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The influence of water desalination systems on load levelling of gen-set in small off-grid islands

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Abstract

In minor off-grid islands, energy is typically supplied by diesel generator set, while water, when not shipped with water tankers, is produced by means of desalination systems (typically based on reverse osmosis). The additional demand of desalination related power to the already inefficient diesel power systems may worsen gen-set performance. State-of-the-art remedial strategies advocate the use of renewable energy technologies in order to reduce the impact on diesel generators. Nevertheless, many small islands, due to their environmental value and tourist vocation or due to the quality of the local grid, do suffer of more stringent limitations reducing the potential of penetration of renewable energy. To this end, the present work aims at reporting on the influence of water desalination system on diesel generators load levelling. The study of different matching scenario, using a time-dependent model, demonstrates the possibility of finding management strategy paying-off with improved generator performance.

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Keywords: Small islands; Off; grid; Diesel gen-set; Desalination; Load leveling

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1. Introduction

In a smart grid perspective, big efforts are dedicated to closing locally material and service cycles. The avenue to return to a local dimension from the present global world is difficult and first attempts have been made on small grid portions (i.e. micro-grids), in order to easily define the cycle limits, introduce system modifications and analyze results [1]. The most important cycles relate to energy, water, food and wastes. Such interventions are even more

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critical in small islands dependent on the mainland for the supplies, entailing additional shipping costs. Besides, islands, which are closed environments for definition, with well-defined edges and highly detectable fluxes, appear the best test sites for experiences conducing to closed cycles trough local synergetic interventions.

In off-grid islands, the energy aspects are of particular interest in the energy transition toward renewable-based systems. In fact there are more than 50 thousand islands, usually off-grid, on Earth, with a population exceeding 740 million people. Frequently, in island frameworks a strong environmental sensibility is growing, demonstrated by several international initiatives [2, 3] and the presence of twenty islands in energy transition toward 100% renewable energy, with ten islands which have already reached the goal [4]. It is worth noting that, with exception of one island, wind energy is always taken into account in the transition process, while solar energy is considered in sixteen of the twenty islands. It is interesting to point out that of those twenty islands, only one is recurring to ocean energy (tides). Also in view of the emission limits defined by the Industrial Emissions Directive for islands within December 31st 2019, the use of renewable energy power systems appears as an opportunity to effectively act the energy transition, especially when most European islands are expecting increases in electricity demand. with an average value of 24% from 2009 to 2020 (note that the EU-27 increase is expected to be 14% [5].

Most Mediterranean off-grid islands share the following peculiarities: a) over-sized and inefficient local gen-sets, with higher COE; b) supplies shipped from mainland, influencing costs and dependent on weather condition; c) strong tourist vocation with high summertime peaks of population, leading to concentrated supplies demand; d) severe environmental restrictions. Such peculiarities often match with reduced availability of land, resulting in additional constraints on renewable technology installations. For instance, in Italy, notwithstanding the presence of 19 small off-grid islands, with an overall population of 42568 inhabitants, only 1048 kW photovoltaic and 36,85 kW wind power systems are installed. In contrast, the mainland boasts 39 completely renewable-based municipalities [4]. On the other hand, the introduction of renewable energy systems, which offer a highly fluctuating power supply, worsen the already unstable and part-load working conditions of the local engines. This situation leads to preventing the neglecting of Diesel Engines Generator Set (DEGS), in order to maintain security and reliability of the isolated energy system. In this framework, the island green energy transition necessarily has to pass through an intermediate phase, represented by the improvement of the DEGS performance, when coupled with renewable technologies, storage technologies or buffering strategies.

When adding the water desalination and supply demand, the power generation problem can worsen. In fact, many island do not have water springs or wells, or their productivity is not enough to satisfy the request entailing the implementation of local desalination plants [6, 7], often with renewable-based power supply [8-12]. Nevertheless, for places with renewable energy penetration limits, new ways of system integration should be sift through, in order to get an integrated water/energy system without negatively impact on the local energy systems.

The present work is a study of the integration of a desalination plant in a small island energy system with the aim to define and validate a desalination plant management strategy in view to load-level the DEGS and improve their performance. The following paragraphs will explain the adopted methodology, introduce the case study and the simulation scenarios and show the obtained results.

2. Methodology

The study represents the progression of a previous one [8] taking Ponza as reference small island for the methodology assessment. The study is based on the results obtained from the comparison of three scenarios of increasing complexity: a) a base case; b) a renewable integrated configuration and c) a load levelling desalination/renewable system. Like previous works on small-islands [8, 13-16], hourly-based transient simulation models, for a reference year, were developed in TRNSYS by adding in-house models for Reverse Osmosis (RO) desalination unit, water and energy control and ISWEC wave energy converter.

The proposed load levelling system model, described in Figure 1, works on a power basis. The developed power control receives information on: power demand from the local users (P_D), available power from wave energy (P_{RES}) and requested power for RO (P_{Cmax}) aiming at the complete replenishment. The water control receives information about water load and tanks state of charge, determining the lacking amount of water and the related power request (P_{Cmax}). Hence the power control compares the power information and defines the working points of RO and DEGS.

In order to evaluate the system behaviour, results will be compared with those deriving from the base case model, representative of the existing energy system, and from the renewable integrated base case model.

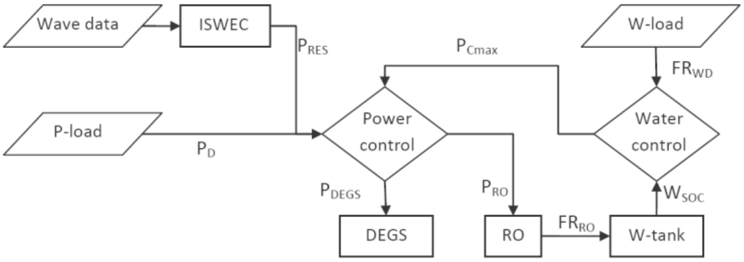

Fig. 1. Load levelling system model flowchart

2.1. Developed control logic

The flowchart of the control module is illustrated in Figure 2. The decisional process is indicated by letters in circles, and end blocks are identified by numbered boxes. The aim of the control logic is to improve the efficiency of the generator set, by deciding the final power set point (P_{DEGS}) and the number of on-duty engines (N_{DEGS}).

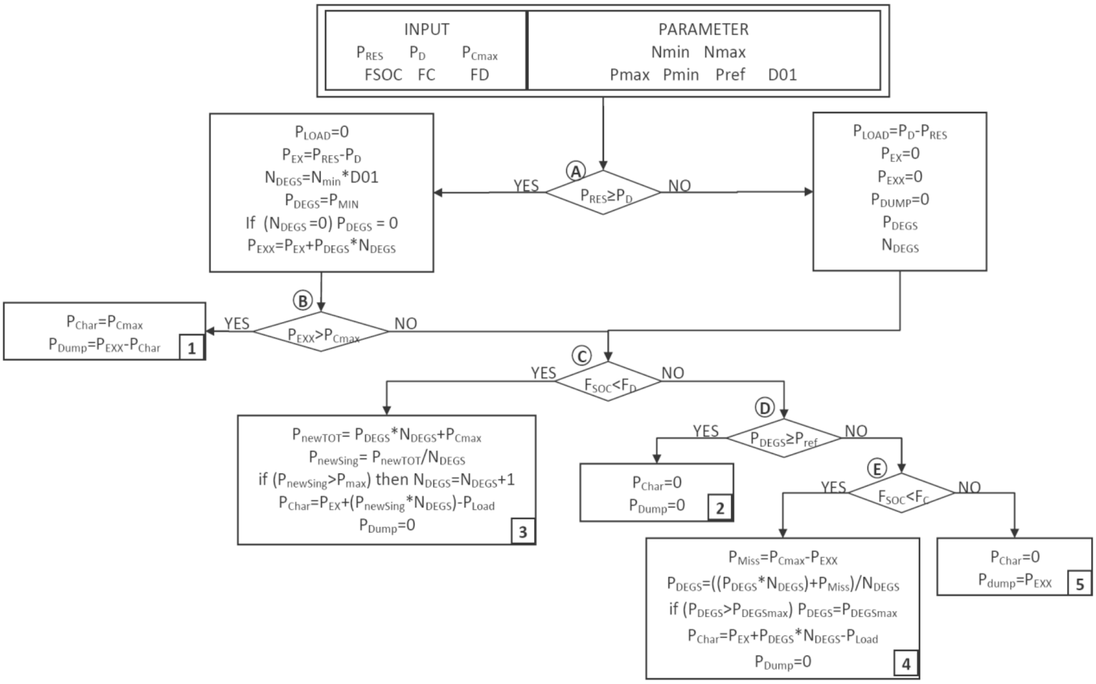

Fig. 2. Energy/water control logic flow chart.

The set point is given by the comparison of renewable power availability (P_{RES}), a reference power set (P_{REF}) and end user power demand (P_D) and clean water production schedule given by the fractional state of charge (FSOC) of the tanks, e.g. between minimum (FD) and maximum (FC) values. The goal is to produce fresh water only by improving the generator set performance. Concerning the grid, renewable power has dispatch priority and an on/off flag (D01) allows to decide whether the diesel energy plant should be on duty at a minimum service point or not in case of renewable power surplus (P_{EX}). The first step determines if there is a renewable power surplus (P_{EX}), hence the basic electric generator power set point and the engines number will be determined by means of the generator set control [17] which takes into account the minimum and maximum power ratio for one engine. In case of available energy surplus such excess will be used for the RO (end block 1). Hence a new generator set point is determined with two options: a) both power and number of on-duty engines change, in order to meet the desalination plant power request when the water tank state of charge is below FD (end block 3); b) only power increase when state of charge is between FD and FC (end block 4). Moreover, when engines already work at a satisfactory duty point, there will be no changes in the DEGS set points and no desalination (end block 2). Desalination is also cut-out when water tanks are full (end block 5). It is worth noting how the FD value affects the control behaviour: if FD=0, then engines are never switched on only for water desalination purposes, if FD is between 0 and 1, then in some cases engines may be switched only for desalination purposes; if FD=1 then engines are always allowed to be switched on for desalination purposes.

2.2. Simulation parameters

The DEGS is modelled by six 1400 kW units (Table 1), with a global power of 8.4 MW. In accordance with NREL [18], it is not recommended for diesel gen-sets to be used under minimum allowed loading (about 25% of the rated capacity), thus the minimum power ratio is set at 0.4. The maximum power ratio is 0.85.Moreover, it was decided to maintain on duty the Nmin engine, also in case of renewable power higher than load power (i.e. D01 equal to 1). The reference power is 600 kW. The wave energy array, based on off-shore ISWEC technology [19] is composed by 8 units of 60 kWp with a total nominal power of 480 kW. A previous study [8] shows the results of the application of such technology in Ponza Island. The RO desalination plant is composed by eight 300 m^3/d capacity units with a seawater feed flow of 32.00 m^3/h and a permeate flow of 12.5 m^3/h. The power consumption of the RO units, equipped with an energy recovery device, and considering the power request for sea-water draw, fresh water raise and brine rejection, amounts to about 360 kW. The control logic of the water production is aimed at maintaining a two days autonomy water level in the storage tanks in case of plant default, by setting FD=0.2 that means 600 m^3.

Table 1. Main technologies description

DEGS	6 units of 1400 kWp	8.40 MW
ISWEC array	8 units of 60 kWp	0.48 MW
Desalting station	8x300 m^3/d	359.44 kW
Water storage	existent tanks	3000 m^3

3. Case study description

The adopted case study is Ponza, major island of the Pontinian Archipelago, in the Tyrrhenian sea. Ponza has a total surface of about 7.5 $km^2$and about 3200 people. The climate is that typical of Mediterranean areas, with mild winters and hot summers. Due to its tourist vocation, the arrivals on the island vary from about 4000 in January to about 55000 in August, leading to severe service problems, in particular concerning energy and water. From the energy point of view Ponza completely relies on two DEGS, respectively a main power station of 6.2 MW provided by four engines, and a peak shaving station of 2.6 MW provided by two engines, which only operates in the summer period. The yearly energy request is approximately 12 GWh/y, with a maximum power request peak of about 5 MW in the summer period. In winter time the request amounts to 1-2.5 MW. From the renewable energy perspective, the scarce land availability and the subjection to the Council Directive 79/409/CEE, on the conservation of wild birds besides other landscape conservation restrictions, are strong factors limiting the possibility of dedicated renewable technologies installations. To this end, besides energy efficiency and photovoltaic technology, previous studies assessed the wave-energy potential, both for an on-shore device [15, 16] and a near shore one [8].Year 2007 has been selected as reference year for the wave data obtained from [20] after the comparison of years from 2001 to 2010. The yearly mean wave height and period are respectively 0.88 m and 4.37 s with a maximum of 6.45 m and 9.34s.

From the water point of view, Ponza is devoid of springs or wells, completely depending to the mainland for its water supply. Water request varies in a 10-40 m^3/h range in winter time and reaches peaks of 240 m^3/h in summer. The global amount of water amounts to 400000 m^3/y, entailing 237 water tank ships trips to bring water from mainland. More details about the present water supply may be found in [8].

4. Results and discussion

With respect to the flowchart in Figure 2, in each simulation time-step the renewable power (globally 60.06 MWh/y) is less than the local power demand (globally 10663.68 MWh/y). Moreover, in the load levelling scenario the system works in end-block 2 for 4524 hours that means that engines are working enough well and there is no water level emergency, for 4055 hours in end-block 3, water level emergency that tends to a complete tank charge, and for 181 hours in block 4 that means engines are working below the reference power but there is no water level emergency. The load levelling scenario allows a desalted water production of 411363 m^3/year, that is 97,99% with respect to the water load. Water deficit amounts to 4887 m^3, occurred in 152 hours and distributed within 42 days from 19 July to 30 August. The lacking water may be produced by increasing the recur to the generator set in July. Imposing a higher value of FD, i.e. the minimum water reserve, may eliminate the water deficit.

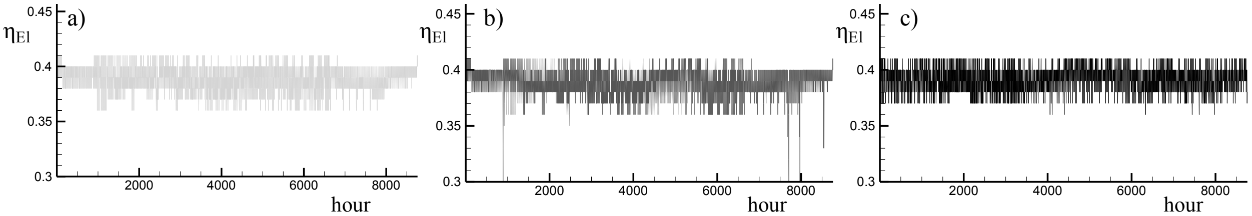

Fig. 3. Hourly based electrical efficiency of the engines for a reference year in the (a) base case, (b) renewable integrated base case, (c) desalination load levelling scenario.

Table 2. Global performance

	Base case	Renewable integrated base case	Desalination load levelling scenario
Engines energy output [MWh/y]	10663.68	10603.79	12126,3
On duty engines	12167	12138	13173
Mean engines power [kW]	893.10	888.71	931.12
Fuel consumption [10^3 l]	2778.27	2763.99	3173.01
Engines mean electric efficiency	0.3888	0.3883	0.3909
Fuel specific consumption [l/MWh]	0.2609	0.2613	0.2595
Energy to desalination [MWh/y]			1522.59
Carbon Dioxide emissions [t_{CO2eq}/y]	8530.91	8483.00	9701.01

Table 2 shows the global performance of the proposed system with respect to the base case and the renewable integrated base case. As expected, the introduction of renewable energy in the existing system has a minor impact, i.e. with only a 0.56% share of the year energy demand. Notwithstanding this limited contribution, it results in worsening of gen-set duty schedule that negatively impact onto the electric efficiency. This is shown by the minor deterioration of annual average, e.g. passing from a value of 0.3888 to 0.3883 and specific fuel consumption increasing from 0.2609 l/MWh to 0.2613 l/MWh. Vice versa, the introduction of the load levelling scenario entails improved performance with respect to both previous scenarios, with an electric efficiency of 0.3909 and a fuels specific consumption of 0.2595 l/MWh. Moreover, in the load levelling scenario, the mean engines power rises to 931.12 kW. Figure 3 shows the hourly-based electric efficiency for the three cases. With respect to the base case (Fig. 2a), it is evident the worst shape of the renewable integrated base case (Fig. 2.b) with values going below 0.35, and the greater compactness shape and the higher mean value of the load levelling scenario (Fig. 2.c). These results are obviously tied to a fuel consumption increase of 14,80% with respect to the existent scenario with wave energy and the employment of 13173 engines versus 12138. the minimum on duty engine increase is registered on July with a value of 3.76%. The most influenced months are January, April and May with increase of respectively 13.98%, 17.83% and 18.58%.

5. Conclusions

The present work adds a tile to the integration of desalination systems in small island energy systems with the aim to avoid a possible energy performance decrease. The main results are: almost a complete local water load coverage, DEGS performance improvement and reduction of almost half of the water-related emissions. In fact although an increase of greenhouse gases emissions of 1218 t_{CO2eq}/y, completely attributable to the desalination process, is registered, such increase corresponds to the 45.35% of the actual emissions for ship water supply, representing a huge improvement with respect to the present water supply system. In conclusion, it was demonstrated the effective capability of a desalination system to level the load, by smoothing the gaps coming from the introduction of a RES system. Further studies will propose the analysis of the effect of higher RES penetration and the development of the control logic applied to a RES/storage integrated system.

6. References

[1]Yoldaş Y, Önena A, Muyeenb SM, Vasilakosc AV, Alana I. Enhancing smart grid with microgrids: Challenges and opportunities. Renewable and Sustainable Energy Reviews 2017; 72:205–14.

[2] IRENA, GREIN - Global Renewable Energy Islands Network, Supporting Island Transitions to a Renewable Energy Future, http://www.irena.org/

[3] Rocky Mountain Institute and Carbon War Room, The Ten Island Renewable Challenge, http://carbonwarroom.com/content/islands-energy-program

[4] Legambiente(Italian League for Environment), Isole 100% Rinnovabili - Come 20 isole nel mondo sono in transizione verso uno scenario al 100% rinnovabile e la situazione delle isole minori italiane. Report Legambiente, Luglio 2016, in Italian.

[5] Eurelectric. EU Islands: Towards a Sustainable Energy Future. Report, June 2012.

[6] Segurado R, Costa M, Duic N, Carvalho MG. Integrated analysis of energy and water supply in islands. Case stdy of S. Vicente, Cape Verde. Energy 2015; 92: 639-48.

[7] Kaldellis JK, Kondili EM. The water shortage problem in the Aegean archipelago islands: cost-effective desalination prospects. Desalination 2007; 216:123–38.

[8] Corsini A, Tortora E, Cima E. Preliminary assessment of wave energy use in an off-grid minor island desalination plant. Energy Procedia 2015; 82:789–96

[9] Mentis D, Karalis G, Zervos A, Howell M, Taliotis C, Bazilian M, Rogner H. Desalination using renewable energy sources on the arid islands of South Aegean Sea. Energy 2016; 94:262-72.

[10] Alkaisia A, Mossad R, Sharifian-Barforoush A. A review of the water desalination systems integrated with renewable energy. Energy Procedia2017; 110:268–74.

[11] Goosen MFA, Mahmoudi H, Ghaffour N. Today's and Future Challenges in Applications of Renewable Energy Technologies for Desalination. Critical Reviews in Environmental Science and Technology 2014, 44:929–999.

[12] GnaneswarGude V, Nirmalakhandan N, Deng S. Renewable and sustainable approaches for desalination. Renewable and Sustainable Energy Reviews 2010; 14: 2641-54.

[13] Corsini A, Rispoli F, Tortora E, Gamberale M. Assessment of H2 and H2O-based renewable energy-buffering systems in minor islands. Renewable Energy 2009; 34:279–88.

[14] Corsini A, Rispoli F, Tortora E, Gonella M, Piccini M. Desalination performance of a concentrated solar power plant for energy and water production. Proceedings of 4th international Energy Conference In Palestine, Ramallah 26-27 January 2011.

[15] Corsini A., Marro E., Rispoli F., Tortora E., Wave energy conversion potential from small scale systems in the Pontinian Archipelago, Proceedings of OWEMES 2009 Conference, Brindisi (Italy), 21-23 May 2009

[16] Corsini A., Marro E., Rispoli F., Tortora E., Space-Time mapping of wave Energy conversion potential in Mediterranean Sea States, Proceedings of ASME-ATI-UIT 2010 Conference, Sorrento (Italy), 16-19 May 2010

[17] Klein SA, Beckam WA, Mitchell JW, Braun JE, Evans BL, Kummert JP, et al. TRNSYS – a transient system simulation program. Version 15.1. Madison: Solar Energy Laboratory, University of Wisconsin; 2000.

[18] Drouilhet S.M., Shirazi M., Wales Alaska high-penetration wind–diesel hybrid power system: theory of operation, National Renewable Energy Laboratory; 2002.

[19] Bracco G., Cagninei A., Giorcelli E., Mattiazzo G., Poggi D., Raffero M., Experimental validation of the ISWEC wave to PTO model, Ocean Engineering 120 (2016) 40–51.

[20] Private communication with ENEA-UTMEA-CLIM.