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Feasibility study of wind-to-hydrogen system for Arctic remote locations – Grimsey island case study

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ABSTRACT

Today a lot of Arctic remote communities rely on electrical energy produced by diesel generators. This type of energy is very expensive as apart from high fuel prices, the transportation costs to the remote location, also need to be added. The goal of this study is to evaluate an application of the wind turbines combined with the hydrogen energy storage system for supporting existing diesel infrastructure on the example of Grimsey island (Iceland). HOMER Energy Microgrid Power Design software is used to perform energy balance simulations and to optimise the size of the system components. The statistical data about electrical energy consumption and wind resources on Grimsey are used as a case study. The results indicate that proposed system infrastructure might be a feasible solution and the payback period of below 4 years was estimated for the optimal system configuration.

1. Introduction

The electrical power generation for island and remote communities in the Arctic often relies on diesel generators powered by fuel transported over large distances. Nowadays wind energy can be cost competitive with the fossil fuel based electricity generation. The wind energy is broadly considered to be attractive for remote communities and a number of demonstration projects currently are being held around the globe [1–6]. Hybrid wind-diesel systems can significantly reduce the fuel consumption, minimise costs and decrease the emissions associated with the electricity generation. On the other hand, increasing energy fraction supplied by the wind turbines requires an energy storage mechanism to accumulate any surplus of electricity generated during high wind periods and to supply this stored electricity during low wind periods (when there exists insufficient wind generation to meet demand). One of the possibilities which could be suitable for island of Grimsey in the Arctic is the use of hydrogen storage with an electrolyser/fuel cell system. In such a configuration hydrogen is produced during the periods of surplus wind through an electrolyser and subsequently is used during times of shortage of wind by the fuel cell to generate electricity to supply the load.

Stored hydrogen could be also used as a fuel for vehicles or boats owned by the island community. This could be the basis of a local hydrogen economy that would make the remote area independent from an external supply of fossil fuels. In this study hydrogen system is designed to support the electrical diesel generation on Grimsey. Additionally a road map is proposed to make this community 100% energy independent in the future.

HOMER (Hybrid Optimization Model for Electric Renewables) software was applied as a modelling tool, which in recent years has been utilised for simulations of micro-grids by number of authors [7–11]. Ashourian et al. in their work simulated application of solar and wind energy supported with battery and hydrogen storages for the Malaysian islands [7], Prodromidis et al. published paper comparing the stand-alone with grid connected island renewable energy systems for application in Greece [8], Zhu et al. modelled applications of solar, wind, microturbines, diesel engine with energy storage for the city of Shanghai [9], application of photovoltaic panels with hydrogen storage for Brazilian Amazon region was studied by Silva et al. [10] and Karakoulidis et al. published techno-economical analysis of applications of photovoltaic panels, diesel generators, batteries for Kavala town, Greece [11]. In this work application of wind turbines with hydrogen energy storage, that could support or substitute existing diesel generator on Grimsey

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was considered. According to our knowledge such a type of analysis was first time performed for the island and it assures the novelty of this publication.

1.1. Wind-to-hydrogen projects review

There are numerous examples of wind-to-hydrogen projects all over the world. Most of them have a demonstration focus, serving as knowledge and technology transfer centres for the local communities [1–6].

The two most prominent examples are on the island of Unst in Scotland and Utsira island in Norway. Promoting Unst Renewable Energy (PURE) project on Unst has two 15 kW wind turbines as the main power generation, an electrolyser and a 5 kW fuel cell acting as a backup. It serves both the electrical and thermal load of five business properties. Produced hydrogen is also used to fuel a small vehicle used in the project. Hydrogen energy project on Unst is the first community owned project of this kind in the world. The wind-to-hydrogen project on Norwegian island of Utsira has a similar architecture with additional flywheels that act as a short-term energy storage [1–3,5].

General interest in this type of hybrid system is also high in Canada. The Ramea Island project started as a typical wind-diesel hybrid system with six 65 kW wind turbines. To increase its electrical output it was upgraded with 100 kW turbines and a 90 m^3/h alkaline electrolyser with 2000 m^3 of hydrogen storage (10 bar). Note that in this installation, four 62.5 kW hydrogen powered internal combustion engine generators are used to produce electricity instead of fuel cells [1,4,5].

Prince Edward Island has the strongest wind potential in Canada, and has around 74 MW of installed capacity in wind turbines. For the wind-to-hydrogen project at Prince Edward Island, one 60 kW turbine is used together with a 66 Nm^3/h unipolar electrolyser. The produced hydrogen is used to run a retrofitted diesel generator and a backup fuel cell power unit, as well as fuel for a small hydrogen powered bus that is also included in the demonstration [1,5].

Spain has a few notable examples of wind-to-hydrogen energy storage systems. The RES2H2 Project located at Gran Canary Island utilises one 500 kW turbine together with a 5 Nm^3/h electrolyser. Additionally to hydrogen generation the system also produces drinking water through a reverse-osmosis plant. The ITHER Project in Aragon region investigates the variety of differently sized turbines (80 kW, 225 kW, and 330 kW) as well as photovoltaic panels for the purpose of hydrogen energy storage. The goal of this project is to optimise all the aspects of hydrogen chain – production, management and efficient use [1,5].

United States has also carried out a few essential wind-to-hydrogen demonstration projects. The Basin Electric, Wind-to-Hydrogen Energy Pilot Project was used to determine the most optimal mode of operation for the wind turbine/electrolyser system. A dynamic scheduling system used to control the intermittent output of the wind turbine to the electrolyser stack was one of the most prominent deliverables of this research. Another project was a result of the cooperation between National Renewable Energy Laboratory and Xcel Energy and is hosted at NREL's National Wind Technology Center (NWTC) in Colorado. In this demonstration renewable energy from wind turbines and PVs in the form of electrolysed hydrogen is used for transportation as well as long term energy storage [1,5,6].

1.2. Grimsey island description

Grimsey is a small (5.3 km^2 area) island located 40 km from the north coast of Iceland. Its location makes it the only Icelandic area that is formally part of the Arctic. It has a community of 76 people and a total of 40 buildings. Its electrical load is served by three 220 kW diesel generators. This location and a few other remote communities, prevent Iceland from claiming the title of having 100% renewable electricity generation. In 2012 the origins of almost all Icelandic electrical energy were hydro (70.3%) and geothermal (29.7%) power plants. The amount of electricity generated from fossil fuels was below 0.1% [12].

There have been a lot of studies done so far, that have proposed alternative energy solutions for the island. An underwater cable that would connect Grimsey to the national grid was discarded as too costly and technically challenging. It would also disturb the local fishing industry. There have been a few studies of wind power implementation, both on a large scale (single 660 kW turbine) and also with small scale wind turbines (connected to a water break for heat generation). Another project specified the installation of heat pumps as well as the experimental drilling for the possibility of geothermal energy. Lately, research has focused on assessing the feasibility of wood biomass for power generation. The Keilir Institute of Technology was involved in a study of a methanol fuel cells implementation on Grimsey. The data regarding electric load and other important information about island gathered for the purpose of that research are used in this study. So far, the only advancement in the island energy system was the utilisation of diesel generators cooling water for space heating in three buildings [13].

The motivation for energy alternatives on Grimsey is that energy generation on the island is heavily subsidised with the public funds. It is estimated that in 2011 more than $400,000 of the government subsidies were spent on that purpose [14]. This creates a favourable economic environment for creating a sustainable fossil-fuel-free solution for the island.

2. Research methodology

HOMER Legacy v 2.68 software was used to model, the proposed solutions for Grimsey. HOMER is micropower optimisation

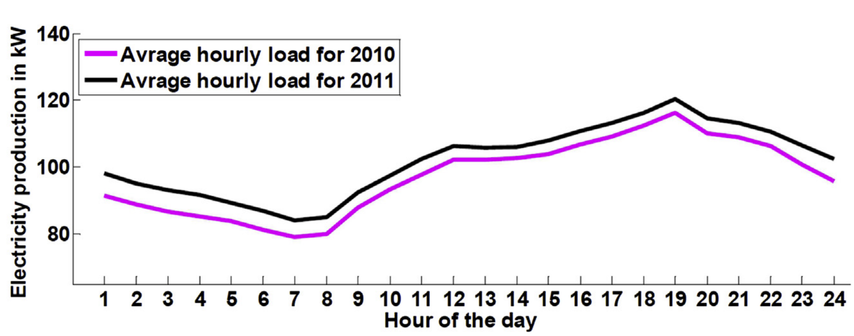

Fig. 1. Comparison between the average hourly load of 2010 and 2011 [14].