

HND Electrical and Electronic Engineering

Electrical power

Design a renewable off-grid power supply for a rural isolated area

By Aneurin Creed

Contents

Introduction	3
Area research	5
Converter	10
Batteries	11
Cost of off grid system & Proposed tariff	12
Discussion	13
Conclusion	14
References	15

Introduction

One of the most prominent renewable energy technologies is wind power, a source of power generation that uses the wind to spin a turbine and ultimately generate electricity. Renewable energy technologies can help communities in meeting their goals for secure, reliable and affordable energy to expand electricity access and promote development. This report aims to offer a solution for the shortage of electrical power within a rural village in Wales (Dyffryn Lledr). The report outlines a plan for the design of a small off-grid wind power plant system that can provide self-sufficient electrical power to the community (100 small cottages, 2 churches and 4 community service buildings) for 24 hours. The average rate of energy consumption is about 6 kWh per day per cottage, 80 kWh per week per church, and 50kWh per day per community building.

In order to solve this shortage of electrical power, this report will look at relevant theories and designs relating to the area and its demand, as well as calculations involving the cost of the hardware proponents and maintenance in comparison to the National Grid.

Village calculations

Properties	No	Average Daily Energy Consumption (kWh)	Total Daily Energy Consumption (kWh)
Small cottages	100	6.00	600.00
Churches	2	11.43	22.86
Community buildings	4	50.00	200.00
Total	106	67.43	822.86

Electricity prices per kwh

Supplier	Tariff	Avg. kWh unit price (ex VAT)	Annual Standing Charge (ex VAT)
 ScottishPower	Online Fix and Save August 2018	12.376 pence	£114.28
 ScottishPower	Help Beat Cancer Fix and Save August 2019 Online	12.376 pence	£142.82
 British Gas	All Online Mar 2019	12.499 pence	£83.15
 Sainsbury's Energy	Price Promise March 2019	12.827 pence	£87.86
 OVO Energy	Better Energy Fixed	12.978 pence	£85.78
 OVO Energy	Better Energy Fixed (all online)	12.978 pence	£85.78
 E.ON	E.ON Go Online 1 Year High User v1	13.119 pence	£77.93

Using the value of 12.499 pence per kWh of electricity. Assuming it stays fixed for 10 years.

	Cost	
Energy demand for 1 day	=822.86 kWh	= £102.85
Energy demand for 1 year	=300,342.86 kWh	= £37,539.85
Energy demand for 10 years	=3,003,428.57 kWh	= £375,398.54

From the figures above, a value for the total energy demand can be calculated at 822.86kWh and the electrical tariff for the area can be calculated at 12.499p.

Multiplying these two figures gives the cost of the daily energy consumption at £102.85. Following this, the daily demand is converted to the annual and decenary demand by multiplying the daily demand by 365 and then by 10 to give us the total demands.

As done to calculate the cost of the daily consumption, the cost of the yearly and decenary consumption is calculated in the same way, giving the totals of £37,539.85 and £375,398.54 respectively.

$$P = E \div t$$

$$P = 822.86 \div 24$$

$$P = 34,285.83W$$

Here, the daily energy demand has been converted to the power required for this demand by dividing it by 24, thus giving us a value for power of 34,285.83W.

Area research

The turbines will be located roughly 4km away from the village on a peak with altitude of 800m. This location has been selected due to it having the highest average wind speed (8.1m/s) within 5km of the village.

Figure 1 shows the average wind speeds within 25km² of Dyffryn Lledr. The most appropriate site is marked with the symbol of a wind turbine. This site has been chosen as it has the highest average wind speed within the surrounding area.

Figure 1

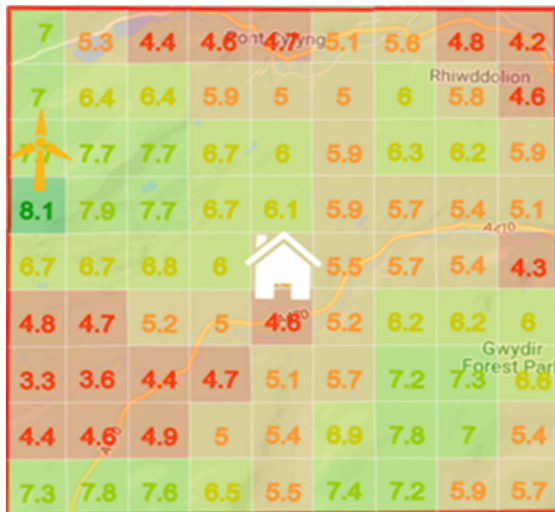


Figure 2

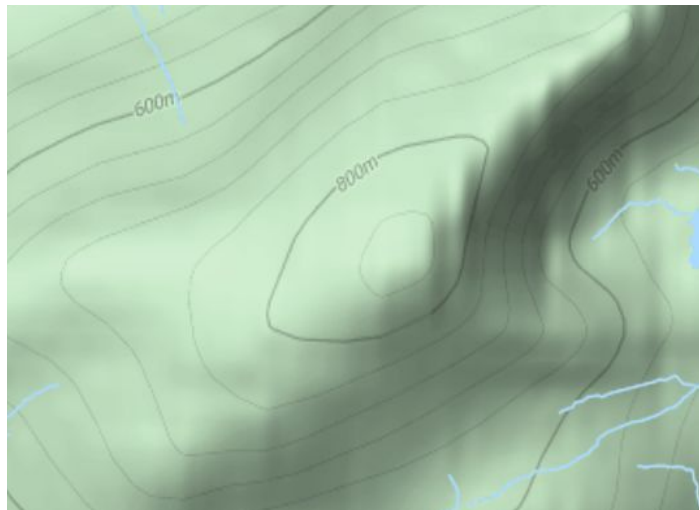
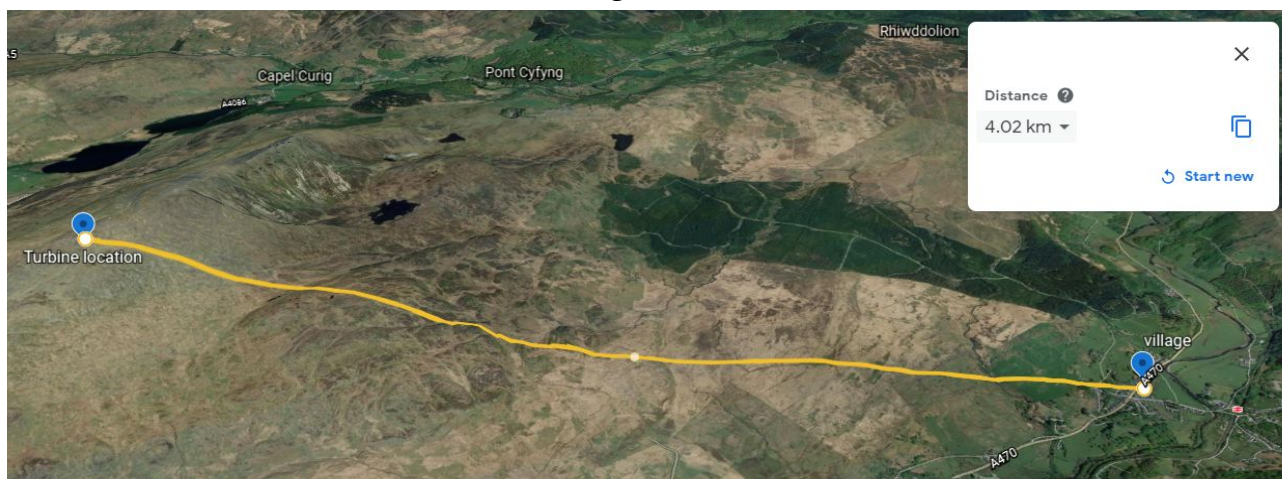


Figure 2 shows the elevation of the proposed site of the turbine (800m). The height of this area is favourable as it contributes to the higher winds speeds.

Figure 3 shows the distance (4.02km) between the location of the turbine and the village on a map. This distance will need to be taken into account later on in order to plan an efficient route for the three phase power lines that deliver the power between the turbine site and the village.

Figure 3



Turbine research

Turbine 1

Company :	Enair
Model:	E200
Max power:	20kW
Diameter:	9.8m
Blade Length:	4.5m
Sweep area:	75.4m ²
Cut in wind speed:	1.85m/s
Cut out wind speed:	30m/s
Cp:	0.41
Cost:	£52,600

<https://www.enair.es/en/small-wind-turbines/e200>



Turbine 2

Company :	Atlantis Wind Turbines
Model:	ASWT
Max power:	7.5kW
Diameter:	6.4m
Blade Length:	2.8m
Sweep area:	24.63m ²
Cut in wind speed:	2.5m/s
Cut out wind speed:	25m/s
Cp:	0.40
Cost:	£29,000

https://www.atlantissolar.com/turbine_5kw.html



Looking at turbine 1, the power of the wind can be calculated using the equation $P = \frac{1}{2}\rho Av^3$

$$P = \frac{1}{2}\rho Av^3$$

$$\text{Air density } \rho = 1.225 \text{ kg/m}^3$$

$$P = 0.5 \times 1.225 \times 75.4 \times 8.1^3$$

$$\text{Sweep area } A = 75.4 \text{ m}^2$$

$$P = 24,543.27 \text{ W}$$

$$\text{Wind speed } v = 8.1 \text{ m/s}$$

However this value is only theoretically possible as we need to factor in Betz' Law.

‘‘Betz' law says that you can only convert less than 16/27 (or 59%) of the kinetic energy in the wind to mechanical energy using a wind turbine (Albert Betz, 1919).

To calculate the true power available from turbine 1 a power coefficient C_p must be introduced into the equation for power. Thus the actual power outputted by this turbine is;

$$P = \frac{1}{2}\rho Av^3 C_p$$

$$\text{Power Coefficient } C_p = 0.41$$

$$P = 0.5 \times 1.225 \times 75.4 \times 8.1^3 \times 0.41$$

$$P = 10,063.74 \text{ W}$$

This equation has shown that if the wind is at its average speed of 8.1m/s then 10,063.74W will be produced. To calculate the number of these wind turbines that would be required to meet the power demands of the village the equation used is:

Number of turbines = Village demand ÷ Power available

$$\text{Number of turbines} = 34,285.83 \div 10,063.74$$

$$\text{Village demand} = 34,285.83 \text{ W}$$

$$\text{Number of turbines} = 3.41$$

∴ 4 turbines are required.

$$\text{Total output: } 4 \times 10,063.74 = 40,254.96 \text{ W}$$

$$\text{Cost of 4 turbines: } 4 \times 52600 = \text{£}210,400$$

Turbine 1			Turbine 2		
Model	E200		Model	ASWT	
Cost (£)	52,600		Cost (£)	29,000	
Sweep area A (m ²)	75.4		Sweep area A (m ²)	24.63	
Power Coefficient C_p	0.41		Power Coefficient C_p	0.40	
Air density ρ (m ³)	1.225		Air density ρ (m ³)	1.225	
Wind speed v (m/s)	8.1		Wind speed v (m/s)	8.1	
Village power demand (W)	34,285.83		Village power demand (W)	34,285.83	
Power @ 8.1m/s P (W)	$P = \frac{1}{2}\rho A v^3$		Power @ 8.1m/s P (W)	$P = \frac{1}{2}\rho A v^3$	
$P = \frac{1}{2}\rho A v^3$ (W)	24,543.27		$P = \frac{1}{2}\rho A v^3$ (W)	8,017.25	
Power available P_a (W)	$P = \frac{1}{2}\rho A v^3 C_p$		Power available P_a (W)	$P = \frac{1}{2}\rho A v^3 C_p$	
$P_a = \frac{1}{2}\rho A v^3 C_p$ (W)	10,063.74		$P_a = \frac{1}{2}\rho A v^3 C_p$ (W)	3,206.90	
Demand $\div P_a$	3.41		Demand $\div P_a$	10.69	
Number of turbines	4		Number of turbines	11	
Total P_a (W)	40,254.96		Total P_a (W)	35,275.90	
Cost of turbines (£)	210,400		Cost of turbines (£)	319,000	

Reviewing the specifications and calculations for these two turbines show that both would be suitable for the village. To exceed the power demand of the village at 34,285.83W, there would need to be four wind turbines of type 1 and eleven turbines of type 2.

Four wind turbines of type 1 would exceed the demand by 5,696.13W and eleven wind turbines of type 2 would exceed the demand by 990.07W. Even though both are sufficient, it is clear that a wind farm made up of wind turbines of type 1 has a much greater output. This is a key factor as this surplus power can be stored in batteries or used in alternate power storage for later use- e.g raising water to give it potential energy or performing electrolysis in order to create stored chemical energy within hydrogen.

The cost of these two turbine types differs significantly too as turbine 1 is almost twice the cost of turbine 2. However, the power available for turbine 2 is roughly a third of turbine 1. This is precisely the reason that the wind farm would require eleven of turbine 2 compared with only four of turbine 1. The difference in the number of turbines required to meet the village's demand means that it is £108,600 cheaper to use turbine 1.

Having fewer turbines to install and maintain also means that the installations and maintenance costs will be lower. Reducing overheads like this means the farm will be more profitable and therefore have a shorter payback period.

In comparing these two turbines it seems obvious and necessary to choose turbine 1, Enair's E200, as the chosen wind turbine for this project. Not only is it the cheaper option in both the short and long term but it provides enough power to explore other possible avenues of power conversion and storage.

Converter

The rotational speed of the rotor varies depending on the wind speed, which means that the electricity produced by the generator within the wind turbine will be unstable. As the electrical energy produced is not consistent, it therefore cannot be directly utilised by the user. The solution for this problem is to convert the unstable currents generated by the wind turbines into direct current. The electricity in a DC form can then be used to charge the battery.

In choosing a converter, it is integral that it can withstand the maximum power produced by the wind farm as previously calculated (80kW), or utilise separate converters that can withstand the maximum power of individual turbines.

Three phase bridge rectifier

http://www.hopewindelectric.com/3-0mw-full-power-electrical-excitation-wind-energy-conversion-system_p3.html

[Wind Turbine Wire Size Guide](#)

<https://www.xppower.com/product/LQ-Series?m=LQ1N20.0>

Batteries

In considering the battery, it is imperative that the batteries offer a cumulative amp-hour capacity that would be sufficient for the required village power demand.



Victron Energy
2V 1500Ah (C10) GEL OPzV Tubular Plate Battery

£1,210.66 inc VAT £1,008.88 Ex Vat

6

ADD TO BASKET

LOGIN FOR TRADE PR



Amp-hour capacity

P is the power required for the rural village,

$$P = 34,285.83W$$

T is the working days,

DOD is the depth of discharge of the battery,

EIN is the efficiency of the inverter,

EBN is the efficiency of the battery bank,

V_B is the battery rated voltage.

$$T = 2 \text{ days}$$

$$DOD = 0.8$$

$$Ein = 0.8$$

$$Ebn = 0.8$$

$$VB = 2V$$

$$A = (P \times T) / (DOD \times EIN \times EBA \times VB)$$

$$A = \frac{(34285.83 \times 2)}{(0.8 \times 0.8 \times 0.9 \times 2)}$$

$$A = 59524.01Ah$$

$$\begin{aligned} \text{The number of batteries} &= A \div \text{rated current} \\ &= 59524.01 \div 1500 \end{aligned}$$

$$= 39.68$$

$$= 40$$

SHOPPING BASKET



2V 1500Ah (C10) GEL OPzV Tubular Plate Battery

PRICE

£1,210.66

QTY

40

Remove

Add Voucher »

Subtotal	£40,355.20
Total Excl. Tax	£40,355.20
VAT	£8,071.04
Total Incl. Tax	£48,426.24

If the aforementioned battery was to be used, the farm would require 40 batteries in order to meet the village's demands.

Cost per battery: £1,210.66

40 batteries: £48,426.24

Cost of off grid system & Proposed tariff

Turbine	£210,400.00	4 × £52600.00
Batteries	£48,426.24	40 × £1,210.66
Hardware Total	£258,826.24	
Maintenance costs	£7764.79	3% of hardware total
2 Maintenance technicians 10 year salary	£193,020.00	20 hour, 52 weeks, 10 years, 2 people, hourly rate £9.28.
Total costs	£459,611.03	

At 0% interest rate on the capital it is possible to calculate an approximate monthly tariff for the 100 cottage owners based on a 10 year payback period.

$$£459,611.03 \div (12\text{months} \times 10\text{ years} \times 100\text{cottages}) = £38.31 \text{ per cottage per month}$$

Discussion

There are many advantages both to the environment and economy in having an off-grid wind farm in comparison to using National Grid power. Firstly, the fact that wind power is renewable means that opportunities for creating electricity are infinite; unlike relying on fossil fuels as the National Grid does. The process of harnessing wind power is non-toxic and has little effect on the immediate or wider environment, which is essential in today's climate. Furthermore, although turbines can be relatively large, they can be placed in areas with limited effect on the surrounding area - e.g, at higher altitudes. Each turbine takes up a very small part of land, and the surrounding areas are still able to be utilised which is especially beneficial for aspects such as local agriculture. In line with this is the fact that there is money to be made from individuals, often farmers, harnessing this wind energy as it helps to reduce their own outgoings and make additional profit.

Another advantage of an off-grid wind farm within a rural community is accessibility. For example, in areas that have poor or no connections to the national power grid, harnessing the energy from the wind can be vital in supplying residents with the power they need. This also becomes a benefit in terms of potentially creating job opportunities for local people as most wind farms require some form of maintenance, which ultimately helps to boost the economy of the area. Further to this, a wide range of people within the area can benefit from wind power - from single residential houses, to villages, towns and cities. The renewable energy source of the wind can be seen as highly accessible to a wide variety of locations and has huge advantages over the power source of the National Grid, which is based on an unstable and dwindling supply of the earth's fossil fuels.

However, there are some aspects to wind farms that can be viewed as disadvantages. One of the biggest disadvantages comes with the inconsistency and unpredictability of the wind. Wind farms require meticulous area planning before they can be built and this still does not ensure constant wind. This can mean that in areas without consistent wind or where wind strength is too low to support the turbines, the heavy upfront investments often go to waste (Bell, 2016). This is one way in which the National Grid can be seen as favourable, as it offers for most locations a consistent and mostly reliable source of electricity.

Furthermore, in considering the area of which they are built, it is true that some locations may not have the appropriate landscape in order for the wind farm to be effective, especially if the location is particularly flat or non-coastal. Moreover, despite wind farms being non-polluting, they can produce a lot of noise pollution. This may become an issue if placed too close to residential areas. Similarly, some people consider the turbines to be an 'eye-sore', and so wind farms in populated areas can be prone to objections. The turbines themselves may also have some small environmental effects, particularly causing danger to birds and bats. For example, research from the London School of Economics estimated that by 2020 there could be anywhere between 9,600 and 106,000 bird deaths a year from wind energy in the UK (Bowen, Bussi and Fankhauser, 2014).

Conclusion

In conclusion, an off-grid wind farm can be viewed as an advantageous scheme for a rural community such as Dyffryn Lledr. With the correct considerations, wind turbines can offer a cost effective alternative to the National Grid as a power source, as well as having many advantages in terms of the environment and the economy of the area.

References

Bell, J., 2016. *Unpredictability Of Wind Energy Makes It Hard To Compete With Coal In China*. [online] CGTN America.

Available at:

<<https://america.cgtn.com/2016/08/07/unpredictability-of-wind-energy-makes-it-hard-to-compete-with-coal-in-china>> [Accessed 24 May 2020].

Bowen, A., Bussi, S. and Fankhauser, S., 2014. *The Case For And Against On Shore Wind Energy In The Uk*. [online] Lse.ac.uk.

Available at:

<<http://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2014/03/PB-onshore-wind-energy-UK.pdf>> [Accessed 20 May 2020].

Betz' Law. [online]

Available at:

<<http://xn--drmstrre-64ad.dk/wp-content/wind/miller/windpower%20web/en/tour/wres/betz.htm>> [Accessed 20 May 2020].