



Value of electric interconnection links in remote island power systems: The Spanish Canary and Balearic archipelago cases



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ABSTRACT

This paper tackles the technical and economical value of island interconnection links in remote island power systems. For this purpose, a novel deterministic hourly unit commitment on a weekly basis is formulated including the possibility of interconnection links between islands. The unit commitment reflects the common practice of the majority of real island power system operators when operating their systems: the economic dispatch is constrained in order to cover the loss of any on-line generating unit and the loss of any interconnection link between islands. Several islands of the Spanish Balearic and Canary archipelagos are used as illustrative real cases to assess the impact of existing and projected links between islands. The paper shows on one hand how reserve constraints drive the economical operation of real island power system. On the other hand, how the use of interconnection links not only enable the flow of cheaper generation power between islands, but also significantly contribute to the fulfillment of reserve constraints which translates into a cheaper and more sustainable island operation.

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1. Introduction

Island power systems are facing considerable challenges in meeting their energy needs in a sustainable, affordable and reliable way. In order to increase island sustainability, different generation-side measures (such as the use of renewable energy sources for power generation and use of energy storage devices for reserve provision), demand-side measures (such as the use of energy storage devices, implementation of demand side management actions and promotion of electric vehicles) and/or grid-side measures (interconnection of island systems with other island systems or the continental system) are available [1,2]. These options need to be customized on each specific island power system, depending on island features, opportunities and constraints [3]. This paper deals with the value of the last mentioned grid-side measures in isolated power systems.

Electric interconnection by means of submarine cables (between islands or between mainland and an isolated island) provides manifold benefits to isolated power systems: increase security of supply, reduce the island power system cost and introduces flexibility for increasing the penetration of variable renewable sources. Electric island interconnections are widely deployed in all over the world. Islands close to mainland are often

already interconnected, while remoter islands cannot afford it in many cases. An alternative to remote islands is to search potential connections between islands. A comparison of climatic, physical and socio-economic features of 1087 island worldwide is performed in [4] to identify island with similar potentials of integrating RES. Even though the effort made by the authors is very significant, the amount of interconnection between islands is not included as variable which can alter conclusions especially on smaller islands where as this paper will show, interconnectors modify the economic dispatch that satisfies reserve constraints.

The operation costs of remote island power systems are higher not only because of expensive fuel transportation and lower efficiencies of power generation technologies (e.g., diesel), but also because of technical requirements on spinning reserves guaranteeing frequency stability. Power system operators of island grids keep a certain amount of generation capacity as spinning reserve to ensure that the island is able to withstand the sudden outage of any generating unit and also address unforeseen load variations. Since each generating unit represents a significant fraction of the total generation in-feed in isolated power systems, spinning reserve requirements displace cheaper units in favor of more expensive units and increase the start-up costs of generators, being a key factor driving the economic dispatch of an island power system. It should be noted that the deployment of electric links between islands (both HVDC and AC) contribute in providing

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power reserve into the connected islands, reducing the need of online thermal unit reserves, and thus reducing the costs.

Unit commitment (UC) models [5,6] over different timeframes serve as the main tool to planning and operating purposes in order to analyze the economic impact of the different options that can be accomplished within an island power system. Common practice among island system operators is to establish a value of minimum spinning reserve requirements to be able to cover the loss of the largest on-line generating unit [7–10]. When island power systems are interconnected the economic dispatch should also guarantee that each island is able to withstand the loss of each interconnection link [11].

Within unit commitment formulations found in the literature, either the reserve power of the lost unit is not excluded or the minimum spinning reserve is considered as a static fixed value for each hour [12]. In addition, the explicit inclusion of interconnection links in UC for island power systems proposed in this paper, has not been tackled in the literature mainly because the size of the interconnectors are small compared to the size of the islands they interconnect. For instance, the study on the role of the interconnection between England and France in integrating RES with the PLEXOS model shows that interconnectors usually operate at its full capacity (around 5.4 GW by 2030) and it seems that reserve restrictions do not limit interconnector operation [13]. The first objective of this paper is to develop a novel deterministic hourly UC on a weekly basis especially adapted in order to reflect the common practice of the majority of real island power system operators when operating their systems and to include the possibility of interconnection links between islands. New features of the proposed UC formulation are: (a) the explicit formulation of the interconnection links between islands is included to take into account the reserve that the interconnector provides to each island, (b) additional reserve constraints are formulated to ensure that each of the islands is able to withstand the loss of an interconnection link, and (c) the UC dispatch guarantees that the island power system is able to withstand the loss of any on-line unit and not only the biggest connected one. Even though the weekly UC is deterministic using demand and renewable as known fixed data, using different scenarios it can be used for a variety of mid-term and long-term island power system technical and economical assessments as will be shown in this paper with the case studies that are provided.

The impact of renewable energy source on generic power systems reserve requirements is of great concern [14,15]. Specific country studies such as Netherlands [16], Quebec [17], USA [16], or Spain [18] are available in the literature. The effect of wind in island reserves has also been studied on specific island power systems such as UK [19], Ireland [20] or Crete [21]. Typically, reserve requirements are extended to include expected RES variations [13]. Studies on the role of interconnections on continental systems can be found in [22] for the 2050 West European power system, or [23] where the effects of promoting electric vehicles on interconnections in Europe is assessed. Case studies specifically tackling the value of island interconnections are reported in: the UK-French interconnection [13], the interconnection between Ireland and UK [24,25] and the 2015 interconnection of island of Malta to Sicily [26]. In the first cases, the size of the systems and links suggest that reserve constraints will not limit the performance. In the Malta study it seems that reserve constraints are not taken into account.

The second objective of this paper is to uncover the technical and economical value of actual and projected island electric interconnections in two real cases, namely the Spanish Balearic and Canary archipelago power systems cases. Within the Spanish Balearic archipelago, Mallorca and Menorca islands are interconnected since 1981, and a new link is has been recently deployed

between the island of Mallorca and the joint power system of the islands of Ibiza and Formentera. Concerning the Canary archipelago, the island of Lanzarote is already interconnected with the island of Fuerteventura, and a new link is under study between the islands of Gran Canaria and Fuerteventura. Whereas case studies on RES penetration and storage and its benefits for fostering RES penetration and reserve provision are available for the Canary archipelago [27,28], the Balearic archipelago has not been studied in the literature. The economic value of interconnection links for both archipelago has not been analyzed neither.

The paper is organized as follows. Section 2 details the formulation of the UC model with interconnection links. The interconnection of Lanzarote and Fuerteventura islands in the Canary archipelago is assessed in Section 3. Case study of the more complex Balearic archipelago with four islands interconnected is presented in Section 4. Finally, conclusions are drawn in Section 5.

2. Unit commitment model with interconnection links

This section details the mathematical mixed-integer linear formulation (MILP) of an hourly unit commitment on a weekly timeframe. The model includes the possible interconnection links between two islands and the key reserve constraints that each island power system must fulfill for security reasons. The start-up cost is a key factor that may in fact determine the unit commitment results and this takes different values depending of the type of start-up (hot, mild or cold). Thus, the model formulation includes a detailed representation of the start-up and shut-down processes of thermal units, taken from the tight and compact formulation of the self thermal unit commitment problem defined in [29] showing better computational performance to other possible formulations as proved in by the authors.

This section starts with the definition of the nomenclature of the model, continues with the definition of the objective function, and ends with the definition of the constraints, namely, demand balance constraint, thermal units technical constraints, thermal units commitment and start-up/shut-down constraints, interconnection links constraints, system reserve constraints.

2.1. Nomenclature

For clarification purposes, symbols are classified in sets, parameters (represented by uppercase letters) and variables -both binary and continuous- (represented in lowercase letters)

Sets	
g, gg	generator thermal unit (1 to N_g)
h, hh	hour (1–168)
st	start up type (hot,mild,cold)
i, ii, iii	island power system (1 to N_i)
Parameters	
C_g^{fix}	fixed cost of unit g [€]
C_g^{lin}	linear component of the variable cost of unit g [€/MW h]
C_g^{qua}	quadratic component of the variable cost of unit g [€/MW h ²]
$C_{g,st}^{start-up}$	start-up cost of generator g [€]
$C_g^{shut-down}$	shut-down cost of unit g [€]
$D_{i,h}$	demand of island i in hour h [MW h]
$Res_{i,h}$	renewable energy production of island i in hour h [MW h]
P_g^{min}	minimum power generation of unit g [MW]

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