Renewable and Sustainable Energy Reviews 52 (2015) 333–346

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Overview of insular power systems under increasing penetration of renewable energy sources: Opportunities and challenges

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ARTICLE INFO

Article history:
Received 15 September 2014
Received in revised form
16 May 2015
Accepted 25 July 2015
Available online 14 August 2015

Keywords:
Demand response
Energy storage
Insular power systems
Renewable energy
Smart grid

ABSTRACT

Insular electricity grids are considered to have a more fragile structure than the mainland ones due to several factors such as the lower inertia because of lower number of generation facilities connected to the system, absence or insufficient interconnection with the main grid, etc. The recent trend of integrating large portions of environmentally sustainable power generation units that have a significantly volatile nature in the generation mix (such as wind and solar energy conversion systems) within this fragile structure, poses profound challenges that need deeper and specific analysis. This study aims to provide an overview of insular power system structures and operational requirements, especially under increasing penetration of renewable energy sources. Firstly, a general evaluation of insular power systems is presented. Then, potential challenges are thoroughly discussed together with opportunities to tackle them. Future technological developments, as well as innovative applications are also given special attention. Hence, this paper contributes to the scarce literature regarding insular power systems by providing a critical overview of issues regarding their operation and possible solutions.

Contents

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http://dx.doi.org/10.1016/j.rser.2015.07.104
1364-0321/

1. Introduction

The term "island" has a basic meaning as a sub-continental land that is surrounded by water, which implies a physical total insularity (that basely means isolation and/or dispersion) from the mainland. Thus, insular power systems correspond to electric power grid structures in physically isolated geographical areas that are mainly islands [1].

It was stated in The Treaty of Amsterdam that "insular regions suffer from structural handicaps linked to their island status, the permanence of which impairs their economic and social development" [2]. In other words, insular areas have limitations that need to be identified. Limited range of resources, inability to achieve economies of scale, often seasonal change of population, higher infrastructure costs, distance from the mainland, climatic conditions and microclimates within the insular area are examples of such constraints. These limitations lead to several negative outcomes including overseas trade dependency, economic weakness that reduces the chance of gaining access to conventional markets, need of oversizing infrastructure including power systems, etc. [3].

Among the mentioned limitations, priority should be given to the fact that insular areas are among the most vulnerable places regarding climate change as the frequency of natural disasters (mostly tropical storms, typhoons, etc.) that has increased because of climate change are a more important threat for insular areas than for the mainland [4]. Climatic effects such as sea level rising, climate variability, abnormal climatic conditions etc. also affect the environment of islands [3].

Thus, the general problems of insular areas can mainly be categorized as dependence on imported fuel, availability of fresh water, management of wastes and other problems related to climatic conditions, etc. [3,5], which are affected by many factors including the components of insular economies.

The economies of most of the insular areas rely on tourism, which is specifically an advantage driven by their geographical added value. For European Islands, a research concluded that dependency ratio of these insular economies on tourism is nearly 70%. Apart from tourism, insular economies mainly depend on agriculture and fishery, since industry development is very limited in islands due to scarce resources, high infrastructure and transport costs, limited competitive markets for companies, etc. [3]. Nearly all the imported goods at many insular areas are shipped over very long distances, a fact which has a serious impact on their economic sustainability. Many islands around the world rely nearly 100% on imported fuel for many activities such as energy production, transportation, heating, etc. Such dependence on imported fuel is a major issue that has economic, technical and social results. Many critical industries like fisheries are highly vulnerable to fuel prices [4].

Tourism is a high-quality water and energy consuming activity. Generally, tourism is mostly seasonal and leads to a significant increase in the island's population for a few months. Tourism also increases waste and the waste management especially in such high population periods is a serious problem due to limited area, high cost and scale of recycling processes, etc. If high-quality water is not available within the own resources of an island, there are two ways to fulfill this requirement: water import from another area or desalination of sea water, both fuel and energy consuming activities. As seen, the mentioned waste management and quality water preparation increase the need of energy together with the fact that the other daily energy needs (air-conditioning, other daily consumptions, etc.) in high population periods are significantly greater than rest of the year. This leads to oversizing infrastructure in all fields as systems sized to accommodate the requirements of the summer period are significantly underutilized in winter time.

The mitigation of dependence on imported fuel especially for electricity production is an important parameter for the economic sustainability of insular areas. The fuels (gasoline, oil, LPG – liquefied petrol gas) required for conventional energy sources are generally carried to islands by tankers which creates both an unsustainable service model especially during peak times and a problematic strategy from environmental point of view. Besides, the energy production from fossil fuels is costly especially due to transportation costs. Thus, the utilization of local resources mainly in form of renewable energy systems (RES) is a pivotal aim of many energy policies especially during the last decade and the structures of electric power grids have started to significantly change with the recently increasing interest in RES. Comparatively weaker electricity grid structures such as insular grids are more sensitive to power quality issues such as frequency and voltage deviations especially if the penetration level of RES is high due to the volatile nature of such units. Insular grids with a lower inertia due to reduced number of generating units connected to the system are more vulnerable to large frequency and voltage deviations, which in turn reduces system reliability and security. Thus, the policies aiming to improve the penetration of RES especially in insular areas are limited by insular power system deficiencies. As a result, insular power systems are considered as a "laboratory" for testing the impacts of such new technologies and strategies including the target of higher RES penetration [3], which underlines the need for deeper examination of insular areas and insular power systems in terms of current status, challenges and opportunities for future technological advancements also ultimately including "smartification" of all operations.

There are many literature studies dealing with the impact of high RES penetration and methods to overcome the drawbacks related to the integration of such systems. Lund et al. [6] presented an analysis on the impacts of high solar and wind power penetration and demand and production side options to mitigate their variability. Luthra et al. [7], Tigas et al. [8] and Eshchanov et al. [9] realized country scale regional analyses for high RES implementation considering respectively India, Greece and Uzbekistan cases. A review of many policies to increase RES penetration considering also methods to overcome existing barriers based on lessons learnt from real cases in different countries of the world was presented in [10]. There are also some studies focusing specifically on different topics related to

Table 1
The power loads of sample insular areas.

Location	Population	Installed capacity	Peak load	Reference
Guam	~170,000	550 MW	280 MW (40,000 customers)	[4]
St. Thomas-St. John (US Virgin Islands)	~53,000 to ~4000	199 MW	86.3 MW	[4]
St. Croix (US Virgin Islands)	~55,000	120.8 MW	55 MW	[4]
Cyprus	~860,000	990 MW	775 MW	[86]
Crete	~600,000	1085 MW	650 MW	[84]
Gran Canaria	~840,000	860 MW	552 MW	[86]
S. Miguel (Azores Islands)	~140,000	160 MW	65 MW	[84]
La Graciosa (Canaria Islands)	~1000	1.3 MW + 1.5 MW from main island	1.2 MW	[84]
San Juanico, Mexico	~640	205 kW	167 kW	[87]