



Optimal green energy management in Jeju, South Korea – On-grid and off-grid electrification



Heetae Kim, Seoin Baek, Eunil Park, Hyun Joon Chang*

Graduate School of Innovation and Technology Management, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea

ARTICLE INFO

Article history:

Received 5 July 2013

Accepted 3 March 2014

Available online

Keywords:

Hybrid system simulation

HOMER

Renewable energy

Photovoltaic

Wind turbine

ABSTRACT

“Green Growth” and “Sustainability” are now keywords for industrial growth engines. This research examines the economic, environmental, and technological feasibility of hybrid systems by simulating a system composed of renewable energy, an existing grid system, and a diesel generator on Jeju Island in South Korea.

Korea depends heavily on oil imports. Thus, in Korea, efficient energy management is imperative. For this reason, the current Korean administration is striving to improve its energy infrastructure with the construction of stable energy supplies and reliable systems the implementation of energy policies, such as smart grids, and the diffusion of renewable energy generation sources.

This study finds that the most economically feasible hybrid system is a grid-connected wind turbine–photovoltaic–battery–converter hybrid system. Given the economic feasibility of this hybrid system, implementing it would decrease the price of electricity in Jeju. Both the implications and limitations of this study will be discussed in the last section of this paper.

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1. Introduction

In 2009, based on a “Low Carbon, Green Growth” vision, the Korean government announced that it should reduce the amount of greenhouse gas (GHG) emissions by up to 70% over 12 years. Although Korea still depends on nuclear energy, which has been a reliable and economical energy source in many countries [1], it is currently attempting to reduce GHGs through its “National Strategy for Low Carbon Green Growth” and “Five-Year Plan”. However, GHG emissions are increasing slightly on a continuous basis because a key Korean industry is manufacturing, which creates large amounts of emissions. In addition, the spread of air conditioning and heating, as well as many home appliances, have increased household energy consumption. As a result, the demand curve of electricity is becoming increasingly steep. The Korean government attempted to find a good solution for environmental issues by creating the Renewable Portfolio Standard (RPS) in 2012. In addition, leading conglomerates in Korea also are worried about a lack of fossil-fuel resources and have begun to expand their businesses to renewable

energy development and technology. As a result of these efforts, many institutes and universities have been holding symposiums to discuss related environmental issues.

In the case of Jeju, the electric power system is different from the rest of Korea because Jeju is an island. Furthermore, Jeju's main engine of growth has been its tourist industry, unlike other regions, which have relied on the manufacturing industry for growth. Therefore, Jeju's level of power consumption for industry is the lowest in Korea, but its level of power consumption for commerce is the sixth largest in Korea. Thus, Jeju's energy consumption is unique in that the amount of electricity used in resort complexes and vacation spots is remarkably higher than in other areas. In February 2013, Jeju Province's electricity consumption increased by 4.2% from the previous year (to 3,864,639 MWh). The power-supply capacity of Jeju is 814.4 MW, and the average demand is 518.1 MW. As such, Jeju has a preliminary power level of 297.2 MW. However, there are often changing circumstances when temperatures rise or fall, and the electricity situation often worsens in the evening [2]. Jeju Island supplies approximately 7% of its electricity production through wind power plants, but many experts believe that Jeju has not utilized the strengths of the region. As such, Jeju Island is expected to generate additional power through wind turbines because it has excellent environmental conditions for the development of wind power. Additionally, at this time, when countries are trying to secure a sufficient electric power reserve rate, Korea

* Corresponding author. Postal address: #2225, KAIST College Building 2 (N5), 291 Daehak-ro, Yuseong-gu, Daejeon 305-701, Republic of Korea. Tel.: +82 42 350 4348, 82 10 8781 1227.

E-mail addresses: hya91@kaist.ac.kr (Heetae Kim), wolihai87@kaist.ac.kr (S. Baek), pa1324@gmail.com (E. Park), hjc21c@kaist.ac.kr, hjc21c@gmail.com (H.J. Chang).

should rely on renewable energy rather than fossil energy sources (such as thermal power plants) to increase its proportion of renewable energy generation by 12% and to achieve its goal of a 22% power reserve margin [3].

Photovoltaic (PV) systems operate intermittently because of environmental conditions and because their initial cost is significantly greater than those of other generating systems. However, it is a clean energy source that does not emit GHGs. Furthermore, compared to other energy sources, solar energy is fairly abundant and has fairly low maintenance costs (especially in terms of operation and management (O&M) costs). Another benefit of PV systems is that it is relatively easy to extend capacity according to energy demand. Furthermore, PV sources generate and supply more power when temperatures are hottest, which is when the energy demand is highest. Wind energy is one of the cleanest renewable energy sources, and offshore wind development has mainly been used during recent years. Wind turbines are more likely to be located offshore than onshore because wind speeds are higher offshore and the noise level associated with wind turbines is less of a nuisance to local residents when located offshore. Using two or more energy sources as part of a power generation system is called a hybrid system, which adds existing diesel engines (which use fossil fuels) to renewable energy generators [4]. Such a hybrid system is consistent with current trends and environmental issues, particularly on islands or low-population zones, which frequently use renewable energy on their outer boundaries.

PV and wind power play large parts in hybrid systems that produce electricity intermittently for the development of renewable energy. Therefore, 24 h electricity monitoring systems and smart grids, which can manage transmission and distribution facilities across the country, are essential for supplying more reliable and better-quality electricity to consumers. If batteries are used to manage the variability of the load and power generated from solar and wind power, then the initial investment costs for these systems could be relatively high; however, these systems could also be very effective [5]. In addition, batteries stabilize power supplies by increasing the efficiency of operation within the system, reducing the amount of electricity purchased from the power grid and ensuring the standard lifespan of the product.

These grid-connected and off-grid hybrid power generation systems are more stable and have an advantage over development approaches that use only conventional fossil fuels because they are more environmentally friendly and have low maintenance costs during their lifetimes. Many existing studies have found that grid-connected and stand-alone hybrid power systems can be economically feasible, particularly in the case of a stand-alone system that is isolated from the grid; however, other papers have found that economic feasibility varies by region [6].

This paper analyzes and designs a renewable energy hybrid system for Jeju Island that is optimized with the Hybrid Optimization Model for Electric Renewables (HOMER), a model that was developed by the National Renewable Energy Laboratory (NREL). HOMER can model both the stand-alone and grid-connected systems that supply electric power for heat and electric loads and verify these calculations by simulating these systems [7]. The HOMER optimized systems can be comprised of secondary batteries, PV panels, wind turbines, fuel cells, hydrogen storages, diesel generators, and flywheels.

HOMER is the most effective as an analytical tool for optimizing systems consisting of both existing power generators that use fossil fuels and renewable energy sources. HOMER considers both technical and economic feasibilities of hybrid systems. Then it ranks all the optimized results according to total net present cost (NPC) [8]. In addition, simulations are based on data extracted on an hourly basis and are used to evaluate the performance and cost

effectiveness of the entire system [9]. As a result, HOMER gives NPC and cost of electricity (COE) values of optimized results [8,9]. So it is a very accurate and useful tool. To analyze hybrid systems using HOMER, one must include data regarding energy sources, economic constraints, controllers, system-specific configurations, installation, O&M and replacement costs, and efficiency. Finally, a sensitivity analysis can be used to derive more accurate results because it can use various combinations of ranges of values rather than exact values.

Some experts still have questions regarding the reliability and suitability of renewable energy power supplies in the suburbs. However, we no longer can rely solely on the existing ways of generating power, such as nuclear or steam power. The potential in the development of new and renewable energy has led it be viewed as an alternative to fossil fuels. This paper analyzes which hybrid system configurations could be the most economical and environmentally appropriate for the power supply of Jeju Island.

2. System configuration

2.1. Load profile

In this study, data from the “Jeju Island List by Date Demand Forecasts,” which was most recently issued in 2012 by the Korea Electric Power Co., Inc., were used in the analysis.

The power supply of Jeju Island is not stable in the winter. Because the weather is unusually cold, there is a surge in power usage in the winter months. As shown in (Fig. 1), both the average and maximum values of power consumption in Jeju are high from July to August and from December to January. The period from May to June and between September and October has shown relatively low levels of power consumption. Surges in power usage because of the heating and cooling equipment could also be one of the most important reasons for these power consumption patterns. In addition, the region of Jeju is heavily affected by the tourism industry because power usage is highest in the peak tourist season. In this study, we analyzed the total load of Jeju Island in kWh instead of MWh to ensure that the simulation is both accurate and easy to understand.

2.2. Solar energy resources

Solar energy, which does not produce any emissions when generating electricity, takes center stage in many discussions about clean energy [10]. This paper used solar irradiance data obtained from “NASA Surface Meteorology and Solar Energy” [11] that are based on Jeju’s latitude and longitude. A sensitivity analysis was conducted with three different values near Jeju’s mean (3.5, 3.98, and 4.5 [kWh/m²/d]), which were calculated from the NASA data. The average level of solar radiation for Jeju Island is greater than the average level for Korea as a whole (Figs. 2 and 3).

2.3. Wind energy resources

The value of wind speed used by this paper was obtained from the NASA Surface Meteorology and Solar Energy using Jeju’s latitude and longitude [11]. A sensitivity analysis was conducted with three values around Jeju’s mean (5.5, 6.62, and 7.5 [m/s]), which were calculated from the NASA data. In addition, the Weibull coefficient, 1 h autocorrelation factor, diurnal pattern strength, and hour of peak wind speed were assumed to be 2, 0.85, 0.25, and 15, respectively. These are the default values provided by HOMER.

From (Fig. 4), which compares Jeju Island’s wind energy resources with the average value for the Korean peninsula, it is clear that Jeju has relatively strong wind power (Fig. 5).

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