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Reliable Power Supply of Islanded Locations through Microgrids

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Abstract. Due to the increase in the price of oil and the attempt to meet the limits of established CO_2 emissions, the technology of microgrids (MGs) has been growing considerably for some years. Its implementation is recommended above all in weak electrical networks, such as the networks of isolated areas and islands, with the aim of solving the typical quality problems in the supply of such networks.
In this paper, the analysis to estimate the implementation of an isolated MG is carried out, located on islands in the Hordaland region of southwestern Norway. Special importance is given to the fact that the MG in question contemplates high penetration of renewable energies and storage technologies.

Key words

Renewable energies, Isolated micro-grids, Geothermal energy, Wind energy, Batteries.

1. Introduction

Power systems have different characteristics, in terms of network topology, demand, installed power generation capacity or type of installed technology. In strong interconnected systems, the voltage levels are difficult to vary, the inertia of the system is high and stability is rarely lost. Therefore, the supply of energy is guaranteed and the quality of supply is high and increasing in developed networks. On the contrary, in weak power grids supply quality problems are recurrent and can have important consequences such as loss of production, economic losses or accidents. By counting isolated areas with weak networks, these supply problems, which can be the result of various factors, are frequently evident. It is necessary to analyse these factors so that the renewable microgrid (MG) provides a viable solution for improving the quality of supply in weak networks. In this context, it is necessary to set what isolated areas means:

- Locations / places of difficult access, long distances from the main network, which have deficiencies in the physical infrastructure and do not have appropriate access roads.

- Areas of high ecological importance, which are characterized by their wealth of natural resources and great biodiversity. Most of the reserves and natural parks are within this group.

- Areas with scarce and deficient basic services, such as: energy, access to drinking water and communication.

2. Weak electrical networks in isolated areas

The IEEE 1204 standard [1] defines a weak alternating current (AC) electrical network based on its static and dynamic performance:

- The impedance of the AC system is high in relation to the power at the connection point, that is, the short-circuit power at the connection point is low. This condition is met in weak electrical networks of large area, normally operated at medium voltage levels and with low X / R ratios.

- The mechanical inertia of the AC system is inadequate in relation to the AC power supply.

The static power intensity is characterized by the short circuit power level, which is low in weak networks. However, this measure is only applied to the common coupling point (PCC) from the side of view of the network. Therefore, it is convenient to take into account the generation connected to the PCC, using, for example, the short circuit ratio (SCR: Short-Circuit Ratio), as indicated in equation (1).

$$SCR = S_{SC}/S_n \qquad (1)$$

Where:
- S_{SC}: the short circuit level in the PCC
- S_n: Installed capacity of the generation plant

Usually, an electrical network is considered strong for SCR values above 20 [2] to 25 [3] and weak for SCR values below 6 to 10 [4].

3. Selection of the microgrid location

As mentioned above, the aim is to demonstrate the feasibility of MGs based only on distributed renewable generation to solve the energetic problems of isolated areas and, especially, for islands. The example is framed in Norway, which has 50,000 islands approximately. Due to the great number of islands, several criteria have to be established to reduce the number of possible locations. The first criteria considered has been the population number. As it is known, implementing a MG requires a high initial investment, whose justification depends on how many people will benefit from it. Thus, the minimum population number has been set in 10,000. Table 1 shows the Norway islands with a greater population number, as well as their surface area. Those islands in the north side are discarded because the climate is not adequate. These islands are Tromsøya, Kvaløya, Hinnøya, Langøya and Vestvågøy. Also, Jeløya has been discarded because of its small surface (19 km^2). Therefore, the possible islands from North to South are Askøy, Store Sotra, Stord, Karmøy and Nøtterøy. By performing an initial analysis in terms of available resources and infrastructures, it has been chosen the Hordaland region as the most appropriate, which includes Askøy, Store Sotra and Stord islands.

Table 1. Islands with largest population and their surface in Norway.

Island	Population	Surface
Tromsøya	36,088	22,8 km^2
Hinnøya	32,101	2.204,7 km^2
Karmøy	33,101	176,8 km^2
Askøy	28,380	100,61 km^2
Nøtterøy	21,621	60,86 km^2
Stord	19,400	241,2 km^2
Langøya	15,844	850,2 km^2
Sotra (Store Sotra)	15,356	178,6 km^2
Jeløya	11,825	19 km^2
Vestvågøy	10,848	423,36 km^2
Kvaløya (Troms)	10,300	737 km^2

Then, the three selected islands have been distributed in two groups based on their location. These groups have been named as Group 1 for the northern islands and Group 2 for the southern ones.

- Group 1: Askoy, Store Sotra and surroundings. Includes the north Bergen islands.
- Group 2: Stord and surroundings. Includes the south Bergen islands.

Also, from the previous analysis of available resources and infrastructures, it has been concluded that Norway presents a great opportunity to locate MGs based on distributed renewable technologies. Deepening the study of the region, it has been concluded that the Group 1 is the most vulnerable area in terms of electric power quality. This area has not been strongly delimitated and there is always the possibility to include several islands close to Askøy and Sotra in the MG, depending on the surface and the available resource, among other factors.

The final delimitation is chosen considering the simulation results. However, it is always possible to expand the MG to the islands that have been left out of the final scenario. In Fig. 1 is graphed the first area chosen to implement the MG (in orange). In this initial area Sotra islands (30,500 inhabitants including Litlesotra island and Fjell city), Askøy (28,380 inhabitants), Holsnøy (7,500 inhabitants), Øygarden city (4,704 inhabitants) and Sund city (6,635 inhabitants) are included. Note that these populations are approximated, since detailed information has not been found. Beyond this point, the population affected is estimated to be 78,000. As it is a large population number, first it has been considered a sample of 1,000 inhabitants for an initial small MG. In the long term, the proposed solution could be scaled, thus covering all the population needs in the delimited area. Askøy has been chosen as the nerve center of the MG, so that it has been introduced in the software.

4. Renewable resources in Norway

As far as hydroelectric energy is concerned, Norway has large hydric resources (Fig. 2). The rivers flowing to the southwest along the steep slope are usually short and with many rapids and waterfalls. Norway also has thousands of lakes of glacial origin, being the largest one the Mjøsa, which is located in the southeast.

Concerning Hordaland, it can be said that it has large hydric resources within the limits of the region. For example, it has three of the largest waterfalls in the

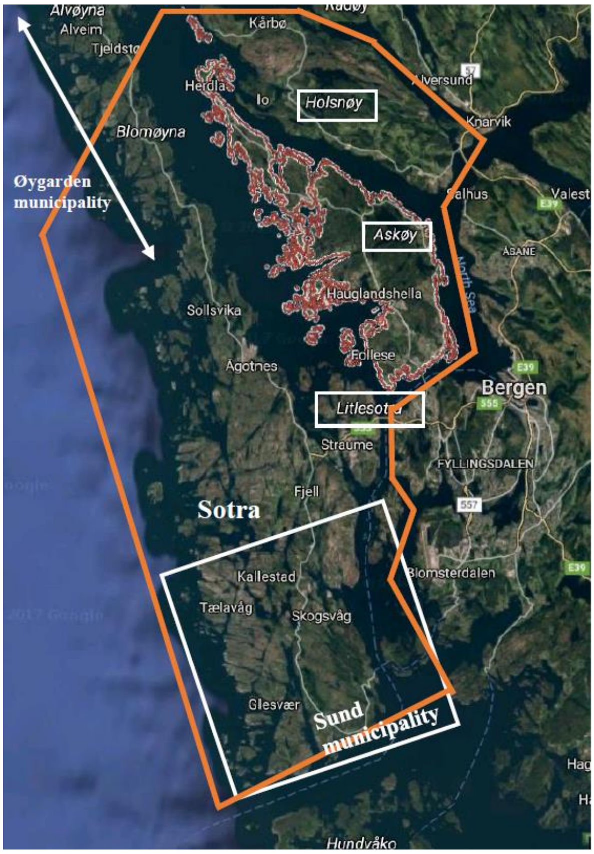

Fig. 1. Initial area for microgrid implantation.

Fig. 2. River-map of Norway.

country, of about 300 m each, which are currently used for electricity generation. These are Tyssestrengene in Tysso, Ringedalsfossen in Tysso and Skykkjedalsfossen in Sima [5].

Hordaland has a rainy climate with continuous rainfall as it is seen in Fig. 3 [6], which corresponds to 2016. As it can be observed, the rainfall in the islands area are about 2,000-3,000 mm per year, becoming a large hydric resource.

Fig. 4 shows the rivers in the region of Hordaland. It can be observed that the rivers are available in both areas Group 1 and Group 2.

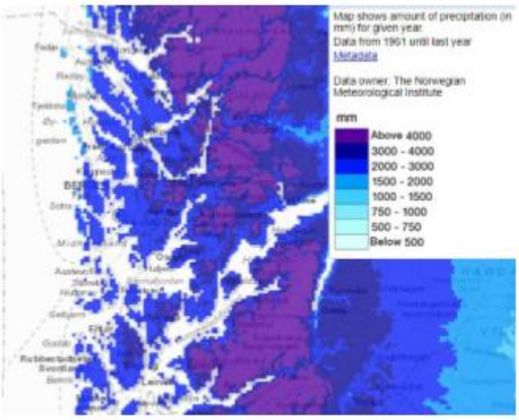

Fig. 3. Rainfall in the area of Hordaland (2016).

- In Group 1 there is a little river in Askøy, in the Eastern side, while in Store Sotra the river is shorter and is located in the center of the island. There are more rivers in the surroundings that can be considered in case of needing a greater hydric resource.

- In Group 2, on the contrary, in Stord there are two rivers that expand along the island. Once more, there is no great distance between the area of study and other rivers of interest.

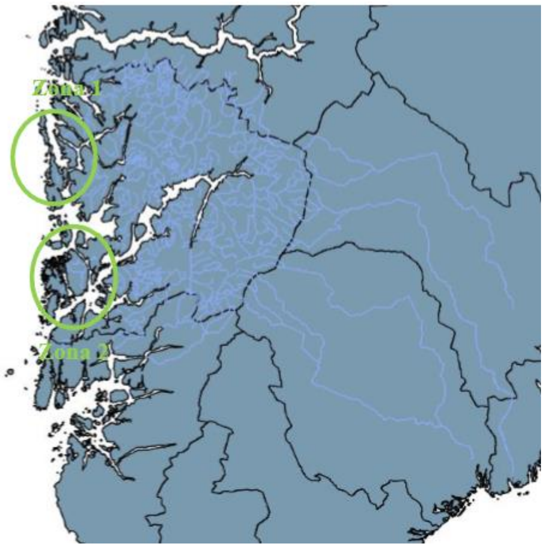

Fig. 4. Rivers in Hordaland region.

Regarding the wind resource, Fig. 5 shows the wind speed map in m/s at 80 m height. As it can be observed, most of the resource is at sea (offshore) and quite far from land, especially in the mid side of Norway. Besides, note that the wind resource is higher in the south of the country and the wind speed is high along the entire coast.

Islands from Hordaland region are located in the south of the country (Fig. 6), which entails quite high wind speeds depending on the island. Most of them are coloured in orange or red, which indicates that average wind speed at 80 meters height is from 7 to 8.5 m/s. In addition, considering the short distance from the islands in consideration to the red zone (8.5 m/s uniform), the analysis of offshore wind farms implantation could be interesting.

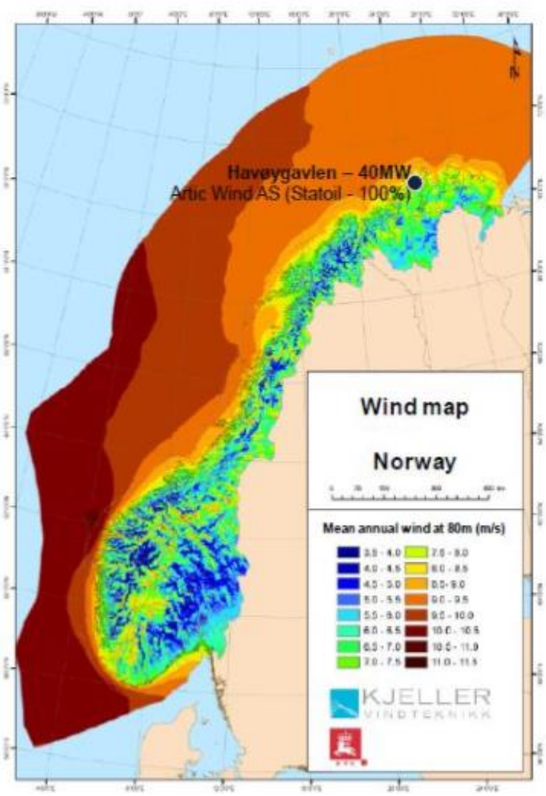

Fig. 5. Wind resource (annual average) at 80 m height [7].

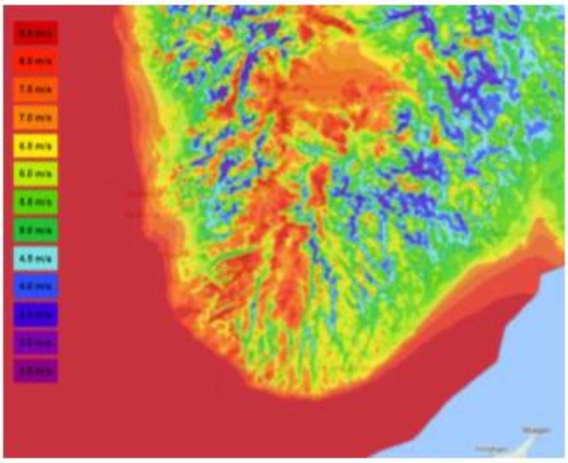

Fig. 6. Wind map of the south of Norway [8]

The geothermal resource of Norway is depicted in Fig. 7, where it can be seen that there is only low temperature resource available. Among all the available applications of this technology, the use of geothermal heat pumps to heat homes predominates in Norway, due to the low temperatures that are reached.

The previous statement is confirmed in Fig. 8, where the temperature for different depths in Bergen is shown. It is observed that half a kilometre depth, the temperature of the subsoil is still low for power generation designed applications.

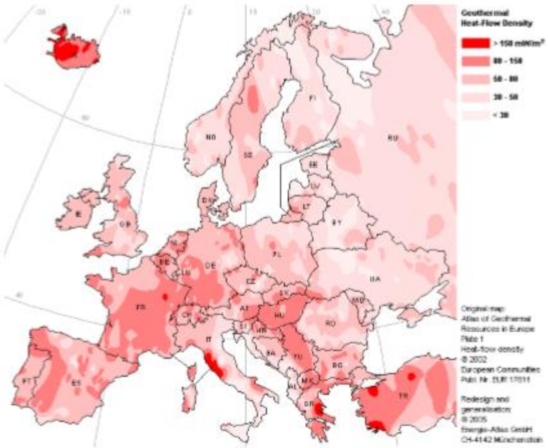

Fig. 7. Geothermal resource available in Europe.

Therefore, all available geothermal resource will aim to extract heat. The great advantage of these systems is that the geological conditions for their use are not very demanding since this type of subsoil energy resources can be used practically in the whole territory. It is an efficient heating and cooling technology with outstanding energy savings.

The first aspect to take into account regarding the solar resource is that Norway is a country located in northern Europe. Therefore, the solar resource is not high when comparing with other countries located further south in Europe such as Spain, Italy or Greece.

In the resource map of Fig. 9, which colours the solar radiation for the optimum inclination of the photovoltaic panels (~30 °), it can be seen that the values are not high.

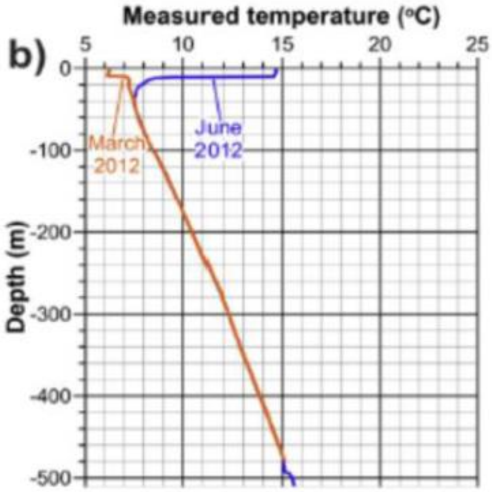

Fig. 8. Temperatures in Bergen at 0-500 m depth.

For example, in Spain, the country with the highest solar radiation in Europe, irradiation values range between 1,300-2,100 kWh/m^2 and electricity generated between 975-1,575 kWh/kWp for the same angle.

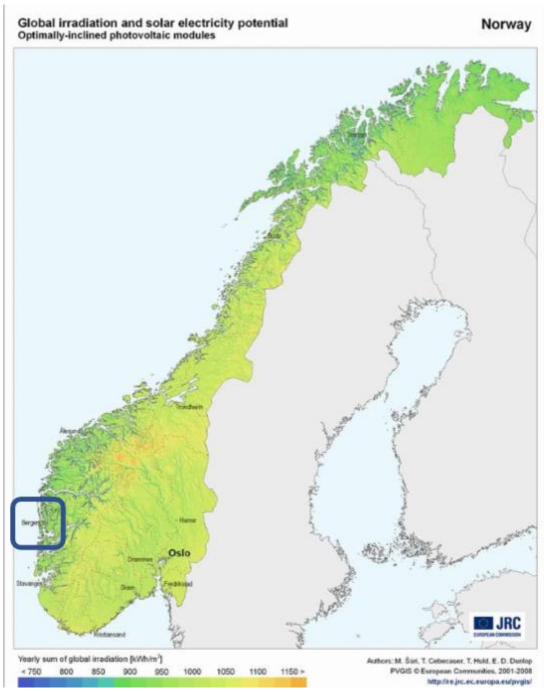

Fig. 9. Solar irradiation map of Norway at the optimal inclination [9].

Biomass resource takes about the 37% of the land of Norway, being larger in the coast areas. Fig. 10 shows the biomass resource throughout the country, and as it can be seen, Hordaland region is not the best place for taking advantage of it.

5. Simulation of microgrids

Once the previous design considerations have been established, it is convenient to use some microgrid design software to try to find the optimal design and be able to validate results.

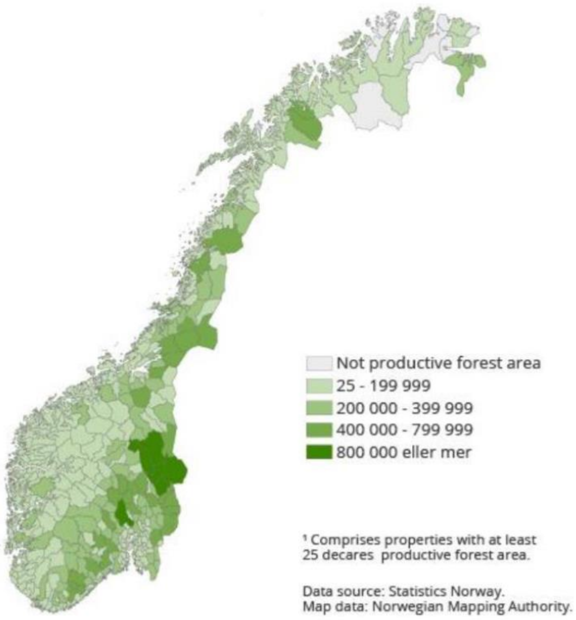

Fig. 10. Biomass resource map of Norway, 2012.

In this case, the software chosen for the simulations is the American Homer Pro. This program, property of Homer Energy, is the world standard to optimize the design of microgrids in any environment, from towns and islands to universities connected to the network and military bases. Homer Pro, or HOMER (Hybrid Optimization of Multiple Electric Renewables), simplifies the task of evaluating designs for both isolated and grid connected systems.
When designing an electrical power system, many decisions must be made about the configuration of the system, such as which components are best for the system or how many and which size of each component is more efficient. The large number of available technologies, the variation in costs and the availability of energy resources are variable when making these decisions. Thus, HOMER's optimization and sensitivity analysis algorithms facilitate the evaluation. In our case and although maximising generation from renewable energies will be prioritised, some conventional technologies such diesel generator will be included.

According to the estimated consumption, the peak electricity power is about 9.5 MW with an average of 3 MW, and the peak of thermal power is about 0.375 MW with an average of 0.14 MW. The installed capacity of the microgrid should be around the peak power, although if the renewable resource is sufficient to cover the average demand, renewable energy will dominate in the energy mix. In such case, the internal combustion engine will only act when the power demanded reach values between the average and the peak power. Several simulations have been carried out establishing different penetration ratios from renewable sources, as well as varying the installed capacity of each renewable technology.

6. Simulation results

After performing the simulations and having analysed all the scenarios, it is concluded that the best option for a microgrid in the studied area is the structure indicated below. The simulation results and therefore the final design of the microgrid can be seen in Fig. 11 and 12. On one hand, the installed capacity is divided into 123 kW from photovoltaic panels, 3 MW from wind turbines (two turbines of 1.5 MW each), 1.059 MW from hydraulic, 1.2 MW from hydrokinetic generators, 0.5 MW from internal combustion engines powered by biogas and 11 MW from diesel generators. On the other hand, the storage necessary is of 15 MWh and the power of the converter needed of 4.014 MW. With this choice, the final renewable penetration is estimated to be around 83 % and there would be no stability problems due to the large storage capacity available. As far as production is concerned, the monthly distribution of electricity generation is shown in Figure 13. As it can be seen in the figure, the distribution of the generation ratio is quite steady throughout the months. Hydrokinetic generation is the most varying one, which increases when the wind resource is insufficient. More specifically, Table 2 shows the annual energy production of each generator and its fraction with respect to the total production. 1,467,326 kWh / year of the produced energy are not used, a figure that represents the 5.25 % of the total production.

It should also be noted that the generation dispatch in the simulation has been carried out using the LF (Load Following) strategy. This strategy states that each generator produces only enough power to meet the primary load. Lower priority objectives, such as the storage charging, are reserved for renewable energy sources. Depending on the chosen strategy, the generation mix recommended by Homer Pro is one or another.

The proposed microgrid has a payback of 11.30 years considering the initial investment of 27,492,073.23 € and annual amortization being 2,423,997 €/year. These values have been calculated using HOMER data and considering a 25 years lifetime. Incomings are calculated using the LCOE proposed of 0.2266 €/kWh. Considering also the replacement and O&M costs as well as the salvage VAN has been calculated, being 2,599,876.61€ with an interest rate of 4%.

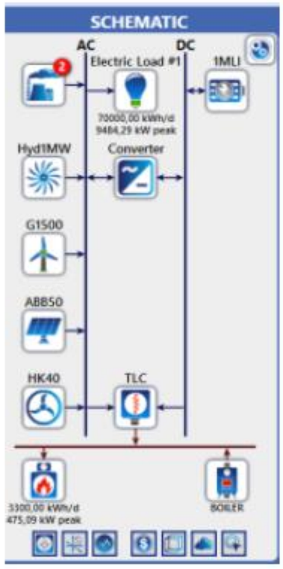

Fig. 11. Proposed microgrid scheme.

	ABB50 (kW)	ABB50-Inv. (kW)	G1500	Bio (kW)	Gen (kW)	1MLI	Hyd1MW (kW)	HK40	Converter (kW)	Dispatch
	123	50,0	2	500	11.000	15	1.059	30	4.014	LF

Fig. 12. Results from final scenario.

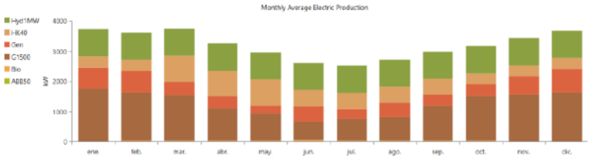

Fig. 13. Monthly electrical generation by the microgrid.

Table 2. Distribution of electrical generation by the microgrid.

Production	Type	Installed capacity [kW]	kWh/año	%
ABB Trio-50.0 with Generic PV	Photovoltaic Solar	123	123,578	0.442
Generic 500 kW Biogas Genset	Internal Combustion Egine (biogás)	500	183,438	0.656
Autosize Genset	Diesel generator	11,000	4,314,937	15.400
Generic 1.5 MW	Wind generator	3,000	10,711,557	38.300
Generic Hydrokinetic [40 kW]	Hydrokinetic genrator	1,200	4,753,042	17.000
Hydro	Hydroelectric generator	1,059	7,888,888	28.200
Total		16,882	27,975,440	100.000

7. Conclusion

In weak networks, such as microgrids located in isolated areas, the penetration of variable source generation implies a challenge both in terms of the impact of generators on the network and the impact of the network on generators. In this sense, the power supply quality may be affected and the generators must face resonance problems in extensive weak networks, large variations of frequency and propagation of voltage drops in small isolated networks, control conflicts, low power supply quality due to the flicker effect, unbalances and harmonics, as well as voltages outside the levels.

In order to solve this dilemma, a microgrid has been designed located in the islands of the Hordaland region, in the southwest of Norway. The first step was to carry out a resource study deep enough, which has defined both the typology and availability of the resources throughout Norway, and more specifically in the Hordaland region and its islands. This investigation has concluded that the water resource is predominant both in the country and in the area of study. The availability of wind and biomass resources has also been determined. On the contrary, the solar resource is really scarce and wave energy has been discarded for being not a mature technology.

Homer software tool has been used to design the microgrid. During the simulations, it has been verified that it is relatively easy to achieve a high fraction of renewable generation in the Nordic islands, considering the actual hydric and wind resources. No danger on network stability has been detected to be caused by the proposed design, thanks to the storage defined in the proposed system. Finally, it has to be highlighted that microgrids are becoming a reality in Europe. Although they are currently in the development stage, the first installations of this type have been installed for a few years now. Nowadays the future of electricity grids is uncertain, but many predict that within a few years the main element of the European electricity network will be the so-called "European Supergrid" and the end users out of reach of this network will be fed by microgrids.

Acknowledgement

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