A Grid-Connected Desalination Plant Operation

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ABSTRACT

In this paper, a grid-connected desalination plant operation approach is suggested. In desalination plant, large amount of energy is needed to operate pump and motor; hence most of energy is electricity. For this reason, the largest part of the operation cost is electricity charges. To demonstrate power usage, small size desalination measuring system mounted plant is used. Finally, to show the result of a grid-connected desalination plant operation, electric tariff rate of Korea is used. The result shows that total cost reduction rate is calculated about 1.6% of annual total electric plant operation cost.

Keywords: Desalination, Smart Grid, Cost reduction.

1. INTRODUCTION

Desalination is a very attractive approach to solve water shortage matter in the world. Seawater desalination plants are rapidly expanding as natural water resources are limited and depleting [1]. Seawater desalination is highly energy intensive (consuming thermal and/or electrical energy) and, as such, energy costs are the major production costs in all large-scale seawater desalination methods including reverse osmosis (RO), multi-effect distillation (MED), and multi-stage flash (MSF) [2–4]. Traditionally, thermal processes (MED and MSF) were the most popular and economical methods for seawater desalination. However, SWRO (Sea Water Reverse Osmosis) is quickly gaining popularity as the most economical method of desalination. In SWRO, the largest portion of the operation cost is the electricity cost [3]. Currently, total SWRO Plant is about 500 million m^3/day in the world. In order to reduce the energy cost, nowadays considerable attention is given to the optimization of operation and management of energy in various systems, including seawater desalination systems, e.g., [5]. A desalination plant costs breakdown graph from water treatment solution LENNITECH are shown in Figure 1. From Figure 1, 41% of total cost is electricity. So various techniques are investigated regarding energy cost reduction matter. But most techniques are only considered energy efficiency problem in plant itself. In this paper, a novel concept of Grid-connected SWRO plant is explained and then suggested the approach for energy cost reduction using smart grid technology.

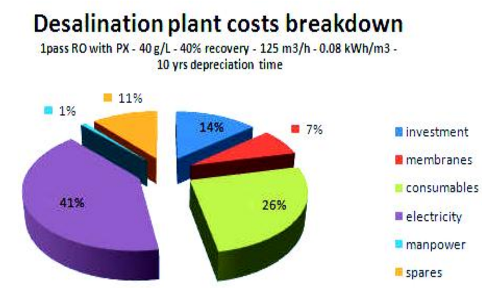


Figure 1. SWRO plant operation cost rate

2. GRID-CONNECTED DESALINATION PLANT

Reverse Osmosis [6]

Reverse osmosis (RO) is a filtration method that removes many types of large molecules and ions from solutions by applying pressure to the solution when it is on one side of a selective membrane. The result is that the solute is retained on the pressurized side of the membrane and the pure solvent is allowed to pass to the other side. To be "selective," this membrane should not allow large molecules or ions through the pores (holes), but should allow smaller components of the solution (such as the solvent) to pass freely. In the normal osmosis process the solvent naturally moves from an area of low solute concentration, through a membrane, to an area of high solute concentration. The movement of a pure solvent to equalize solute concentrations on each side of a membrane generates a pressure and this is the "osmotic pressure." Applying an external pressure to reverse the natural flow of pure solvent is reverse osmosis.

The process is similar to membrane filtration. However, there are key differences between reverse osmosis and filtration. The predominant removal mechanism in membrane filtration is straining, or size exclusion, so the process can theoretically achieve perfect exclusion of particles regardless of operational parameters such as influent pressure and concentration. Reverse osmosis, however, involves a diffusive mechanism so that separation efficiency is dependent on solute concentration, pressure, and water flux rate. Reverse osmosis is most commonly known for its use in drinking water purification from seawater, removing the salt and other substances from the water molecules.

Smart Grid [7]

A smart grid is a form of electricity network utilizing digital technology. A smart grid delivers electricity from suppliers to consumers using two-way digital communications to control appliances at consumers' homes; this could save energy, reduce costs and increase reliability and transparency if the risks inherent in executing massive information technology projects are avoided. The "Smart Grid" is envisioned to overlay the ordinary electrical grid with an information and net metering system. Smart grids are being promoted by many governments as a way of addressing energy independence, global warming and emergency resilience issues. The idea of two way communications from suppliers to consumers to control appliances is not new, and systems have been implemented using analog technology for many years. The growth of an extensive digital communication network for the internet has made it practical to consider a more sophisticated type of smart grid. The increased data transmission capacity has made it conceptually possible to apply sensing, measurement and control devices with two-way communications to electricity production, transmission, distribution and consumption parts of the power grid at a more granular level than previously. These devices could communicate information about grid condition to system users, operators and automated devices, making it possible for the average consumer to dynamically respond to changes in grid condition, instead of only utilities and very large customers. A widely overlooked fact about the smart grid is that it is not a substitute for a real grid, but only an enhancement. The construction of a larger and better infrastructure of high-voltage transmission lines for the efficient delivery of electric power is a prerequisite to the construction of an effective smart grid.

Grid-Connected

A Grid-Connected desalination plant architecture and concept is shown in Figure 2. To design a Grid-connected system, a gateway portal concept is used. A Gateway portal is a smart bilateral communication and service infrastructure component between Grid and Plant. Gateway Portal is an infrastructure component to collect information and control devices in Desalination plant. Gateway Portal Concept is summarized:

1) The Gateway portal has two parts device portal and service portal (platform).
2) The device portal plays a role to collect information from devices and equipment in desalination plant.
3) Multiple device portals are able to communicate each other in peer-to-peer method to exchange information and service applications and also send/receive various data, meta-data, information, and control & management commands required by service portal.

The gateway portal will give the strategy to reduce electric cost through Demand Response. Peak shifting, Peak-shaving are the main technology of Demand Response.

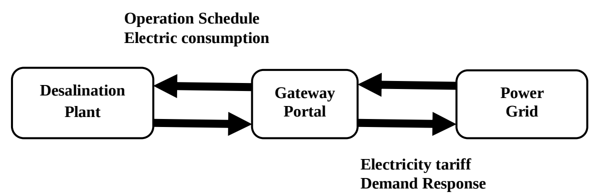


Figure 2. Grid-Connected desalination plant

3. Power Usage Measuring System

A power usage measuring system is shown in Figure 3. Configured system is composed measuring part in plant, monitoring part as a gateway and management part. Between measuring part and monitoring part is communicated with Zigbee wireless network which enables measuring point in desalination plant and gateway located anyplace in plant. Monitoring part as a gateway gathers measuring device data in real-time and shows current power consumption, total power consumption in today, electric tariff of today based on electricity price table from power supplier, and each device power usage in real time. Management part as a server in this system shows detailed location of power measuring point in desalination system, measured data statistics as a time, day, month and year.

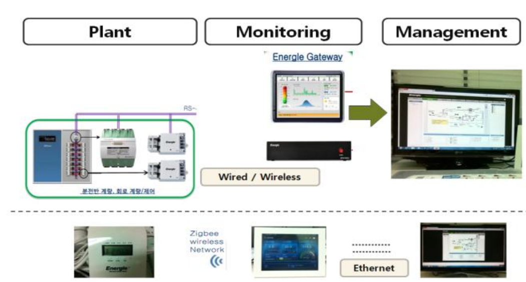


Figure 3. Power Usage Measuring System Configuration

To demonstrate the suggested detailed power consumption measuring system, small size of desalination plant is used. Small size desalination plant has a feed pump, reverse osmosis pump and permeate pump. To measure each pump power usage a measurement device is connected each pumps and gathered each power usage data. Figure 4 shows the small desalination plant with measuring device and figure 5 shows measured power data in each pump from small size desalination plant. Measured data show total power consumption of this plant is 798 [W] as an average. Permeate pump usage is 225 [W], feed pump usage is 400 [W] and RO pump is 173 [W]. Currently electricity cost is not connected directly to the Power Grid system. Therefore to show Grid-connected effect, electric price table is used in section 4.

Figure 4. Measuring System Mounted in Small Size Desalination Plant

Figure 5. Measured Power Usage Data from Small Size Desalination Plant

4. ELECTRICITY PRICE REDUCTION

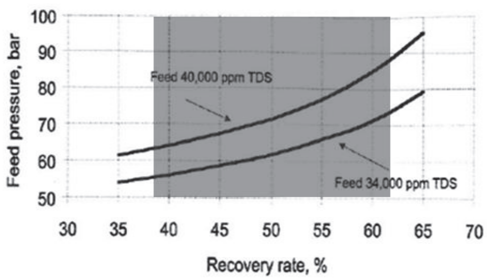
In general, electricity tariff is a different as a season and usage hour. Table 1. is a electricity price from Korea Electric Power COoperation (KEPCO). Electricity prices are high during the peak electricity demand hours and low during off-peak load time period. From this electricity price table, High-Voltage B, Option III is used in order to show Grid-connected desalination plant operation cost reduction. If desalination plant operation can be scheduled using the estimation production demand and electricity price, operation cost can be reduced compare to traditional operation.

Table 1. Electricity price, Korea, Industrial service (C)

Classification		Demand Charge (won/kW)	Energy charge(won/kWh)			
			Time Period	Summer	Spring, Fall	Winter
High-Voltage A	Option I	6,070	off-peak load	46.70	46.70	50.10
			mid-load	89.30	65.80	84.00
			peak-load	152.50	89.30	116.50
	Option II	7,000	off-peak load	42.00	42.00	45.40
			mid-load	84.60	61.10	79.30
			peak-load	147.80	84.60	111.80
High-Voltage B	Option I	5,590	off-peak load	45.70	45.70	49.00
			mid-load	87.60	64.60	82.40
			peak-load	149.90	87.60	114.00
	Option II	6,210	off-peak load	42.60	42.60	45.90
			mid-load	84.50	61.50	79.30
			peak-load	146.80	84.50	110.90
	Option III	6,890	off-peak load	40.90	40.90	44.20
			mid-load	82.80	59.80	77.60
			peak-load	145.10	82.80	109.20
High-Voltage C	Option I	5,550	off-peak load	45.10	45.10	48.30
			mid-load	87.40	64.30	81.90
			peak-load	149.30	87.40	113.70
	Option II	6,340	off-peak load	41.10	41.10	44.30
			mid-load	83.40	60.30	77.90
			peak-load	145.30	83.40	109.70
	Option III	6,800	off-peak load	40.20	40.20	43.40
			mid-load	82.50	59.40	77.00
			peak-load	144.40	82.50	108.80

Recovery Rate

The Desalination recovery rate is the product water recovery relative to the input water flow. Figure 6. shows recovery rate curve as feed pressure, the production can be controlled either change feed pressure or recovery rate during TDS is constant. Increasing pump head and flow rate, the production of desalination plant will be increased. But the membrane will be harmed by high pressure. Lowering pump head and flow rate, the production of desalination plant will be decreased. But the membrane will be maintained by low pressure. In general, recovery rate is between 48% and 50%. Therefore, if recovery rate can be controlled based on the electricity price, desalination operation cost can be saved. For the purpose of this study, electric consumption of pump in desalination plant is used. Table 2. shows the power usage in test-bed desalination plant in Korea. This test bed is composed 2MIGD (Million Imperial Gallons per Day) and 8MIGD capacity.



TDS : Total Dissolved Solids

Figure 6. Recovery rate curve

Table 2. Electric Consumption, Pump in plant

name	Flow	% rec	Head	density	gravity	Hy eff	Mo eff	power
Energy for 2MIGD HP Pump	834	48	386.11	1024	9.81	85	95	1112.7
Energy recovery Pelton drive	432		503.53	1024	9.81	75		455.24
Energy for 8MIGD HP Pump	1612	48	548.31	1024	9.81	85	95	3054.3
	1612	62	647.82	1024	9.81	85	95	3608.6
	1612	37	468.7	1024	9.81	85	95	2610.9
Energy recovery PX drive	1725		502.53	1030	9.81	100		2433.1
8MIGD booster Pump	1725	48	45.509	1030	9.81	80	95	289.92
	1725	62	45.509	1030	9.81	80	95	289.92
	1725	37	45.597	1028	9.81	80	95	289.92
2nd Pass RO pump	1070	91	133.49	1000	9.81	80	95	512.13
	1344	88	112.09	1000	9.81	80	95	540.16
	864	94	152.85	1000	9.81	80	95	473.51

Hy eff : Pump efficiency (%)
Mo eff : Motor efficiency (%)

Table 3. Electric consumption, recovery rate

Recovery Rate(%)	37	48	62
Total energy for RO (kWh)	4,969	5,551	4,487
Pump energy for RO (kWh)	2.596	2.402	2.830

Table 3. is calculated electric consumption based on recovery rate. Calculated value is applied to Table 1. Electricity price. This approach is the Grid-connected desalination operation. When electricity price is high, 37% recovery rate is used. However, electricity price low, 62% recovery rate is used. Figure 7. shows Grid-connected desalination operation based on electricity price.

In Figure 7. total production is same but the production rate is different from electricity price. From table 1, peak load charge is expensive so the production is smallest than other time period. Figure 8. illustrates a comparison between traditional desalination operation and Grid-connected operation. Traditional desalination operation cost is about 3.3 billion KRW (3 million USD) and Grid-connected total saving cost is about 53,000,000 KRW/yr. This is 1.6% of total electric consumption cost.

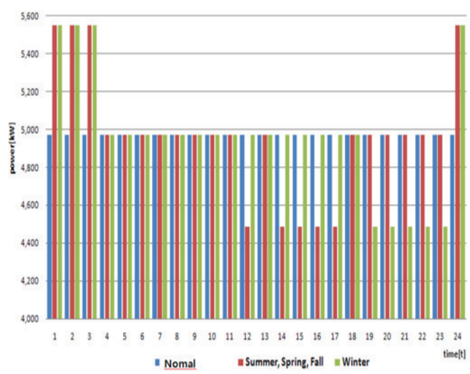


Figure 7. Operation based on electricity price

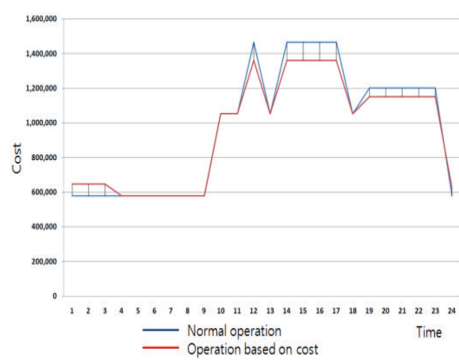


Figure 8. A comparison of normal operation and based on electricity price

5. CONCLUSION

A grid-connected desalination plant operation approach is suggested. A suggested approach is operated based on electricity price rate schedule. To show the result of suggested approach, Electric price rate of Korea is used. The result shows that total cost reduction rate is calculated about 1.6% of annual total electric plant operation cost.

ACKNOWLEDGEMENT

This work was partially supported by a grant for the Plant Technology Advancement Program funded by the Ministry of Construction & Transportation of the Korean Government (10-seaheroB04-1)

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