Sizing of WT-PV hybrid system supplying a desalination plant comprising water storage

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ABSTRACT

This paper presents a method to determine the optimum size of a hybrid system, consisting of Wind Turbine generators (WT) and PhotoVoltaic modules (PV), supplying the electricity demand of a desalination plant, which operates with Reverse Osmosis (RO) technology.

The proposed optimization method takes into account both, economic and technical aspects. The water reservoir size is considered as part of the system.

The mathematical model of the above energy management approach is analyzed and results for a typical case study are demonstrated.

KEYWORDS: desalination, hybrid system, renewable energy, energy management, optimization, linear programming.

1. INTRODUCTION

The modern lifestyle and the increase of the population have caused a growth to the water consumption. Beside, the water deposits are continuously decreasing. Among the solutions to the problem of the water lack is the desalination technology, which however has the disadvantage of consuming a great amount of energy. On the other hand, renewable energy sources (WT, PV) produce energy under low operational cost and therefore the combination of those technologies can lead to a cost effective solution for a viable operation of the RO plant [1-3].

The aim of this study is the estimation of the optimum size of the WT-PV park (optimum number of WT and PV modules), which supplies the RO plant. A water reservoir integrated into the RO plant contributes to a lower size hybrid system required. Thus, the reservoir optimum size is also investigated. The amount of the water in the reservoir is taken into account at each time in order to determine the best energy management [4].

The desalination plant is considered to consist of a number of identical RO modules. The design of the RO modules allows operation at fluctuating water flow and pressure, and facilitates them switching on and off. The energy consumed by the RO plant follows closely the energy produced by the hybrid system by switching on and off the appropriate number of RO modules, accordingly to the available energy. Even when the number of operating RO modules is kept constant, the consumed energy can vary because each RO module can operate over a wide range of input power [5].

An effective algorithm has been developed for the computation of the optimal system sizing and is applied to a case study of a Cretan community.

2. DESCRIPTION OF THE METHOD

At each time step t_i the WT-PV park supplies the RO plant and an amount of fresh water is produced. The difference between the water production and the demand is added to a water reservoir. Thus, the current water amount stored is the amount at the previous time step t_{i-1} together with the above difference and can vary between a maximum and a minimum value, which are the marginal values of the reservoir capacity. Notice that it is desirable always the reservoir to contain a minimum amount of water.

When the WT-PV power is inadequate to produce the demanded water, the reservoir supplies the consumption. Contrarily, when there is an excess of WT-PV power the produced water is stored into the reservoir.

The energy generated by the stochastic generators (WT and PV) produces a proportional amount of desalinated water. Thus, for homogeneity purposes, the water amount is expressed in energy units (kWh).

The mathematical model, which describes the algorithm, consists of the technical constraints mentioned above and the objective function comprising the costs that must be minimized.

The constraints are given by the relation:

$$C_{\min} \le N_{wt} \cdot W_{wt_i} + N_{pv} \cdot W_{pv_i} - W_{l_i} + C_{i-1} \le C_{\max} \qquad (1)$$

where,

W_{wt_i} is the energy generated by one WT at each time step t_i (kWh)

W_{pv_i} is the energy generated by one PV module at each time t_i (kWh)

N_{wt} is the number of WT generators

N_{pv} is the number of PV modules

W_{t_i} is the amount of water consumption at each time t_i (kWh)

C_{i-1} is the amount of water in the deposit at the previous time t_{i-1}, that is:

$$C_{i-1} = N_{wt} \cdot W_{wt_{i-1}} + N_{pv} \cdot W_{pv_{i-1}} - W_{t_{i-1}} + C_{i-2} \quad (kWh)$$

$C_{\min}$ is the minimum amount of water in the reservoir (kWh)

$C_{\max}$ is the maximum amount of water in the reservoir (kWh)

The objective function to be minimized is the following:

$$\min\left(K_{wt} \cdot N_{wt} + K_{pv} \cdot N_{pv} + K\right) \qquad (2)$$

where,

K_{wt} is the installation and maintenance cost (€) for one WT

K_{pv} is the installation and maintenance cost (€) for one PV module

K is the installation cost of the water reservoir and other costs (€)

The Linear Programming procedure is employed for solving the above problem, where the constraints are given by (1) and the objective function by (2).

$$\left.\begin{array}{c} \min\left(K_{wt} \cdot N_{wt} + K_{pv} \cdot N_{pv} + K\right) \\ C_{\min} \le N_{wt} \cdot W_{wt_i} + N_{pv} \cdot W_{pv_i} - W_{t_i} + C_{i-1} \le C_{\max} \end{array}\right\}$$

The algorithm is programmed in MATLAB environment.

3. CASE STUDY

The proposed study is applied to the water demand case of the community of Paleochora/ Crete/Greece, which has a mean daily consumption of 500 m^3. It is considered that the community is supplied by desalinated water from the RO plant, the WTs are Vestas 47 (the technical characteristics are shown in Table 1), the PVs are Siemens SP75 (the technical characteristics are shown in Table 2), the power consumption of each RO module is 25 kW and its rated daily water production is 110 m^3/day (the sampling interval is taken 10 minutes).

Table 1. Characteristics of the wind generator

Model	VESTAS V-47
Rated power	660 kW
Rated voltage	690 V
Rated wind speed	17 m/s
Cut-in wind speed	4 m/s
Cut-out wind speed	25 m/s
Diameter of the blades	47 m
Rotor height	45 m

Table 2. Operation characteristics of the solar panel

Model	SIEMENS SP75
Maximum power	75 W
Rated voltage	17 V
Rated current	4,4 A
Open-circuit voltage	21,7 V
Short-circuit current	4,8 A
Dimensions	1,2 m × 0,527 m

The cost per WT is analyzed as follows [6]:

- The installation cost (including the purchase of the WT, the purchase of the land where the WT will be installed, civil engineering's works and electromechanical works) with a subsidy of 30% is estimated at 476.600 € [4]
- The annual cost of insurance and maintenance is estimated at 5.870 €

The common cost of the WTs (e.g. the cost of the control room of the wind park) is estimated at 293.500 €.

The cost per PV module (1 kW) is analyzed as follows:

- The installation cost (including the purchase of the PV panel, inverter and the purchase of the land where the PV will be installed), with a subsidy of 50% is estimated at 4.770 € [4]
- The annual cost of insurance and maintenance is estimated at 42,5 €

The investment cost of a 10 km medium voltage transmission line connecting the wind park with the RO plant is estimated at 220.000 € (22.000 €/km), given a subsidy of 50% [7].

The annual cost of staff's salaries is estimated at 59.574 €.

The cost of a 1.000 m^3 capacity water reservoir is 176.000 €.

The above investment costs are reduced to an annual base estimating the annual capital recovery of them with a rate 10%. So, the above costs become:

- WT: 55.960 €
- PV: 499 €
- Common cost of WTs and transmission line: 66.200€
- Water reservoir (1.000 m^3 capacity): 11.890 €

4. RESULTS

Using the values for the case study described above, the number of WTs, the number of PVs and the cost (annual capital recovery) of the hybrid system vs. the capacity of the water reservoir in days of sufficiency is investigated (the mean water demand is 500 m^3 per day). The above functions are plotted in Figs. 1, 2 and 3, respectively.

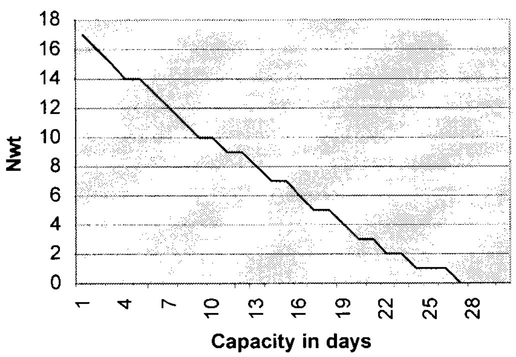

Figure 1. Variation of the number of WT

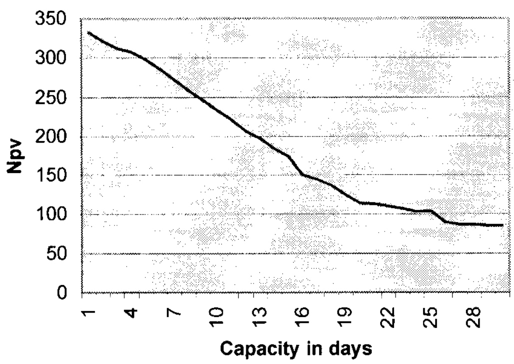

Figure 2. Variation of the number of PV

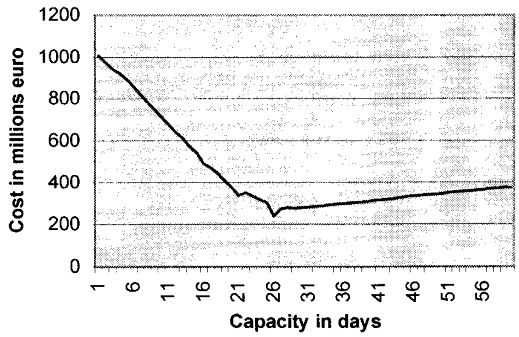

Figure 3. Variation of the total cost of the hybrid system

Notice that the number of WTs and PVs (and subsequently, the cost of the hybrid system) is decreased as the capacity of the water reservoir is increased. This happens because the cost of a WT or a PV decreases more than the increase of the water reservoir cost.

The size of the water reservoir cannot become infinite and it is limited due to technical reasons. Assuming that the reservoir size is unlimited, then, beyond a value for the reservoir capacity, the number of WTs and PVs does not decrease and therefore the total cost increases, as is depicted in Fig. 3.

Hence, the integration of a water reservoir in the hybrid system (WT-PV park, RO plant) is a cost effective solution and decreases the total system's cost.

5. CONCLUSIONS

A methodology proposed for the evaluation of the impact of a water reservoir to a hybrid system (WT park, PV park, desalination plant) and the determination of the optimum size of them has been presented. The methodology is applied to a Cretan community as case study and the results are displayed. A general conclusion of this study is that the integration of a water reservoir results in reduced total system size and consequently lower cost.

6. ACKNOWLEDGEMENT

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