STRATEGIES FOR ENHANCING THE USE OF SOLAR ENERGY IN UTILITY-SCALE DESALINATION PLANTS

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EXTENDED ABSTRACT SUMMARY

The current expansion of desalination faces the challenge of the amount of energy required to operate the plants. The extra pressure of the electricity consumption of reverse osmosis (RO) plants running 24 hours a day at a certain location is not always met by the existing electric grids. In addition, for the sustainability of desalination, the new sources of energy that must be incorporated into the grid to meet the demand for RO should be renewable, and renewable energy sources are variable. Photovoltaic (PV) plants are proposed as the first option since they produce the cheapest renewable electricity, and solar radiation is highly available where desalination plants are required. However, without using batteries that are expensive, PV can only supply a reduced fraction of the total energy needed. Concentrated Solar Power (CSP) plants generate electricity that may not be as cheap as PV. Still, it is more manageable because thermal energy storage is much more feasible and cheaper than batteries, so CSP electricity can be produced during a much larger fraction of the day (even at night) compared to PV electricity. In this work, we analyze how the hybridization of PV with CSP technologies can significantly increase the total fraction of solar electricity that can be effectively supplied to the grid to meet the demand of RO plants. Several scenarios are compared and discussed considering a typical RO plant and a discussion on cost implications is used to suggest the most favorable case.

Keywords: Desalination, Sustainability, Solar energy, Photovoltaic, Concentrated Solar Power.

EXTENDED ABSTRACT

I. INTRODUCTION

Desalination capacity has risen significantly, going from 35 million m^3/d in 2005 to approximately 100 million m^3/d in 2021, with an expected increase to 150 million m^3/d by 2025 [1]. This has a strong impact on the energy demand, which increases significantly and, in many cases, demands an extension on the existing grid. In the current climate of decarbonization of industrial activities, the incorporation of solar energy is being considered with the expansion of the desalination capacity in the world, given that the regions that require desalination tend to be those that have high levels of solar irradiation.

Reverse osmosis (RO) is the standard desalination technology, and its high technology maturity level means that practically all future large-scale desalination plants will be based on RO.

Solar Photovoltaic (PV) electricity is the cheapest amongst all the renewable energy technologies. Levelized Cost of Electricity (LCOE) reported for utility-scale PV projects commissioned in 2019 was an average of 68 USD/MWh, with an expected decrease to a third in 2050 [2], and the minimum cost reported is 20 USD/MWh (at Mohammed bin Rashid Al Maktoum Solar Park, Dubai). However, the relative movement of the Sun in the sky means that the solar radiation is not constant and follows a (predictable) curve during the day, with the peak at the highest solar altitude each day. In addition, cloud covering, fog and dust reduce the solar irradiance in a less predictable way, augmenting the variability of the PV energy produced and reducing its capacity factor, which is the ratio between the actual energy produced by the solar plant and the total energy demand (the peak power assumed constant during the whole day). In the best conditions, the capacity factor of PV energy is rarely above 30% [3].

To enhance the capacity factor, the PV plant can be dimensioned with a peak power above that of the demand. This means that there will be times when the instantaneous energy production will be above that consumed. If that excess energy is stored in batteries, it can be used at other times when the PV is not able to supply the full power required. This increases the operating time that the solar energy is available but increases the CAPEX of the solar facility, not only by the increase of the size of the PV field but by adding the cost of batteries, which has an impact on the cost of electricity. From estimations by NREL, the LCOE of utility-scale PV with batteries (about 4-hour storage) rises above 75 USD/MWh [4].

On the other hand, concentrated solar radiation can also be used to generate solar thermal electricity (the so-called concentrated solar power or CSP). In this case, the solar collectors are used to produce heat, from which electricity is generated. There is the possibility of storing heat in molten salts at 400-550 ºC to operate the turbine when there is no solar irradiance. This makes CSP the only dispatchable renewable energy since it can be produced on demand from molten salts, which are a more affordable and sustainable means of energy storage than batteries for electricity (and they do not use critical materials with environmental and geopolitical limitations) [5]. CSP is, therefore, a very attractive supplement to PV energy, which otherwise must be coupled to a non-renewable source of energy to supply the constant operation of a desalination plant.

The costs of CSP are higher than those of PV but on a descending trend, and the cheapest plant awarded has an LCOE of 74 USD/MWh, which is amongst the range projected for utility-scale PV with batteries. Deployment policies have significantly reduced the cost of CSP in the last decade, with further decreases expected if further investments in new power plant capacities are undertaken. Furthermore, there is room in CSP to increase the efficiency, as is the case of using Brayton cycles based on air (or even supercritical CO_2) in high-temperature central receivers (>700 ºC) using air or falling particles, and this can lead to significant cost decreases in the LCOE of CSP [6].

II. RESEARCH

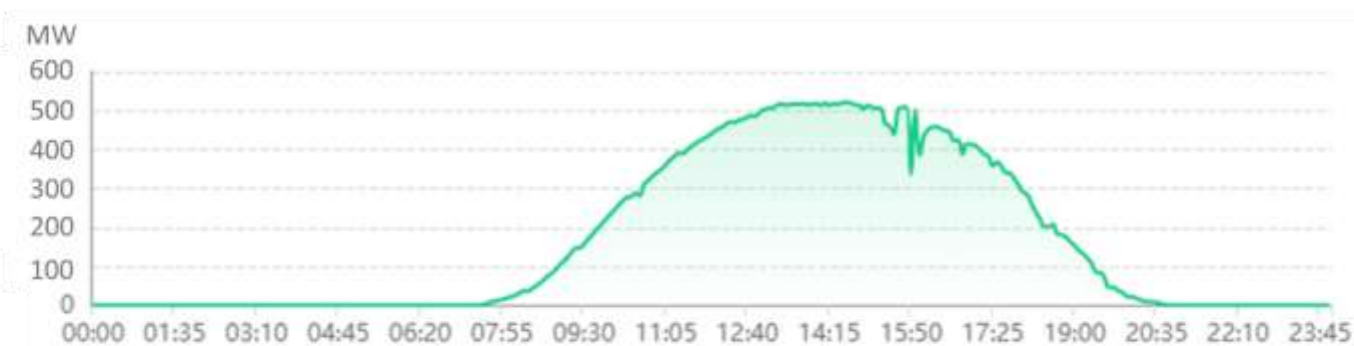
To perform the research, a daily production of 4 Hm^3/day of desalinated water has been considered, which is a figure that can be expected for the total seawater desalination capacity of Spain in a few years. The average consumption of a RO plant for seawater desalination (SWRO) has been taken as 3 kWh/m^3, which is a figure in the low end of the current state of the art [7], as can be expected considering new or retrofitted plants for high efficiency. This gives roughly a total power required for the RO plants of 500 MW.

An analysis was done using the System Advisor Model software [8] to estimate the Levelized Cost of Electricity, the capacity factor and the total land footprint of PV and CSP power plants to meet the 500 MW capacity (net AC electricity) required.

The preliminary comparison was performed considering solar radiation data of Palomares, a location near the sea in Almería, SE Spain. To meet this power with solar PV, state-of-the-art collectors with 1-axis tracking without batteries have been considered. In the CSP case, parabolic trough collectors with 1-axis tracking were considered, as well as heat storage with 24-hour overall capacity using molten salts, to benefit from the advantage of CSP regarding heat storage.

III. RESULTS

Figure 1 illustrates the total power generated during a day (summer solstice) by a 500 MW installation of PV energy. It can be seen that only at solar midday (around 14:20 local time considering GMT+1 time zone and daylight-saving time, as corresponding to the location suggested for the study).



The results of the simulation are indicated in Table 1, which shows the LCOE, the capacity factor and the total land occupation for supplying 500 MW of solar energy in the two cases considered.

Table 1: Data for the solar power required for a 4 Hm^3/day SWRO plant

	500 MW PV	500 MW CSP with 24-h heat storage
LCOE	5.25 USD/MWh	7.13 USD/MWh
Capacity factor	21%	72%
Total land use	342 Ha	828 Ha

As hinted in Figure 1, Table 1 shows that, with a PV plant without batteries, only 21% of the total energy required for SWRO can be supplied. The rest should come from another source of energy which produces more during non-solar hours. However, the capacity factor of CSP with heat storage can reach 72%. The advantage of CSP electricity is that it is dispatchable, so it can be used in non-solar hours to supplement that PV energy produced instantaneously. Thus, the hybridization of PV and CSP could reach almost full solar energy supply for desalination. For the 4 Hm^3/day production with SWRO, a land area of 342 Ha would be required for PV and for CSP about 828 Ha. The cost of electricity in all cases could be acceptable compared to the fossil option. A cost of 5.25 USD/MWh in the case of PV (without batteries) and a large cost of 7.13 USD/MWh in the case of CSP. It is true that the latest cost might be excessively favored by the economy of scale, given that a 500 MW CSP plant is much larger than the current state of the art. However, the calculations for a 25 MW plant with similar conditions of solar radiation and total heat storage would result in an LCOE of 7.5 c$/kWh, which is still competitive with the current costs of grid electricity during non-solar hours.

IV. CONCLUSIONS

This study shows that CSP with 24-hour thermal energy storage can be a good supplement to PV for incorporating solar energy towards the full decarbonization of desalination. A hybridization combining 500 MW of PV and 500 MW of CSP would produce in SE Spain a total amount of solar energy close to that required by RO plants to produce a total of 4 Hm^3 of SWRO desalinated water per day. In that case, the costs of electricity would be about 5.3 c$/kWh for PV, and 7.1 c$/kWh for CSP, with a total land use for PV of 342 Ha, which is equivalent to that of Central Park in New York, and 2.4 times more for CSP.

V. REFERENCES

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