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Optimal Hybrid Power System Using Renewables and Hydrogen for an Isolated Island in the UK

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Abstract

A distributed electrical power system using renewable generations (RG) on an island was studied. The original system includes micro hydropower stations, wind turbines and solar PVs with a bank of batteries for storage of the extra power from the renewables; and two diesel generators were used as the back-up units. From the analysis of historic electricity generation and consumption data, it was found that the RG alone could not meet the total demand and the diesel generator(s) needed running occasionally in 8 months in one year. In order to make the electric power supply completely from renewables, one novel solution using hydrogen generated from extra renewable electricity to replace diesel as the fuel for the diesel generators was proposed, i.e. a sub-system of renewable hydrogen generation (RHG), which composed of extra wind turbines, a water electrolyser and a hydrogen storage tank, were added to the renewable system. A technical and economic performance evaluation of the RG system was carried out using HOMER software. The results showed that the RHG sub-system produced and stored enough hydrogen for the diesel generator(s) to generate electricity whenever needed. In this way, the power supply on the island will be completely from renewables and zero CO_2 emission without using diesel. The cost of electricity (COE) of the new system was £0.776 per kilowatt hour.

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Keywords: Distributed power system, hybrid, renewable, hydrogen, HOMER

1. Introduction

Due to the public environmental concern to the global warming and climate change, it is requested to reduce carbon dioxide emissions to the atmosphere significantly by reducing the use of fossil fuels. One

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solution is to increase the utilization of renewable energy. For isolated communities where using grid are impossible or uneconomic, distributed power system is an option [1]. These distributed systems in the past have mostly been designed and powered by diesel engine generators as they are widely available and reliable, and the running cost was affordable. But with the growing concern on the increasing greenhouse gas emissions, these distributed systems are gradually and partly replaced by renewable hybrid systems where renewable energy sources are available and the generators are used as a backup sub-system. Islands are typical cases of these isolated communities. Therefore, researchers paid more attention to the area of renewable energy system for islands. Paska et al [2] described hybrid systems as a good means for islands to increase the availability and flexibility of power supply systems and to have available and flexible sources of electricity from different primary energy carriers. A similar study to that carried out by Senjyu, T., et al [3] and Ashok, S [4]. They analyzed the energy usage and the optimum configuration of a hybrid renewable energy system for a typical farming village of Western Ghats in Kerala, India. The study concluded that the optimal hybrid configuration including a micro-hydro, two wind turbines and battery storage could contribute to 100% of 24-hour energy demand for the communities. Parissis, O. et al [5], carried out a case study for an island using two wind turbines, two diesel generators, a fuel cell, a water electrolyser and a hydrogen storage tank. They found that a remarkable reduction (43%) in the power generation cost and 80% of the electricity needs of the island could be covered by renewable energy. Gokcek, M. [6] investigated the potential of hydrogen generation from small-scale wind-powered electrolysis system, the results showed that both electrical energy and hydrogen production depended on the hub height of wind turbine; and only the grid-integrated system was profitable when the extra electrical energy sold to the grid. Bajpai, P. and Dash, V. [7], reviewed hybrid renewable power generation systems (HRPS) for stand-alone applications, they found that economic viability and grid interconnection were the major challenges to make the HRPS applicable. Ahadi, A. et al [8], investigated the potential of a hybrid renewable energy with storage system to replace diesel generators for an isolated communities. They found that a hybrid PV/wind system with battery storage backup satisfied the load demand with minimized cost. These studies revealed that the hybrid renewable energy power systems (HRES) were possible to provide electricity for isolated areas with relative high cost; but diesel generators were still needed to provide back-up support in case the HRES could not meet the demand due to weather condition varied. In order to find a feasible, sustainable and renewable solution for the island, it is therefore necessary to carry out further research. The aim of this study was to investigate the feasibility of using hydrogen generated from renewable sources to replace diesel for power generation to realize a completely renewable and reliable power supply system for island using a selected case study.

2. The Case Study

The island in this case study is located off the west coast of Scotland. There was not a link to the national grid power supply. Two diesel generators were used to supply electricity for the island. So the islanders set about creating and building their own renewable electricity grid, which would depend as much as possible on renewable sources [9]. In 2008 the electrification project was switched on and the sole use of the noisy diesel generators was no longer on the island. This gave the islanders 24-hour power for the first time. The system consists of wind, hydro and solar natural resources. It is estimated that approximately 95% of the islands energy demand can be generated from the renewable sources, with diesel generators present as back-up.

2.1. Current System

From the analysis of the information provided from the island, the contribution of each resource can be seen for the given year (see Fig 1). Initially it was expected that the wind turbines and hydro power plants would provide the majority of energy in the winter months and the solar panel would contribute greatest during the summer months to offset the reduction in wind and rainfall. The current system that is in place consists of: 4×6kW Wind Turbines, 3×Hydro Power (1×10kW, 1×9kW, 1×100kW), 10kW PV Array, 2×40kW Back-up Diesel Generator, 4×48V DC Ah Battery Store (212kWh Total). The schematic of the system is shown in Fig 2. From Fig 1, it can be seen that the system could not provide enough power by renewables, diesel generators were used to make up for the shortage in 8 months.

Fig 1. Power generated by sources

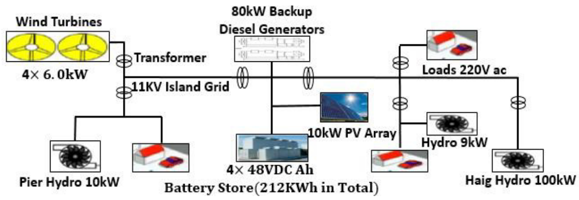

Fig 2. Schematic of Original System

2.2. Current System Analysis

The system that was designed and put in place to take full advantage of all the resources that are available on the island and to increase the security of supply to the islanders [10]. However the system was not an optimized system from the data provided in Fig 1. Firstly the capacity of the hydro power plants is 119 kW, but due to restriction of the weather and other conditions, the hydro power plants run at a lower capacity factor and therefore reduce the output. As for the use of wind turbines it appears that the number that is used is quite low, given the location and the wind potential that is available on the island. The installation of the photovoltaic (PV) panels was primarily to compensate for the low flow rates of the streams and the lower wind speed in the summer months. The capacity of the installed PV was low, considering the efficiency of PV panels, the contribution from this component is small. And the average daily energy use per month on the island varies between 28kW and 41kW. This may have been a factor in choosing the size of the back-up generators (2×40kW) this ensures that the average daily load can be supplied by the generators in the case of failure of all renewable sources.

3. A Novel Design for a Completely Renewable System

3.1. Hydrogen System Design

Having analyzed the current system that is in operation on the island, it was found that the summer months of June and July was mainly where there was a deficiency in the energy generated from the renewables to meet the demand because of less rains in these two months. As a result of this the hydropower stations generated much less power, the diesel generators must be in operation to meet the demand. This is what need to be solved. Obviously, the current battery storage unit could not meet the demand. One option is installation of more batteries with more wind turbines to act as energy storage and therefore the energy can be used on demand. Because the battery lifetime is relatively short [11], another option is then needed. Based on our previous research outcome [12], hydrogen (H_2) can be used as fuel to replace diesel fuel. H_2 can be generated from renewable energies such as wind, solar and hydro. On the island, water resources for hydropower is limited in the summer; solar PV is efficient in the summer but not in the other seasons. Only wind resource was available for installing more wind turbines. Therefore, wind is the option. Hydrogen can be generated and then stored in tanks for use when required.

The generators did not contribute to meet the demand in the months of March, April, August and October. It was found that the contribution of electricity from the diesel generator was 22047 kWh, which equaled to around 6153 kg of diesel fuel. The total heating values of the diesel was estimated as 1890 kg hydrogen that would be required to meet the demand in a whole year. From this estimated data, the quantity of renewables needed to produce this amount of hydrogen can be determined. It is expected that the required amount of hydrogen can be produced, with the installation of more wind turbines for generation of excess electrical energy to electrolyser water. Fig 3 shows the schematic of this system. It can be noted that the original system, which can be seen in Fig 1, still remains in this design and that the additional components that are included make up the hydrogen system.

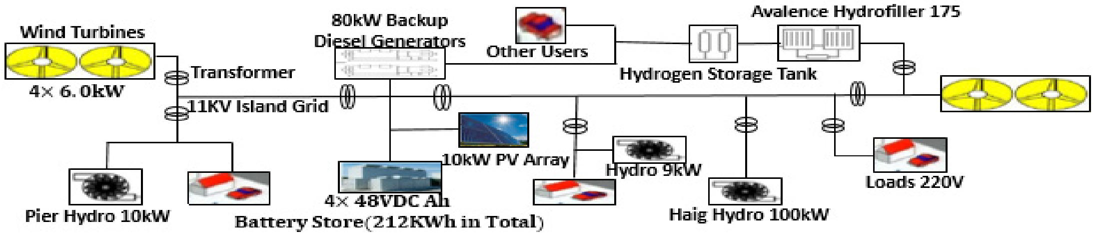

Fig.3 Schematic of Novel System Design

The additional components that are required to form the hydrogen generation and storage system. The selected wind turbines were 4×20kW Coemi, which provide additional generation used for both to power the electrolyser and to supply the grid. The electricity generated by the wind turbines is in AC therefore it must undergo a conversion to DC, hence the converter was required. The electrolyser was then powered and hydrogen was produced. The hydrogen was compressed before entering into the storage tank where it can be stored until it is required to power the hydrogen-fueled diesel engine generator to ensure that the demand is met.

3.2. HOMER Software

HOMER 2.68 is used in this study. It is developed by the National Renewable Energy Laboratory in the USA, which is a software tool to get access to process a tech-economic feasibility evaluation for the renewable hybrid system. HOMER works based on the model inputs which are used to simulate different configurations and combinations of components and generate results that will list the feasible configurations. This allows for comparisons to be made and the best option to be decided upon. HOMER can also be used to identify which factors have the greatest impact on the design and operation of the power system [13].

4. Results and Discussion

4.1 Technical Results

Several different types turbine were considered for this application. The simulation results showed that the most suitable turbine was Coemi's 20kW wind turbines. The total hydrogen that was produced when six Coemi 20kW turbines were used is 3673kg. As shown in section 3.1, the hydrogen that is consumed by the generators is 1890 kg/year. This leaves an excess of 1783kg/year which will ensure the reliability of power supply from the back-up engine generators; and the stored hydrogen can be used at a later time. Other alternatives were to use the H_2 fuel for heating or for the vehicles on the island subjected to the engines being modified to hydrogen-fuel engines. The fourth option is to sell the hydrogen, this would provide an additional income to the island which could be used to offset the high cost of the electrolyser and the hydrogen storage facility. However, if the number of turbines that are installed is reduced to four Coemi 20kW, the hydrogen produce will be reduced to 3260 kg/year which was sufficient to meet the hydrogen demand (1890 kg/year).

Figure 4 shows the HOMER simulation results over the year. The hydrogen production rate per month is indicated in the figure. It is also found that the cost of producing hydrogen with this system is US$55.60 (£37.97) per kilogram.

Figure 5 shows the stored hydrogen in 12 months. It can be seen how hydrogen is being produced and stored, where it is being used and there is a significant drop in the stored hydrogen during July, this is as a result of the hydrogen being used in the generators to meet the demand.

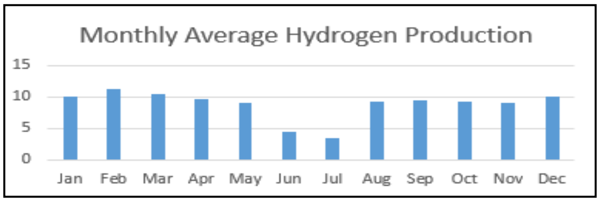

Fig.4. Hydrogen Production (4 x Coemi 20kW)

Fig.5. Stored Hydrogen(kg)

4.2 Economic results

All the costs involved with this system were found from the market and input to HOMER. A sensitivity analysis was carried out based on the cost of modification of the diesel generators. This was assumed to be between £10,000 and £20,000. It was found that the difference in initial capital based on minimum and maximum situation was £24,000 and the effect on the cost of electricity was US$0.006 (£0.004)/kWh.

The cost of modification of the diesel generators was estimated as US$21,966 (£15,000) per generator or US$549 (£375) per kilowatt. The results from system which incorporated four Coemi wind turbines were shown in Table 1. It can be seen that the optimized system eliminated the use of the hydro plants and the PV array, as this significantly reduces the initial capital. However if we look at the system which incorporates all the components the initial capital is the greatest, but the COE is US$0.874/kWh. Similar to Economic Analysis of the original system, the system is eligible for Fit in tariffs (FITs). Using the FITs for immediate installation, the results were shown in Table 2. The yearly income based on the system generation for period Nov 2008 – Oct 2009 was £127,389, the FITs received over the lifetime will be in the region of £2,555,249.

Table 1. Simulation Results (4 × Coemi 20kW)

Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.
$ 551,836	39,639	$ 1,058,554	0.354	0.95
$ 607,291	36,882	$ 1,078,761	0.361	0.96
$ 255,835	302,583	$ 4,123,861	1.384	0.17
$ 200,380	309,576	$ 4,157,795	1.395	0.14

Table 2. Income from FITs

Component	Total kWh	FIT (p/kWh)	Lifetime of FIT	Yearly Income (£)	Total over Lifetime (£)
Hydros	254607	17.8	20	45320.05	906400.92
Wind	223206	36.1	20	80577.37	1611547.32
PV	6191	24.1	25	1492.031	37300.775
				Total	2555249.015

5. Conclusions

From the above results it can be concluded that: The merits of the adding hydrogen production system include the use of non-polluting renewable energy sources, and the security of supply that was experienced by the islanders, compared to the past were the diesel generators were shut down at night.

Now the islanders would have 24-hour electricity supply, this was one of the objectives set by the islanders themselves when they took the initiative to build a system and to incorporate renewable sources. The only issue with this is that the diesel generators are present to provide back-up power and therefore the system emits CO_2, albeit a considerably low level compared to average UK households.

The new system that was designed which integrates hydrogen into the system would also provide 24-hour electricity supply to the islanders. The merits of this system are that the use of fossil fuels for generating electricity has been removed from the island and that the emissions are now non-existent. If the hydrogen is also used for the cars on the island, the islands energy usage can be seen as completely green, as well as the possibility of the sale of hydrogen and the income that would be associated with this.

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Biography

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