

Electrical Power

Design a renewable off-grid wind/solar power supply system for rural isolated area.

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Abstract

The aim of my report is to demonstrate that I can design, solve and deal with realistic renewable energy problems. I will look at low-cost solutions that are simple to manufacture, assemble and maintain and assess the quality of the solutions in terms of their efficiency, and reliability.

In order to draw my conclusions, I will;

1. Calculate the cost of electricity supplied by the national grid over the next 10 years, assuming a fixed electricity tariff from year end of 2021 (before the Ukraine war).

2. Design a wind power system:

- Wind machines property and number.
- Wind viability survey.
- Turbine.
- Battery property and number.
- Inverter

3. Design a solar power system.

- Sunshine viability survey.

4. Calculate the cost of chosen renewable energy system, including:

- Capital cost of the hardware for the system.
- Maintenance cost, assuming the cost of the spare components is 3 % for the wind system per year and 10 % for the PV generator system per year, and each power system will need two part time maintenance technicians.

5. Justify my chosen renewable energy power system.

6. Assuming the provider pays the cost of the renewable energy system, calculate an appropriate tariff (regular fixed monthly fee) that must be paid, per cottage, in order for the 10 year payback period for this project to be met. Assuming 0 % interest rate on the capital.

7. Discuss the comparison of the cost of electricity tariff generated by national grid power and my chosen off-grid energy system after cost recovery.

8. Discuss the environmental impact of the chosen renewable energy system.

Introduction

The reliance of the European Union and, indirectly, the United Kingdom on Russian natural gas supplies has increased over the last decade. Since the start of the war in Ukraine, Russia has suspended the supplies of the natural gas that continental Europe and the UK used for years to run factories, generate electricity and heat homes. Accordingly, the price of natural gas is nearly 5 times what it was two years ago, putting governments worldwide under enormous pressure. Rising energy prices are accelerating the cost-of-living crisis; increasing food and energy poverty; and increasing social unrest. The current global energy crisis and the impacts of environmental/climate change accelerate the transition towards cleaner renewable and cheaper energy sources than fossil fuels.

In the United Kingdom there are many rural small villages that suffer from:

- a) Poor or insufficient electrical power supply due to technical and environmental problems in connecting these villages with the high voltage grid.
- b) Current worldwide energy price crisis.

The daily average energy demands in these villages is low and varies in the range of 8–10 kWh per household. Some of these villages are in regions with high winds that enable the use of wind turbines, while other villages are in regions with high solar potential that allow the use of Photovoltaic (PV) generators for electrification purposes.

A rural village to the south of Colwyn Bay, Llanrwst valley, in north Wales suffers from a shortage of electrical power supply. The local village council decided to look at harvesting the potential energy resources in the area to generate reliable and adequate electrical power that can supply the village with electricity 24 hours a day for a whole year. There are 120 small cottages, 7 community services buildings (two schools, a police station, a hospital, sport centre and two worship houses), plus 80 street and traffic lights. The average rate of energy consumption is about 10kWh per day per cottage, 100kWh per day per school, 250kWh per day for the hospital, 40kWh per day for the sport centre, 120kWh per day for the police station, 40kWh per week per worship building, and 2kWh per day per street and traffic lights.

As an Electrical and Electronic Engineering specialist, the local council has asked me to design a small off-grid of Renewable Wind Energy System (Task-A)/ Renewable Solar Energy System (Task-B). The designed electrical power system must provide self-sufficient electrical power based on the natural potential energy resources available in the geographical site of the village.

Theory and design

1. Calculate the cost of electricity supplied by the national grid over the next 10 years, assuming a fixed electricity tariff from year end of 2021 (before the Ukraine war).

I have calculated the cost of electricity supplied by the national grid over the next 10 years, assuming a fixed electricity tariff from year end of 2021 (before the Ukraine war) taken from ofgem.gov.uk [Ref. 05]. Ofgem gave the maximum charges for electricity for North Wales and Mersey based on three different methods of payment; standard credit (on receipt of bill), prepayment and other payment method (I have assumed this to be direct debit as this is the most common other method of payment) [Table 01]. From this table, I have assumed that “Nil kWh” is the annual standing charge and therefore calculated the unit rate for each payment method [Table 02] using the formula:

$$\frac{3100\text{kWh charge} - \text{Standing charge}}{3100} = \text{Unit Rate (£/kWh)}$$

The unit rates were 22.07p/kWh for standard credit, 20.62p/kWh for prepayment and 20.95p/kWh for direct debit. I will later use these values to calculate the total cost for Llanrwst Valley’s annual usage and, for the purpose of my report, assume that the village pays the smallest figure. This should force me to design a renewable system to the lowest possible cost.

I next calculated the village’s total consumption per day, per year and per ten years [Table 03]. The total consumption for the village over 10 years that I calculated is 7232.21 MWh. I used this figure to calculate the cost of electricity for the village over the course of 10 years for each payment method taking account of standing charges and unit charges [Table 04]. This gives me the basis from which to decide if the chosen renewable energy system is viable and meets the payback period of 10 years.

My calculations revealed that prepayment is the cheapest form of payment and that my target cost to beat is £1.62m over 10 years.

2. Design a wind power system.

Wind machines

I have looked at two wind turbines. The NPS 100C-21 (Appendix A) [Ref. 03] and the Norvento nED100 (Appendix B) [Ref. 04].

Wind viability survey

In order to calculate the wind potential in the village of Llanrwst, I have taken met office figures from a weather station in Capel Curig [Ref. 02]. This is the nearest weather station to the village of Llanrwst at only 7 miles away. From the met office data, I have created a table that shows the monthly and annual average wind speed over the course of 20 years from 1991 to 2020 [Table 05]. This shows that the annual average wind speed at 10m above ground is 6.5m/s. This figure can be adjusted to account for varying heights of wind turbine using a wind profile calculator that I found online [Ref. 12]. This calculator takes into account the increased height of the wind turbine, as well as the roughness of the terrain. Entering the appropriate information into the calculator I can adjust the 6.5m/s figure as below;

Height above ground	10 m
wind speed	6.5 m/s
Roughness length z_0 (see table below)	0.4 m

Roughness class	Roughness length z_0	Types of terrain surfaces
0	0.0002m	Water areas: sea and lakes
0.5	0.0024 m	Open terrain with a smooth surface, e.g. concrete, airport runways, mown grass, etc.
1	0.03m	Open agricultural land without fences or hedges, possibly with widely scattered buildings and very rolling hills
1.5	0.055m	Agricultural area with a few houses and 8 m high hedges more than 1 km apart
2	0.1m	Agricultural area with a few houses and 8 meter high hedges approximately 500 m apart
2.5	0.2m	Agricultural area with many houses, bushes and plants, or 8 m high hedges at a distance of approx. 250 m
3	0.4m	Villages, small towns, agricultural areas with many or high hedges, forests and very rough and uneven terrain
3.5	0.6m	Larger cities with tall buildings
4	1.6m	Big cities with tall buildings and skyscrapers

Height above ground	wind speed
150 m	11.97 m/s
140 m	11.83 m/s
130 m	11.68 m/s
120 m	11.52 m/s
110 m	11.34 m/s
100 m	11.15 m/s
90 m	10.94 m/s
80 m	10.70 m/s
70 m	10.43 m/s
60 m	10.12 m/s
50 m	9.75 m/s
40 m	9.30 m/s
30 m	8.72 m/s
20 m	7.90 m/s
10 m	6.50 m/s

After looking at the specification of a few wind turbines, I have seen that a good hub height to work with is 20m. This gives me a new wind speed of around 7.9m/s. This will help me more accurately calculate the annual energy production (AEP) of any chosen wind turbine.

Turbine

Wind Turbine Comparison

Manufacturer	NPS	Norvento
Model	100C-21	nED100
Power rating	100kW	100kW
Rotor diameter	20.7m	22m/24m
Hub height	37m, 29m, 22m	24.5m/29.5m/36m
Generator type	Permanent magnet	Multi-pole permanent magnet
Rated wind speed	15m/s	10m/s
Cut in wind speed	3m/s	3m/s
Cut out wind speed	25m/s	20m/s
Extreme wind speed	59.5m/s	59.5m/s/52.5m/s
AEP @ 8m/s	369MWh/year	435MWh/year
Project Cost Estimate	£350k	£440k
Spares cost (3%/year)	£105k	£132k
Design life	20 years	20 years

Based on the comparison table above [Table 06], I have opted for the NPS 100C-21 wind turbine. I believe the 22m hub height means that it would be slightly less of an eyesore than the shortest Norvento option. The NPS has a higher cut out wind speed which will mean that it can remain operational for longer than the Norvento. Although the annual energy production is slightly lower for the NPS, I would need two of either of these models to meet the demand of Llanrwst village and therefore the lower cost of the NPS makes it preferential.

$$\frac{\text{Llanrwst total energy consumption (MWh/year)}}{\text{Annual energy production (MWh/year)}} = \text{Required number of turbines}$$

$$\frac{724\text{MWh}}{369\text{MWh}} = 1.96 \text{ turbines}$$

2 turbines will be required to provide enough power to Llanrwst village.

Batteries

A typical battery that would be used with an off-grid system would be a lithium ion 12V 200Ah type. It is important to work out desired backup time and energy requirement to decide the configuration and number of batteries required.

I believe 12 hours (half a day) of battery backup would be sufficient. This would allow for any planned maintenance (shifts of 10 hours) shutdowns for maintenance or repair. If ever the turbines were required to be off for longer than this, diesel/HVO generator(s) can be arranged at relatively short notice to maintain the supply. Add to this that planned shutdowns can be planned overnight when peak consumption is low, the 12 hours redundancy should be more than adequate.

An average day of electricity consumption in Llanrwst village is 1.98MWh [Table 03]. Divide this by two to get the required backup output (0.99MWh). To achieve this output from 12V 200Ah batteries I would need to wire the batteries as multiple strings of blocks. As a typical inverter works from a 48V DC input, each block of batteries would need to be 4x 12V batteries. This would give me 48V X 200Ah = 9.6kWh.

The amp hours required can be calculated by;

$$\frac{\text{Required output (kWh)}}{\text{Design voltage (V)}} = \text{Required Ah}$$

$$\frac{990\text{kWh}}{48\text{V}} = 20625\text{Ah}$$

$$\frac{\text{Required Ah}}{\text{Ah per battery}} = \text{Required No. battery strings}$$

$$\frac{20625\text{Ah}}{200\text{Ah}} = 103.125 \text{ battery strings}$$

The total number of batteries can then be calculated by the number of batteries in each block (4) multiplied by the number of battery strings (104).

$$4 \times 104 = 420 \text{ batteries total.}$$

Wiring these as 104 parallel strings of 4 would give me $48\text{V} \times 20800\text{Ah} = 998400\text{kWh}$ (0.998MWh) which satisfies the villages average usage over 12 hours.

This number of batteries will need to be stored within their own housing, likely a sufficiently vented shipping container. They would also need to be maintained at a stable temperature of around 20°C , requiring an air conditioning unit to be installed. The cost of these I will consider negligible in the grand scheme of the project.

A pack of 4 batteries costs £2440 (Renogy.com, 2024) (Appendix C) [Ref. 06]. Therefore, the cost to purchase all the required batteries would be $\text{£}2440 \times 104 = \text{£}253760$.

Inverter

To work out the rating and number of inverters required, I need to work out the average demand. I have found this by taking the average daily usage for the village and dividing it by 16 hours (average waking hours).

$$\frac{1980\text{kWh}}{16\text{h}} = 123.75\text{kW}$$

An inverter I have found online (Victron Energy) (Appendix D) [Ref. 11], can deliver 15kW continuous. I would therefore need ten on these inverters to deliver a total of 150kW continuous. They can have 6 units wired in parallel, so 5 inverters in parallel, per wind turbine, will be acceptable.

The price per inverter is £4690.70. Therefore, ten inverters will be £46970.

3. Design a solar power system.

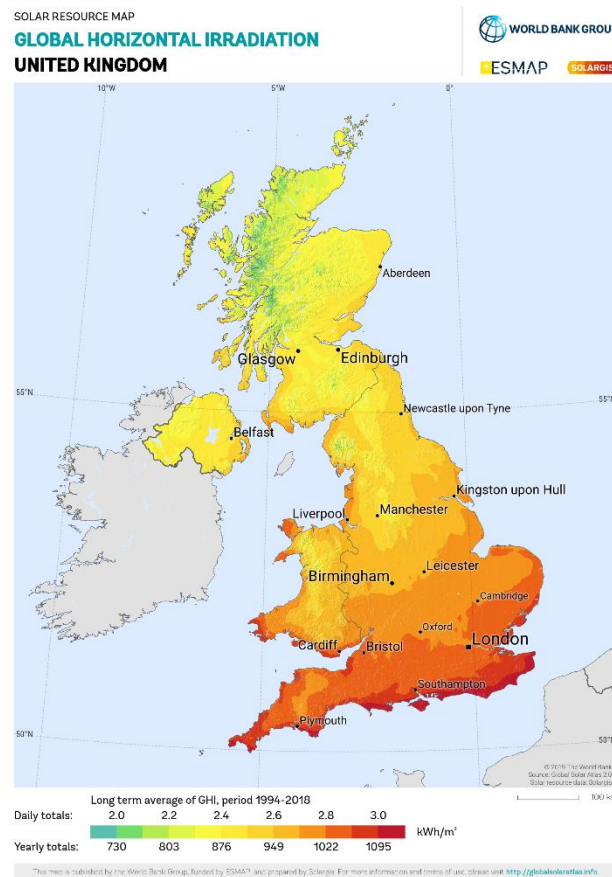
In order to design a solar power system, I must work out the solar potential for Llanrwst. Solar potential is best calculated using global horizontal irradiation (GHI) data. GHI is defined online as below.

Global Horizontal Irradiation (GHI)

GHI is the most important parameter for energy yield calculation and performance assessment of flat-plate photovoltaic (PV) technologies. This solar resource map provides a summary of the estimated solar energy available for power generation and other energy applications. It represents the long-term average of yearly/daily sum of global horizontal irradiation (GHI). The underlying solar resource database is calculated by the Solargis model from atmospheric and satellite data with 10, 15 or 30-minute time step (depending on the region). The effects of terrain are considered at nominal spatial resolution of 250 m.

(Solargis.com, 2024) [Ref. 08]

I have found the map below that shows the long term average global horizontal irradiation across the UK, between 1994-2018. From this map, I have estimated that the kWh/m² for Llanrwst village is around 850kWh/m².



(Solargis.com, 2024) [Ref. 07]

Based on the solar potential value and the average consumption of electricity, I have calculated that the footprint required for solar panels alone would be 853m².

$$\frac{\text{Llanrwst total energy consumption (kWh/year)}}{\text{Solar potential (kWh/m}^2\text{)}} = \text{Solar panel footprint (m}^2\text{)}$$

$$\frac{725000\text{kWh}}{850\text{kWh/m}^2} = 853\text{m}^2$$

As this Llanrwst is only a small village, I find this footprint to be unacceptable compared the footprint of two wind turbines. Especially when you consider that this is for the panels alone, before even considering the battery storage and land area for maintenance access. I will therefore be choosing a wind power system.

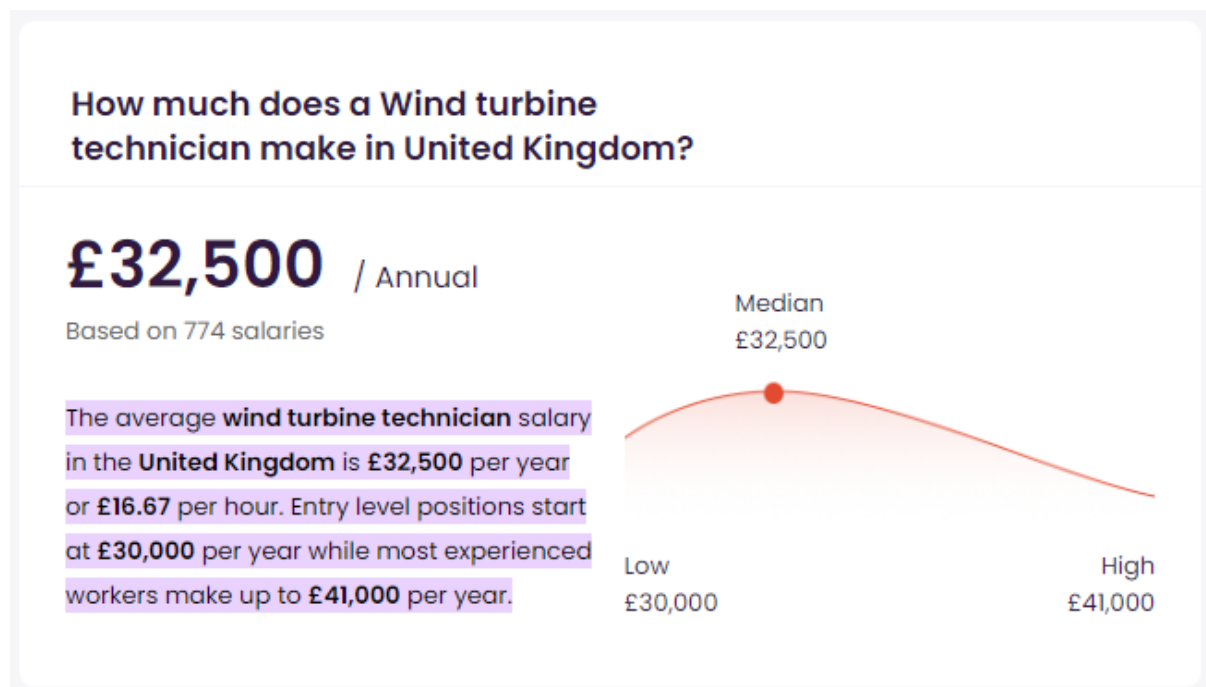
4. Calculate the cost of chosen renewable energy system.

Capital cost

The capital cost is worked out as the sum total of the project cost, battery cost and inverter cost. As can be seen on the table below [Table 07], I have accounted for the fact that the batteries and inverters will require renewal within the payback period (after 5 years). The total capital cost of my wind power system is £1.05m.

	Qty.	Cost per	Renewals within 10 years	Cost total
Turbines	2	£350,000	1	£700,000
Batteries	420	£610	2	£512,400
Inverters	10	£4,700	2	£94,000
Total				£1,306,400

Maintenance cost



(Talent.com, 2024) [Ref. 09]

Using the information above, and the assumption that two part time wind turbine technicians will visit Llanrwst wind power system for one shift per week (20 hours/week total), I can work out the labour costs of the wind turbines per year and over the 10-year payback period, as below.

$$£16.67/\text{hr} \times 20\text{hrs/week} \times 52 = £17336.80$$

$$£17336.80 \times 10 = £173368$$

This value added to the cost of spares (3 % /year) will give me the total maintenance costs of the wind power system, as per the table below **[Table 08]**.

	per year	10 years
Spares (3%/year)	£10,500	£105,000
Labour (£16.67/h)	£17,340	£173,400
Total		£278,400

The grand total cost of my wind power system over 10 years is £1306400 + £278400 = £1.59m.

5. Justification of my chosen renewable energy power system.

A wind power system, using 2x NPS 100C-21 wind turbines, is the best choice for Llanrwst because it meets the energy demands of the village. My calculations above show that with all capital costs and maintenance costs, over a period of 10 years, it is more cost efficient than taking the supply from national grid. There is a saving of £30k throughout the 10-year payback period. As I have mentioned previously, a negligible amount of the savings may be taken up by additional components i.e., battery containment, but these components are unlikely to require renewal within a significant period and are relatively low cost. The money left over could also be put towards generator hire, if required, throughout any extended periods of maintenance. Due to the 20-year design life of the most expensive components of this system, there will be much larger savings to be seen in the 10 years following the payback period.

6. Calculate an appropriate tariff that must be paid, per cottage, for the 10-year payback period to be met.

Assuming the provider pays the cost of the wind power system, and there is 0 % interest to be paid on the capital, the 10-year cost of the system can be divided by all the cottages to work out a fixed fee for each cottage to pay.

$$\frac{\text{Total cost (10 years)}}{\text{No. of cottages}} = \text{Fee per cottage (10 years)} \quad \frac{£1.59\text{m}}{120} = £13250$$

$$\frac{£13,250}{10} = £1325 \text{ (per year)} \quad \frac{£1,325}{12} = £111 \text{ (per month)}$$

In order to pay back the provider, each cottage will need to pay a fixed fee of £111 per month for 10 years.

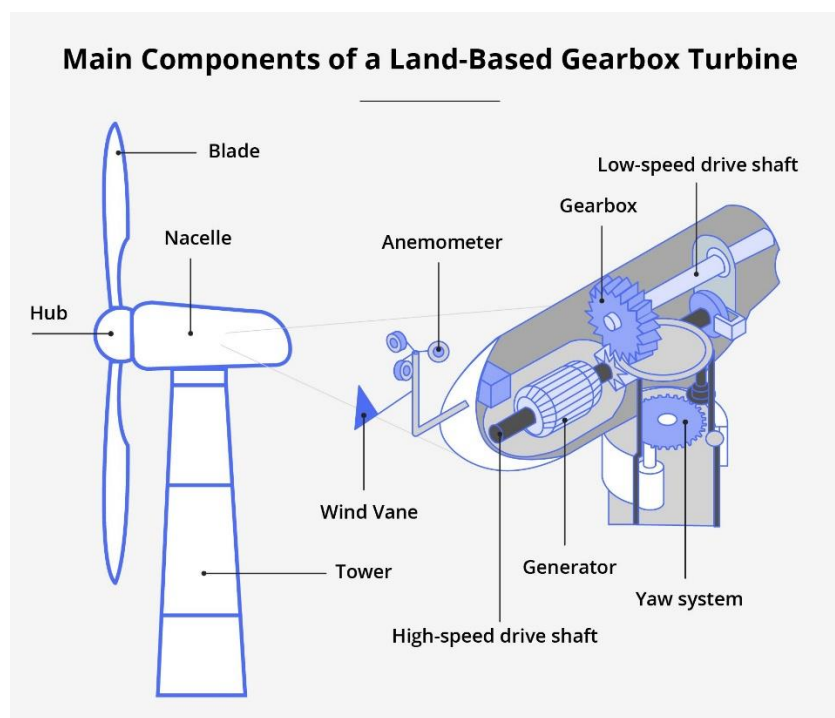
General principles

In order to better understand which type of renewable energy system will best suit this project, I have researched both wind and solar systems and how they work.

Wind turbines

A wind turbine converts the kinetic energy of wind into rotational energy in order to generate electricity. As the wind blows, the rotor blades rotate, driving a shaft connected to a gearbox. The gearbox speeds up the rotation of a second, higher speed, shaft which is connected to a generator. This is where the rotational energy is converted to electrical energy. The various control systems of the wind turbine monitor and react to changing wind conditions in order to maximise the return. This can be done by changing the pitch of the blades or the direction in which the hub is facing.

Below is a diagram outlining the components of a wind turbine followed by a description of what each component does.



Tower

Wind turbine towers reach from the foundation to the nacelle, allowing the rotor to access high wind speeds far above ground level. Turbine towers are made of tubular steel to successfully support the weight of the nacelle, hub, and blades. In the United States, utility-scale, onshore wind turbine towers reach an average of over 100 meters (328 feet), particularly in the Midwest and Northeast. For this massive section of the turbine to be successfully transported and assembled, the tower is typically manufactured in three sections. A wind construction company will assemble the tower and other major parts on-site at the wind farm, using heavy-duty cranes.

Nacelle

The nacelle houses the mechanical components needed to convert the rotation of the turbine blades into energy – also known as the drivetrain. From a distance, the nacelle may seem like a relatively small section of a wind turbine, especially when compared to the tower and turbine blades. However, this part of a wind turbine can weigh over 50 tons (100,000 lbs). Transporting nacelles requires special equipment for supersize loads, as normal flatbed trailers do not have the capacity to handle that weight.

Gearbox

The gearbox helps to convert the relatively slow rotational speed of the turbine rotor to the high speeds needed to run the generator. The rotor achieves around 18 revolutions per minute (rpm), while the generator will need around 1,800 rpm to successfully generate electricity. The gearbox connects the rotor hub to the generator by a series of drive shafts.

Drive Shafts

The turbine's drive shafts are integral parts of the drivetrain, working in conjunction with the gearbox to increase rpm and run the generator. The low-speed shaft (also known as the main shaft) connects the hub to the gearbox. A smaller, high-speed shaft connects the gearbox to the generator.

Generator

The generator is ultimately what converts wind power to electrical energy by means of electromagnetic induction. Wind energy is an increasingly popular renewable energy source because it does not require mining or digging for fossil fuels, instead running on an endless supply of kinetic energy provided by the wind. It's also a "clean" form of energy that doesn't burn fossil fuels or release carbon emissions.

Hub

The hub is part of the rotor, securing the three blades and connecting them to the drive shaft in the nacelle. The hub has a cast iron structure weighing between 7 and 14 tons (14,000-28,000 lbs), as it needs to be sturdy enough to support the weight of the turbine blades. Wind turbine hubs have an average length of 4-6 meters (13-20 feet), and a diameter of 3-4 meters (10-13 feet). Wind turbines are often measured in terms of "hub height," which refers to the distance from the ground to the centre of the hub.

Yaw System

The yaw system underneath the nacelle is responsible for orienting the turbine according to wind direction (determined by the wind vane and anemometer). The yaw drive and yaw motor work together to adjust the nacelle so it captures wind power as effectively as possible. This system is crucial for maximizing the value of the turbine and keeping the generator running at a more constant rate.

Blades

Blades for onshore, utility-scale turbines in the U.S. average between 200-300 feet long – and they're consistently being manufactured at larger sizes to achieve a higher power output. Turbine blades are adjusted by the "pitch system," which is based on wind speeds. The pitch system helps turn the rotor at an optimum speed – ensuring that high winds that are too strong don't damage the turbine. Modern turbine blades are primarily made of aerodynamic fiberglass and are hollow. These factors make turbine blades lighter than the steel tower and even the nacelle – but they still weigh several tons at least, and their sheer size poses significant logistical challenges.

(Titan Worldwide, 2023) [Ref. 10]

Solar Photovoltaic System

Solar photovoltaic (PV) panels use cells containing a semi-conductor material to capture the sun's energy and convert solar radiation into electricity. The most commonly used semi-conductor material is silicon, which is an abundant natural resource found in sand. When light strikes the cell a certain amount of energy is absorbed within the semiconductor material, knocking electrons, the negatively charged particles that form the basis of electricity, loose.

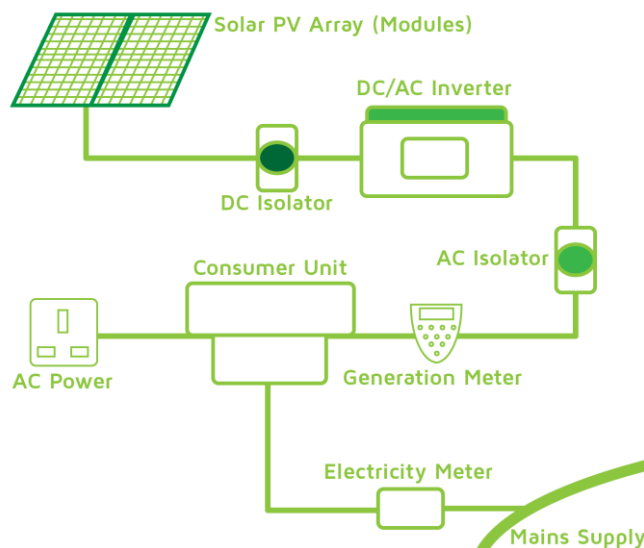
Most PV cells have two layers of semi-conductor material, one positively charged and one negatively charged. When light shines on the semi-conductor the electric field across the junction between these two layers causes electricity to flow, generating direct current (DC). By placing metal contacts on the top and bottom of the PV cell, we can draw that current off for external use.

Solar PV electric panels do not require bright sunlight in order to operate, meaning that you can still generate electricity on cloudy days, however in general the greater the intensity of light the higher the flow of electricity. Although, due to the reflection of sunlight, days with slight cloud can result in higher energy yields than days with a completely cloudless sky.

It is important to realise that you can only use your free solar electricity when it is being generated – so unless you also invest in batteries to store power for use in the evenings and at night, you will need to pay for your energy use as normal when the panels are not producing electric.

Direct Current (DC) needs to be converted into alternating current (AC) so it can be used in a domestic building; this is performed by an inverter. The AC electricity then passes via the generation meter, which measures how much electricity has been created, and on to the consumer unit where it can be fed into the property for use or exported back to the national grid via the electricity meter.

A typical grid connected roof mounted system consists of a number of components, as shown in the diagram to below.



Photovoltaic Solar Panels or Tiles

Solar panels form the heart of every PV system. These contain the cells that capture the solar energy.

Inverters

Inverters convert the DC current produced by the solar panels into AC current which is then fed into the electricity supply for use in the home, with any surplus electricity fed back into the national grid.

Generation Meters / Monitoring Systems

In order to conform to regulations and qualify for feed in tariff payments you need a meter or system that will accurately register the total kWh of PV electricity generated by the solar panels.

(EWS Solar Power, 2015) **[Ref. 01]**

Discussion

7. Discuss the comparison of the cost of electricity tariff generated by national grid power and my chosen off-grid energy system after cost recovery.

Assuming the village also splits the cost of the national grid supplied energy equally between each cottage, each cottage would originally be paying an equally share of £1.62m over the 10 years.

$$\begin{aligned}\frac{£1.62\text{m}}{120} &= £13500 \\ \frac{£13,500}{10} &= £1350 \text{ (per year)} \\ \frac{£1,350}{12} &= £112.5 \text{ (per month)}\end{aligned}$$

Each cottage would be paying £112.50 per month for 10 years to be supplied by the grid. As the wind power system is £111 per month, this does not initially appear to be a huge saving. However, when you consider the 20-year design life of the wind turbines further savings can be realised over the next 10 years before the wind turbines need to be replaced.

I have produced a table [Table 09] that shows the costs of renewals and maintenance throughout the second 10 years would be £884800. This means that the monthly fee for each cottage would be roughly halved.

$$\begin{aligned}\frac{£8.85\text{k}}{120} &= £7375 \\ \frac{£7,375}{10} &= £737.5 \text{ (per year)} \\ \frac{£737.5}{12} &= £61.46 \text{ (per month)}\end{aligned}$$

This is a saving of £6125 per cottage over the second 10 years. The same model can then be followed every 20 years, renewing the system and making the large savings in the second half of the design life. The village occupants could also opt to “pay it forward” by overpaying in the second 10 years so that, when it comes to the 20-year renewal, they need only borrow a portion of the costs of the new system. Thus, bringing the payback period down. They can continue to do this until such time that they can pay for a new system upfront from a communal pot of money and begin paying for the maintenance costs only.

8. Discuss the environmental impact of the chosen renewable energy system.

The positive impact on the environment that wind turbines have is twofold. They do not have any inherent emissions or by-products that can harm the environment and, by their use, reduce the reliance on fossil fuels for energy. They also do not use other natural resources, like water, for cooling. It is true that natural resources are used in the construction, but most are not a finite resource. Fossil fuels may also be used in the installation/erection of such large structures, for example, diesel lorries and cranes. However, as technology advances, these vehicles should eventually transition to more sustainable sources of fuel, like HVO or electric.

Conclusion

It is clear from the report I have produced that Llanrwst village would benefit greatly from the installation of a wind power system. The area has a great potential to harness the power of the wind as the wind records show a relatively stable level over the years. There are many options available to the residents of Llanrwst with regards to the payback of such a scheme, be it that they take the saving immediately as they come or opt to invest/save as a community towards the purchase or upgrade of the system, thus reducing future payback periods and reaching a point where they can reduce monthly fees to an equal share of the maintenance costs. The village would no longer be dependent on national grid, whose supply has proven to be unreliable. They would also be unaffected by future price hikes of energy provided by natural resources, as we have seen with the increase since the start of the Ukraine war.

Tables and figures

Table 01 –

N Wales and Mersey Maximum Charges for Electricity August 2021

	Single-Rate Metering Arrangement (benchmark consumption per annum), £	
Payment method	Nil kWh	3100 kWh
Standard Credit	97.48	781.57
Prepayment	96.92	736.04
Other Payment Method	81.69	731.10

Table 02 –

N Wales and Mersey Unit Rate for Electricity August 2021

	Single-Rate Metering Arrangement (benchmark consumption per annum), £			
Payment method	Nil kWh	3100 kWh	Usage charge	Unit rate (£/kWh)
Standard Credit	97.48	781.57	684.09	0.2207
Prepayment	96.92	736.04	639.12	0.2062
Other Payment Method	81.69	731.10	649.41	0.2095

Table 03 –

Llanrwst Valley total electricity consumption

Property type	Qty.	Average energy consumption (kWh) per property	Average energy consumption (kWh) per property type		
		Per day	Per day	Per year	Per 10 years
Cottage	120	10	1200	438000	4380000
School	2	100	200	73000	730000
Police Station	1	120	120	43800	438000
Hospital	1	250	250	91250	912500
Sports Centre	1	40	40	14600	146000
Worship House	2	5.71	11.43	4171.43	41714.29
Street/Traffic Light	80	2	160	58400	584000
		Total kWh	1981.43	723221.43	7232214.29
		Total MWh	1.98	723.22	7232.21

Table 04 –

Llanrwst Valley total cost of electricity

		Assumed number of connections to the national grid	Standing charges		
Property type	Qty.	Qty.	Standard Credit (£974.80/10years)	Prepayment (£969.20/10years)	Direct debit (£816.90/10years)
Cottage	120	120	116988	116304	98028
School	2	2	1949.8	1938.4	1633.8
Police Station	1	1	974.9	969.2	816.9
Hospital	1	1	974.9	969.2	816.9
Sports Centre	1	1	974.9	969.2	816.9
Worship House	2	2	1949.8	1938.4	1633.8
Street/Traffic Light	80	4	3899.6	3876.8	3267.6
		Total standing charges (£)	127711.90	126965.20	107013.90
		Unit charges			
		10 year consumption (kWh)	Standard Credit (£0.2207/kWh)	Prepayment (£0.2062/kWh)	Direct debit (£0.2095/kWh)
		7232214.29	1596149.69	1491282.59	1515148.89
		Total cost = Unit charges + Standing charges (£)	1723861.59	1618247.79	1622162.79

Table 05 –

Average wind speeds at Capel Curig weather station 1991-2020 (at 10m)

Month	Knots	Knots:m/s	m/s
January	15.52	0.514	7.984
February	15.06	0.514	7.747
March	13.61	0.514	7.002
April	11.41	0.514	5.870
May	11.43	0.514	5.880
June	10.97	0.514	5.643
July	10.89	0.514	5.602
August	10.77	0.514	5.541
September	11.08	0.514	5.700
October	12.92	0.514	6.647
November	13.42	0.514	6.904
December	14.90	0.514	7.665
Annual	12.67	0.514	6.515

Table 06 –

Wind Turbine Comparison

Manufacturer	NPS	Norvento
Model	100C-21	nED100
Power rating	100kW	100kW
Rotor diameter	20.7m	22m/24m
Hub height	37m, 29m, 22m	24.5m/29.5m/36m
Generator type	Permanent magnet	Multi-pole permanent magnet
Rated wind speed	15m/s	10m/s
Cut in wind speed	3m/s	3m/s
Cut out wind speed	25m/s	20m/s
Extreme wind speed	59.5m/s	59.5m/s/52.5m/s
AEP @ 8m/s	369MWh/year	435MWh/year
Cost	£350k	£380k
Spares cost (3%/year)	£10.5k	£11.4k
Design life	20 years	20 years

Table 07 –

Capital costs

	Qty.	Cost per	Renewals within 10 years	Cost total
Turbines	2	£350,000	1	£700,000
Batteries	420	£610	2	£512,400
Inverters	10	£4,700	2	£94,000
			Total	£1,306,400

Table 08 –

Maintenance Costs

	per year	10 years
Spares (3%/year)	£10,500	£105,000
Labour (£16.67/h)	£17,340	£173,400
Total		£278,400

Table 09 –

10–20-year costs

	Qty.	Cost per	Renewals between 10- 20 years	Cost total
Turbines	2	£350,000	0	£0
Batteries	420	£610	2	£512,400
Inverters	10	£4,700	2	£94,000
Spares (3%/year)	N/A	£10,500	10	£105,000
Labour (£16.67/h)	N/A	£17,340	10	£173,400
Total				£884,800

Appendix A – Northern Power 100C-21 Wind Turbine



NPS 100C-21

» The NPS 100C-21 features state-of-the-art hub and blade technology with superior aero-dynamics providing a larger swept area. This increases the annual energy production (AEP) of the NPS 100C-21 is up to 11% over the previous model.

» The turbine is a complete redesign of NPS' distributed wind platform that has been deployed around the world since 2008. The nacelle is now 30% smaller with a completely new tower configuration. This results in lower weight and load characteristics reducing foundation and installation costs.

» Over 25 million hours of cumulative run time makes the NPS 100 turbine series one of the most reliable and proven wind turbines in the world. The average availability of Northern Power's global fleet currently stands at 98%.

Key Benefits

» Optimised for medium to high wind regimes

The NPS 100C-21 starts making power at wind speeds as low as 3 metres per second and provides maximum generation at 12-15 m/s

» Reliable

Reinforced blades, gearless design, industry leading yaw configuration, and best-in-class brake system make Northern Power turbines the most reliable small wind turbines available today.

» Generate profitable income

With low ownership costs over the lifetime of the turbine, the NPS 100C-21 pays for itself quickly and will generate a healthy income stream over its 20+ year life.

2 Year Warranty

» Our Warranty options cover up to 2 years, with service options that extend up to 20 years. Various levels of service packages are available to meet varying customer needs. The Premium package includes an availability and power curve performance guarantee. Northern Power Systems will remain your service and maintenance provider for the entire duration of the program. With several multi-year options, Northern Power Systems guarantees operational costs, optimized for your specific needs.

Operation and Maintenance

» Our service network guarantees rapid response and swift repairs thanks to our dedicated teams and spare part warehouses distributed across Europe.

» 24/7 monitoring is provided by our LI technicians in order to minimize turbine downtime.

» Upon request, customized reporting services and integration into third-party plant monitoring systems are available.



Specifications

General configuration

Model	Northern Power® 100C-21
Design Class	IEC WTGS II/A air density 1.225 Kg/m³, average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s
Design Lifetime	20 years
Rotor Diameter	20.7 m
Tower Types	Steel tubular tower
Hub Height	37 m, 29 m, 22 m
Orientation	Upwind, 3 blades
Yaw System	Active yaw drive, electromechanical controls guided by wind speed and direction sensors; automatic cable unwind.
Power Regulation	Variable speed, stall control
Certification	CE compliant, CEI 0-21

Performance

Rated Wind Speed	15 m/s
Cut-in Wind Speed	3 m/s
Cut-out Wind Speed	25 m/s
Extreme Wind Speed	59.5 m/s

Weight

Nacelle & Rotor (21 m)	6,500 kg
Tower (37 m)	12,000 kg

Drive train

Gearbox	No gearbox (direct drive)
Generator Type	Permanent magnet

Braking system

Redundant Braking System (IEC 61400-1ed3)	Dynamic generator brake and multiple hydraulic calipers
---	---

Control system

Controller Type	DSP-based multiprocessor embedded platform
Converter Type	IGBT frequency converter with PWM (pulse-width modulated) technology
Monitoring System	SmartView® remote monitoring system; ModBus TCP via ethernet

Electrical system

Rated electrical power	100 kW, 3 Phase, 400 VAC, 50 Hz
Power factor range	Set point adjustable between 0.9 lagging and 0.9 leading
Reactive power	+/- 45 kVAR
Grid connection	Utility approved protective relay included

Noise

Apparent Noise Level	50 dBA at 50 metres from nacelle
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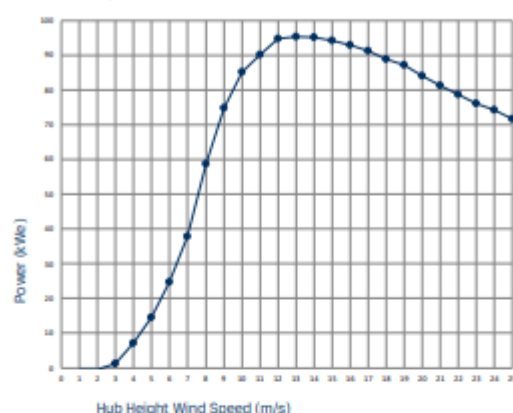
Environmental specifications

Operating Temperature Range	-20°C to 40°C
Temperature Range in Storage	-30°C to 50°C
Lightning Protection	Receptors in blades, nacelle lightning rod and electrical surge protection

Power Curves

NPS 100C-21 Class II/A Power Curve

21m Rotor, Standard Conditions*

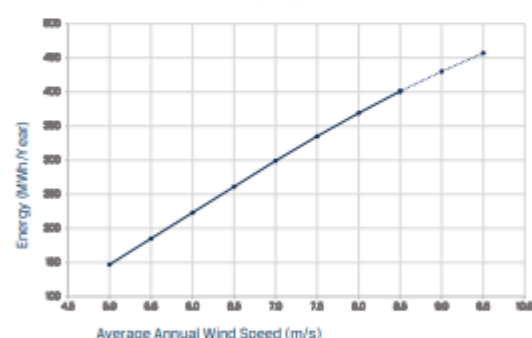


Wind Speed (m/s)	1	2	3	4	5	6	7	8	9	10
Power (kWe)	-0.6	-0.6	0.5	4.1	10.5	19.0	29.4	41.0	54.3	66.8

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
77.7	86.4	92.8	97.8	100	99.9	99.2	98.4	97.5	96.8	96.4	96.3	96.8	98.0	99.2

Annual Energy Production: 21m Rotor

Standard Conditions*, Rayleigh Wind Distribution



Average Annual Wind Speed (m/s)	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0**	9.5**
Energy (kWe)	147	185	223	261	299	335	369	401	430	457

* Standard conditions: air density 1.225 kg/m³, equivalent to 15°C at sea level.

** Above IEC 61400-1 class II

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Northern Power Systems Srl

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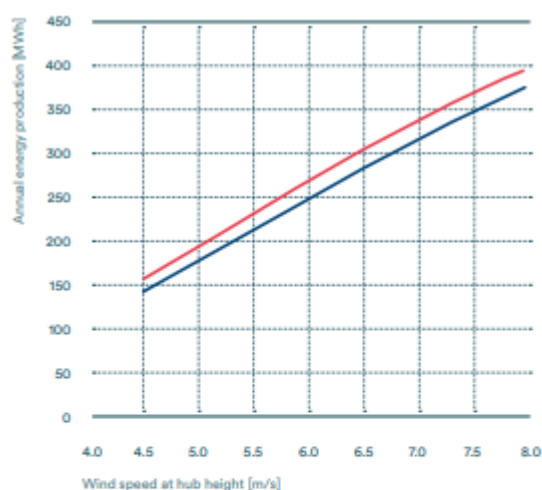
(Northern Power Systems) [Ref. 03]

Appendix B – Norvento nED100 Wind Turbine

Energy production

Wind speed [m/s]	AEP [MWh]	
	Ø22	Ø24
4.5	138	155
5.0	183	203
5.5	230	252
6.0	276	300
6.5	321	346
7.0	363	388
7.5	401	425
8.0	435	454
8.5	464	483

Energy production at converter output, for 100% availability, standard air density (1.225 kg/m³) and Rayleigh wind distribution.



General characteristics

Rated power	100 kW
Rated wind speed	10 m/s
Cut-in wind speed	3 m/s
Cut-out wind speed	20 m/s
Wind class	IEC IIA IEC IIIA
Max wind gust speed	59.5 m/s 52.5 m/s
Power regulation	Active variable pitch Active variable speed
Powertrain	Permanent magnet direct drive generator
Power delivery	Electronic power converter
Design life	20 years

Configuration

Rotor	Three blades, upwind
Type	Fiberglass-epoxy composite
Blades	
Powertrain	Multi-pole permanent magnet
Generator type	No
Gearbox	Surface ventilated passive air cooling
Cooling	
Control and electrical system	State of the art industrial PLC
Controller	Oil free electromechanical
Pitch drive	
Braking system	Blades feathering
Aerodynamic	Brake chopper fed through electronic power converter
Electrical	2 hydraulic callipers
Mechanical	
Orientation System	Electric Gearmotor
Actuator	Hydraulic Calliper
Jamming	2 independent supercapacitor systems
Emergency power supply	
Tower	Tubular steel tower
Type	2 or 3, depending on hub height
Sections	

Customization to your site

Available hub height	24.5 m (IEC IIA) – 29.5 m (IEC IIIA) – 36.0 m (IEC IIIA)
Available rotor diameter	22 m (IEC IIA) – 24 m (IEC IIIA)

Quality and safety standards

Wind Turbine	Manufacturing evaluated IEC 61400-22:2010 H&S evaluated directive 2006/42/CE EMC tested mach. directive 2006/42/CE Electrical safety tested mach. directive 2006/42/CE Power quality measured IEC 61400-21:2008 Acoustic noise measured IEC 61400-11:2012	TÜV SÜD SGS SGS SGS Barlovento ARESSE
Blades	Design for IEC IIIA IEC 61400-1:2005 Blade tested (extreme & fatigue) IEC 61400-23:2014	TÜV SÜD TÜV SÜD

Monitoring / Operation / Maintenance

Monitoring	Remote supervision via internet with client's app Norvento Control Centre (24/7/365 available)
Access to nacelle	From within the tower
Operations at nacelle	User-friendly and safe up to 12m/s average wind speed

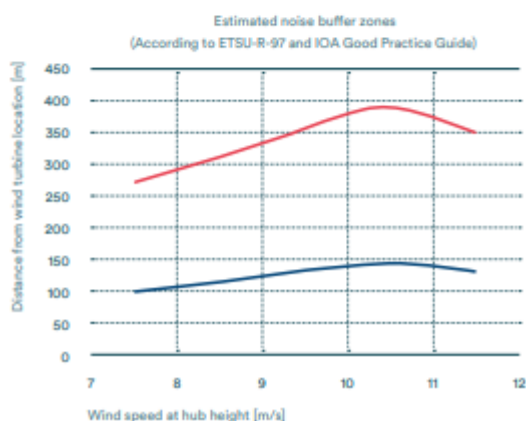
Grid connection and interoperability

Electrical interconnection	Output Alternating current, three-phase Voltage 400 V Frequency 50 Hz / 60 Hz Protection G59
Capabilities	Power delivery control in real time Reactive power control Power factor compensation Low voltage ride through Black start
Integration	Communication with smart grid and system operator Supports grid power/frequency stability Reinforces grid Voltage Stability
Applications	Connected to main power system Connected to weak grids Connected to a micro-grid Operated as stand-alone Wind - diesel / biogas systems / Wind - PV systems / batteries

Noise data

Wind speed at hub height [m/s]	Distance from wind turbine location [m]	
	$L_{A80}=45$ dB(A)	$L_{A80}=35$ dB(A)
7 – 8	100	275
8 – 9	115	310
9 – 10	130	350
10 – 11	145	385
11 – 12	130	350

nED100 can operate a Low Noise mode which reduces the maximum noise level emitted by 2dB by the wind turbine in its Normal mode operation. Such feature allows a significant reduction in the required noise buffer.



(Norvento) [Ref. 04]

Appendix C – Renogy Core-12V 200Ah Batteries



RENOGY Core Series **Deep Cycle Lithium Iron Phosphate Battery**

The Renogy Core Series 12.8V 200Ah Deep Cycle Lithium Iron Phosphate Battery is designed for the drop-in replacement of deep-cycle lead-acid batteries with its standard Battery Council International (BCI) group size.

Weighing only half of the lead-acid counterparts, the battery can be safely discharged to 100% Depth of Discharge (DOD), delivering twice the energy. Manufactured with automotive-grade battery cells, the battery features the highest safety standards and an extended 5000+ cycle life. In addition, the reliable Battery Management System (BMS) provides comprehensive protection to the battery.

KEY FEATURE

- **Unparalleled Performance**

Features a greater energy density, a deeper discharge capability, a higher round-trip efficiency, and a faster charging speed in a smaller size over counterparts in the market.

- **Uncompromising Quality**

Ensures an exceptional lifespan with more than 5000 cycles (80% DOD), a continuous charge current of 100A, a continuous discharge current of 200A, and a wide range of operating temperatures with the automotive-grade battery cells.

- **Reliable Protection Mechanisms**

Designed with a sturdy internal structure for RV use, and includes multiple levels of protection such as low temperature cut-off and precise balancing through the battery management system.

- **Higher Capacity than Competitors**

212Ah instead of 200Ah, for a longer-lasting application.

- **Easy to Expand**

Upgrade to lithium batteries seamlessly with the standard BCI group sizes; up to 16 batteries in 4 series and 4 parallel system connection delivering a maximum of 48V (51.2V) 800Ah with 40.96 kWh.

renogy.com

5050 South Archibald Avenue, Ontario, CA 91762, USA

 **RENOGY**

TECHNICAL SPECIFICATIONS

General

Product Name	RENOGY Core Series Deep Cycle Lithium Iron Phosphate Battery
Model Name	RBT12200LFP-G1
Battery Cell Type	Lithium Iron Phosphate
Rated Capacity (0.5C, 25°C)	200Ah
Nominal Voltage	12.8V
Voltage Range	10V to 14.8V
Cycle Life (0.5C/1C, 25°C)	5000 Cycles (80%EOL, 80%DOD)
Dimension	20.55 x 9.45 x 8.62 in / 522 x 240 x 219 mm
Weight	47.3 lbs. / 21.45 kg
Connection Method	Series & Parallel (4S4P)
Terminal Bolt Size	M8 x 1.25 x 15 mm
Recommended Terminal Torque	88.5 inch-lbs to 106.2 inch-lbs / 10 N-m to 12 N-m
Protection Rating	IP65
Certification	MSDS, UN38.3, FCC, CE, PSE, and UKCA

Operation Parameters

Charge Voltage	14.4V
Maximum Continuous Charge Current	100A
Maximum Continuous Discharge Current	200A
Peak Discharge Current	400A@10s
Charge Temperature Range	32°F to 131°F (0°C to 55°C)
Discharge Temperature Range	-4°F to 140°F (-20°C to 60°C)
Storage Temperature Range	-13°F to 149°F (-25°C to 65°C)
Operation Relative Humidity	10% to 95%



(Renogy) [Ref. 06]

Core-12V 24V 48V 200Ah Deep Cycle Lithium Iron Phosphate Battery

SKU: RBT12200LFPx4-UK

★★★★★ 5 (3) [Write a Review](#)



~~£3,559.99~~ **£2,439.99**

VAT INCLUSIVE Free shipping in the UK.
Here you can find out when VAT exclusive applies.

+ **24390** Renogy Rays after purchase. [Learn more](#)

Shipping Cost Notice [Learn More >](#)

- One stop for upgrade from lead-acid to lithium.
- Max. 6% positive capacity tolerance.
- Support series, parallel, or series-parallel connections.
- A true 200A BMS with low-temperature cut-off.
- 5-year limited warranty & 24-hour timely assistance.

[See the specs >](#)

Bundle Options:

1 Battery

2-pack of Batteries

4-pack of Batteries

Have question?
[Talk to us, get answers](#)

Appendix D – Victron Energy Quattro inverter



Quattro inverter/charger 3kVA - 15kVA 230V

Lithium Ion battery compatible



Quattro
48/5000/70-100/100



Quattro
48/15000/200-100/100

Two AC inputs with integrated transfer switch

The Quattro can be connected to two independent AC sources, for example the public grid and a generator, or two generators. The Quattro will automatically connect to the active source.

Two AC Outputs

The main output has no-break functionality. The Quattro takes over the supply to the connected loads in the event of a grid failure or when shore/generator power is disconnected. This happens so fast (less than 20 milliseconds) that computers and other electronic equipment will continue to operate without disruption.

The second output is live only when AC is available on one of the inputs of the Quattro. Loads that should not discharge the battery, like a water heater for example, can be connected to this output.

Split phase option

A split phase AC source can be obtained by connecting our autotransformer (see data sheet on www.victronenergy.com) to a 'European' inverter programmed to supply 240V/60Hz.

Three phase capability

Three units can be configured for three phase output. But that's not all: up to 4 sets of three 15kVA units can be parallel connected to provide 144kW/180kVA inverter power and 2400A charging capacity.

PowerControl – Dealing with limited generator, shore side or grid power

The Quattro is a very powerful battery charger. It will therefore draw a lot of current from the generator or shore side supply (16A per 5kVA Quattro at 230VAC). A current limit can be set on each AC input. The Quattro will then take account of other AC loads and use whatever is spare for charging, thus preventing the generator or mains supply from being overloaded.

PowerAssist – Boosting shore or generator power

This feature takes the principle of PowerControl to a further dimension allowing the Quattro to supplement the capacity of the alternative source. Where peak power is so often required only for a limited period, the Quattro will make sure that insufficient mains or generator power is immediately compensated for by power from the battery. When the load reduces, the spare power is used to recharge the battery.

Solar energy: AC power available even during a grid failure

The Quattro can be used in off grid as well as grid connected PV and other alternative energy systems. Loss of mains detection software is available.

System configuring

- In case of a stand-alone application, if settings have to be changed, this can be done in a matter of minutes with a DIP switch setting procedure.
- Parallel and three phase applications can be configured with VE.Bus Quick Configure and VE.Bus System Configurator software.
- Off grid, grid interactive and self-consumption applications, involving grid-tie inverters and/or MPPT Solar Chargers can be configured with Assistants (dedicated software for specific applications).

On-site Monitoring and control

Several options are available: Battery Monitor, Multi Control Panel, Color Control GX or other GX devices, smartphone or tablet (Bluetooth Smart), laptop or computer (USB or RS232).

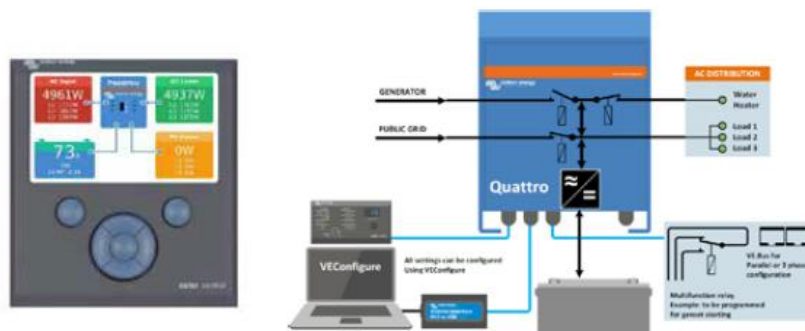
Remote Monitoring and control

Color Control GX or other GX devices.

Data can be stored and displayed on our VRM (Victron Remote Management) website, free of charge.

Remote configuring

When connected to the Ethernet, systems with a Color Control GX or other GX device can be accessed and settings can be changed remotely.



Color Control GX, showing a PV application

Quattro	12/3000/120-50/50 24/3000/70-50/50	12/5000/220-100/100 24/5000/120-100/100 48/5000/70-100/100	24/8000/200-100/100 48/8000/110-100/100	48/10000/140-100/100	48/15000/200-100/100
PowerControl / PowerAssist	Yes				
Integrated Transfer switch	Yes				
AC inputs (2x)	Input voltage range: 187-265 VAC Input frequency: 45 – 65 Hz Power factor: 1				
Maximum feed through current (A)	2x 50	2x100	2x100	2x100	2x100
INVERTER					
Input voltage range (V DC)	9.5 – 17V 19 – 33V 38 – 66V				
Output (1)	Output voltage: 230 VAC ± 2% Frequency: 50Hz ± 0.1%				
Cont. output power at 25°C (VA) (3)	3000	5000	8000	10000	15000
Cont. output power at 25°C (W)	2400	4000	6400	8000	12000
Cont. output power at 40°C (W)	2200	3700	5500	6500	10000
Cont. output power at 65°C (W)	1700	3000	3600	4500	7000
Peak power (W)	6000	10000	16000	20000	25000
Maximum efficiency (%)	93 / 94	94 / 94 / 95	94 / 96	96	96
Zero load power (W)	20 / 20	30 / 30 / 35	60 / 60	60	110
Zero load power in AES mode (W)	15 / 15	20 / 25 / 30	40 / 40	40	75
Zero load power in Search mode (W)	8 / 10	10 / 10 / 15	15 / 15	15	20
CHARGER					
Charge voltage 'absorption' (V DC)	14.4 / 28.8	14.4 / 28.8 / 57.6	28.8 / 57.6	57.6	57.6
Charge voltage 'float' (V DC)	13.8 / 27.6	13.8 / 27.6 / 55.2	27.6 / 55.2	55.2	55.2
Storage mode (V DC)	13.2 / 26.4	13.2 / 26.4 / 52.8	26.4 / 52.8	52.8	52.8
Charge current house battery (A) (4)	120 / 70	220 / 120 / 70	200 / 110	140	200
Charge current starter battery (A)	4 (12V and 24V models only)				
Battery temperature sensor	Yes				
GENERAL					
Auxiliary output (A) (5)	25	50	50	50	50
Programmable relay (6)	3x	3x	3x	3x	3x
Protection (2)	a-g				
VE.Bus communication port	For parallel and three phase operation, remote monitoring and system integration				
General purpose com. port	2x	2x	2x	2x	2x
Remote on-off	Yes				
Common Characteristics	Operating temp.: -40 to +65°C Humidity (non-condensing): max. 95%				
Maximum altitude	3500 m				
ENCLOSURE					
Common Characteristics	Material & Colour: aluminium (blue RAL 5012) Protection category: IP 21				
Battery-connection	Four M8 bolts (2 plus and 2 minus connections)				
230 V AC-connection	Screw terminals 13mm² (6 AWG)	Bolts M6	Bolts M6	Bolts M6	Bolts M6
Weight (kg)	19	34 / 30 / 30	45 / 41	51	72
Dimensions (hwxwd in mm)	362 x 258 x 218	470 x 350 x 280 444 x 328 x 240 444 x 328 x 240	470 x 350 x 280	470 x 350 x 280	572 x 488 x 344
STANDARDS					
Safety	EN-IEC 60335-1, EN-IEC 60335-2-29, EN-IEC 62109-1				
Emission, Immunity	EN 55014-1, EN 55014-2, EN-IEC 61000-3-2, EN-IEC 61000-3-3, IEC 61000-6-1, IEC 61000-6-2, IEC 61000-6-3				
Road vehicles	12V and 24V models: ECE R10-4				
Anti-islanding	See our website				
1) Can be adjusted to 60 Hz. 120V models available on request		3) Non-linear load, crest factor 3:1			
2) Protection key:		4) Up to 25°C ambient			
a) output short circuit		5) Switches off when no external AC source available			
b) overload		6) Programmable relay that can a.o. be set for general alarm,			
c) battery voltage too high		DC under voltage or general start/stop function			
d) battery voltage too low		AC rating: 230 V / 4 A			
e) temperature too high		DC rating: 4 A up to 35 VDC, 1 A up to 60 VDC			
f) 230 VAC on inverter output					
g) input voltage ripple too high					



Digital Multi Control Panel

A convenient and low cost solution for remote monitoring, with a rotary knob to set PowerControl and PowerAssist levels.



VE.Bus Smart Dongle
Measures battery voltage and temperature and allows monitoring and control of Multis and Quattros with a smartphone or other Bluetooth enabled device.



Computer controlled operation and monitoring

Several interfaces are available:



Color Control GX and other GX devices

Monitoring and control. Locally, and also remotely on the [VRM Portal](#).



MK3-USB (VE.Bus to USB interface)
Connects to a USB port (see ["A guide to VEConfigure"](#))



VE.Bus to NMEA 2000 interface
Connects the device to a NMEA2000 marine electronics network. See the [NMEA2000 & MFD integration guide](#)



BMV-712 Smart Battery Monitor

Use a smartphone or other Bluetooth enabled device to:

- customize settings,
- monitor all important data on single screen,
- view historical data, and to update the software when new features become available.

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