or other reasons (e.g., biofuels have been subsidized to support the production of corn by farmers), the impact on energy markets has been significant.

Subsidies on renewable investments are often hidden away, and the impacts not well understood. For example, in South Australia, the Renewable Energy Target has led to a very high penetration of intermittent energy leading to a reduction in grid stability. While not directly responsible for the recent blackouts in SA, the reduction in system strength was a contributing factor.

The subsidies to renewables have a more direct impact causing a loss of thermal plants, which has been noted in many countries, for example, in the USA:

> I have solar on my house. I've supported wind generation. But, we cannot underestimate the escalating costs as we more deeply penetrate the market with [renewables]. So, where Indiana is now is where Texas was a decade and a half ago, making decisions about really big, weighty, costly things; and, I'd simply ask, look to Texas and learn the lessons from it. …
>
> … The biggest miss, other than transmission, the impact of subsidization. I think you all know this but when you get $23 a megawatt hour for putting wind on the grid, in the form of a subsidy, and the price of electricity drops low, and you only get that subsidy if you generate, you bid the price of electricity negative.
>
> You literally, in the Texas market, see one out of every three bids negative. In other words, paying to stay on the grid. So, that has two effects. One, it destroys and distorts the marketplace and, two, it erodes the capital of existing thermal: nuclear, coal, and I will tell you new gas. …
>
> … people and banks are not going to invest in a marketplace where a subsidy is driving the price of electricity to below zero. Guthridge et al. [17]

Subsidies are political/social impact on markets and always create distortions in markets. Many, such as low-income rebates in some countries, are supported by the community. The key issue is to ensure that their existence and impacts are understood, and the benefits outweigh the market impacts and costs.

3 Future Scenarios and Their Market and Regulatory Requirements

A key consideration is, if we are looking at two potential futures,[20] what market and regulatory conditions would be required to support those futures. The chapter will therefore also consider whether there are preferred regulations and market

[20]We note the discussion in Sect. 1.1, that noted that some regions and markets are not pursuing competition and where there may be little scope for fully decentralized approaches. There will still be, however, opportunities for distributed control within centrally operated markets.

approaches. The two scenarios will be covered in Sects. 3.2 and 3.3, with a summary in Sect. 3.4. The two scenarios will, however, have a common set of general factors, which are covered in Sect. 3.1, below.

A Continuum of Outcomes

The key parameters will be whether control and settlements are focused on the center of the market or grid, or if they are decentralized with the focus at the edge of the grid. The two scenarios will require different regulatory approaches to support the focus required for the two cases.

As will be seen, it is not necessarily a choice between two stark options but rather a description of two sides of a single market design, differentiated by how the markets are managed and settled. In fact, it is likely, that both approaches will be used for different countries and markets and, potentially, even regions within countries.

The regulatory approaches in countries and regions should be sufficiently advanced to allow variations of the two options to coexist and potentially move between the options as technology, pricing, and reliability varies.

3.1 General Developments

There are general developments in technology that are occurring and will continue, forcing changes in all markets. Some may be covered in other chapters, but a summary of key changes that will impact markets and regulation is summarized in this section.

3.1.1 Microgrid Development

Microgrids are becoming more common as DER costs and control systems are reducing. Navigant have recently published a report [19] showing that:

> The cost of microgrid technologies continues to drop and the controls continue to improve in functionality. And although regulatory barriers and the long project development cycle still frustrate efforts to move this market into the mainstream, significant progress has been made since Navigant Research first sized this market a decade ago. Different market segments have shifted in prominence over that time period, but what has remained consistent is overall growth across all five major regions profiled.
>
> Among the high level regional findings, Asia Pacific is expected to continue to be the largest overall market for microgrids, with remote segments making up the majority opportunity. North America remains the top market for grid-tied microgrids, as a flurry of projects identified in 2019 increased starting point capacity levels in 2019 beyond those previously forecast. Latin America is the fastest growing market due in part to the major island-wide microgrid program in Puerto Rico.
>
> This Navigant Research report forecasts regional capacity, implementation spending, and business model type by six primary market segments: campus/institutional, commercial and industrial (C&I), community, remote, utility distribution, and military (US only). The study provides an analysis of market drivers, barriers, and technology issues. Global market

forecasts, segmented by region and market type, extend through 2028. Capacity is expected to grow by more than 22% over the forecast. Navigant 2019 [19]

Both of the potential futures described in this book will include microgrids to a greater (option 2) and lesser (option 1) extend. In fact, the development of Distributed Services operators can be viewed as a form of grid connected microgrid.

The development of technical controls is covered in Chapters "Power System Operation and Control" and "Active Distributed Systems and Distributed Energy Resources", but each microgrid will require:

- A means for valuing energy and capacity. Given their small size, it is likely that the two will be priced separately, but if the end user pricing is efficient, energy only may be an option.
- Provision of ancillary and related services to allow the microgrid to operate islanded, if necessary, or to contribute to the larger grid.
- A trusted means of settlement. Parties must be able to be assured that the market will work effectively as a means of trade. Developments of distributed ledgers, like Blockchain, are increasingly allowing for distributed and isolated markets, and it is interesting to note that Southeast Asia is also leading the adoption of Blockchain-based markets.

As noted in the Navigant report, the technologies are advancing and only being hampered by regulatory constraints and the long project lead times. Like the penetration of Blockchain and the adoption of mobile phones versus landlines, the lack of existing infrastructure and rules is a benefit to the development of microgrids and the business case is clearer as the adoption of microgrid approaches can be weighed up against establishing a full, widespread market.

3.1.2 Metering and Measurement

One of the limitations of trading in electricity is the ability to measure the key characteristics; demand,[21] energy, power quality, etc. At the level of the discussion in this chapter, the two key parameters are demand and energy.

For settlement purposes, the meter for each connection (usually for each site but not always) is the key measure and the "source of truth" for trading. Currently, the quality of metering is low across many markets; from incomplete coverage to simple meters that accumulate energy across periods as long as three months. This form of metering limits the ability of customers to interact with the grid as the impact of their actions cannot be accurately assessed.

Increasingly, grids are being equipped with more advanced meters. These can:

[21]This discussion relates to small-scale supplies and loads. Bulk energy supplies use SCADA to assess sent out energy and therefore the capacity being supplied. With increased use of advanced metering and relaxation of some metering standards, it is possible that this level of detail will be available for all forms of supply. This discussion, therefore, focuses on loads and, in later sections, pricing for loads.

- Allow measurement of energy across shorter periods, typically half-hourly but in some cases as finely as five minutes;
- Provide a better estimate of the maximum demands at a site, possibly with a specific measurement;
- Measure import and export separately. This can include separate measurement of generation, consumption, and storage at a site;
- Assess key power quality metrics at the supply point, such as voltage or power factor;
- Include control tools such as:
  - Circuit switching under local or remote control; and
  - Capacity limiting, to limit demand under certain criteria;
- Provide communications between the meter and the meter provider/operator and possibly the customer. This can allow:
  - Remote reading of meter information for settlement and control;
  - Communications between the parties registered to the meter;
  - Remote operation of controls; and
  - Upgrading of meters without attending the site.

Currently, many countries and regions have programs to extend advanced metering to all customers. It is assumed for this chapter that this effectively completes by 2050.

Metering and measurement have extended to device or control system level allowing more granulated trading and tariffs within sites and for EVs and other mobile systems. For example, electric vehicles could meter their own demand and energy at any connection they make with the network and the enhanced communication would allow trading of the energy via the using Web/cloud-based platforms like (e.g., Blockchain) making trading more flexible.

3.1.3 Information Systems and Automation

The automation of control systems for industry, commercial installations, and even to household is gathering pace. It is already possible to control devices in people's homes (and has been for some time), but the use of AMI now allows two-way communications. This aspect of IT development will be covered more in Chapter "Information Systems and Telecommunications".

An example of the use of automation (at a simple level) is provided by the Olympic Peninsula Trial. Households,[22] see Fig. 3, were given access to a simple range of options covering from increased comfort to reduced cost. The households were able to adjust the settings at any time, although most set it once. Household bills reduced around 10%, while the utility noticed an average of 15% reduction in peak demand,

[22] From Smart Grid Demonstration: Olympic Peninsula Project (PNNL, 2007), energyinnovation-project.com.

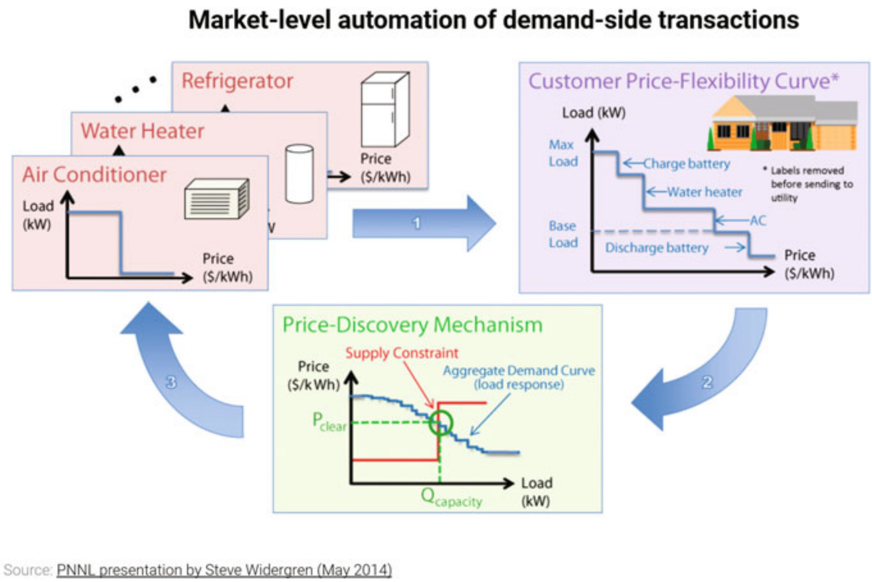

Fig. 3 Olympic Peninsula trial

with 50% on some days. There have been many trials of this form, and they are well documented in the literature.

The key point is that allowing end users to interact with grid participants will allow a more optimal system, given effective pricing. By 2050, this can be expected to be routine and coordination between the energy system and uses will be routine and algorithm based using machine-to-machine interactions (M2M) rather than requiring human oversight of the details.

For example, a person might have a control system that interacts with their load serving entity. They have set a rule that requires their car[23] to be at least 80% charged by 8 a.m. (the minimum to do the days tasks) and to pay no more that 55c for energy prior to 4 a.m. at which time charging becomes the priority. This rule allows the person to be sure that their car is ready for use in the morning at minimum cost.

As part of the either option, the choices that the person makes could be included in the estimates of cost outcomes and impact forward price estimates. All other parties would have similar rules, and as each price perturbation occurs, the system would oscillate and return to a new optimum price for the dispatch/load configuration.

Communication and control ubiquitous. Allow ready interaction between sites and local and centralized dispatch and settlement.

Alternatively, end users may prefer a simpler interface, like that used in the Olympic Peninsula trial, where their energy supplier or aggregator (or Microgrid operator) provides cost minimization services through control devices at the user's

[23] By 2050, it can be assumed that EVs are the norm either for airshed or other emissions reasons.

site. This would still allow two-sided market optimization where DER is included in the dispatch and pricing calculations.

The key point is that ubiquitous communication and control systems, combined with efficient pricing, allow the users to manage their own costs and the market to fully optimize.

3.1.4 Network Constraints

Efficient network pricing means that customers and suppliers fund the efficient development of networks that networks can handle two-way flows of energy, and constraints are at the efficient level that balance generation (local or remote) with appropriate levels of network. The planning and other considerations to achieve this are covered in Chapter "Power System Development and Economics".

3.2 Option 1—A Highly Connected Grid Incorporating Renewables at All Levels

The thinking in this section is based on Transactive Energy[24] in the USA, supplemented by work by CIGRE SC C1 [13] and Task Team 4 from ACTAD (IEC) on Global Electricity Interconnection.

This option is an extension of the current approaches to markets as:

- The grid still has supply side and demand side;
- Pricing of DER is competitive but not reliably cheaper; and
- Large-scale supplies are still needed for industry and large commercial operations.

The developments are the use of communications and DER, possibly via some microgrids, but mainly TSO and DSO operations will provide a two-way market and allow for efficient prices at all levels.

In addition, the current approaches for Global Electricity Interconnection (GEI), being pursued by SC C1 [13] and other parties [26, 27], are expected to have come to fruition by 2050. This would mean that not only would regions like North American and Europe be interconnected but also that there would be interconnections between continents and regions.

[24]Transactive energy is a concept for integrating grid operations. There was a trial, called the Northwest Trial, that tested the concepts across a variety of technologies and a number of states. The trial ran for 5 years and spanned 5 states, involving 11 Utilities (112 MW of assets) a number of technology participants and 60,000 metered users. The study was supported by two universities. The results of the study were collated by Brattle. www.gridwiseas.org.

In almost all cases, the global interconnections are expected to be UHVDC,[25] which will allow cross-border exchanges driven by comparative wholesale market prices. These developments, on top of increasing integration at the regional level, would mean:

- Common pricing across regions with interconnected AC grid, allowing efficient charging within regions; and
- Harmonized (or aligned) regulatory frameworks and pricing mechanisms at the international level allowing price differentials across the UHVDC networks to drive cost-efficient transfers of energy.[26]

At the wholesale level, then, the wide interconnection of energy sources would allow competitive dispatch (competitive markets permitting) of all sources of supply, providing efficient outcomes in terms of pricing. The improved incorporation of DER would ensure that the price was related to consumers value of supply.

In addition, wide interconnection would allow full reserve sharing and a larger grid to absorb intermittent supplies and ameliorate the reliability and system strength concerns. One of the aims of Global Electricity Interconnection[27] is to allow the wide transfer of reliable renewable energy from rich sources (Western China, Northern Europe, Canada, etc.) to areas with high demand but less capability to access reliable renewables.[28]

At the retail level, efficient tariffs based on efficient wholesale prices would allow customers at all levels to efficient invest in local DER and to make efficient decisions on its use. In this way, the grid will allow best use of assets and energy from empowered participants and end users.

The mechanisms for centralized supply will require efficient exchanges for capacity and energy to be in place and for the settlement of those exchanges to be linked in real time so that the true value of energy is known across the entire system. Major developments are expected in terms of governance of electricity markets to achieve the targeted scheme.

The key point is that efficient exchanges and pricing will allow value not technical standards to drive the efficient delivery of energy.

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[25] HVDC is common now as a means of transferring energy. Ultra-High Voltage Direct Current (UHVDC) links are being developed for even longer distances, with some success. In twenty years, this should be standard technology.

[26] It can be expected that some form of efficient charging for networks will develop, including nodal pricing and financial transmission right. For this paper, a solution is assumed, although fully efficient network pricing has been an intractable problem to date.

[27] IEC whitepaper, page 3 [26].

[28] The author recalls a concept developed by EDF to use the, then promising, development of superconductivity to the same end. Like Global Electricity Interconnection, the EDF concept linked continents electronically to allow transfer of, mainly, solar power to provide continuous, renewable supplies. GEI serves the same purpose.

3.2.1 Operation of the Centralized Approach

As discussed above, the centralized concept, termed "Transactive Energy," has been trialed in the USA, via a US-government-funded project, the North West Trial.

The Transactive Energy approach implemented a unique distributed communication, control, and incentive system. The combination of devices, software, and advanced analytical tools gave homeowners more information about their energy use and cost and allowed them to act on the information. The project expanded upon the region's experience in the 2006 Demonstration Project on the Olympic Peninsula, also discussed above, which successfully tested demand-response concepts and technologies.

In the Transactive Energy model,[29] shown in Fig. 4, the Transmission System Operator (TSO) manages the larger grid (and in our model, between the larger grids), while distribution system operators (DSO) manages the local grid, which may include microgrids, power producers, and various types of customers. The network operators provide and manage information flows between all participants in the grid, including market operators, TSOs and DSOs, and retailers if their operations are separated from DSOs (together referred to as MSORs) (Fig. 4).

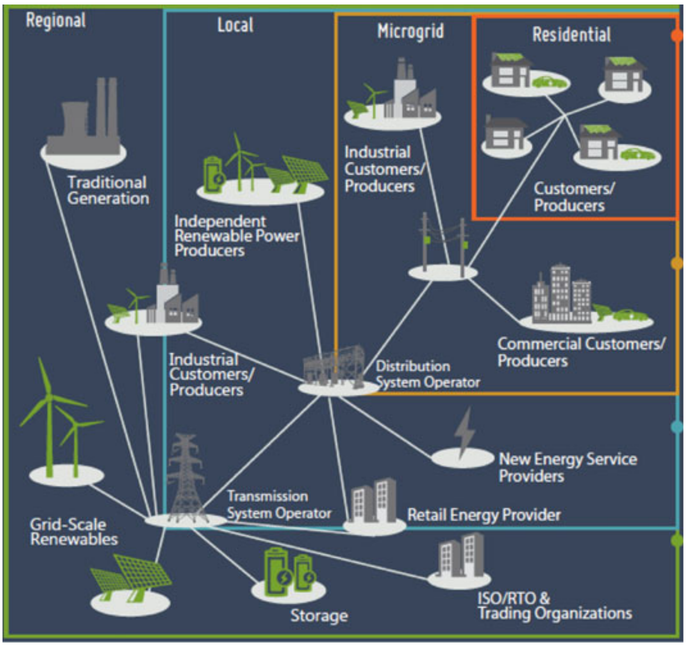

Fig. 4 A model for a highly centralised approach

[29]From www.gridwiseac.org. Adapted from diagrams developed by Battalle, Pacific North West Smart Grid Trial, 2015.

The MSOR systems provide load and the effective local price at each level and site connection point for all parties in the system and, like now, would also provide a forecast of prices for a set of future intervals.

Customers can choose to buy, sell, or store their energy based on dynamic prices and forecasts. The customer chooses how they use their own energy based on their own priorities between comfort, control, and cost. Importantly, they can adjust their plans based on new information.

MSORs in the transactive control area have more resilient grids due to improved DER response and better information for dispatch of grid-based resources. They are also incentivized to provide accurate price forecasts, so that decentralized decision making is efficient.

The trial reported that 97% of participants were happy with the system and technology, and reduced outage times were observed for networks in the trial.

3.2.2 Price Iterations

Prices for customers in this form of grid will be based on the latest information on market and network loadings.[30] While this is common in wholesale exchanges, and conceptually applied for vertically integrated systems, this will be new for all but the largest of customers. This will require improved control systems and automation described in Sect. 3.1.3.

Some examples:

EV Charging

A person arrives home at 6 p.m. and plugs in their car. They tell the system that they intend to charge their EV commencing in 5 min and it will require 4 h of charging.[31] The system responds that the price for the supply at that time, based on the current usage by others and adding the EV load, will be 65c per kWh reducing to 60c at 8 p.m. The system also predicts that the price will be 40c at midnight and remain at that level until 8 a.m.

Based on the prices, the person decides to commence charging at midnight. The system then recalculates and responds that, with that change, the price now will be 55c reducing to 50c at 8 p.m. but rising to 45c at Midnight and reducing down to 40c at 4 a.m. The person is happy with that outcome as it is probably optimal and leaves the system to run.

Optimizing Demand

A person puts on an electric toaster, the control system notes the additional loading

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[30]Note that the market price for dispatched energy could still dominate unless a grid element is stressed or there is an outage but energy price fluctuations in the longer timeframe will assist in moderating peak loadings due to more efficient dispatch and investment.

[31]Recalling the discussion in Sect. 3.1.3, that this would probably be a M2M discussion not an actual human interaction.

and, knowing that a toaster only loads for a few minutes, signals the fridge and air conditioner to not cycle during this period, therefore minimizing site demand.

Similarly, at an industrial site that uses electric presses for manufacturing, when the presses operate during periods signaled by the grid as high demand, the site control system would reduce non-essential supplies to minimize cost and site demand.

3.2.3 Requirements

The range of functions required to manage distributed services was examined by the New York Market Design and Platform Technology Working Group[32] that noted:

> DSP operational functions include real-time load monitoring, real-time network monitoring, enhanced fault detection/location, automated feeder and line switching, and automated voltage and VAR control. The DSP will commit and dispatch market-based DER and integrate net load impact information… thereby providing greater visibility and control of the grid. The monitoring and dispatch of DERs will complement the increased use of intelligent grid-facing equipment such as sensors, reclosers, switched capacitors, and voltage monitors.

The MDPT report[33] identifies a set of core technologies to support the functionalities identified with respect to system planning, grid operations, market operations, and data requirements. The identified technologies include:

- Geospatial models of connectivity and system characteristics, sensing and control technologies needed to maintain a stable and reliable grid;
- Optimization tools that consider demand-response (DR) capabilities and the generation output of existing and new DERs in the grid.

These tools will need to be supported by a secure and scalable communications network and a system that provides forecast as well as current pricing to allow all participants to respond to prices and system demands. This information is already available at the wholesale level, often termed predispatch, day-ahead prices or balancing prices. For fully two-sided markets, the necessary communication and pricing will need to extend to every end user.

3.2.4 Development of New Assets and Governance

The large interconnected system will allow efficient development of large-scale assets based on their cost including the transmission assets to transfer the energy to the regions that need the energy. These will compete with local supplies of energy and

[32] Market Design and Platform Technology Working Group (MDPT) in support of the New York State Public Service Commission's (PSC) Reforming the Energy Vision (REV) proceeding, 17 August 2015.

[33] The report also notes that the North West trial has developed the protocols for DSO interactions as well as the necessary equipment and software to allow these transactions to occur in real time.

DER where there are resources and the ability to use local supplies, potentially augmented with storage for intermittent resources.

The range of technologies and the large number of permutations supply and demand alternatives will need coordination and control. Full optimization of the larger system will need an expansion and development of the coordination that has developed in Europe and North America.

Markets, states, and governments are coordinating developments of networks now, and this coordination will need to extend to the examination of generation and transmission options versus local supplies. The decision making that is currently being done at the country level may need to be centralized into regional districts, like used in North America now. Also, the allocation of risks between generation companies, end users, and system operators may evolve significantly.

This development is important if the benefits described at the beginning of Sect. 3.2 are to be realized.

3.3 Option 2—Loosely Connected Microgrids

The option where the future grid comprises many loosely connected microgrids is predicated on an extension of current developments where:

- The price and availability of DER have increased so that central supplies are needed less and small-scale gas, PV generation, co-generation, and local wind power provide most of the supply;
- Local microgrids develop at the town/community scale using their own range of energy sources and site-based DER to meet the local demand;
- A local MSOR manages the exchange in value and the operation of the grid at the local level; and
- Local markets exchange energy and capacity, not to balance their local grids but purely to optimize the value of grids.
  This approach could allow for long-term supply arrangements between the local grids, but the supplies between grids are managed as if they were generators or load on the edge of the local grid and not essential to the management of the local grid.

The reasons for this form of future grid could be:

- Economic, where economies of scale have reversed and the cost of transferring energy across large distances is greater that the local production, storage, and use of energy;
- Community based, where a values-based[34] approach for sharing energy causes the development of local markets either isolated from the grid or only loosely connected to it; or

[34] A review into the operation of embedded network in Australia by Oakley Greenwood established that some of these partially self-contained networks existed for community reasons.

- Technical, where there are benefits from the ability to separate the grid into separate sustainable sections due to physical disruptions that can cause loss of supply in some areas, for example, in Japan [29, 30].

Many trials of microgrid operations and small-scale grids are used for remote communities and islands [28]. Therefore, the technical requirements are known and can be managed. Other chapters will detail how these capabilities are being developed toward 2050.

For this chapter, it is sufficient to establish how the market will:

- Attract and remunerate the supply of energy, including DER so that the microgrid is able to balance the supply and demand for energy. This is for both:
  - Capacity to meet peak demands (including managing demand); and
  - Energy for meeting dispatch requirements;
- Remunerate the ancillary services necessary to support islanded operation if the microgrid is to truly be self-sufficient and trading and not just a subsidiary grid;
- How prices can be developed for customers and suppliers that meet the economic requirements described in Sect. 1.1, above.

This section will expand on the concepts of microgrid trading to a greater extent than required in the discussion of option 1 because this is a more radical departure from current approaches.

3.3.1 Roles in Providing Microgrid Services

To examine potential market operation within a distributed model, it is necessary to define the roles required to provide the various services. Figure 5 shows a hierarchical system embedded within a smart grid.[35] The system uses five levels from transmission through to the control systems within a facility. This is a complicated scheme covering all layers from processes to market. For our purposes, a simpler, three-level model is sufficient, like that shown in Fig. 6.

The layers, shown in Fig. 6 are suitable for this chapter, since the focus is on customers and the market arrangements. The three layers are:

- The technology layer, which deals with metering, network operations, and security of the distribution system or local network;
- The market operation layer, which deals with dispatch and pricing of energy for the participants of the local grid market; and
- The customer service layer, which deals with interactions between the customer and the market.

[35] Xanthus International Consulting—SIWG Phase 3 Advanced DER Functions—November 2015.

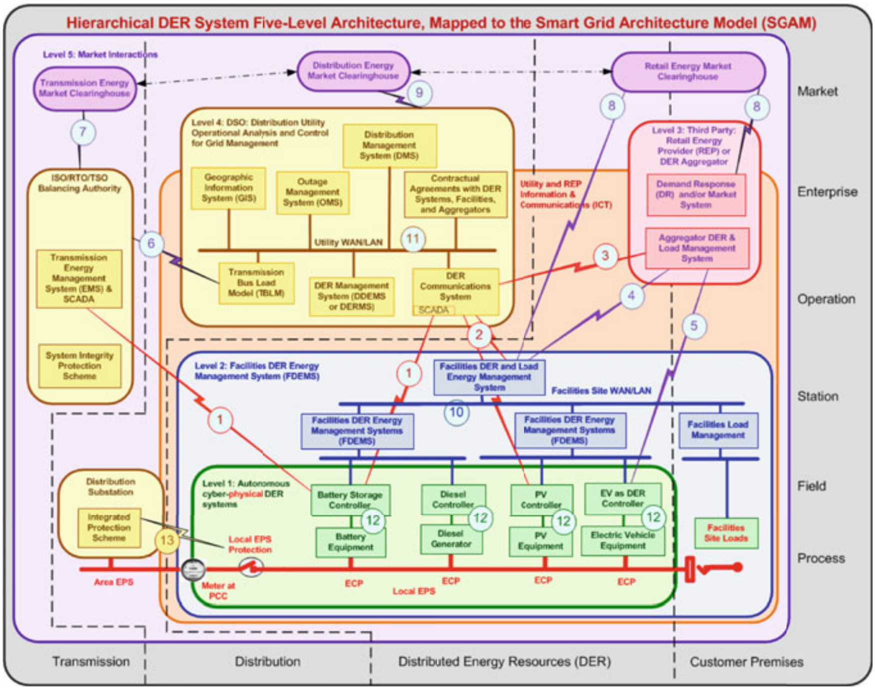

Fig. 5 DER systems based on Smart Meter models

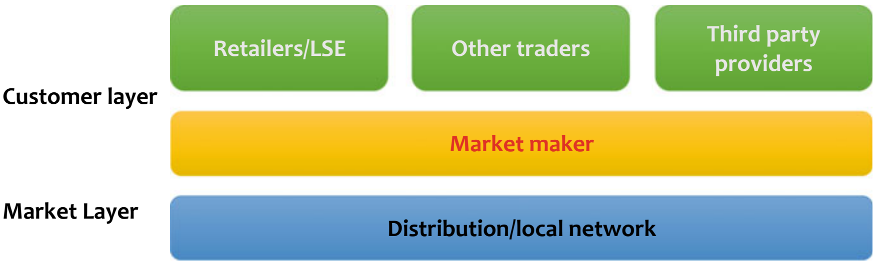

Fig. 6 Simplified operation of distributed market

3.3.2 The Technology Layer

The essential operation of the network must be maintained in any market. The technology layer in microgrid operation therefore covers all of the current grid operations, namely:

- Security of the grid, including management of new connections;
- Switching and load balancing;
- Outage management and maintenance planning and execution; and

- Customer operations requested by retailers and third parties.

The technology layer also supports the market layer. This requires:

- Short-term load forecasting to identify congestion and network issues. This function would take weather[36] and load forecasts and assess critical network elements for congestion and other stresses. It would also use planned outage information to create a network capability map for a defined future period. This information would be updated as circumstances, such as unplanned outages or weather, change.
- Recording distributed energy resource—embedded generation and demand management—(DER) "on" and "off" plans and operations. The planned and actual DER activity timings and quantities are required to forecast loads and for predispatch pricing.
- The network congestion shadow price, which would be combined with the value of supply, calculated in the energy layer, to calculate a price for each connection point for dispatch of energy into the system or purchase of energy from the system. The price would vary from:
  - A negative price, where there is excess supply, to create incentives for parties to reduce supply or increase demand; to
  - A maximum price, up to the Value of Unserved Energy, where supply, including DER, would reduce the network constraints or maintain supply. This price would be communicated to the market layer for incorporation into the customer connection price.
- Metering information on a five to fifteen-minute basis (for dispatch and demand response). The actual metering would be used for settlement, although probably aggregated into settlement blocks.

Advanced metering means that more than one party could be providing metering data at the small customer level, it would be expected that metering would be provided on a competitive basis. This may mean that the actual provision of meters is part of the customer layer rather than the technology layer. This would require some standardization or regulation to coordinate between the market and system operators, if they were separate parties, complicating the operation of the technology layer unless all connected parties are required, as part of their connection agreement, to ensure that necessary data is made available to the technology layer provider.

3.3.3 The Market Layer

The market layer involves:

[36]The exact management and location of forecasting will depend on the model/options chosen. If a fully integrated DSO is used, it would be efficient for all forecasting—load, solar output etc.—would be done in a single group. If the layers are to be separated, then it is likely that the technology layer would be confined to network load forecasting.

- Registration and communication with participant market players. The market operator would record all of the necessary details for participants, including settlement information and prudential obligations. The nature of connected DER and any limitation on its use would need to be recorded much like performance standards are required for generating units now;
- Recording of all supply consumption and other participant actions. Any planned operations of DER and significant (responsive) loads would interact with the market in the same way as major generators to optimize the system operation, to reduce the cost of supply by:

  - Optimizing the dispatch of generation
  - Allowing participants to either to reduce the cost of energy consumed at their site or to maximize the value of energy exported from a site.

  Note that this is recording for dispatch and forecasting purposes, and would be shared with the technology layer operator, not settlement information. Settlement would be based on actual 15-min data provided after the event;
- Calculation of the price at supplier and customer connection points. The market operator would calculate the current and expected price[37] for the microgrid based on:

  - Expected loads;
  - Network congestion and pricing;
  - Expected DER operation and charges; and
  - Regional market operators provide additional schemes to manage security of supply at least cost.

- Publication of current and forecast prices. The market operator will publish the current and forecast prices to participants. The price would be available electronically to all participants and will also be sent via M2M channels to support dispatch and allow DER. The price and forecast of prices would be recalculated when significant changes occur; and
- Settlement of the customer prices. The market operator would need to provide data for settlement between the parties. Settlement could be gross or net, depending on the particular microgrid and their choices of market forms.

Systems to provide these services could be extensive, but the bulk of the necessary protocols and the underlying IT systems are in use in the USA and in Europe now.

Operation of a market, using registered parties, is a form of "exclusive dealing," and therefore, some regulatory and legislative approvals will be required. This will involve defining the rules and operation of the market and seeking authorization from relevant regulatory bodies for the arrangement or gaining legislative support from governments.

[37]Treatment of losses will have to be considered if material in the microgrid. All markets adjust for losses either by varying the price at the connection points or by adjusting physical quantities.

3.3.4 The Customer Layer

The customer layer is similar to the current retail regimes. The parties provide equipment, sales and billing services, and contract with end use customers for the provision of services. In the DSO model, participants in the customer layer could be:

- Retailers or load serving entities (LSE). These licensed entities would provide energy at a price. The contract may include some form of cost reflective pricing (not directly price responsive), pricing for responsive loads using prevailing prices and pricing for DER. The DER pricing would be contract based with prices for reducing a site and prices for export into the grid;
- Beyond the meter providers—exempt sellers or energy providers, where DER equipment is provided to meet the customer needs but they are not the retailer. The DER equipment could be set up to be price responsive or simply to provide on-command DR;
- Demand or generator aggregators. These are parties that split out the responsive load or the DER from the normal loads at a site and aggregate that into marketable quantities. This group of participants would actively work to maximize their income using the price at the customer sites and may contract with retailers to assist them to manage normal risks; and
- Network entities seeking to use DER to manage network issues. In a microgrid, the ancillary services necessary to operation the market could either be contracted directly or purchased in the market.

The customer services layer is where participants would take advantage of the advances in technology, for example:

- Storage, which allows the control and dispatch of other generation sources[38] as well as allowing price arbitrage of energy supplies. Storage would operate based on the price at the node to consume or export energy to minimize cost or maximize profits over a defined period.
  As storage is an energy constrained supply, the key aspect is to store or export at the appropriate times. The provision of forecast prices would therefore allow the use of storage to be optimized;
- Electric vehicles. A special form of storage with both some limitations and also the ability to be located at different parts of a network at different times. The DSO environment will allow flexible pricing for both electric vehicles as a load and as moveable storage.

The participants in this layer will require sophisticated management systems that:

- Allow visibility of loads, DER, and market prices;
- Active and rule-based control over all devices at a site; and
- The ability to interact with prices and forecast prices that come from the market layer of the DSO.

[38] While initially focused on Solar PV or wind, the use of storage on co-generation would allow optimal use of these generators.

These systems and devices are now available in Europe and the USA. Preferably, the systems will use open-source software, to maximize interoperability and minimize the cost of changing providers.

3.3.5 Operation of the Layers

These three layers are currently required for many familiar markets, for example

Service/Operation	Technology layer	Market layer	Customer layer
Central markets, e.g., Australian National Electricity Market, PJM	Grid operations, communication systems, metering, protection systems	Market dispatch engine, systems access. Web publication of prices. Settlements	Customer registration and transfers and related processes, retailer customer systems. Trading rules
Ride-sharing services, such as Uber or Ola	Internet, Web access for operations	Customer and car registration, trip matching algorithm, collections from customers and payment to drivers	Phone apps to allow access, information on car locations, and contract formation tools
Hotel and home share services, such as AirBnB, Booking.com	Internet, Web access for operations	Customer and accommodation registration. Site and customer matching and reservation process. Settlement services	Web site and phone apps for access, review service, contract formation, additional venue services (local guide information)
Distributed System Operations	Distribution utility operation and control systems. Metering providers	Participant registration, forecasting and dispatch, settlements	Retail, beyond the meter services, provision of home energy management equipment and customer billing

The layers for a service can be provided by a single party where the industry is not competitive or by a combination of parties. In the examples shown:

- For the current energy markets, the technology layer is provided by the networks, predominantly, in conjunction with the grid or a system operator. The system operator may also provide the market layer in some countries (e.g., the Australian Energy Market Operator).
- For Web-based services, on the other hand, the technology layer is provided by multiple parties using a cooperative standard, while the Web provides both the market and customer layers. Increasingly, tools such as Blockchain are allowing distributed settlement systems for smaller-scale markets.

For a microgrid, it may be possible to operate without formal competition that some or all of these layers could be provided by one party. Logically, the layers would be provided by:

- The technology layer would predominantly be provided by the distributor or local network provider in the microgrid area;
- The market level is open to a number of parties and could be different for each microgrid. It is likely, however, that standard forms could be developed and provided by a single or a small number of market system providers; and
- The customer layer should be competitive allowing various parties to interact, including LSEs, aggregators, customers, generators, with some regulated oversight to ensure anti-competitive activities do not occur.

It is hard to be prescriptive, but the market layer could be cooperatively owned by the members of the customer layer. This is how markets such as PJM developed. If this was the approach, then, subject to some regulatory oversight, each market would be able to develop their own rules.

The operation of the layers for the DSO model would evolve as the concept is more widely adopted and could involve many parties at the technology level as well as the customer level.

3.3.6 Market-Based Trading Across the Region and Between the Microgrids

Given each microgrid is self-contained, or able to be self-contained, to the point of operating in isolated mode, then trading between the grids is for economic purposes, that is to minimize the overall cost of each grid. For example:

- Two or more local grids trade via a range of collectivization platforms, possibly sharing large-scale generators, such as nuclear facilities or large-scale PV generation. This could be via cloud-based exchanges;
- Local markets with attributes that complement each other, say a hydro-based microgrid and a largely solar/storage grid, agree to share some balancing duties to reduce costs to both grids. This could be season or weather condition specific to manage winter periods; or
- If the purpose of the microgrid is technical resilience, the grids could operate as a combined unit for normal periods but be capable of separate operations when necessary. Each microgrid would be able to operate independently, but the most economic operation would be as a combined unit.

Once there are microgrids operating independently and interdependently, the forms will vary according to the needs of participants. As discussed above in Sect. 3.3.5, there could be standardization if that is economic, but the regulation should be such that a wide range of options is possible. This means that regulation should focus on minimizing anti-competitive outcomes.

3.3.7 Development of New Assets

In this option, assets would be developed cooperatively between the communities and the microgrid operators. The balance between supply from microgrid and shared resources and distributed or customer resources would be based on economic choices of the customers and community rather than central planners. From this perspective, investors may request specific risk mitigation measures.

Of course, like trading between microgrids, it may be possible for two or more microgrids to pool resources and share assets. This would include joint development of network interconnections to allow trading between the microgrids. This is being done between countries and markets and will be possible at the more local scale as well. This is discussed in the next section.

3.4 A Range of Potential Outcomes

In the introduction, it was noted that a large number of markets are not liberalized at all. For these markets, some movement down the option one approach is possible, depending on political developments. It is unlikely, however, that, given the time required to develop current markets, the full microgrid outcome is possible.

In addition, the range of trading between microgrids described in Sect. 3.3.6 suggests that options One and Two are just the ends of a continuum. If efficient pricing is adopted for wholesale markets and current technologies are allowed to develop, the only barrier to the efficient aggregation or fragmentation of markets is regulations that prevent efficient outcomes.

This issue was described in the introduction; political concerns, reliability concerns, and monopoly concerns can all derail efficient market designs and outcomes.

The outcomes in Europe, for example, where efficient markets already exist, would tend toward option one with large-scale interconnection already in place. For Asia (not counting China), the more fragmented approach could be more suitable where large-scale integration is not already underway and it is possible to adopt lower-cost renewable approaches supported by local storage without abandoning expensive infrastructure.

It is therefore likely that describing the two options in this chapter is simply describing the intermediate steps to the longer-term outcomes, shown in Fig. 7.

This was discussed at the recent Microgrid Conference in Newcastle, Australia,[39] where potential future outcomes were discussed and one participant (ABB) gave its own projection of the future, shown in Fig. 8, which mirrors CIGRE's ideas in this chapter and the work of many of the working groups.

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[39]Both Figs. 7 and 8 are drawn from the ABB presentation to the Microgrid conference, September 2017, Newcastle.

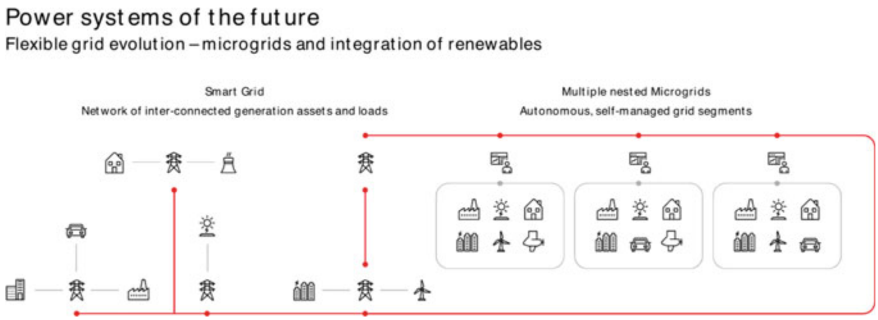

Fig. 7 A range of smart grids and microgrids (ABB)

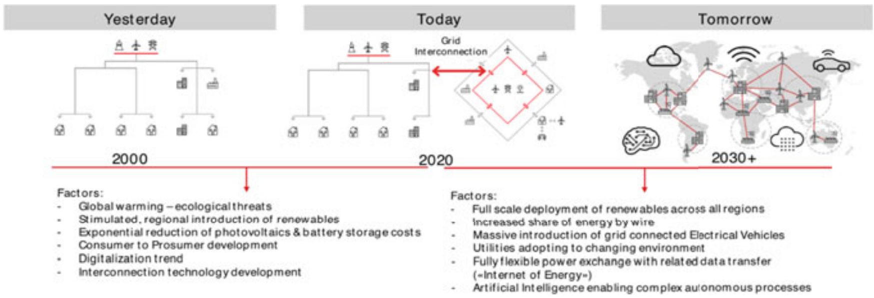

Fig. 8 The future of the grid

Contributors **Country material provided by**

David Bowker, AU
Adam Keech, US
Yannick Phulpin, FR

Editorial panel members for this chapter
Versions of the chapter were reviewed by members of SC C5:

Praveen Agarwal
Kankar Bhattacharya, CA
David Bowker, AU
Al DiCaprio, US
Adam Keech, US
Stefan Linder
Konrad Purchała
Patricio Valenzuela
Jarrad Wright, ZA

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Alex Cruickshank (Chairman SC C5, B.Sc., Dip.Ed., MBA) Alex has around 30 years of experience in energy markets within a range of organizations, including a vertically integrated utility (ETSA), a generator/retailer (AGL), a rule making body (NECA), and government (SA Treasury). Alex commenced consulting in energy markets and regulation in 2016 after leaving AGL, where he had various roles, including Head of Energy Market Regulation. Alex was involved in the initial design of the Australian National Electricity Market; including market design, process optimization, network development approaches, and access rules. He continued in the developmental role with NECA and oversaw all rules change applications and changes. Alex was involved in the market development from a private sector perspective and assisted in the expansion of AGL initially into generation but later into new technologies, holding senior roles in the Corporate Affairs division, including Head of Energy Regulation. In these roles, Alex was involved in developments in wholesale and retail markets and was often involved in working groups and task team examining specific rule changes. Alex and his colleagues are currently completing a study on the economic integration of distributed energy resources (DER) into the Australian market.

Yannick Phulpin (Secretary SC C5, M.Eng. (Elec.), Ph.D.) Yannick Phulpin graduated from both Supelec, France (2003), and TU Darmstadt, Germany (2004), in electrical engineering and received the Ph.D. from the Georgia Institute of Technology, USA (2009). Yannick worked as Assistant Professor with Centrale Supélec, France, Senior Researcher with INESC TEC, Portugal, and Researcher with EDF R&D, France. Since 2015, Yannick has worked as an expert in market design and market integration with the Direction of Optimization and Trading of EDF. He is the Vice-Chairman of the Eurelectric working group "Market Integration & Network Codes," and the French representative in the Eurelectric working group "Market Design & Investment Frameworks." He also contributes to the European Commission's expert group on electricity interconnection targets. He is the Secretary of CIGRE Study Committee C5 on electricity markets and regulation.