# Smart Grid, Future Innovation and Investment Opportunities

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**Abstract**

The electricity industry is going through a massive transformation which is fundamentally changing the way the electrical energy is generated, transmitted, distributed and consumed. This change will bring about challenges and opportunities for the different players in this massive system of supply and demand. The drivers for this transformation are numerous, which include the desire to shift to a more sustainable energy supply, advancement in technology and reduction in cost of renewable energy. Power system operators around the world are dealing with the challenges of operating grids which behave differently compared to originally designed concepts. However, there are vast opportunities for innovation and investments which can benefit from low cost energy. This chapter explores different ideas on how this massive low-cost energy can be harnessed in order to create value.

## 1 Introduction

The electricity grid is commonly referred to as the largest machine mankind has ever created. It is a machine because it works in harmony in its entirety; and there are common figures and standard values that apply to the whole of the grid as a system of various systems. Since their inception more than a hundred years ago, the electricity grids have been merely passive systems or machines that performed as means of transferring the energy of large generators to the end customers. These passive machines started to change in many ways when power electronics enabled a shift from production of electricity of conventional generators to electronic devices

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commonly known as inverters. This shift itself was caused by the development of renewable energy and harnessing the power that exist in the wind and the Sun. Since around two decades ago and most importantly since the last decade, this shift has become so prominent that it is now the single most important factor in transformation of the electricity system from the conventional passive grid to an active smart grid. The smart grid of today enables energy to flow bidirectionally from large-scale generators to the consumers, and from the consumers, who are now also producers of energy, or for a better word, prosumers, to other consumers and to the grid itself. These prosumers do so via their rooftop photo-voltaic devices, batteries electric vechicles, smart appliances and other devices which we now call Distributed Energy Resources (DER).

## 2 Energy Transformation

To manage such a complex system of energy flow, the electricity grids have evolved and gone through a journey of transformation, enabled by advancement in information and communication technology (IT), operational technology (OT) and increasingly importantly data technology (DT). Digitalisation has brought about ample opportunities to innovate the grid and make investments in new business models.

The changes in electricity grids and the shift from production of energy using fossil fuels, to renewable energy resources is generally referred to as energy transformation. This changing energy landscape has transformed many aspects of how we consume energy and the time energy is consumed. It has also transformed, in many ways, the concepts historically used in regulation of energy services as well as their applicable standards. This transformation has created many challenges for the grid operators, as well as many opportunities for innovation and investment. We will discuss these opportunities further in this chapter, but let us see how these changes have affected the energy ecosystem.

Renewable energy resources by nature create a variable supply of energy, because wind does not blow all the time and when it blows its intensity and speed is not constant. The same is true for the Sun, as there are different levels of irradiation in different times of the day, different seasons, and the energy reaching the Earth depends on cloud coverage and other environmental conditions. Currently, grid operators manage the electricity demand levels using a mix of conventional generators which can operate up their maximum capacity levels when required, and the variable renewable generators, which can only operate to a level that their fuel (wind, solar energy, etc.) allows them. The trend in future generation in most advanced countries is a shift from conventional generators to renewable variable energy resources; therefore, in future we will have much more variable generators and just enough fast-moving conventional generators which can compensate for the variability of renewable generators, in order to keep the supply of electricity at the demand level all the time.

Solar and wind energies are in abundance at certain times, and with renewable sources which can supply more than the required demand at these times, there will be an excess in total energy produced during these times. Similarly, there is an energy deficit at times of low energy production. These two effects can create opportunities for innovation and future investment.

## 3 Smart Grid and Renewable Energy

Smart Grid is a concept enabled with the electricity grid transitioning from a passive low-intelligence asset-intensive grid to a high-intelligence active grid. Smart Grid refers to an electricity system which can intelligently integrate the activities of all players involved in the energy ecosystem including generators, consumers and prosumers in order to deliver a secure, sustainable and economically efficient electricity system using intelligent communication, monitoring and control devices, and innovative products and services. The need for Smart Grid came about when customers started producing energy and taking control of their energy needs. In most countries this was due to customers installing rooftop Photo-Voltaic (PV) panels on their roofs to harness the energy of the Sun, or installing smart meters to distinguish between time-of-use of energy or other smart functionality. For some time, Smart Grid was synonymous with Smart Meters, but Smart Grid is now much wider in concept and functionality than a grid which is just equipped with Smart Meters. Smart Grid is an interactive grid capable of variety of functions which may include, but are not limited to, measurement of energy usage, control of appliances and orchestration of the load for various purposes. Smart Grid is both necessitated by, and most importantly an enabler of, integration of renewable energy. Smart Grid has been made possible by advancement in communication technology, enabling the grid operators to understand load consumption and patterns of energy usage. Smart Grid is now a modernised hybrid energy system integrating the whole components of the grid from transmission down to distribution and home appliances. Smart Grid will be much more interactive and modernised in the future by necessity and due to the rapid growth of the DER.

One important aspect of Smart Grid is decentralisation. In most advanced grids which have enabled customers to take an active part in the energy supply and consumption chain, the electricity system and its critical components have shifted from large central power stations to energy generated by small and distributed resources. While in the past decades, the system planners were mostly concerned about load ensuring adequacy of large generators to meet the peak demand, in present times and most critically in the future, the interaction between load and generators at both ends of the electricity supply chain will be important. Given the changing source of energy production from conventional fuels which were controllable, to the natural environment as a major source of fuel, which is uncontrollable, the future generation will be highly variable.

By 2050 wind and solar will make up around 50% of generation according to forecasts of global generation mix, while renewables collectively will form more

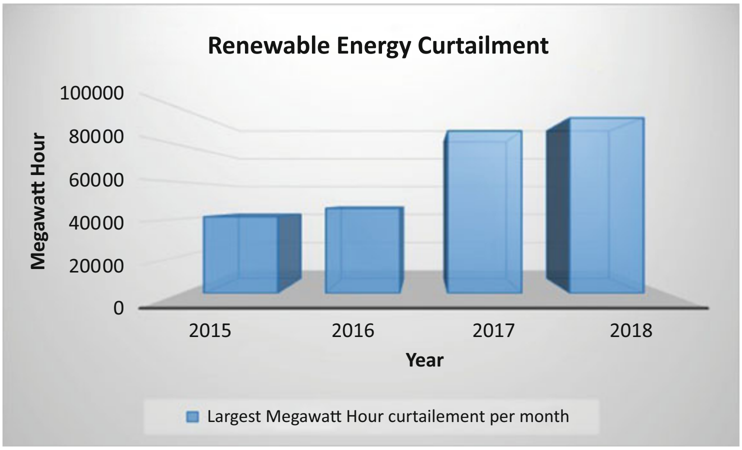


**Fig. 1** Curtailment of renewable energy. Data from California Independent System Operator (2019). Source: author

than 60% of the generation fleet. Nuclear energy will fall to the levels we saw in 1980s and coal generation will have a share of even less than 1970s. The dominant share of generation mix will then become renewables and gas generators such as open-cycle gas turbines. Therefore a massive amount of energy production in energy mix of the future is atmosphere dependent and will be subject to significant curtailment, because at times the produced energy will be in excess of need. The energy systems which have a large share of renewables in their current energy mix have already faced this curtailment. For example, California has curtailed increasing amount of energy from variable sources, year after year since 2014. This excess energy translates into negative electricity market prices during the times of abundance and creates opportunities for many energy-intensive technologies which previously were not economically viable. More details are depicted in Fig. 1.

## 4 Harnessing Variability

An ideal electricity system is one which is secure, reliable, cost effective and environmentally clean. In making an electricity system reliable, the supply (generation) and demand (load) must be in equilibrium all the time. Until about two decades ago, the variable side of this equation was only the load side; the load changed when consumers varied their energy consumption; generators adapted their output to satisfy the demand. With Variable Renewable Energy (VRE), the variability is now on both sides of the equation, namely both the generation and the load sides. In harnessing this variability, there are opportunities on both side of this supply/demand equation that can be used for businesses investment and innovation.

### 4.1 Harnessing Variability at Distribution Grid Level (Small Energy Level)

Distribution Electricity Markets: Electricity markets are now established in many countries in the world. These electricity markets are wholesale markets which can be characterised as a one-way pipeline model, in which distribution connected producers and consumers have no, or limited access to participate in the localised energy systems. There are other markets known as Essential Reliability Services (or Ancillary Services) which can only be accessible to large generators. The energy produced in the distribution grid is exported into the network, which acts as an infinite storage. The PV owner who produces this energy can only trade the energy with the local utility/retailer. This one-way pipeline model has worked relatively well since the inception of the electricity markets under the traditional structure of the electricity supply system, because the share of DER in the supply–demand equation has been relatively small. With the rapid growth of DER (PVs, electric vehicles, battery storage, etc.) these technologies are increasingly being connected by many businesses and homes who were traditionally passive energy consumers. These energy prosumers are now able to generate, convert and store energy. Aggregation to a large level will enable these small energy producers to become active participants in the future distribution energy and ancillary services markets. The current pipeline model shifts all energy trading to the wholesale markets which were designed based on traditional supply–demand equilibrium using price and quantity as the only metrics for energy trading. This has worked so far because supply has always been dispatchable and the demand has always been assumed inflexible. This situation has changed drastically with VRE, such that supply is variable (not dispatchable) and demand can become flexible to match the variable supply. Current reliability standard requires supply of the load almost 100% of the time, assuming an inflexible load, whereas in reality, there are many types of loads with varying degrees of tolerance to supply reliability. The examples of such loads are pool pumps, electric vehicle charging, water heaters, home energy storage, etc. for which time of service/reliability can be flexible. In order to realise the full potential of the DER and their variable nature, new business models and innovations need to be developed. Energy trading can be made more sophisticated than the traditional wholesale markets through innovative approaches, enabling reliability as a new metric for trading of energy in addition to quantity and price. In such a model, distribution connected generators can trade locally with other distribution customers to maximise the full consumption of their energy resources, as well as full financial benefit. A business model which can facilitate such interactions using digitalisation (cloud computing, machine learning, data science, blockchain technology, etc.) can derive the full value of excess energy of renewables which currently may only be exported into the transmission grid. This excess energy currently is exported to the grid reducing daytime operational demand, creating an undesired phenomenon commonly known as the Duck Curve as depicted in Fig. 2.

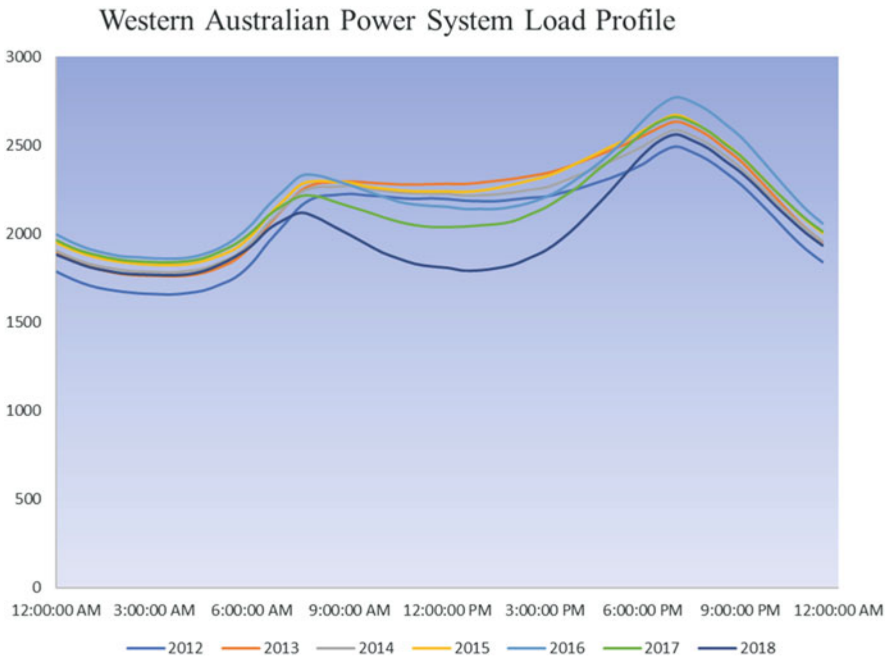


**Fig. 2** Sketch of the Western Australian power system duck curve. Reduced operational demand during daytime due to increased penetration of DER. Source: author

During the low operational demand times, the electricity prices are very low or even negative. Any business model able to create flexibility in load, both behind-the-meter and at large-scale levels, in order to match it in real time with the supply, can gain from the low or negative energy prices. This can be done by understanding load patterns and characteristics at the grid and home level using accurate forecasting, Data Science and Machine Learning. The objective will be creating a flexible load through communication and control of home smart appliances, routing energy to certain types of load when required and redirecting the energy generated inside the house to the grid, when this energy can help to stabilise the power system. An example of a load which has a large tolerance to low reliability is a water heater acting as a resistive load and an effective energy storage. Energy routers which can act like internet routers can facilitate this objective. For example, an electric water heater can be fed through an energy router capable of measuring the grid metrics such as frequency and voltage in real time. This router can supply part of the energy generated by DER to the water heater; and redirect the energy from the water heater to the grid in a fraction of a second, acting as a means of firming variable energy. Further innovation can be the transformation of the current technology of home cooling into a technology based on freezing liquids such as water, which can capture a large amount of energy when it turns into ice. This cooling process can work with variability of DER generation as it has a large tolerance to low energy reliability and is not strictly time critical.

There are also many opportunities to harness the variability of renewable energy at large energy levels. Some of these technologies are mentioned below.

## 4.2 Hydrogen Production

Hydrogen can be produced by electrolysis of water and splitting it into the atoms that make up water molecules, namely oxygen and hydrogen. This process is very energy intensive and the high cost of this process has so far made it uneconomical. However, with the advent of renewable energy and their zero-emission technology as well as abundance and low cost of production of energy from these sources, hydrogen production has become more viable in the last few years. The performance of hydrogen production and the efficiency of the process has also considerably increased. In Australia, where the proliferation of renewable energy industry has transformed the power system and has opened a new era in clean energy, hydrogen production using zero-emission energy has been given the name of "Liquid Sunshine". This is due to abundance of solar energy in Australia where practical research, trials and technology innovation has vastly emerged around hydrogen production value chain. Conversion of hydrogen as a gas into liquid has also created other opportunities for storage and transport of this high-energy density fuel, using existing gas networks. Moreover, hydrogen as a gas can be directly injected into the domestic gas network and used as a natural domestic fuel for burning and cooking purposes (Fig. 3).

Hydrogen production at a large scale can be a practical way of converting power into gas (P2G) which can then be used in many different ways, including using the gas to produce other types of energy. For example, hydrogen can be used again to generate power for grid stability functions such as ancillary services (P2G2P), or as fuel cells for transport (P2G2T), or heating purposes (P2G2H).

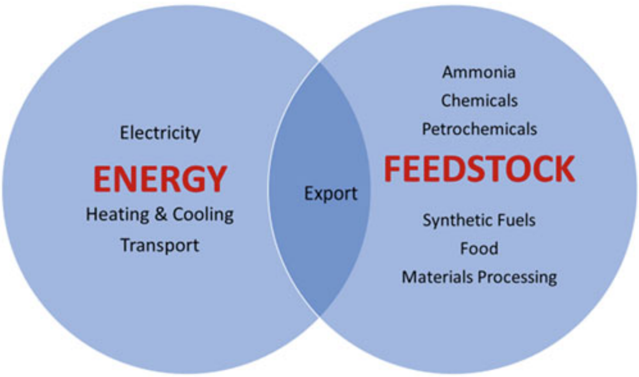


**Fig. 3** Various applications of hydrogen. Source: author

Hydrogen can also be used for optimisation of electricity, gas and transport sectors.

Through a relatively simple process hydrogen can be turned into another useful product, ammonia. Ammonia, which consists of one nitrogen atom bonded to three hydrogen atoms, has many applications in the industry. It has historically been used as a fertiliser, but as a fuel its energy density by volume is nearly double that of liquid hydrogen and it is easier to store, transport and distribute. Ammonia can also be converted back into hydrogen and nitrogen.

## 4.3 Desalination Plants

Water scarcity will be a feature of many economies in the coming years. Population growth, climate change and industrialisation will compound this problem for some countries in the next decade. Some of these countries, such as Middle Eastern or African nations have the potential for clean energy production due to abundance of renewable energy resources. The two major technologies for desalination plants, namely Thermal Desalination and Reverse Osmosis Desalination are both energy intensive and energy price is a major factor in their operating costs. Figure 4 shows the detail and breakdown of the operational costs of desalination plants,

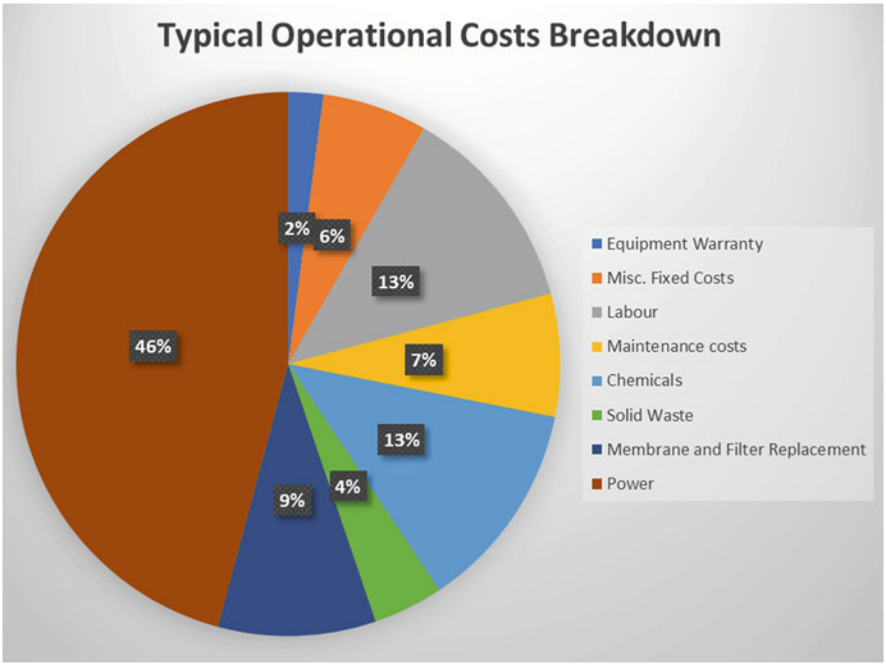


**Fig. 4** Price of energy compared with other operational costs of reverse osmosis desalination plants. Data from Advision (2019). Source: author

demonstrating the major share of energy costs in operation of these facilities. The business cases for these plants are now much more attractive due to renewable energy and abundance of energy during certain times. Furthermore, due to advancement of technologies related to this industry, the capital cost of desalination plants has decreased in recent years. In future, the desalination plants will be using free energy to turn unconsumable water into clean, drinkable water, and sometimes they are paid to do so, when the energy prices are negative. Some of the desalination technologies are more reliant on higher reliability power and some have a degree of tolerance to lower reliability energy. The opportunity to use free energy is maximised by development of small-scale desalination plants with low-reliability energy requirements, such that these plants can operate when the price of energy is low and temporarily stop production when the energy is in high demand. A desalination plant capable to switch off instantly when required can also take part in the Ancillary Services markets and provide power system support functions.

## 4.4 $CO_2$ Extraction from Nature

Chemical industry has a large carbon footprint. Many chemical substances are produced using energy-intensive processes. It is now possible to extract $CO_2$ directly from the atmosphere and through electrochemical conversion, turn it into chemical products and fuels. This process is depicted in Fig. 5 and has two benefits, firstly reducing the impact of $CO_2$ in the nature and secondly closing the carbon loop and turning the waste into useful products. The key to viability of such a process

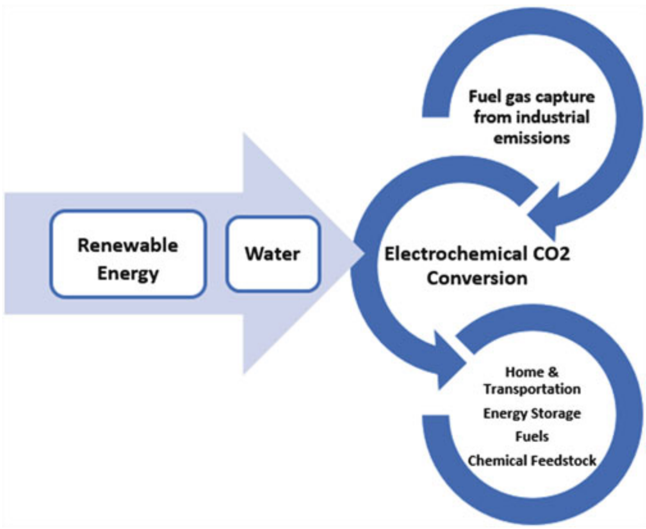


**Fig. 5** Electrochemical $CO_2$ conversion: a negative emission process involving renewable energy sources. Source: author

is the renewable energy technology which can produce energy from zero-emission sources; therefore, this whole process will become a negative emission footprint. Recent research in this area has highlighted a variety of substances can be made in this process. These include alcohols, oxygenates, synthesis gas and other products. The $CO_2$ extraction from the atmosphere using renewable energy has the potential to act as a long-term storage of energy generated from renewable sources in the form of other products and fuels, a process that decarbonises the atmosphere and provides new clean sources of energy and feedstock.

Fuels generated from this process can be stored long term and turned into another forms of energy when required. The electrochemical conversion process can be conducted in times of energy abundance such that the process running costs are as low as possible. Decarbonisation of the atmosphere is a business that will be very profitable should the price for carbon reflect the true cost of its effects on the natural environment. Renewable energy and its clean production of abundant energy will soon make this business opportunity viable and attractive.

## 5 Conclusion

Renewable energy and its continued penetration into the energy supply mix has caused an energy transition that will continue to transform the power grids and energy ecosystem. This transformation has created opportunities for investment and innovation that can effectively utilise the surplus of energy that otherwise would be wasted, and turn it into value and opportunities for further decarbonisation of atmosphere. These opportunities will make energy-intensive industries more viable compared to the past when the energy was produced by conventional generators. The surplus of renewable generation can provide abundant inexpensive energy for innovative and future-looking industries to become sustainable and return a stable profit.

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