Agronomy Research **21**(3), 1154–1160, 2023
https://doi.org/10.15159/AR.23.063

Sustainable power generation expansion with RES and energy storage

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Received: February 10th, 2023; Accepted: April 30th, 2023; July 6th, 2023

Abstract. Several island power systems have a tremendous protentional for RES use. Nevertheless, present infrastructures and system operations emerge with limitations, preventing the technology from further exploitation. Specifically, this paper presents and analyzes a representative interconnected island power system operation and highlights the benefits and challenges of embedding an ultra-high share of RES. This level of power and energy penetration could be technically feasible, taking into account interconnections and electricity storage systems, which could provide under specific implementation strategies advantages in stability, reliability, and energy adequacy.

Key words: renewables, island power systems, interconnection, energy storage.

INTRODUCTION

Maximization of wind and solar power exploitation is particularly desirable. Still as far as it concerns the island system, careful consideration is needed so that a high level of reliability and stability of the system operation can be maintained (Hatziargyriou, 2013). Due to significant levels of uncertainty in production predictions, the main problems identified concerned the operational scheduling and mainly unit commitment (Mantri, 2021). The aforementioned issues may considerably limit the amount of wind and PV generation that can be installed on island systems, increasing the complexity of their operation (Rylander, 2016).

On the other hand, based on their geographical and natural position, European Islands play a vital role in implementing a sustainable energy policy (Jäger–Waldau, 2020). More precisely, the European Commission identified three primary dimensions concerning energy planning. The abovementioned include security of supply, sustainability and competitiveness (Jäger-Waldau, 2020; Mantri, 2021). Furthermore, several barriers and technical restrictions are evident in the island's energy system, such as higher total costs, price fluctuations and power supply insecurity (Macedo, 2017). However, these disadvantages can be outweighed by inherent advantages, primarily through renewable energy technology owing to the relatively high wind and solar exposure (Ndreko, 2019). This potential should be thoroughly exploited in order to investigate the operational and planning limitations and estimate the possible remedies (Varma, 2020).

The new operational and planning policies imposed by the present demands for increased efficiency and sustainability dictate the need to operate the power system more attentively. More precisely, several previous studies have analyzed the feasibility and benefits of a high percentage of energy supply from RES technologies in interconnected islands such as Crete (Varma, 2020). Renewable energy sources incorporated into Crete's power system already contribute up to 25% of its total energy balance.

Even though that there is a greater capacity of renewable energy available to be employed, the use of RES infrastructure has not increased. The existing power system operation imposes restrictions that hold back their further expansion (Estorque, 2016). More precisely, this study analyzes the island's present system operation and highlights the benefits and obstacles of interconnection and extensive energy storage utilization with the mainland of Greece alongside local units' installation to accomplish a significantly high share of RES remaining technically feasible, while providing stability, reliability, and energy sufficiency benefits under specific implementation strategies.

MATERIALS AND METHODS

As it is well acknowledged, island power systems face increased problems related to their steady state operation and dynamic performance (Dubey, 2015) since mismatches in generation and load and unstable system frequency control might lead to system failure much easier than conventional interconnected systems (Abad, 2018).

This study examines, Crete's Island power system, where exploitation of renewable energy sources, especially wind and solar energy, are significant. The island of Crete already has a considerable amount of installed wind parks and PV plants with almost 25% contribution to the annual energy balance. However, to maintain high levels of system stability and security, a more significant amount of RES penetration, particularly wind power, must be carefully considered (Ahmed, 2021; Cicilio, 2021).

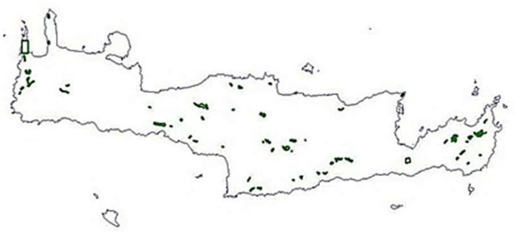

Figure 1. Allocation of installed Wind parks on the island.

Conventional generation is based on three oil-fired thermal power units with a total capacity of approximately 700 MW. Additionally, there are several wind parks with an installed power of up to 230 MW across the island, as it is depicted in Fig. 1.

Furthermore, there are more than 1,200 small PV plants, adding up to 120 MW in total, as shown in Fig. 2 which is retrieved by RAE data base (Regulatory Authority of Energy).

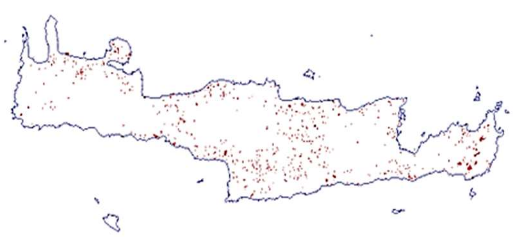

Figure 2. PV plants allocation.

Fig. 3 which is retrieved by HEDNO (Hellenic Electricity Distribution Network Operator) the corresponding share of RES (wind and solar energy) in the island's monthly energy balance. In this case, small-scale RES installations (< kW) are not included due to a lack of monitoring or supervising capabilities. These installations contribute majorly to the decrement in the mainstream electricity load demand.

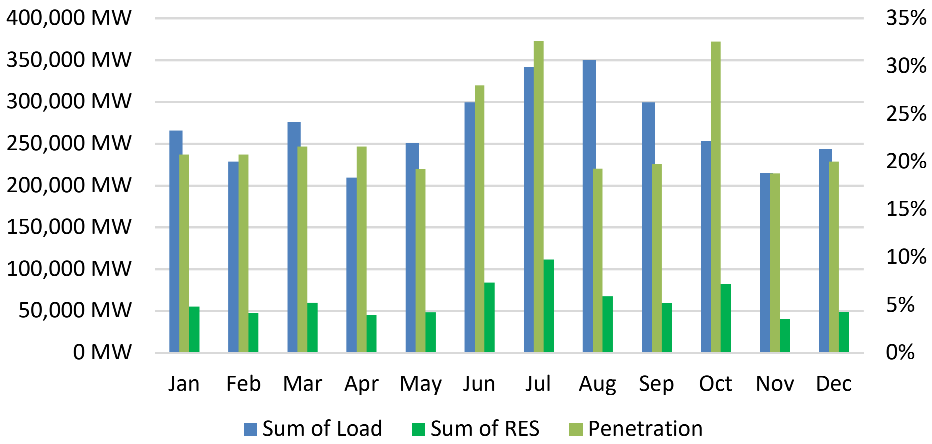

Figure 3. PVs and WPs monthly energy contribution of 2022.

Interconnection of Crete's system with the mainland system has been implemented since November of 2021, as shown in Fig. 4 (120 km 150 kV AC line).

After one year of existence of the interconnection of Crete's electricity network with the Greek mainland system, conclusions can be drawn about the contribution of this recent.

Thus, from the total demand of 3.23 TWh for the year 2021–2022 in Crete, 64% of the energy was derived from local conventional power plants and 23% was derived from local RES production, with a maximum hourly output of 232 MW and a maximum hourly attendance of 68.9%. Finally, 12.8% of the required energy came from the interconnection of the grid, reaching a maximum capacity of 150 MW and a maximum hourly contribution of 55%. In contrast, the incoming power to the island's system was 417 GWh. On the other hand, it was found that the energy exported to the mainland's system was 4 GWh, giving a maximum power of 75 MW.

Figure 4. Current (green line) and future (red line) interconnections.

A future scenario takes into account a second interconnection of a DC links, significantly increasing the reliability and the system's general performance. Thereinafter, the proposed types of DC link and their corresponding power capacity are

Voltage source converter (VSC–based HVDC) with the use of IGBTs (Insulated Gate Bipolar Transistors) and capacity levels of 1,000 MW, 1×1,000 MW and 2×500 MW (Kim, 2019; Duan, 2021).

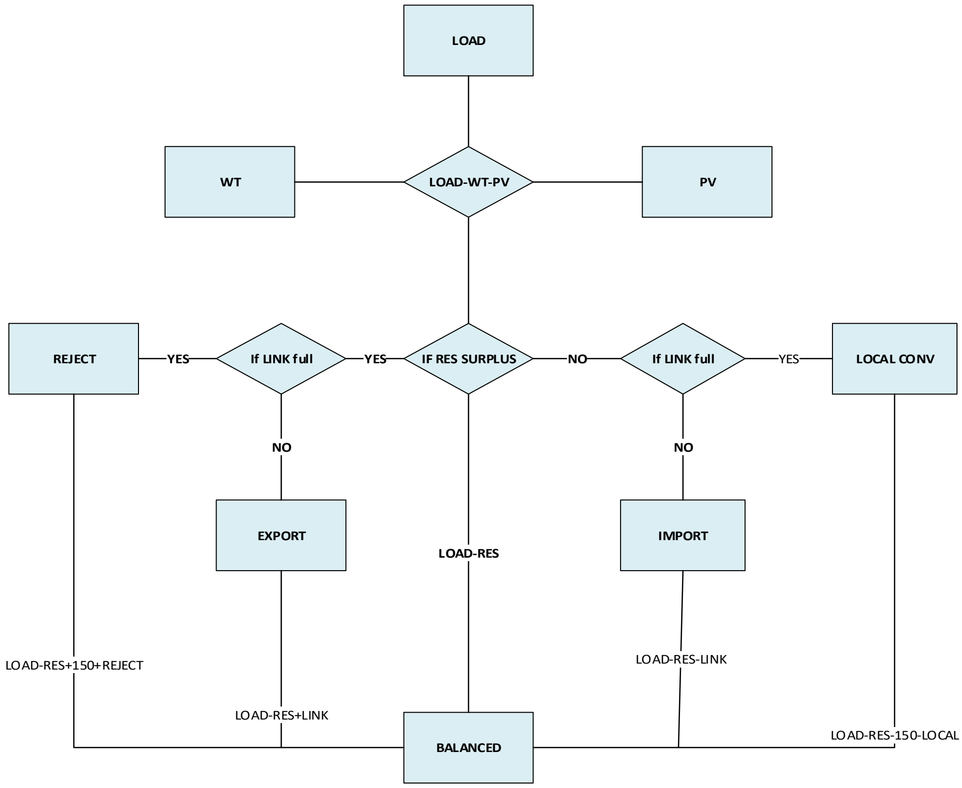

Figure 5. Power balance method's flow chart.

Moreover, one additional critical issue regarding interconnection power capacity level is the operational status of the local conventional power plants. Thus, two (2) main approaches have resulted:

– In order to preserve an adequate stability and reliability level, taking into consideration the unique characteristics of Crete's power system, it is of great importance to keep all or most of the local power plants in a hot spinning reserve;

– Keep all or most of the local power plants in cold spinning reserves. In this case, either the existence of two different interconnections is required, or the installation and use of local energy storage systems.

This study analyses and presents the power expansion and the operation of the interconnected power system of Crete under several scenarios. More precisely, the main variables of this study are:

– Further utilization of RES, particularly WTs and PVs;

– Development and operation of energy storage systems (input varies from 0 MW to 250 MW).

Bearing in mind all the previous system variables, a representative set of hourly data was collected. These data are:

– Hourly load demand;
– Hourly wind park demand;
– Hourly photovoltaic demand.

The main purpose was to estimate the level of higher RES utilization on the island and especially of wind and solar power exploitation.

The algorithm, as it is described in Fig. 5, imports the hourly load demand (LOAD) and the corresponding wind (WT) and photovoltaic (PV) production. Consequently, calculate the deficit or the surplus of this energy balance. If there is an excess of energy, the algorithm exports the rest through the interconnection. The excess energy is rejected if the system is balanced. On the other hand, if there is an energy deficit, the system imports the deficit quantity through the interconnection. If the capacity of the interconnection line is insufficient to meet this demand, then this quantity is produced locally, maintaining the system balanced.

RESULTS AND DISCUSSION

The primary purpose of this study is to find ways to increase the share of electricity generated by RES while keeping the amount of rejected RES to a minimum (up to 10%). More specifically, in the first scenario, where there is no wind power generation, there must be 0.754 GW of photovoltaics (Fig. 6) installed to keep the RES Reject at 10%. According to this scenario, the penetration of RES is around 65%, and the amount of energy flowing through the interconnection is 662 GWh. RES fulfills slightly more than half of the overall demand, while the remaining power is evenly split between interconnection and local production/generation.

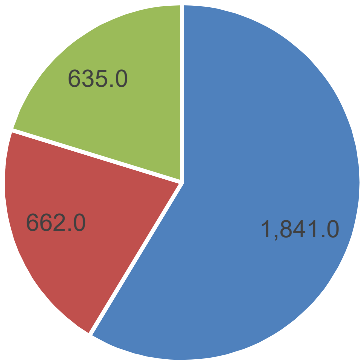

Figure 6. Energy balance in case of further PV utilization without additional WT.

In the second scenario, assuming that the solar power is zero, there is a requirement for 0.85 gigawatts (GW) of wind power (Fig. 7). Under these conditions, the level of penetration is 100.43%, as the energy provided by the interconnection is 31 GWh and the local production/generation is 271 GWh. It is obvious that RES adequately fulfills the demand, while the contribution of interconnections and local generation is negligible.

Finally, as a third scenario, wind and photovoltaic production are combined. Specifically, 0.65 GW wind power and 0.4 GW photovoltaic power are required (Fig. 8). Because of this, the penetration is at 103.74%, while the interconnection is at -3 GWh. This indicates that the quantity of energy that has been exported is more than the imported. In the meantime, the electricity generation in the local system is 216 GWh. As a result of renewable energy sources having the most significant percentage of demand coverage, this is undeniably the best alternative.

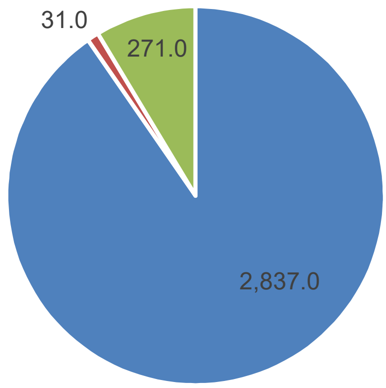

Figure 7. Energy balance in case of further WT utilization without additional PV.

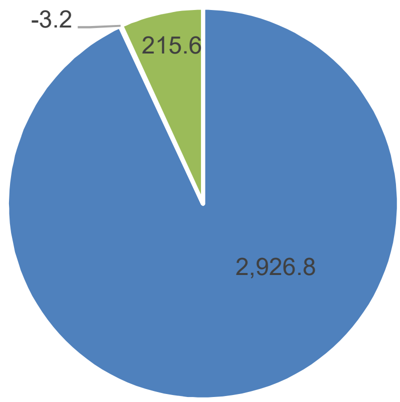

Figure 8. Energy balance in case of further both PV and WT utilization.

Up to the point where 1236 MW of installed wind power was reached, the examined performance of Crete's system was maintained within marginally acceptable levels. The energy produced by the island's operational wind farms is included in the aformentioned amounts. Coextensively, the performance of all subcases improved when a sufficient number of local units were in operation, whether the power flow via the interconnections was either low or high. The most important condition, which comprised a poor load flow profile and unsteady performance, was the case in which no coventional units were in operation in the local system.

CONCLUSIONS

The main problems with weak interconnection between power systems are the potential for voltage instability and in parallel the power balance in case of large share of RES. Weak interconnections occur when the power transmission lines between two or more power systems are not strong enough to handle the flow of needed electricity between them. In weak interconnections is more difficult to balance the supply and demand, as it is the case in Crete's island, which can lead to a decrement of reliability of the smaller power system. Therefore, it is clear that relevant power flow studies should be contacted in order to invastiagte and to determine the several power generation expansion limits.

The most critical points of this type of studies are the type and volume of energy flow of the interconnections of an island electricity system with the mainland grid and the optimal planning regarding the use of local conventional and renewable energy. Therefore, in this paper different scenarios were proposed in this study, given the recent interconnection of the Crete's power system with the mainland grid of Greece.

More precisely, this study has examined (a) three different cases of interconnection types regarding capacity 700 MW, 1,000 MW and 2,000 MW, two different cases of DC link types S-monopole and bipolar VSC–HVDC, (b) the operation of all the 'to be installed' pumps with storage units up to 250 MW in total, (c) the operation strategy of the local conventional power plants and finally (d) further wind power utilization till 2.74 GW in total.

In conclusion, the findings of this preliminary study indicated that the implementation and operation of Crete's interconnection (DC link) with the mainland, along with adequate local conventional production, will assist the further wind power utilization on the island up to 1,236 MW while maintaining the required level of reliability and stability sufficiency. This was validated by comparing the results of this study with the official studies that had been conducted (Kabouris, 2018) by greek Independent Power Transmission Operator (IPTO).

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