Chapter 14

Water operations using renewables – some cases

> "By seeking and blundering we learn."
>
> **Johann Wolfgang von Goethe 1749–1832.**

Various renewable energy applications for water operations are described here. Some of them are utility-scale and others are small-scale. Our purpose is to show both the applicability at various scales and, when relevant information is available, the cost/efficiency patterns. Some of the installations are connected to electric power grids that can be used for balancing the production and load and others are isolated and off-grid.

14.1 DEVELOPING COUNTRIES VERSUS HIGH-INCOME COUNTRIES

The need to balance production and load can look quite different in high-income and in low-income regions. People in higher-income areas will require power availability round the clock and will usually not accept too many interruptions in power delivery, whereas people getting their first electric power source will probably be more tolerant

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of lack of delivery during the night. This will define the ambition of the storage capacity (see Chapter 10.2).

Economy is crucial. As noted by Professor Akhlesh Lakhtakia, Penn State University, U.S.: “Poor people don’t need the most efficient sources. They need affordable ones, and a helpful nudge to improve their lives; that motivated us in our research.” Research is ongoing into developing solar cells that are less efficient (up to 17%) than most on the market but can produce a viable level of electricity at a greatly reduced production cost. Instead of using silicon the researchers are exploring indium gallium nitride, which could give some advantage with its semiconducting properties.

It is apparent that renewable energy can play a major role in extending energy access to communities in the developing world. However, many of these countries suffer from a lack of technical expertise to implement these facilities. As noted previously, a shortage of local human resources is a key barrier to fulfilling the high potential of renewable development. Therefore, it is important to ensure technical education in these regions. High-income countries have a huge responsibility to make this happen. This can enable the development of local industries to provide the country with renewables.

14.2 IRRIGATION AND WATER PUMPING

Irrigation water requirement (IWR) is site-specific and depends on the particular crop. IWR values can be anywhere between 20 and 70 m^3/hectare/day (Campana *et al*., 2015). As a comparison, a precipitation of 1 *mm* corresponds to 10 m^3/hectare.

Example 14.1: *Pumping for Irrigation Using Solar PV, Senegal.*

A low-cost and simple solar pumping system was implemented in Senegal in 2013 (www.youtube.com/watch?v=bPvPJuvLw9Q). The potential source of water is a small river nearby and the pumping system is used for irrigation. Solar panels were becoming affordable and the challenge was to find other affordable components of the system. There are reliable solar pumps available, but they are more expensive than the solar panels.

The system has five solar panels with a capacity of $5 \cdot 80\ W = 400\ W$. In Senegal solar panels are easily available even at the roadside.

The cost of these panels was less than 1 USD/*W*. The panels are mounted on a wheel cart that can easily be pushed around. This innovative thinking made it possible to turn the panels into the best possible position, towards the sun and avoiding shadows from trees: in other words, they became a manual tracking system. The panels were placed at the irrigation site at some distance from where people live and could easily be stolen at night. With the cart the panels can instead be moved to a safe stored location overnight.

The aim was to find an affordable pump and keep the cost down by avoiding using batteries. By using a DC pump the cost of DC/AC conversion was avoided. The drawback is that DC motors have a shorter life than AC motors. Marine pumps were found to be a good choice, but many of them are designed only for low heads (see Chapter 4). The actual pump can deliver around 15 m^3/hour or 4 litres/second at zero head. It can work at 5–6 m head, but then the flow rate is lower (compare Figure 4.2) albeit sufficient for the purpose. In this case the motor is assumed to have a life of around one year. However, the profit from the irrigation could pay for the replacement of the motor. Altogether the pumping system cost was less than 1,000 USD. No electronic controllers were used, only a simple circuit breaker. The pump can irrigate around half a hectare (=5000 m^2). A flow rate of 4 m^3/hour for six hours will provide almost 50 m^3/hectare/day.

14.3 DESALINATION

The integration of renewable energy resources in desalination and water purification is becoming more viable as costs of conventional systems increase, commitments to reducing greenhouse gas emissions are implemented and targets for exploiting renewable energy are set. Many PV-based desalination systems have been demonstrated throughout the world, especially in remote areas and on islands. The examples and cases illustrate both utility-scale installations and small-scale implementations. They are shown to exemplify both efficiency and economy.

14.3.1 Solar PV desalination installations

Example 14.2: *Village of Ksar Ghilène, Tunisia*

A solar PV-based system for water supply was already in existence in 2005 in the village of Ksar Ghilène, located in southern Tunisia (www.

adu-res.org/pdf/ITC.pdf). The village has about 300 inhabitants, 50-plus families, who live off agriculture and cattle raising. The nearest drinking well is located 60 *km* away. The solution to the water supply challenge was a reverse osmosis (RO) plant supplied by a solar PV system. The project was financed internationally, and technical support provided by the Canary Island Institute of Technology, which had experience of supplying drinking water through stand-alone systems.

The village's daily water consumption during the summer is about 15 m^3, the solar irradiation annual average 5,600 kWh/m^2 (compare Table 8.1) and the annual average temperature 26°C, varying from 0 to 45°C.

The raw water is pumped from an artesian brackish (around 3,500 *ppm*) water well located inside the oasis, some 2 *km* from the village. The water is desalinated in an RO unit. The water is used for irrigation of palms and crops and for tourist services.

The electric energy is used for the feedwater pump from the artesian well and for the compressor in the RO unit. Some of the system parameters are:

PV generator	Peak power 10 kW_p; operation time = eight hours/day
Feed pump	Max power = 1 *kW*; pumps water from the well through a 2 *km* pipe; flow rate = 3 m^3/hour; pressure = 3 bar
High-pressure pump for the RO unit	Requires 3 *kW* for pressure <15 bar; flow rate = 3 m^3/hour
Disinfection	200 *W*
Lighting	250 *W*
Battery storage	capacity = 600 *Ah*; C10 batteries (→ discharge current will discharge the battery in ten hours)
Produced water	Production = 15 m^3/day; salinity <500 *ppm*
Specific power	2 kWh/m^3 of produced water

Example 14.3: *Abu Dhabi*

The United Arab Emirates (UAE) is considered a “water-scarce” country. It has just 83 m^3 of water per person per year – well below the UN scarcity threshold of 1,000 m^3. As a consequence, UAE relies to a large extent on seawater desalination to satisfy the demand for water supply.

Mascara Renewable Water has developed an off-grid, solar-powered desalination solution in Abu Dhabi (Masdar, 2018). The plant uses a beach well to obtain seawater from a borehole near the sea. The natural sand filtration of the beach well eliminates the need for a dedicated pre-treatment system. The intermittent power production is compensated for by a hydraulic energy accumulator used as storage. The system is powered by a 30 kW_p PV plant, and the system operates only during sunlight hours, producing 30 m^3/day. Biofouling is avoided by automatically flushing the membranes before sunset every day.

A number of identical desalination plants have been designed, based on solar energy and located in isolated desert areas of Abu Dhabi, outside the power grid. A typical solar system is built up of 300 m^2 panels that will produce a maximum of 45 kW, in other words 150 W/m^2, which is in the same order of magnitude as described in Chapter 8.

The first installation was completed in 2009. The desalination plants designed by Hitachi are pumping saline groundwater and applying reverse osmosis to clean the water. The salinity ranges from brackish water to 35,000 mg/l, similar to seawater. The production of the system is 4 m^3/hour of fresh water.

The groundwater is first pumped to a storage tank before treatment in the RO unit. Even in a sunny area like the Abu Dhabi desert the sunlight may be shaded during the day, for example due to sandstorms. Therefore, a battery backup is provided.

There is an evaporation pond, designed to get rid of the brine reject (see 5.3.4).

Example 14.4: *Gran Canaria, Spain*

A solar PV-powered system for the desalination of seawater, called DESSOL, has been installed close to the beach on Gran Canaria (Espino *et al*., 2003). The desalination system is based on RO and produces an annual average flow of 3 m^3/day (or 0.4 m^3/hour) during eight hours of operation in the summer and six hours in the winter. Some of the system characteristics are:

Solar panels	Total capacity = 4.8 kW_p 64 modules of 75 W_p each
Battery storage	19 kWh
Well pump	Max altitude above the sea = 3 m Capacity = 1 kW Max flow rate = 2.5 m^3/hour; pressure = 3 bar
High-pressure pump for RO	Capacity = 2.2 kW Max flow rate = 1.5 m^3/hour; pressure = 60 bar
Effluent salinity	<500 mg/l

The authors describe an interesting aspect of the operation to protect the membranes. When the plant is shut down at the end of every day there is a flushing process, using produced water, to keep the membranes clean. The membranes are submerged in low-salinity water, preventing deterioration due to their intermittent operation (see 10.1.3; Lienhard *et al*., 2016).

Example 14.5: *Solar Heating for Desalination, California*

In the California Central Valley, the Panoche Water District is using a solar thermal system for desalination (Lavelle, 2015). The solar energy is not used to produce electricity. Instead, parabolic trough mirrors turn the solar radiation directly into heat to distil salty water.

Example 14.6: *India*

India has a highly seasonal pattern of rainfall, with 50% of precipitation falling in just two weeks. The Central Water Commission estimates that the total annual rainfall in the country is 4,000 billion ($4 \cdot 10^{12}$) m^3. The utilisable or internally renewable water resources are estimated to be 1,200 billion m^3. The annual water demand is increasing: it was around 800 billion m^3 in 2010 and is estimated to approach 1,500 billion m^3 in 2050. This will not be sustainable, and many regions will face severe water shortage. Furthermore, the impact of climate change will lead to variation in rainfall patterns and evaporation rates. A growing population and industrialisation will put a lot of pressure on water resources. Several regions are already suffering from excess contaminating factors like salinity, fluoride, iron, arsenic, heavy metals and microbial contaminations of groundwater. The need for sustainable water-supply solutions is urgent.

Example 14.7: *Village Installation, Rajasthan, India*

In Kotri, a small village of 300 families in the region of Rajasthan in north-western India, a solar-based RO plant has been put into operation. The plant produces drinking water for more than 1,000 residents from both Kotri and surrounding villages (IRENA, 2015b). Brackish water from a nearby lake is pumped through the RO plant and produces around 600 litres/hour of water for six hours every day. The salinity of the water is reduced sufficiently to make the water drinkable. The RO plant is served by a 2.5 kW power plant. The village is in fact connected to the grid, but the supply is very unreliable with only three hours/day of power most of the time. The solar-powered system guarantees six hours of electric power supply, which gives some surplus power for light, fans and computers.

Example 14.8: *Village Installation, Andhra Pradesh, India*

A rural village in India gives a typical example of the application of solar PV to treat water (WEC, 2016, Chapter 8). The SANA organisation (Social Awareness Newer Alternatives) identified a village that had no access to clean drinking water and where the power supply was irregular: the N. Chamavaram village in the state of Andhra Pradesh in south-east India. Energy from the solar PV system has been used to purify contaminated water to WHO drinking-water standard. This is a typical example of decentralised water supply where the raw water intake can be either contaminated well water or used water that is reused. The capacity of this system is 1,800 m^3 of water yearly or 5 m^3/day. This will supply 1,000 schoolchildren from economically backward homes with five litres of water daily for their families, who live in slums nearby.

14.3.2 Wind power desalination installations

The electrical and mechanical power generated by a wind turbine can be used to power desalination plants, in particular RO units. In general, wind power-based desalination can be one of the most successful options for seawater desalination, especially in coastal areas with high wind potential. As for solar PV, wind desalination has the drawback of the intermittence of the energy source. Possible combinations with other renewable energy sources, batteries or other energy storage systems can provide smoother operating conditions. As with solar PV, water desalination itself can provide an excellent storage opportunity in the case of electricity generation exceeding demand.

Various wind-based desalination plants have been installed around the world, including in Gran Canaria, Canary Islands (wind-powered RO, seawater, 5–50 m^3/day), Fuerteventura, Spain (wind-diesel hybrid system, seawater, 56 m^3/day) and the Centre for Renewable Energy Systems Technology in the United Kingdom (wind-powered RO, seawater, 12 m^3/day) (Kalogirou, 2005; Gude *et al.*, 2010; Al-Karaghouli and Kazmerski, 2011).

Example 14.9: *Sydney, Australia*

Sydney Water desalination plant supplies about 15% of the water for Australia's most populous city (www.metrowater.nsw.gov.au). To help minimise the carbon footprint of the desalination plant, the power requirements are being 100% offset with renewable energy generated at a 67-turbine wind farm near Bungendore, about 270 *km* to the south. The wind farm generates more than enough electricity to power the plant: the plant needs around 42 *MW* while the wind farm's capacity is 132 *MW*. Notice that the 132 *MW* is a peak capacity, so the desalination plant needs some 32% of the wind power peak capacity, which is close to the wind power efficiency.

Example 14.10: *Perth, Australia*

The city of Perth in Western Australia has a large desalination plant, the Perth Seawater Desalination Plant, producing around 140,000 m^3/day (www.watercorporation.com.au). With energy demand at 3.5 kWh/m^3, this will require around 490 *MWh*/day, which corresponds to a continuous power supply of 20 *MW*. The power is delivered from a wind farm located 260 *km* away from the plant. It is documented that the desalination plant requires an average wind power peak capacity of 82 *MW*, which means that the average delivery of power is about 25% of the capacity.

Example 14.11: *Texas, U.S.*

Another example of wind-powered desalination is from Texas, U.S. (Swift *et al.*, 2009) in a region suffering from severe water scarcity and depending on deep high-salinity aquifers. RO treatment of this kind of brackish water is a realistic and economically feasible solution. There is not only high salinity (around 2600 mg/l of total dissolved solids); arsenic and fluoride concentrations are also high. RO technology would lower these to acceptable limits. A feasibility study has been made for a municipal, integrated wind-water desalination system for an inland small community. The study from Texas demonstrates that the integration of the two relatively mature technologies of wind energy and RO becomes an attractive option for addressing an emerging threat to any region heavily dependent on affordable energy and potable water. In the Texas study a small 5 kW wind turbine provided the energy for an RO desalination plant with the capacity of about 6 m^3/day. The energy requirement was found to be around 0.82 kWh/m^3 of treated water. The Swift report gives a detailed account of not only wind power supply but also operating and maintenance experiences of desalination facilities.

14.4 FURTHER READING ON DESALINATION AND RENEWABLE ENERGY

There is a lot of literature and information concerning desalination using renewable energy. Some useful sources are:

- *Desalination* journal (Elsevier);
- Elemental Water Makers, a Dutch start-up company offering desalination using renewable energy (www.elementalwatermakers.com);
- Fraunhofer Institute for Solar Energy Systems ISE (www.ise.fraunhofer.de);
- Lenntech, a company offering solutions for desalination systems (www.lenntech.com);
- EIP Water (The European Innovation Partnership on Water): an initiative within the EU 2020 Innovation Union. The EIP Water facilitates the development of innovative solutions to address major European and global water challenges (www.eip-water.eu).