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Large Scale Grid Integration of Renewable Energy Sources

Edited by
Antonio Moreno-Munoz

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Chapter 1
The power grid as part of a 100% renewable energy system

Math H.J. Bollen[1] and Antonio Moreno-Munoz[2]

1.1 Introduction

Worldwide, energy demand is constantly increasing. It is expected that global energy consumption will increase more than a third in the period to 2035. Among all the energy demand, the residential sector represents an average 30% of the total energy consumption in most of the developed countries, showing an upward trend in the last 10-year period with an average growth of about 5% in the European countries. Currently, most of this demand is being met by fossil fuels, which contributes to increased emissions of greenhouse gases and the warming global. It is true that last years' falling prices increased demand for fossil fuels, but prices apparently cannot fall much further. OECD countries have been reducing demand for almost a decade; in China, fossil fuel consumption has also flattened. Only developing countries show rapidly expanding fuel demands, though at a slower rate.

Renewable energy sources (RES) can be divided into two categories: dispatchable (e.g., hydro, geothermal and biomass power) and non-dispatchable or variable renewable energy or VRE (e.g., solar and wind) due to the dependence of its production on weather conditions. Of late, VRE played only a minor role in most countries' energy portfolio. While public institution and non-governmental organisations desired an increase in the share of RES in their energy market, the economic issues for new sources (wind and solar) were challenging. Up until recently, VRE has remained a more expensive alternative because of the upfront costs of installing these technologies – requiring public subsidies to get a look-in. However, according to [1], a major change of trend in the growth of low carbon technologies is observed. Prices for inputs – particularly for PV panels and wind turbines – have come down so far that VRE is now cost-competitive with retail electricity in an increasing number of markets globally. The results of the analysis show that the main driver of grid parity is the decrease in VRE system components price. Public subsidies have been helping wind and solar get a foothold in the global energy

[1]Luleå University of Technology, Skellefteå, Sweden
[2]Universidad de Córdoba, Córdoba, Spain

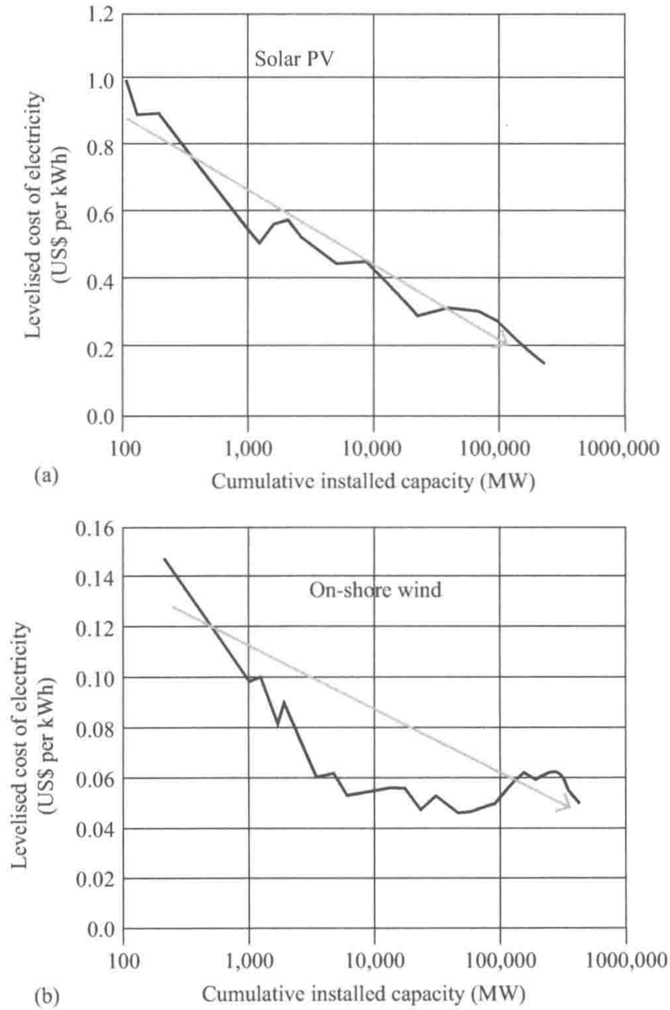

Figure 1.1 *(a) Solar PV costs have decreased as installed capacity has increased. The logarithmic trend line is close to linear and can be explained by the learning curve in manufacture of PV modules and by reduction of soft costs. (b) On-shore wind costs have decreased as installed capacity has increased. Cost increases at the end of the last century were from higher site costs and larger turbine designs, but the trend appears to be continuing downward. Courtesy of the Pembina Institute. https://www.pembina.org/pub/true-price-of-wind-and-solar*

markets, but the real driver of lower prices has been economies of scale. As seen in Figure 1.1, installed capacity increase and competition among module manufacturers in established solar markets led to significant reductions in module costs [2]. The reason is that it is a technology, so over time the improvements increase efficiency and lower prices. Likewise, the price of batteries is falling between 40% and 60%, so that there is already talk of a boom in the energy storage market. Distributed energy resources (DER) include distributed generation, or on-site small-scale power generation sources, but any distributed energy storage system (ESS) can also be classified as a DER system. Recent reports indicate that the global ESS market for smart grid is expected to grow 73% through to 2020, also forecasting that solar energy combined with batteries and electric vehicles will soon be cheaper than grid electricity and fuel in key markets such as Germany, Spain and Italy.

As stated in a recent study for solar electricity, roughly 30 countries are currently at grid parity. And it is expected that electricity prices worldwide will double over the next 10–15 years making the case for solar grid parity even stronger. In the increasing energy production of recent years is observed a clear decrement of the energy produced from solid fuels (18.8%) and a higher penetration of new renewable sources, whose annual average growth rate is currently 7% [3]. Although grid parity by itself is no guarantee of market creation, the outlook for VRE looks promising, and equally optimistic prospects are expressed in the commercial and utility scale segments. Thereby, in a 'business as usual' scenario, RES could reach 25% of the global energy mix already by 2018. But this industry is nowadays speeding up towards the goal of the cent per cent renewables.

1.2 Status and trends in the voluntary use of renewable energy

Voluntary green power markets are those where consumers and institutions voluntarily purchase RES and other DER to meet their electricity needs. In the mid-1990s, there were few options for commercial and institutional customers who wanted to employ RES. An end user could install a solar photovoltaic system in place, or he/she could select a retail provider that combines renewable energy certificates with normal power, in a deregulated market. By the middle of the last decade, the solar power purchase agreements (PPAs) were born. They are allowed more frequently in locations with deregulated electricity markets. Since then, a number of companies, universities and others have negotiated long-term purchases of renewable energy through them. Consequently, the most popular method of solar installations transitioned from ownership to PPAs, and the upward trend continues as more countries approve third-party financing. Purchasing options in the voluntary markets for renewable energy have continued to evolve and diversify until today, as has been thoroughly reported [4]. Some of the new purchase options are providing a hedge against future increases in electricity prices or other benefits as discussed below.

1.2.1 World's leading companies pledge to use 100% renewable

Clearly, we are at a turning point today how corporate and institutional organisations seek to use renewable energy. Renewable energy markets have fundamentally changed in profound ways. Commercial prosumers may be even able to reach self-consumption ratios of close to 100%, covering a fair amount of their base load by DER. Nearly two-thirds of the Fortune 100 and nearly half of the Fortune 500 companies are committing to 100% renewable power, by joining the RE100 [5] initiative. Worth to mention the leadership in solar power generation carried out by many of them, operating over 445 MW of solar capacity at more than 950 facilities in the United States. These non-energy companies are becoming major DER players, with a view to diversifying their energy supply, hedging against fossil-fuel price and supply volatility, reducing their long-term operating costs and earning market-based returns on investment, as well as cutting emissions that contribute to global warming. The scale of their energy savings is likely to grow substantially. They are tapping solar and wind and creating new markets, no longer only just responding to them. So, as companies in adaptation to being more dynamic participants in the energy marketplace, they are developing DER in emplacements where policies conditions are most acceptable. Regulatory inconsistency could dissuade companies from meeting ambitious commitments because of uncertainty around the price, supply, and deployment of VRE.

1.2.2 The islands leading towards 100% renewable

Particularly, the most ambitious targets are being raised on small isolated islands. This is not by coincidence; most islands rely on fuel imports to run their stand-alone grid. These shipments of diesel, oil or natural gas are very expensive. It is not only the savings, it also means less reliance on imports, increasing energy security. Hawaii announced its plans to transition its electric grid to 100% renewables by 2045. El Hierro, one of the Spanish Canary Islands off the coast of Africa, inaugurated year ago a hybrid wind-hydro power plant to serve its population of 11,000 and run power-hungry desalination plants. The hybrid plant has just completed one year of successful operation [6].

Many other islands are expanding the amount of electricity from renewables, as has been addressed elsewhere [7]. Obviously, an island seems like a hard place to VRE like wind and solar or even DERs. Island grids are usually isolated and weak island grids generally have to pay more attention to power quality and reliability (PQR), raising the overall costs of DER.

1.3 The 100% renewable energy system

A vision for a 100% renewable energy system is shown in Figure 1.2. The renewable energy can be in the form of wind or solar power, but also as small- or large-scale hydropower installations. Also certain types of biomass are considered as renewable energy. For this chapter, the discussion about what exactly constitutes renewable energy is not relevant. Important is only that there will be a mix of energy sources of different sizes and at different locations, a lot of which will be constrained in time and in location. Solar and wind power will only be available when the sun is shining or when the wind is blowing. A lot has been written about this already, where the somewhat inappropriate and confusing term 'intermittency' is typically used. But the actual situation is much more complicated. Next to the

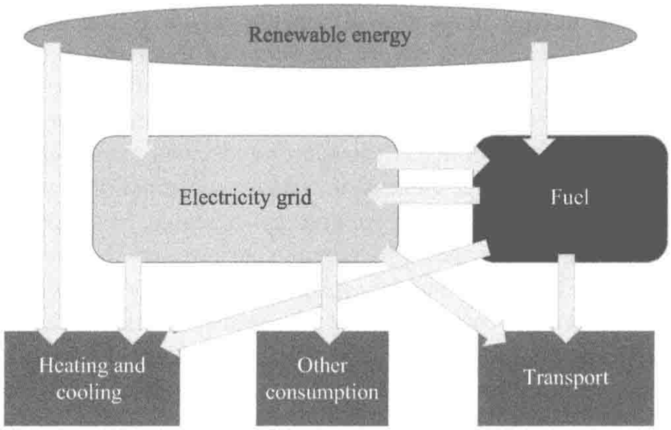

Figure 1.2 A vision of a 100% renewable energy system; the arrows indicate the different energy conversions

variations in availability, the availability of sun and wind is also difficult to predict. This holds especially for regions with fast-changing weather patterns, like north-western Europe. The availability of hydropower is easier to predict, at least up to a few months in advance, and at least where it concerns large-scale reservoir-based hydropower. Unfortunately, this is also the type that is most difficult to build in many parts of the world, not only technically but also politically. At timescales longer than a few months, also hydropower becomes less predictable. The amount of water in the reservoirs depends on the amount of rain or snow in the preceding weeks or months. Countries with large amounts of hydropower (like Spain and Sweden) are very much aware of the existence of 'wet years' and 'dry years'. To which extent there is a correlation between dry years, years with little sun, and years with little wind are not known at the moment. But the overall impression from various studies is that the probability of lack of energy will reduce by mixing different sources of renewable energy, for example, combining wind power, solar power and hydropower.

The renewable energy will be used for a range of applications. An important part of the transition to a 100% renewable energy system will be an overall shift from energy-intensive activities to non-energy-intensive processes as well as an overall increase of efficiency of the energy-intensive processes. Some of the on-going or heavily discussed changes are:

- Insulation of buildings to reduce the amount of energy needed for space heating or cooling;
- A shift from gas heating to electric heating and from direct electric heating (resistive heating) to heat pumps;
- A shift to more energy-efficient (electric) heating, ventilation and air-conditioning;
- The shift from incandescent lamps to LED lamps;
- The shift from gasoline-powered cars to electric cars and the continued electrification of the railways.

But a certain energy demand will remain, which is the one indicated in Figure 1.2. Energy efficiency is beyond the scope of this book; it is assumed that the energy demand is the one that is necessary and that is the most efficient one.

For simplicity, a distinction is made in Figure 1.2 between three types of energy consumption: 'heating and cooling'; 'transport'; and 'other consumption'. Note that we use the physically incorrect expression 'energy consumption' when referring to an energy conversion process where the entropy increases. In almost all cases it is obvious to the reader what is meant by energy consumption, despite the term being physically incorrect. Note also that the vision in the figure does not include a 100% electrical transport system. Instead, some of the transport will use fuel. But this fuel will not come from fossil fuel but from renewable sources, like biogas. Part of the fuel will also be produced from electricity through processes that go under the terms 'Power2Gas' and 'Power2Liquid'. (We will use the general term 'Power2Fuel' where needed.) During periods with a surplus of fuel and/or a shortage of electricity, either locally or globally, the fuel can be turned back into electricity.

Heating and cooling will be partly using renewable energy directly, e.g., solar panels for water heating, partly based on electricity, and partly using the fuel from renewable sources or from Power2Fuel. In the latter case, this will most likely be in the form of combined heat and power (CHP, co-generation). Burning fuel just for space heating is rather inefficient compared to modern heat pumps and CHP installations.

Energy conversions, the arrows in Figure 1.2, numbered in Figure 1.3, are an important part in the energy system. It is these transitions that allow electricity to become the heart of the energy system. But these conversions are also, in many cases, where the losses are. The lower the losses, the sooner a 100% renewable energy system with sufficient reliability can be reached. The amount of conversions thus has to be limited to get an efficient energy system. Increasing the efficiency of

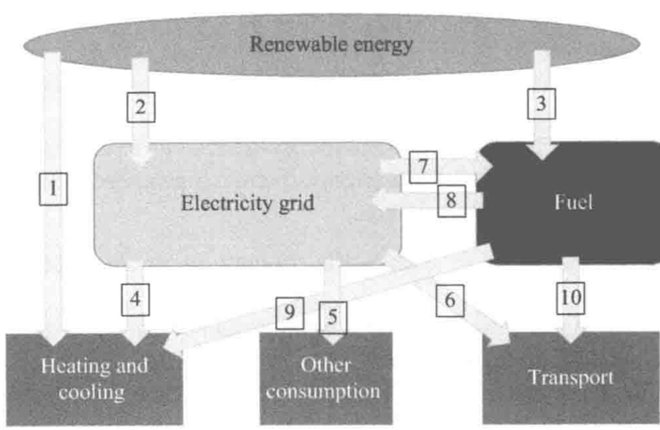

Figure 1.3 Different energy conversion processes in a 100% renewable energy system