Demand Response Desalination

A multi-module approach to reverse osmosis desalination offering a flexible energy demand.

This paper presents a new way to design and operate reverse osmosis desalination plants using a multitude of relatively small, fully integrated RO modules that could replace large pressure centers. The desalination plant could then coordinate production with energy prices by automating the number of modules in operation. By leveraging cheap energy, operating costs would be substantially lowered. This offers valuable demand response to grid operators who are tasked with balancing the grid with increased levels of wind and solar PV.

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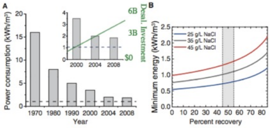
Desalination Will Be Necessary.

A 40% gap between freshwater supply and demand is predicted by 2030, and the stress on natural water systems can be seen now in every part of the world. In addition to all methods of water recycling and conservation, new sources will be necessary. Seawater is the only source that is drought-proof and virtually inexhaustible. Unfortunately, purifying it is also the most energy-intensive way to provide freshwater today. Desalinated water typically costs 4 to 8 times more to produce than other sources, with energy often accounting for more than half of the operational costs.

Further Energy Reductions Are Limited.

Reducing desalination costs has centered around energy efficiency. Reverse Osmosis (RO) has emerged as the leading process with over 60 years of technological advancements. Current water shortages have drawn more attention and investment than ever to RO efficiency. However, all methods of desalination are bound by laws of thermodynamics that require a minimum energy level to separate a pure liquid from its dissolved minerals[1]. This limitation explains the reduced rate of efficiency improvements despite record investment seen in Figure A. There are decreasing opportunities to improve efficiency as the process gets closer to the minimum energy requirement.

Figure A:



As power consumption approaches the minimum energy requirement (the dotted line), there are less opportunities for improvements. Figure B shows how salt concentration and RO recovery rates affect the minimum energy requirement.

Given this limitation, we suggest that too much attention and money may be presently channeled into improving the efficiency of membranes, pumps, and energy recovery devices (ERDs) and not enough to reduce costs by integrating water production with the availability of cheap energy.

1 http://pacinst.org/wp-content/uploads/sites/21/2013/05/desal-energy-ghg-full-report.pdf

Electricity prices are cheaper than ever, but not always.

As with any commodity, electricity prices drop when demand decreases. Demand is much lower at off-peak hours, such as nights and weekends (Figure C). When demand is low, only the least expensive generators to operate will be running (Figure D).

Figure B: Weekly Demand in Mid-Atlantic Market with Seasonal Variations

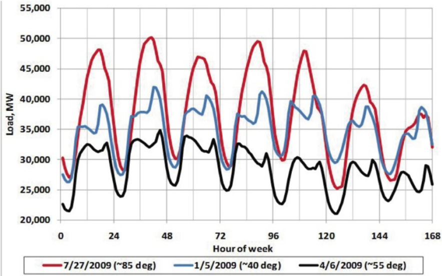
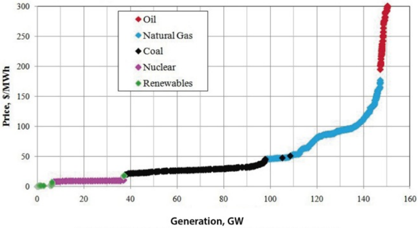


Figure C: Marginal Cost by Generator



Source: Penn State (https://www.e-education.psu.edu/ebf200wd/node/151)

Inflexible generators create supply imbalances.
The cheapest generators to operate are inflexible and not suitable for following demand. These include coal and nuclear power plants that are expensive or impossible to cycle off and on. As a result, these plants sometimes operate at a loss. Negative energy prices occur when it is cheaper to pay the grid-operator to take excess energy than it would be to shut off and restart the plant. Anytime there's a surplus, wholesale energy prices will drop until enough generators reduce their output.

Intermittent renewables such as wind turbines and solar PV can further compound the imbalances between supply & demand. They have no incremental production costs and their availability and intensity is not controllable. Solar production peaks too early for peak demand while wind turbines often generate the most electricity at night when demand is the lowest. High inflexible generation during periods of low demand will always translate to cheap or negative wholesale prices.

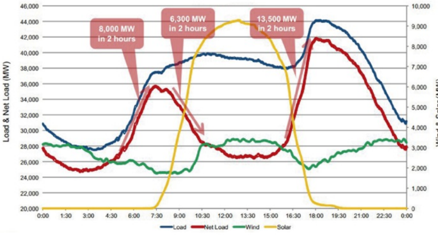
Figure D: Negative Wholesale Prices: Germany Example

Prices went negative for several hours on Sunday, May 11th, 2014 in Germany[2]. Negative wholesale prices, usually associated with wind and solar PV production have occurred throughout Europe and The United States.

2 http://energytransition.de/2014/05/german-power-prices-negative-over-weekend/

Electricity is more expensive than ever during peak hours.
Intermittent renewables sometimes move in the opposite direction of what is required, creating a reverse correlation that intensifies the peaks and valleys that need to be actively followed by specialized grid resources. Power plants with ramping capabilities are usually the most expensive and inefficient to operate. Grid operators must also pay a premium for flexible plants because they are used infrequently. The following simulation from CAISO[3] shows how ramping requirements increase with high levels of intermittent renewables.

Figure E: CAISO Load, Wind & Solar Profiles - high Load Case January 2020



**Net load is calculated by subtracting the electricity produced by wind and solar PV from actual consumer demand. Grid operators must follow net load in real time using dispatchable resources. Note that both wind and solar output are declining during the critical 13,500MW ramp-up.*

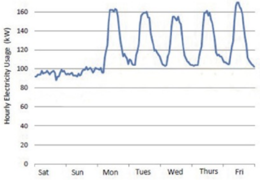
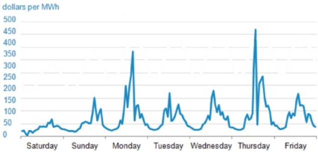


Figure F:
The typical hourly and weekly electricity usage in industrial regions with moderate climate.

3 The California Independent Service Operator (CAISO) is the independent, non-profit operator of 80% of the electrical grid in California.

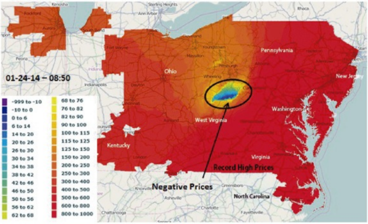
The costs associated with meeting demand fluctuations are reflected in wholesale energy markets. The following shows the non-linear increases in generation costs that result from meeting critical demand.

Figure G: Real Times electricity prices in the PJM Interconnection Saturday, July 13-Friday, July 19 2013



While energy markets can be erratic on normal days, weather extremes create some of the most volatile markets in history. In 2011, record high temperatures in the southwest United States pushed demand for electricity while a corresponding drought threatened the water resources needed for thermal power plants to operate. Wholesale energy prices soared to 60 times their normal summer prices[4]. The cold weather throughout the U.S. in January 2014 had similar price action, resulting in an 86-fold price increase in the PJM interconnect[5]. Due to transmission constraints, negative energy prices occurred simultaneously in the same market.

Figure H:



4 http://online.wsj.com/news/articles/SB10001424053111904823804576502592393033486
5 http://avalonenergy.us/blog/?p=867

Flexible Users Will Be Rewarded.
Naturally, these costs are beginning to be passed on to industrial and residential consumers by implementing time-of-day pricing, a form of demand response (DR). This is a way to reduce demand when electricity is the most expensive to generate. The value of shaving peaks is equal to generating the same amount of electricity at that time. FERC[6] has regulated that DR resources be compensated the market price for wholesale generation at the time they're utilized[7]. This presents a tremendous opportunity for flexible energy users, who can be compensated as a grid resource and leverage cheap energy whenever it's available.

DR makes higher levels of renewable energy possible by providing contingency for a sudden loss of generation caused by clouds or a lack of wind. By automating the response, DR can reduce the energy load without the need for advanced notice. NREL models show DR can handle 85% of flexibility reserves if properly integrated[8]. DR can play a critical role in balancing the grid. The challenge is finding enough energy users that are suitable for flexible operation.

Reverse Osmosis plants are ideal for demand response because they are not labor-intensive, seawater is always available, and treated water can be easily stored. However, most RO plants today use very large horsepower pumps with a narrow operating range. They demand constant energy at a time when flexibility is more important than ever.

Demand Response Desalination (DRD).
Designing desalination plants with an adaptable energy demand seems to be an obvious solution. Sisyan LLC is applying over 14 years of continuous research desalting seawater using an intermittent source, the sun, to the concept of Demand Response Desalination (DRD). The system uses a multi-module design concept to accommodate the variability of solar irradiance. Each module is independently switched on and off to achieve the desired energy load of the plant. Below is a description of a multi-module RO system in operation at the Sisyan R&D facility in Baja California, Mexico.

OFF-GRID PILOT SYSTEM

Between 2000 and 2004 Sisyan LLC developed what we believe to be the first continuous production photovoltaic seawater reverse osmosis (PVSWRO) system using axial piston pumps and motors (APP/APM) as a high pressure pump and ERD.

The torque generated by high pressure brine fed to the APM is added directly to the torque of the APP electric motor. The torques are combined by means of an adjustable ratio V-belt transmission. This arrangement enables the optimization of the yield of the system. In our case, the most cost-effective proved to be a yield of 33 percent.

It consists of three 3 hp modules. Each module is a fully integrated unit. The modules share a seawater beach well, sourcing pump, ultrafiltration, permeate collection and management, brine disposal, permeate storage, PV array and battery bank.

Each module contains one Danfoss APP 2.2, one Danfoss APM 1.0, one 3 hp 3-phase electric motor, an adjustable ration V-belt transmission, a variable frequency drive (VFD), electric controls, two 4" pressure vessels housing six 4" x 40" seawater membrane elements, an assortment of titanium fittings and adapters, HP synthetic rubber hoses, gauges, sensors and Victaulic couplings.

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6 The Federal Energy Regulatory Commission (FERC) has jurisdiction over interstate electricity sales, wholesale electric rates, and other energy
7 http://www.ferc.gov/media/news-releases/2011/2011-1/03-15-11.asp
8 http://www.nrel.gov/docs/fy14osti/58492.pdf

Figure I:

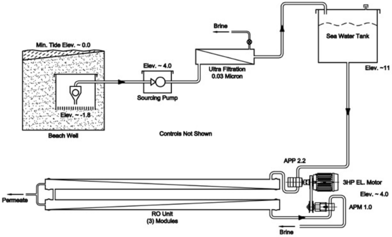

Figure J:

Figure K:

Figure L:

Figure M:

The battery bank has a capacity of 1.6 kwh. The 6-volt lead acid batteries are configured in strings of 48. The operating voltage varies from 295 VDC to 354 VDC. The array of PV panels has a capacity of 18 kWp and is connected directly to the battery bank.

The voltage of the battery bank changes with the applied charging current and the load current. The charging current changes with the solar irradiance, and the load current with the number of modules in operation. The electrical control switches ON/OFF the VFD of the modules, monitoring only the battery bank voltage. The starting and stopping voltage for each module is preset at different values. The VFDs are connected to the DC bar on the battery bank. No battery chargers are used.

The system has been in operation for over 12 years and has produced over 68,000 m3 (18M gallons) of permeate with TDS lower than 300. The seawater salinity is 33,000 TDS. Initially we used media filters and 5 micron cartridge filters. Seven years ago those were replaced by 0.03 micron membrane elements. Adding ultrafiltration resulted in almost doubling the service life of the APP/APMs and membrane elements. The average annual production is 6500 m3 (1.7 M gallons). The seawater flow is 21.5 liters per minute (5.7 GPM) per module. The average seawater pressure is 680 psi.

The UF membranes have never needed to be cleaned or replaced.

Grid Integrated Design.

Analyzing the performance of the pilot system, we determined that it would be practical to design a RO plant with larger modules based on the same mechanical and hydraulic principles. This design makes possible the construction of a desalination plant with flexible energy-demand. Such a plant can use intermittent energy sources directly and/or utilize grid energy in the most cost-effective way possible. The proposed design is shown below. The number of modules can be adjusted to fit the desired size of the plant. We envision DRD plants in the range of 5-500 modules. The average daily operation time of each module should be more than 14 hours.

DEMAND RESPONSE DESALINATION SYSTEM

The modules are fully integrated and consist of one Danfoss APP17, one Danfoss APM 10.2, one 30 hp 3-phase electric motor, one adjustable ratio V-belt transmission, one VFD, electric controls, 2 pressure vessels containing ten 8" SW membrane elements, an assortment of titanium fittings and adapters, HP synthetic rubber hoses, gauges, sensors and Victaulic couplings.

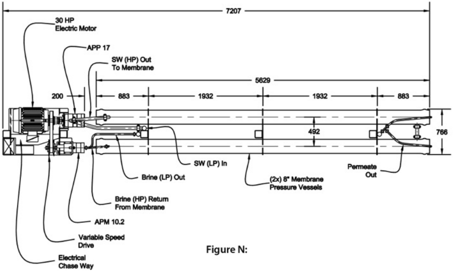

Figure N:

Each module will process 303 LPM (80 gpm) of seawater. Maximum SW pressure is 720 psi. With modules configured in columns stacking 6 modules vertically, the surface requirement of the plant floor would be in the order of 1m2 per 128 LPM (or 3.2 gpm/sf) of seawater flow.

The pressure vessels and the elements of the pressure center can be removed sideways to the access corridor and carried either by an overhead crane or a forklift to the service bay.

This arrangement of the components offers the advantage of short high-pressure lines which would total 1.35m (53") per module. There is no connection of HP lines between the modules.

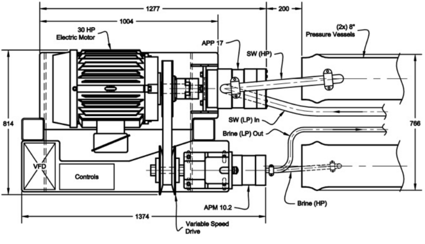

Figure O:

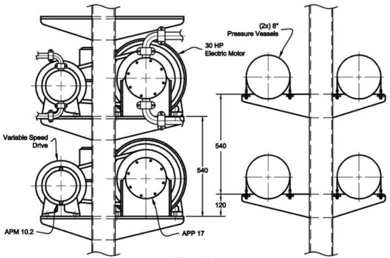

Figure P:

With the use of titanium fittings and rubber hoses for high pressure connections and the use of PVC for low pressure connections, corrosion is practically eliminated. Flushing with permeate would not be necessary.

The performance of all the components has been deliberately lowered in order to compensate for the start/stop characteristic of the work pattern of the system.

The 30 hp module design described above is based on off-the-shelf APP/APMs. The displacement of selected APP and APM will deliver relatively high yields. In the present arrangement, the lowest yield will be 42%. It may be advantageous to change the angle of the swash plate to allow a final yield adjustment by changing the ratio of the v-belt transmission in a larger range.

A DRD plant is a unique industrial installation since inputs (saltwater) are inexhaustible and production is completely flexible. The number of employees can remain constant, advanced production schedules are not necessary, and the time when the modules operate is not relevant.

As a system, the proposed plant can adjust energy demand in increments of 22kW, providing practically a stepless adjustment that is desirable for grid balancing. It can absorb sudden losses from both renewable and conventional generators, providing a valuable contingency service.
DRD plants can utilize energy generated during off-peak hours and compensate for inflexible generation at all times. In addition to controlling energy costs, a DRD plant can receive revenue for performing valuable grid services including frequency regulation, spinning contingency reserve, and flexibility reserve.

Early Adopters.
Compared to most modern RO plants, the proposed DRD plant will require more startup capital and offer lower efficiency on a kWh/yield basis. DRD will not currently compete with large desalination plants that can co-locate with thermal power plants and share intakes. As such, our concept may not be cost-effective on a large-scale until everyone is required to pay time-of-day pricing or intermittent renewable capacity is much higher. Potential early adopters of DRD include:

- DRD can be immediately considered for proposed desalination plants in areas with aggressive Renewable Portfolio Standards (RPS). The cheapest way to increase renewable capacity is wind and solar PV, which require corresponding flexibility. To meet renewable targets of 33%, California ISO believes "ramp rates may triple, which is not possible for the ISO's conventional generation as configured today[9]."
- Islands or independent grids who struggle with high energy prices, grid stability, and water shortages.
- 'Eco-cities' or anywhere it's impractical or unpopular to use fossil fuel to compensate for renewable variability.
- Anywhere with unstable power infrastructure. DRD may be the only practical option for RO desalination where power outages are common.
- DRD can be applied to brackish water and to fight saltwater intrusion. Note that the design proposed in this paper is only applicable to seawater desalination.

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9 http://integrating-renewables.org/grid-impacts/

DRD offers fast, practically stepless flexibility that can be utilized by grid operators in multiple ways. Finding the optimum balance between water production, grid-operator incentives, and energy prices requires proper modeling and cooperation with the site-specific grid operator and regulatory agencies. Good modeling and studies have been done on the value of Demand Response that can be directly applied to DRD. Nearly all grid operators are evaluating or have already implemented DR programs and will have a good idea of the value and how to best utilize DRD.

The number of modules will also be site-specific. The larger the plant the more value it will provide the grid. Decentralized DRD plants will generally be desirable for both water delivery and grid balancing.

Conclusion.

The UN, The White House, and The World Economic Forum each issued reports in 2014 finding the relationship between water and energy so important that coordinated approaches are necessary to find long-term solutions to either[10]. By aligning their energy profile with grid availability, RO plants have the opportunity to be integrated with the grid in a mutually beneficial way. A desalination plant built with independently controlled modules allows the plant to react to energy prices in real-time. Without flexible operation, desalination plants are fragile to current energy trends. The multi-module RO plant suggested by Sisyan LLC can help to reduce the cost of desalination, contribute to the use of renewable energy and play an essential role in balancing the grid.

Desalting water with renewable energy = energy storing

10 http://nca2014.globalchange.gov/report , http://www.unwater.org/publications/publications-detail/en/c/218614/ , http://www3.weforum.org/docs/GAC/2014/WEF_GAC_ClimateChange_AdaptationSeizingChallenge_Report_2014.pdf