CONCEPTION AND OPERATION OF A UNIQUE LARGE-SCALE PV HYBRID SYSTEM ON A HEBRIDEAN ISLAND

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ABSTRACT: The realization of large hybrid off-grid systems is one of the challenges in the energy supply of remote areas in the coming years. Increasing demands for such systems have become obvious. We present the field experience of an innovative autonomous hybrid energy system for a British Island, the Isle of Eigg. This project can be considered as a reference and standard for future applications. The system integrates multiple renewable energy sources such as wind, hydro and solar with two conventional diesel gensets. The power sources and loads are coupled by a medium voltage grid across the island over several kilometers. We analyze and discuss the technical data, determine the energy balance and discuss the economical energy balance before and after the commissioning of the system. We proof that technical solutions for large scale off-grid applications in the 100 kW range are available and come along with significant cost reductions for customers, even today. In addition, we show that the demands of increasing energy consumption along with new properties on the island can be fulfilled by the modular concept of this unique hybrid energy system.

Keywords: Hybrid, Stand alone PV Systems, Storage

1 INTRODUCTION

The Isle of Eigg is one of the Hebridean Islands close to the Scottish coast. With a distance of 16 km to the Scottish west coast it was never served by electricity from the mainland. Its small scattered community on the Island with a north to south extension of 9 kilometers and east to west extension of 5 kilometers also never possessed a mainland type grid in the past. The people on Eigg have been dependent on their own produced energy, mostly by diesel generators. These have been switched off at night.

In 2008, the Isle of Eigg became almost independent from oil imports from the mainland and from fossil power sources by actuating a unique hybrid system. For the first time, this system ensures 24 hours energy for the community on Eigg Island.

The mini-grid has been designed as a decentralized system which integrates multiple renewable energy sources and loads – interconnected via 11 km of a medium voltage power distribution grid. Twelve battery inverters in multi-cluster-topology provide a 3-phase electric power system. Each household is connected to this hybrid system.

The power generation system of Eigg consists of 10 kWp PV, 3 hydro plants (100 kW, 2 x 6 kW), 4 wind turbines (4 x 6 kW) and 2 diesel gensets (2 x 64 kVA). Each of these sources has been sensitively sited to cause minimum visual and physical impact upon the island’s landscape. Nearly 100 inhabitants owning around 40 residential and 5 commercial properties must be supplied by the system.

The power demand has been limited with approval of the residents; domestic and small business supplies have been limited to 5 kW, and larger business supplies to 10 kW. The Sunny Island 5 kW inverters are connected in four three phase clusters providing a total output peak power of 100 kW. The Multicluster-Box enables the communication among the inverters and provides contactors for the connection to the island grid, to the PV and wind inverters and the backup gensets. Each cluster is connected to a 48 V battery bank.

The main benefit of the PV array will occur during the summer months when its output is high, complementing the lower output that is expected from the hydro generation and the wind turbines (due to minor summer rainfall and low summer wind speeds). Because of the uncertainty regarding the load profile and the intermittency of the renewable sources, diesel generation will provide backup power to ensure that a reliable supply for the island is maintained.

The life for the people dramatically changed after the system has been enabled. Now they can enjoy the luxury of modern living by using almost only renewable power sources. This unique system is entirely stand-alone and almost all the energy is generated on-site.

2 SYSTEM OVERVIEW

2.1 The power sources

The system is being powered by an integrated mix of renewable power sources. The major renewable source is a Gilkes 100 kW hydro electric generator. This generator is supported by two smaller hydro generators, a 5 kW Platypus and a 5 kW generator from Scoraig Wind. They produce electricity from flowing water. Further renewable sources are four Proven 6 kW wind turbines on 15 m towers as shown in Figure 1. Each turbine is connected to an SMA Windy Boy WB 6000A inverter. Finally there is a 10 kWp photovoltaic array which consists of 60 BP Solar BP3165S 165 W modules. The PV array, as shown in Figure 2, is connected to three SMA Sunny Boy SB 3000 inverters.

When renewable energy generation is not sufficient, the system can be supported by two 64 kW Thistle diesel generators. They are used as emergency backup power sources and can be switched on or off automatically. The power sources and buildings are connected around the island by an 11 km long medium-voltage network. This cable grid has been installed below ground to minimize the impact on the landscape. 11 transformers at various locations convert the grid voltage to domestic voltages.

They also connect the various renewable generators and the system control building to the grid [1].

2.2 The system manager

The whole system is controlled by 12 Sunny Island 5048 battery inverters. They manage the power balance between loads and generation of power and control the system voltage and frequency. The Sunny Islands are connected in four 3-phase clusters with a total nominal power of 60 kW. These clusters are connected to a Multicluster box and to a 48 V 4400 Ah (C10) battery bank consisting of 4 x 24 Rolls Solar RB 4KS25PS deep cycle batteries. The battery bank can provide up to approximately 12 hours power for the whole island. The Sunny Island also automatically starts and stops the generators. The electrical schematic is shown in Figure 3.

Figure 1: 6 kW Proven wind turbines located in the southern part of Eigg.

Figure 2: 10 kWp PV array. Additional 22 kWp will be installed in September / October 2010.

3 SYSTEM CONTROL

The battery inverters monitor and control the whole system automatically by calculating the state of charge (SOC) of the batteries and controlling the power via grid frequency. When the three renewable resources produce more energy than being consumed, the energy is used to charge the battery bank. If, on the other hand, the resources generate less energy than being used, the batteries provide the needed margin. The Sunny Islands continuously monitor the SOC of the batteries. If the SOC decreases below 60 %, the inverters start the generator. The generator will be disconnected at 90 % SOC.

With commissioning, the Sunny Island inverter configuration was set to default, requesting the diesel generator to run between 40 % to 90 % SOC. This was changed to avoid deep cycling of the batteries and thus maintain long life. Now the generator is operating more frequently, but for shorter periods.

The operation in frequency droop mode [2] allows the battery inverters to share the load with the diesel genset and the hydro generators.

3.1 Frequency shift

If the battery bank is fully charged and the renewable sources produce more energy than being used, the system frequency rises, driven by the Frequency Shift Power Control (FSPC) function of the Sunny Island. Additional loads (space heaters in community buildings) are connected as a first measure (load adding). If the energy production is still too high, the frequency continues to rise and the output of the wind generators will be converted into heat and then dumped into the atmosphere. As a final measure, when the frequency is still rising, the energy of the 100 kW hydroelectric generator as well as the Sunny Boy and Windy Boy inverter output will be limited by the Frequency Shift Power Control of SMA.

3.2 Monitoring of the system

Data of the Sunny Island inverters are logged continuously on SD cards. These data contain information about the battery and the sum of the external power of the generators. An SMA Sunny WebBox datalogger in the system house monitors the Sunny Boy PV inverters; a second WebBox monitors the Windy Boy. The hydro power generators and the loads are monitored by external meters.

4 ENERGY BALANCE

4.1 Power generation

To provide an almost constant power generation over the year with changing weather conditions, a sophisticated control of the different power sources is essential. The three renewable power sources will be used prior to the diesel gensets. The data to evaluate the fraction of the different renewable power sources are taken from meters which are located between the renewable power sources and the transformers. Data between November 2008 and October 2009 are presented in Figure 4 and Table 1.

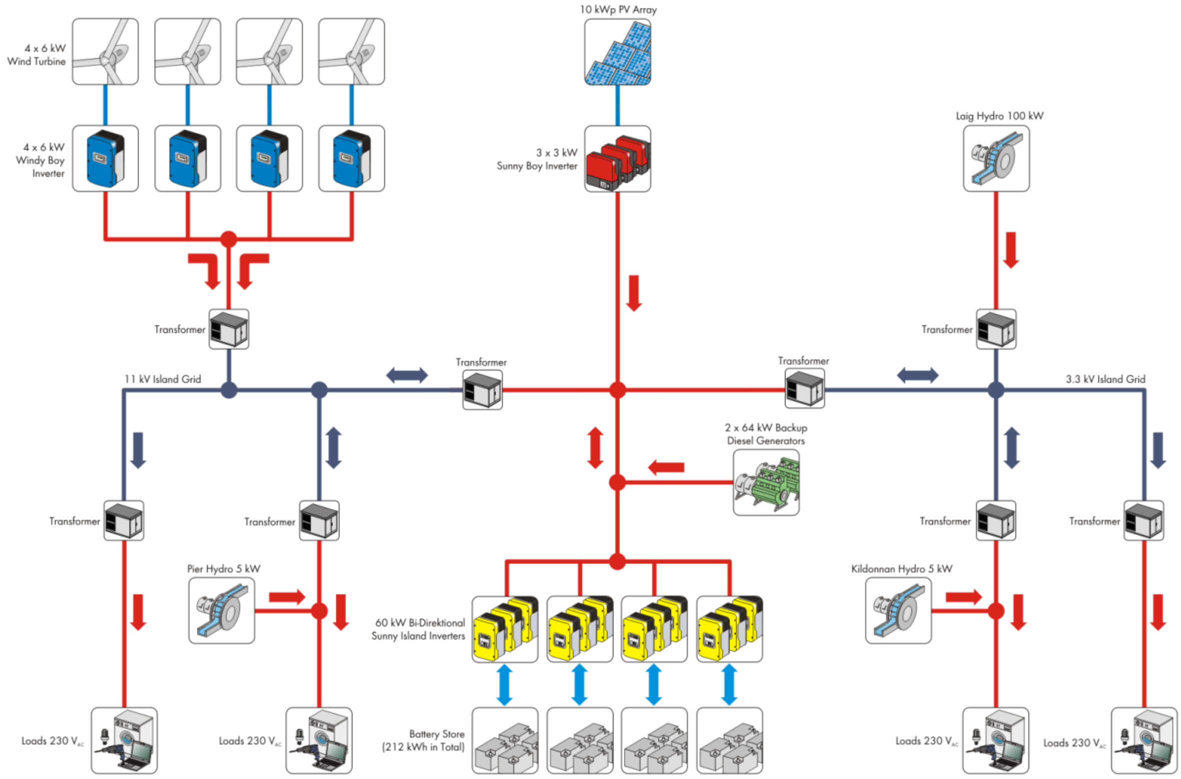

Figure 3: Electrical Schematics of Eigg Island

About 80 % of the total power is generated from the hydro generators, about 10 % from the wind turbines and only 2 % from the PV arrays. But nevertheless PV provides a relevant benefit in June and July when its output is high. During these summer months the hydro generators produce lower output due to low summer rainfall.

The wind, PV and hydro power generation is each complementing the lower output of another renewable energy source in a sophisticated way. The diesel generators mainly have to provide backup power. During June and July less than 50 % of the power can be taken from the hydro generators, whereas between November 2008 and October 2009, 93 % of the power has been generated from renewable sources.

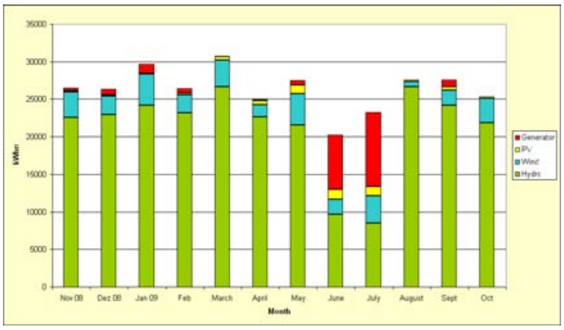

Figure 4: Power generated per month by the components of the system (kWh) [3], [4]

Table I: Total power generated between November 2008 and October 2009 (as shown in Figure 4) by the components of Eigg Electric system (kWh).

Hydro	Wind	PV	Diesel	Total
254607	33411	6191	22047	316220
80.5 %	10.5 %	2 %	7 %	100 %

4.2 Power Balance of the System

The systems overall performance is characterized by the complexity of the system control. The power balance between the different loads and the different energy generation must be guaranteed at all times. Figure 5 demonstrates the system behavior in the critical month of June 2009, when the energy from the hydroelectric generators is low. The inverter power is indicated as a blue, the generator power as a red and the consumption as a green line.

The fluctuating inverter and generator power in Figure 5 indicate that the generator is started and stopped several times. In times when hydro, wind and solar power are low, the system is powered by the diesel generator and the battery by means of Sunny Island power. The consumption line reflects the morning, lunch and evening peak of about 40 kW and the basic load of about 15 kW. Hence, even if the hydro generators are not running and the diesel generator starts and stops several times per day, the system provides the demanded power at all times automatically.

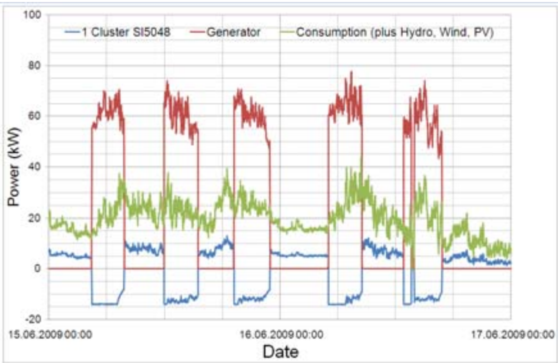

Figure 5: The inverter power, the generator power and the consumption between the 15th and the 17th June 2009.

4.3 Recent developments in 2010

In May / June there has been very little rain on Eigg, consequently the hydro generators have not been working and the diesel generator starts more often. The islanders also tried to reduce consumption in this time period.

There are several new properties being built on the island. That means that the demand of electricity is steadily increasing.

To compensate this lack of energy with renewable power sources, an additional 22 kWp PV array has been ordered. The array will be installed in September / October 2010. Further measures are under consideration.

5 THE OVERALL COSTS

5.1 The costs

The total investment costs of the system were £ 1,697,130. The end user now has to pay 20 pence per kWh, plus 12 pence per day total standing charge and VAT. This also covers maintenance and operation of the system. Households are limited to 5 kW, and businesses are limited to 10 kW. If these limits are exceeded, a trip is triggered and a charge of £ 20 to reconnect has to be paid.

5.2 The cost reductions

The diesel fuel consumption has been reduced from 51,000 litres to 7,800 litres per year. This is a total saving of 85 %. Depending on the household or business, the inhabitants report that the costs are between 25 % and 40 % now compared to before. In addition, they no longer have noise or trouble with maintaining their own system.

5.3 The costs to connect Eigg Island to the mainland grid

To connect Eigg to the mainland has been estimated to a total of circa £ 4-5 million, which has therefore not been taken into consideration.

6 SUMMARY OF THE FIELD EXPERIENCE

We have shown that large modular hybrid systems with standard components out of series production are already feasible. The main benefit of this concept is the high reliability; a second benefit is the easy service by local electricians due to the fact that series inverters and components have been used. The modular concept of the system also ensures a flexible upgrading of the power sources and loads. The system is stable and running although the loads within this systems are constantly increasing. The control and system management based on the SOC calculation, communicated via the grid frequency solely has successfully been approved in large off-grid systems. This system management is already integral part of the battery inverters, hence superior control mechanisms and control devices are not necessary. The integration of new power sources such as PV will be the next step to provide sufficient renewable power to this growing community. Further steps to upgrade the system are under consideration.

7 CONCLUSION AND OUTLOOK

This article presents the field experience of a unique hybrid system on the Isle of Eigg. This complex system with different renewable and conventional power sources works automatically by means of a frequency and SOC dependent load management.

Above all, the system on Eigg Island becomes unique by two characteristics, namely:

1) AC-Coupling of 4 different and distributed power sources is possible via a medium voltage grid.
2) The system control has been carried out without additional communication lines or additional communication devices exclusively by the grid frequency, i.e. for the power sources and the loads.

Therefore, complex and distributed systems with medium voltage coupling are easy to install with standard Sunny Island battery inverters.

Multiple benefits for the people on Eigg Island have been achieved since the commissioning of the system. They now have electrical power 24 hours a day, are nearly independent from oil imports from the mainland, and have the luxury to use the electricity without running and maintaining their own power generating systems. Furthermore, the people on Eigg Island now pay less for their electricity than they did before this system was installed. They encounter the same quality of supply as main grid customers.

This system provides the technology necessary to proof the potential of large sophisticated hybrid off-grid applications: Modular, large scale PV hybrid systems are already feasible. This system can be considered as a reference and standard for future projects with renewable energy sources.

8 REFERENCES

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